MFM 4-electrodes EC meter

Organization: Waterschap Scheldestromen multiflexmeter

Final report

Student name: Haobo Guo

Student number: 88488

Information

Title: Research proposal – MFM 4-electrodes EC-meter

Authors: Haobo Guo
(Guo0013@hz.nl, 88488)

Organization: Waterschap Scheldestromen multiflexmeter

Educational institution: HZ University of Applied Sciences

Visiting address
Edisonweg 4
4382 NW Vlissingen
Phone: 0118 489 000

Mailing address
info@hz.nl
Mailbox 4380 AJ Vlissingen

1st examiner: Willem Haak
w.haak@hz.nl

2nd examiner: Connor Reekers
c.reekers@hz.nl

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Summary

This report described the whole process of designing an EC meter system in a continuous project: MFM EC meter. From the designing until the testing, detailed explanation about every part will be mentioned. From a view of engineering student, the report starting from introduction of the assignment and project background. During the introduction, readers can acknowledge the motivation and the final target of the project, what did previous worker done is also listed. From the analysis of the assignment, the problems will be point out and divided by priority. After introducing, the choice of design method will be showed, method chapter will explain about which method has been chosen, why making that choice and how to implement that method in this project.

Then next part of the report will starting the elaboration of design. Following the structure of V-model design method, the design of system, sub-system, and components will be explained and out comes of the design will be listed. After designing, the most important part is testing and validating. To make sure the validating and tests are rigorous and convincing, every test has its own test-plan, these test-plans are checked and proved by in-company mentor.

Following the test-plan, system and sub-systems are selected, those parts up to standard and be permitted to integrating phase. Then, followed the system test-plan the final integrated EC meter system will be test and compare with the list of demands.

Additionally, finishing a prototype is not the end of a design. The following discuss and recommendation to further research need to be given.

During the full reporting of the assignment, the designing ideas and engineering thoughts are presented.

Foreword:

Dear readers,

Hello! My name is Haobo Guo, 4th year's student in HZ University of Applied Sciences. My major is Mechatronics Engineering. Before I took over this 4-electrodes EC meter project, this assignment has been researched by Mick van Eerd and Pinqi Guo. A commercial resistance meter we called "yellow box" gives them inspiration. The idea of the project is to make a 4 electrodes EC meter by implement Wenner method, this method can enlarge the measuring range compare with a 2 electrodes meter. By achieving that the measuring work in Waterschap will be more accurate and easier.

By reading the previous working report from Mick van Eerd and Pinqi Guo. It is clear that Wenner method is suitable for the system, by the main challenge is the Power source. DC source will cause polarization, so they decided to implement AC source. From their recommendation a frequency adjustable AC square wave source is the best. By doing research and making the most use of my creativity, the new version of power source is finished and passed the tests. Luckily, this power source also helps my fellow student Xuesong Zhang over overcome a critical dilemma. After 5 months work and nearly a thousand of tests and measuring, I finally finished the improved prototype of 4-electrodes EC meter. But we all know that the research of this project is not going to stop here, I hope the conclusions and recommendations from my report will provide some help to further improvements. In this process, I learnt a lot on microelectronics, signals and even chemistry. Also improved my skills on programming and designing. It is an unforgettable experience for me.

Because of the length of this report, I put lots of pictures that take lots of space into the appendix part. To make it easier for reader to find them, I made lots of links on referring words. By pushing "ctrl + mouse button" readers can jump to the right position in appendix.

During this thesis period, I have met lots of good friends, teachers, and colleagues, they gave me lots of help and encourage. Some of them help me with the difficulties, some of them help me with research and life. I would like to express my thank to my in-company mentor Mr. Jos Goossen, my colleague Mr. Mick van Eerd and Xuesong Zhang. Besides, I also want to say thank to my tutor in HZ, thanks Mr. Willem Haak and Conner Reekers. From the beginning of the assignment until the end of the term, they spent lots of time on me, gives me so many valuable suggestions and feedbacks. Especially for Mr. Haak, he kept attend our online meeting even in the bed of hospital. Without all the helps from all of them above, it could be an unimaginably difficult task for me to finish this report.

Haobo Guo
Vlissingen, the Netherlands
2022-06-04

Table of Abbreviation

Abbreviation	Explanation
AC	alternating current
ADC	Analog to digital signal converter
DAC	Digital to analog signal converter
DC	Direct current
EC	Electrical conductivity
MFM	Multiflexmeter
I	Current
U	Voltage
mins	Minutes
mS/cm	Milli siemens per centimeter
M	Molar mass
P	Power
PEC	The phase of the EC measurement
S	Sample standard deviation
Tu	Water temperature(unknown)
U	Voltage
µS/cm	Micro siemens per centimeter
Ω	Ohm
S/cm	Siemens per centimeter
V-model	System design method
meter	Measuring equipment
sec	seconds
K	Calculated compensation constants

CONTENT

Chapter 1. Introduction

In this chapter, basic information will be discussed and let reader have a clear overview of this assignment. Background will be discussed first and then going into problem state and problem analysis. After that goals and objectives will be list and boundaries are the last.

1.1 Background

1. Company background

Multiflexmeter is a special innovation department/project of Waterschap Scheldestromen which won the award of “Voldoende water” in 2017. In order to replace expensive and single function equipment, Jan van Kranenburg and Jos Goossen push out Multiflexmeter.
Multiflexmeter is using cheap and high reliability platform “Arduino” to design and produce their unique measuring equipment, these products are also open-sourced and accessible for everyone.
Researching directions of Multiflexmeter contain not only energy support, computer programming, measuring methods, design but also all process from costs, plan until management.

2. Project background

Waterschap nowadays is searching for the possibility of using a digital method to measure multiple water-related data. Related hydrological data that are expected to be detected contain but not limited to water level, wave head, water salinity and soil salinity that nearby the sea.
There are more than 1300 water data meters installed around the target area, however, because of the limitation of measuring range and measuring accuracy, some of them seems old fashioned and need to be replaced by better equipment. Thus, a measuring equipment which have compatibility to different function and working range is needed.
As an innovative project group, Jan van Kranenburg and Jos Goossen rolled out the multiflexmeter. Mutiflexmeter normally include a microcontroller, power source, communication unit and shell which can be connected to different sensors to achieve different measuring functions.
On most locations people monitor the salinity via periodic manual measurement with an EC meter(Electrical conductivity meter). This sensing principle is based on the measurement of electrical conductivity. Measuring equipment with the desired accuracy and measuring range is relatively expensive. In addition, manual measurement is time-consuming. This means that this traditional way is usually applied with relatively large time intervals.
Multiflexmeter currently has an EC meter with 2 poles in the prototype(principle shows in Figure 1), but this prototype still has some shortcomings:

- Limited measuring range (to approximately 1000 mg chloride/liter).
- Low sensitivity at higher salt contents.
- Limited stability, especially at higher salt concentrations.

These short comings are mainly caused by the polarization and this is the fatal drawback of 2 poles meter. To get rid of these shortcomings, the 4 electrodes method can be used, this method is similar with resistance meter(shows in Figure 2).

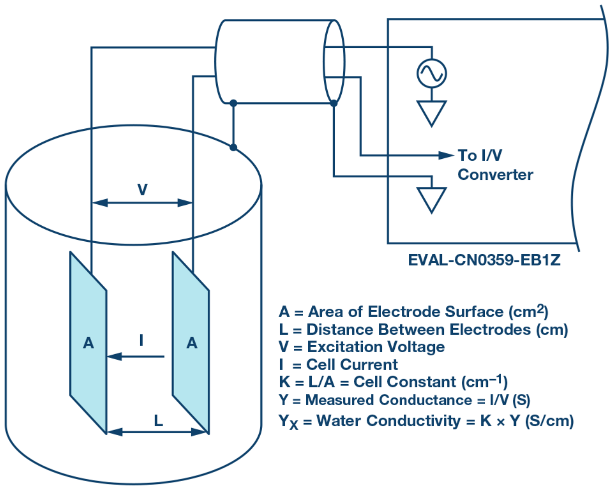


Figure 1 2 electrodes EC meter sketches (Kester, fully-automatic-self-calibrated-conductivity-measurement-system, n.d.)

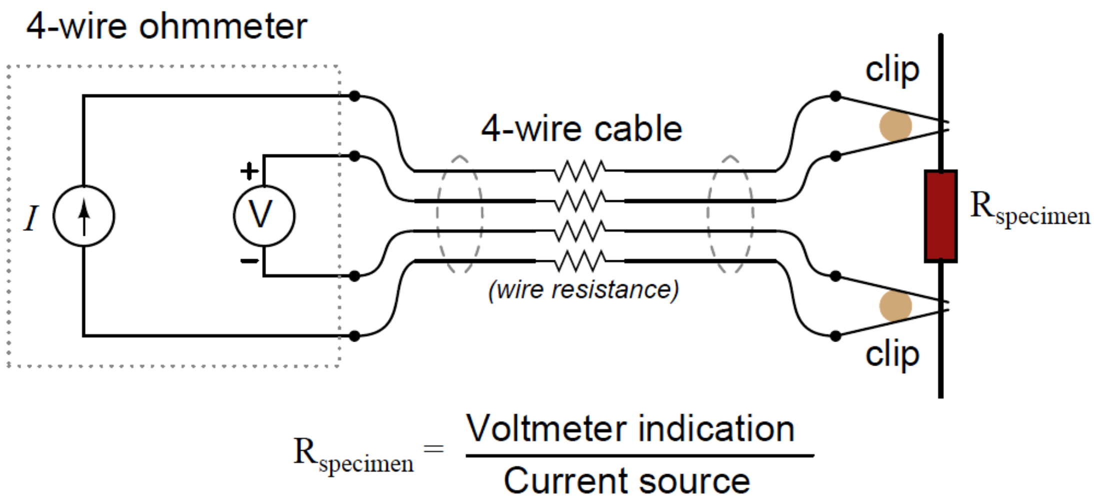


Figure 2 Sketches of 4electrodes EC meter (Guo, 2021)

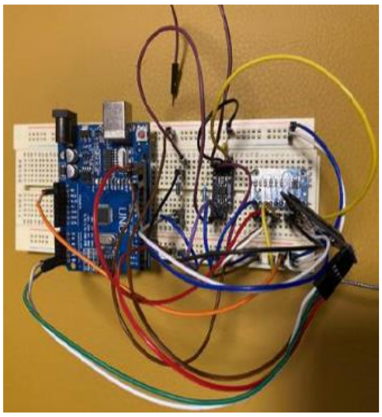


Figure 3 Prototype from Pinqi Guo (Guo, 2021)

As we discussed above, the essence of EC measuring is resistance measuring, 4-wire ohmmeter is the prototype of 4 electrodes EC meter. Following this principle of measuring, an ADC can be used to measure voltage and transfer the signal into digital which can be identified by processor. Using the processor, the data can be calculated and transfer to EC value. Previous work has been done by Pinqi Guo last year, the photo of his prototype shows in Figure 3. During his project, He proved that 4 electrodes meter are better than 2 electrodes meter, but the appropriate AC square wave power source which used to avoid polarization is not developed, only measuring system are made and there also have an error of nearly 30%.

1.2 Problem statement

This section will introduce about the actual question comes from the problem. The scope is to design a 4 electrodes EC meter which have a larger measuring range than 20mS/cm and lower error rate of 10%. Next chapter in 1.3 problem analysis, more about the problem will be discuss.

1. Main question

The project in priority is salt measurement in surface water. (Goossen, 2022)
Thus, in this assignment, the main question is:

What is the design of 4 poles EC meter which have a larger working range(more than 0-20mS/cm) and higher accuracy(lower than 10% error) by using AC power source and V-model design methodology? (Multiflexmeter, 2022)

2. Sub-questions

First 4 weeks:

- **What kind of system is suitable for 4-electrodes EC-meter to achieve its measuring function on larger working range and higher accuracy?**
- **What is the design of system description of 4-electrodes EC meter?**

2 weeks:

- **What is the design of sub-system description of 4-electrodes EC meter?**
- **What is the design of test plan for 4-electrodes EC meter?**

2 weeks:

- **What is the validation of the working range and measuring accuracy of the 4-electrodes EC-meter in lab and presenting room?**

2 months:

- **What are the test results and data analysis of 4 electrodes EC meter?**

3. Requirements

There are several drawback of current system mention in main question that need to be improved. So, the requirement of this new system should achieve the following requirements :

1. **Higher measuring range, larger than approximately 1000 mg chloride/liter(shows in Table 1 & Table 2)**
2. **Better performance on sensitivity on higher salt concentration(shows in Table 1 & Table 2)**
3. **Able to prevent electrolysis and corrosion reactions around the electrodes**
4. **Able to prevent polarization around the electrodes (the major reason of higher the accuracy by use a 4-electrodes setup instead of 2-electrodes)**
5. **Electrode’s part should be as cheap as possible without a clear number required, electronic parts and chips should be lower than 100€.**

i. Delivery

The final delivery can be divided into hardware part, software part and demonstration. Hardware is the practical prototype itself. Software should be upload and shared. Demonstrate would contain the process of measuring target liquid. Live presenting of demonstration or demonstration video that have been recorded.

ii. Capacity

Capacity is the quantitative index of different kinds of function for the prototype.
Normally include measuring range, error range and robustness. The performance criteria will be further discussed in the chapter of theoretical framework.

iii. Price

A list for components and parts needed should be delivered which can clearly show out the cost per EC-meter. Electrode’s part should be as cheap as possible without a clear number required, electronic parts and chips should be lower than 100€.

iv. Proof and criteria

Items	numbers	units	remark
Measuring range	0mS/cm - >20mS/cm	mS/cm	The larger the better
Required temperature	20-30℃	℃	Normal environment
Accuracy	10% of error	%	Compare with a commercial EC meter given by client. The less the better
Robustness	N/A	N/A	No need for now

Price	100€	Euros	Price of electronic devices, not include electrodes and labor costs, (according to in-company mentor labor costs are not going to be think about during this project)

table 1 Criteria table

Items	proof
Measuring range	Test result and test report for measuring the liquid from 0mS/cm to 40mS/cm(more than 20mS/cm), proved by 10 times of measuring at different concentration
Required temperature	Test report and test log shows that the meter can work at the temperature from 20℃ to 30℃,
Accuracy	Calculation and results of the error percentage during substantive tests, result compare with “yellow box” have error lower than 10%, 10 times test per concentration
Robustness	Demonstration that shows the prototype can work functionally, keep measuring for at least 30 times
Price	A price list of all used components and devices which shows every prototype have the costs lower than 100€

table 2 Proof table

1.3 Problem analysis

After introduction of the basic problem for this assignment, this section is going to analysis these problems by using SMART and 5W method.

1.3.1 Assignment description

SMART

Specific	Design a 4 poles EC meter which can be used to measuring the salinity of surface water
Measurable	The requirement can be present by EC measuring on a wider range more than 20mS/cm and compare the deviation with the result from previous prototype
Assignable	This project has a bachelor’s degree level which can be accomplished within 6 months including thesis.
Realistic	The requirement of final product is a physical prototype which can be produced and demonstrated
Time-related	The assignment should be finished before July 2022, starting from February 1st

What

The goal of this assignment is: develop an on-line EC meter without the drawbacks below.

- Limited measuring range (to approximately 1000 mg chloride/liter).
- Low sensitivity at higher salt contents.(measuring value errors going up to 40% when measuring the liquid with EC higher than 20mS/cm)
- Limited stability, especially at higher salt concentrations.(measuring value cannot be stable when measuring the liquid with more than 20mS/cm EC)

These disadvantages come from an earlier internship; an EC meter was developed based on a 2-electrode system in combination with a 555-timer circuit. (Goossen, 2022)

Why

Salt concentration is one of the most important water quality parameters. In Zeeland, most surface water has relatively high salt levels. However, too high salinity values in surface water may limit the usability of the water. (Multiflexmeter, 2022) Irrigation of crops with surface water that is too salty also have a negative effect on crop growth.

Salinity can fluctuate during the year due to precipitation and evaporation. Therefore, in water management, frequent monitoring of the salinity is of great importance.
That's the reason for designing an equipment which can be used in salty measuring with low cost and high reliability.

How

By investigating most of the testing environments, the one conclusion has been found that electrical conductivity is highly related with the salt concentration. Since then, salt concentration measuring can be transfer to electrical conductivity.

Communication plan

With in-company mentor:

1. **Regular meeting on every Friday (may adjust)**
2. **Email contact during worktime**
3. **WhatsApp message**

With 1st examiner:

1. **Regular meeting every Friday(may adjust)**
2. **Email contact during work time**
3. **WhatsApp message**

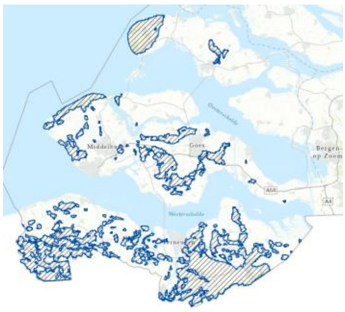


Figure 4 Target measuring area (multiflexmeter-ec, 2021)

Documentation

All project-related document should de upload to google drive given from in-company mentor.
Link of google drive: https://drive.google.com/drive/folders/1UASQ1BjAYHVcw9Y2jSwjMKAXKzxkSu7S
Also an offline file pack are stored at one special folder in working PC.

1.3.2 Current situation

Since the EC meter project started, several different prototypes and concepts are rolled out. Beginning with the 2 electrodes EC meter(shows in Figure 5) which innovatively using the Europlug coupled and 555 timer which make the prototype easy to produce and much cheaper(Shows in figure 6).

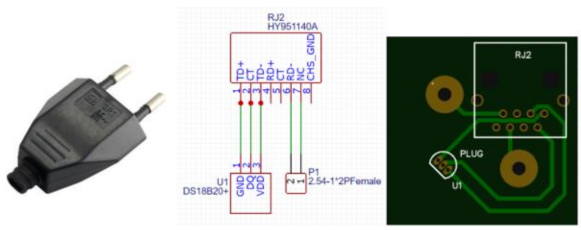
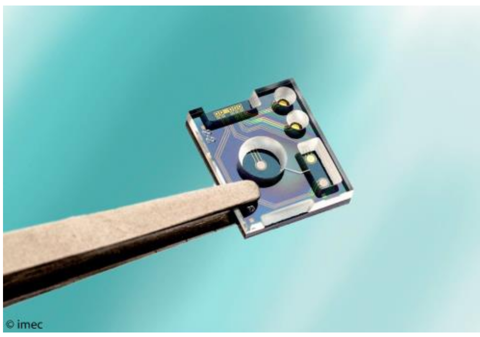


Figure 5 previous EC meter parts (multiflexmeter-ec, 2021)

Figure 6 Previous 2 electrodes EC meter (multiflexmeter-ec, 2021)



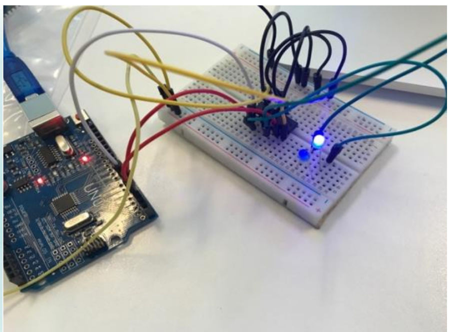


Figure 7 IMEC chip (Du, Research proposal_FeifanDu_V5_20210318, 2021)

Figure 8 Test setup from Yige Li (Li, thesis report_Yige Li_2019-06-11, 2019)

However, 2-electrodes EC meter still have the short comes caused by polarization. Only using 2 electrodes have a limited measuring range and a relatively big error. To improve the performance of the EC meter, MFM decided to extend the electrodes to 4. By doing research there is already have a proven product from

IMEC which using the 4 electrodes. So the priority is to demonstrate the capability and find out if it is possible to improve the current 2 electrodes MFM by using 4 electrodes system. From the previous project did by Yige Li, a 555-timer circuit is using to set up an AC square wave power source. However, from the test AC square wave that have been generated are not clear enough which brings noise and effect to test result. According to the recommendation from Yige Li's final report, AC square wave adjustable source is recommended, he noted about 555-timer circuit but from the report of Mick van Eerd, it is more suitable to use DAC or digital power source.
Apart from Pinqi Guo and Yige Li, Feifan Du also did contribution on EC meter, she tested the EC sensor from IMEC(shows in Firgure 9) and proved that 4 electrodes' method is a better way out.

1.4 Goals and objectives

The main target for Multiflexmeter in this assignment is to develop a measuring equipment which meet the requirements below:

- **Online monitoring of water level and quality in surface- and groundwater**
- **Robust**
- **Energy efficient**
- **Open Source**
- **Cheap**

Thus the main objective now for this project is to roll out a functional prototype which using 4 electrodes to measure the EC. Design should be open sourced according to the idea of multiflexmeter, this means using "black box" product on the market is not an option.

1.5 Boundaries

1. The network function which relative with LoRa-WAN and IoT is not part of this project
2. The optimize of 2 electrodes EC-meter is not contained in this project
3. The demonstration should be convincing, so unknown outdoor environment test is not available for this assignment
4. Processor part can be chosen from Arduino and Raspberry PI.
5. Labor costs are not part of the price during this project, this means the cost during design or assembly the product is not going to be shown on the price list

Chapter 2.Theoretical Framework

After an overview of this assignment, this chapter will unfold the related knowledge in different areas. This will begin with a plan of doing search. Then searched information will be listed by order.

2.1 Search plan

Num	title	details	key words	source	remark
1	Processor	Micro-processor or microcomputer use to do calculation and data process	Arduino, nano, uno,STM328, Raspberry PI, microcontroller	Official website, Data sheet, previous project	Chapter 2.1.1
2	4 EC-METER	EC meter with 4 electrodes, photos, principle, and sketch	EC meter, 4 electrodes, electrical conductivity	scientific reports, experts, previous project, commercial product report	Chapter 2.1.3
3	2 EC-METER	EC meter with 2 electrodes, photos, principle and sketch	EC meter, 2 electrodes, electrical conductivity	scientific reports, experts, previous project, commercial product report	Chapter 2.1.3
4	Electrical conductivity	Physical and mathematical based information contained calculation and units	EC, electrical conductivity, electrolyte,	scientific reports, experts, previous project, physical teaching material	Chapter 2.1.2
5	Chemical reactions	All kinds of chemical reactions that can affect to the measuring results	Polarization, electrolysis	scientific reports, experts, previous project, physical teaching material	Chapter 2.1.4
6	Performance criteria	quantitative index for commercial product and previous prototype	measuring range, accuracy, resolution,	commercial product data sheet, previous prototype report, experts	Chapter 2.1.5
7	Testing skills	skills about how to do test and standard on related testing	test skill, testing, standard, criteria	teaching material, scientific reports, experts	Chapter 2.1.6
8	Pricing	Information about related devices and electronic components, also about the costs of producing PCB	Sensor, EC sensor, temperature sensor, ADC, DAC, PCB	scientific reports, experts, previous project, commercial product report	Chapter 2.1.7

table 3 Table of searching plan

This table shows the titles of researching information and knowledge, contained the searching key words that needed and potential information sources. Remark line noted which chapter can reader find the information.

2.2 Summary

Num	title	details	key words	source	remark
1	Processor	Micro-processor or microcomputer use to do calculation and data process	Arduino, nano, uno,STM328, Raspberry PI, microcontroller	Official website, Data sheet, previous project	Chapter 2.1.1

From the table of searching plan above, number 1 processor contained related information about processor which used to receiving digital or analog signal and doing calculation. In this 4 electrodes EC meter, this processor has several usage: generating output voltage, receiving digital signal from ADC and making calculation.

2	4 EC-METER	EC meter with 4 electrodes, photos, principle, and sketch	EC meter, 4 electrodes, electrical conductivity	scientific reports, experts, previous project, commercial product report	Chapter 2.1.3
3	2 EC-METER	EC meter with 2 electrodes, photos, principle and sketch	EC meter, 2 electrodes, electrical conductivity	scientific reports, experts, previous project, commercial product report	Chapter 2.1.3

Arduino UNO, NANO and Raspberry Pi are both need to be used during different sub-systems' test.
Number 2 and 3 are going to explain about the principle of 4 electrodes measuring method and 2 electrodes method.

4	Electrical conductivity	Physical and mathematical based information contained calculation and units	EC, electrical conductivity, electrolyte,	scientific reports, experts, previous project, physical teaching material	Chapter 2.1.2

Number 4 listing the information about electrical conductivity, figure out what kinds of mathematical relationship between the value that can measuring and the final value that wanted. Also include all kinds of chemical reactions that happened during the measuring.

5	Chemical reactions	All kinds of chemical reactions that can affect to the measuring results	Polarization, electrolysis	scientific reports, experts, previous project, physical teaching material	Chapter 2.1.4

Number 5 shows the criteria of the performance for 4 electrodes EC meter.

6	Performance criteria	quantitative index for commercial product and previous prototype	measuring range, accuracy, resolution,	commercial product data sheet, previous prototype report, experts	Chapter 2.1.5

Number 6 contained related testing skills on the area of electrical, chemical, and physical.

7	Testing skills	skills about how to do test and standard on related testing	test skill, testing, standard, criteria	teaching material, scientific reports, experts	Chapter 2.1.6

Number 7 analyzed related information of costs on electronic components, also include the price of labor and producing PCB.
Apart from information about searching direction, the using sources are also given in "source" line, information are not only coming from experts, scientific reports, official data sheet but also coming from some teaching materials and related previous report.

2.2 Searched information

This section will list all kinds of related searching knowledge and discuss on their usage.

2.1.1 Micro-controller

Micro-controller is the core part of data processing, this section using to making choice of different kinds of platform.

Details about Arduino and Raspberry Pi will be discussed to make comparison. By compare from software and hardware, the choice made is using Arduino NANO. First reason is the costs of these two platform, considered that this assignment has a limitation of 100€, Raspberry Pi is much expensive than expect. Secondly, Arduino can be coded easily by connecting to PC by using its IDE and Raspberry pi deed starting the operation system on itself. This operation system can did much beyond a micro-chip, what need to be processed do not need such a thorough OS. And finally, although the hardware of Arduino NANO is not so abundant(such as the number of I/O pins) but it is enough for this assignment.

Introduction of Arduino platform can be find in Appendix.

2.1.2 Electrical conductivity

Electrical conductivity or specific conductance is the value used to represent the ability of materials to conduct current. Its value normally is the reciprocal of the electrical resistivity which have the unit of Siemens per meter(s/m). Electrical conductivity can be signified by the letter of σ, κ and γ. (MFM EC-meter, 2022)

At ideal situation the electrical conductivity can be calculated by electrical resistivity ρ, and ρ can be represent by resistance, area and length:

$$\rho = R \cdot \frac{A}{l}$$

R = resistance between two electrodes
A = shadowed area between two electrodes
L = shadowed length between two electrodes

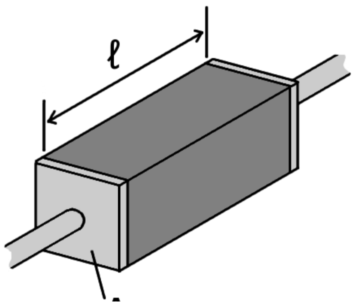


Figure 9 electrical resistivity calculation (multiflexmeter-ec, 2021)

Electrical conductivity represents by ρ:

$$\sigma = \frac{1}{\rho}$$

ρ = electrical resistivity

In ionic liquids/electrolytes:

The resistivity of ionic liquids or electrolytes is highly related with the concentration.
This can be shown:

The feature is α:

$$\alpha = \frac{N_0}{N}$$

N_0 = concentration of molecules of the dissolved substance
N = concentration of ions

The specific electrical conductivity σ is:

$$\sigma = q(b^+ + b^-) \cdot \alpha \cdot N_0$$

q = module of the ion charge
$b^+ and\ b^-$ = mobility of positively and negatively charged ions
α = the coefficient of dissociation (Kester, Fully Automatic Self-Calibrated Conductivity Measurement System, 2016)

Temperature correction

The conductivity of an electrolyte solution increases with temperature. Temperature correction is required for EC measurements as a result of this impact. A raw EC value must be converted to a value at a reference temperature of 25 degrees Celsius. The conversion formula therefore:

$\sigma 25 = \sigma T / (1 + \alpha(T-25))$

Where:

$\sigma 25$ = EC value at 25°C as a reference temperature;

σT = measured (raw) EC value;

T = temperature of the solution being measured.

α = coefficient of temperature.

(multiflexmeter-ec, 2021)

Cell constant

To make it clear when detecting the current between two electrodes in liquid, the shadow volume needs to be sure. The meaning of cell constant is this specific volume. The conductivity of the solution is calculated by multiplying the observed current by the cell constant. The cell constant, denoted by the letter K, refers to a hypothetical electrode made up of two 1cm square plates. The cell constant is measured in 1/cm (per centimeter), with the number referring to the ratio of the distance between the plates to their surface area. (what-is-conductivity-cell-constant, 2017).

2.1.3 EC-meter

EC-meter is the equipment used to measuring the electrical conductivity in the liquid. By measuring the resistance and processing temperature correction, the processor can calculate the EC value from sensor's input value. Laboratories usually use potentiometric method with 2 or 4 electrodes to achieve the feature. (cole-parmer, 2020)

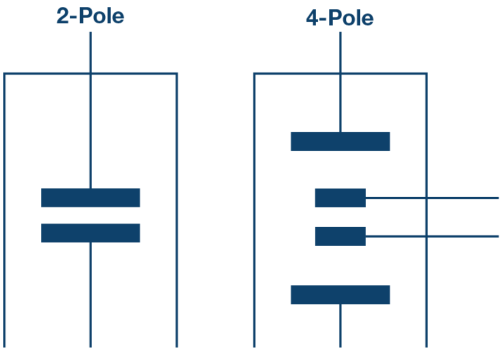
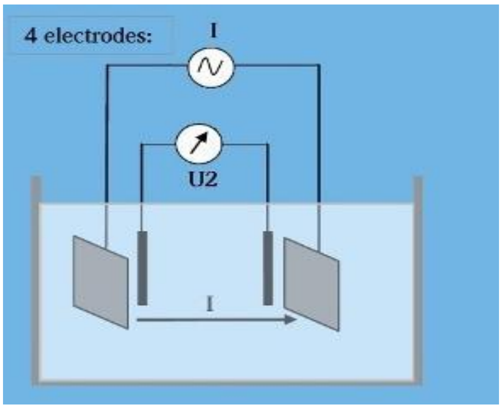


Figure 10 electrodes layout (Kester, Fully Automatic Self-Calibrated Conductivity Measurement System, 2016)

Normally there would be two electrodes that use to provide voltage or current, in 2 electrodes system, two poles provide a stable current DC or AC, these two poles are also used to measuring the current and voltage in between. When look into 4 electrodes system, there still are two poles used to provide current or voltage but two additional poles that used to measuring the resistance are placed between the power sources. (See 2 electrodes and 4 electrodes in figure 10 figure 11 and figure 12)

"The 2-pole sensor is more suitable for low conductivity measurements, such as purified water, and various biological and pharmaceutical liquids. The 4-pole sensor is more suitable for high conductivity measurements, such as wastewater and seawater analysis." Said by Robert Lee and Walt Kester. (Kester, Fully Automatic Self-Calibrated Conductivity Measurement System, 2016)



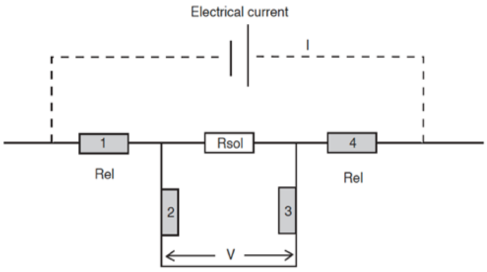


Figure 11 4 probes EC measuring (Guo, 2021) (right)

Figure 12 4 probes EC measuring(left)

Commercial EC meter

To make sure the design principle is correct, related research on commercial product is needed. The product be chosen is CA6460, therefore more information about this device will be list.
A yellow box which is the source of the idea of this assignment is a well-developed commercial example. This assignment is mainly focusing on the same principle of this yellow box.

System type	Measuring range	Resolution of measurement	Effect to environment	Polarization effect	Robust
2 electrodes	Limited	Normal	Low	High	Normal
4 electrodes	Larger than 2 poles	Higher than 2 poles	Much lower	No	Normal

table 4 compare of EC meters

	2-electrode	4-electrode	Inductive
Polarization effect	Yes	No	No
Field effect	Yes	No	No
Cable resistance	Yes	No	No
Anti-corrosion	No	No	Yes
Price	low	Medium	High
Work environment	Low concentration	Low to high concentration	High concentration
Accuracy	High	High	Reduced
Power consumption	Low	Medium	High

table 5 compare of EC meters (Li, thesis report_Yige Li_2019-06-11, 2019)

From the user UI panel it is able to find out that there are 4 IO port used to connect to the electrodes. This device is used to measuring the resistant of the soil, for the project of 4 EC meter, EC measuring can be seen as a Reciprocal of resistance which is the mathematic process of the measuring resistant. (measuring sketch shows in figure 13)
To make it clear of the yellow box, several tests also need to be down with this device.

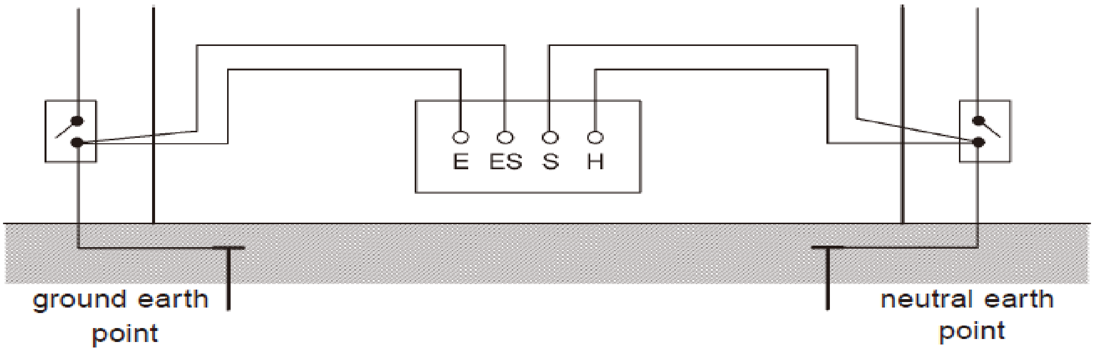


Figure 13 Measuring sketches (C.A. 6460 or C.A. 6462 User manul, 2021)

2.1.4 Chemical reaction

Polarization

When a voltage is supplied to the electrodes, the ions would tend to move toward the opposite electrodes (cations to anode and anions to the cathode). Applying DC voltage for a long period would generate ionic double layers (polarization). This will increase the resistance between the electrodes resulting in a resistance higher then expecting value. (multiflexmeter-ec, 2021)

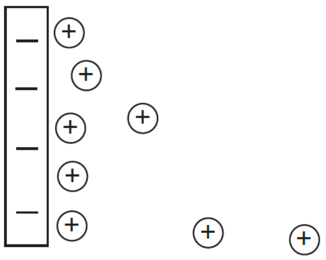
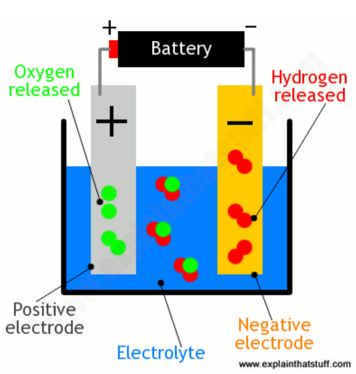


Figure 14 polarization (Li, thesis report_Yige Li_2019-06-11, 2019)

Compare with DC power source used to do the measuring, AC power source have a better performance on avoiding polarization. (polarization shows in figure 14) However, using AC source with 2 probes can only lengthen the time that polarization effect to the results. To get rid of the effect from polarization, 4 probes method can be used, by divided the power probes from measuring probes, polarization will only happen around powering electrodes which means it will not change measuring value.

Electrolysis

Water can be decomposed into hydrogen and oxygen by direct current. When an electric spark passes hydrogen and oxygen together with gases, they combine to form water. Both experiments show that water is composed of hydrogen and oxygen, and their volume ratio is 2 : 1. When there are two electrodes put into water, a circuit are made.(electrolysis shows in figure 15 and figure 16) This kind of circuit can provide electrolyzation. The water will be divided into oxygen and hydrogen at different poles. To avoid this chemical reaction, high frequency AC power source are chosen to apply.



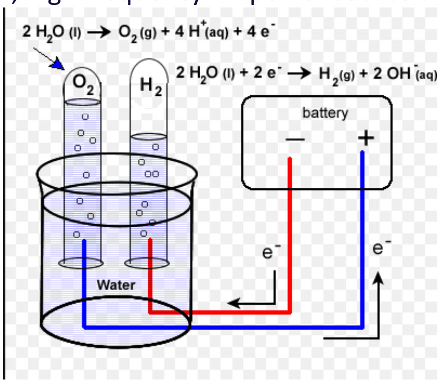


Figure 15 Picture on principle of electrolysis (Du, Final Report Hydrogen, 2020)

Figure 16 Picture about the structure of electrolyze (Du, Final Report Hydrogen, 2020)

2.1.5 Performance criteria & standard

Table 6 Performance criteria table

Items	numbers	units	remark
Measuring range	0mS/cm - >20mS/cm	mS/cm	The larger the better
Required temperature	25℃	℃	Normal environment
Accuracy	10% of error	%	The less the better
Robustness	N/A	N/A	No need for now

Measuring range of EC-meter

Currently Waterschap MFM have a commercial 2 electrodes EC meter which only have the measuring range of 20mS/cm, any of higher EC liquid would cause an error. (shows in figure 17) Thus, the criteria of this 4 electrodes' EC-meter are to have the ability of measuring the liquid that have a higher EC value than 20mS/cm. (Li, thesis report_Yige Li_2019-06-11, 2019)

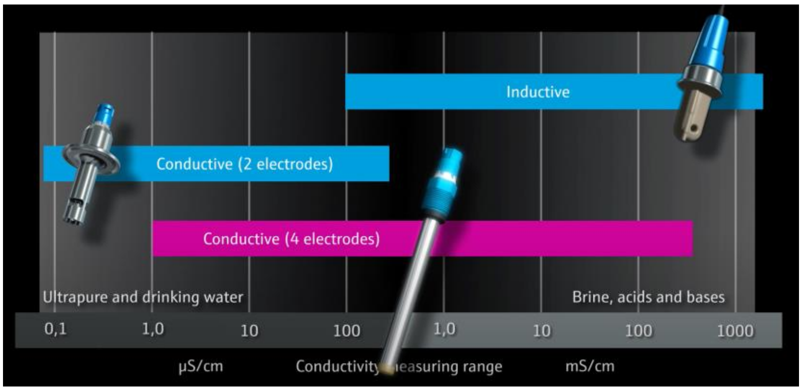


Figure 17 Different type of EC-meters measuring range (Endress+Hauser, 2016)

Measuring temperature
The EC value of a certain liquid is highly affected by its temperature, by listing its temperature-EC graph, relationship between temperature and EC value can be find out and represent by mathematic function or equation. In is assignment, temperature measuring is not required and because of its slight influence, there have no need to making correction in real time.

Measuring accuracy
According to the report from former research team, MFM EC-meter V2 is targeting to have the accuracy of 10% of error. By doing research and discussing, 10% of error is acceptable for this EC meter project. However, considered that 4 electrodes structure may have a better performance, 10% of error are going to be the doable threshold. (Li, thesis report_Yige Li_2019-06-11, 2019)

Measuring robustness
Robustness is a very important evaluating criteria for a product, but as a functional prototype is the final delivery of this assignment, the robustness is not evaluated as a mature commodity. The requirement for prototype is to be functional acceptable, whether it is robust or not is not important for now. It is also not able to test the robust of the prototype for years of using while there have only several months' time for the assignment.

2.1.6 Testing skills

Testing sites
From the assignment objective and prototype function requirements, the test is going to happened in electrical area and chemical area. To making saline solutions that have known concentration, chemical use container and working space are needed, one of the best place is Dockwise of waterschap MFM Vlissingen.(see soil testing site in figure 18) At the Dock, Weighing apparatus for both liquid and salt and mixing tools are able to be used during tests. (GLOBE, 2014)

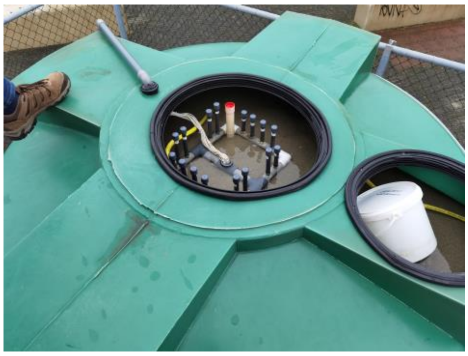


Figure 18 soil salty test site

Equipment
For doing the EC measuring in a certain liquid, equipment that used to contain the testing liquid and other related equipment are needed.

Standard solutions are prepared in two ways:

(1) Direct preparation method

A certain amount of reference reagent was accurately weighed, and then the solution was transferred to a volumetric flask, diluted with reagent water to the scale, and shaken well. The accurate concentration of the reference substance was calculated according to the mass of the reference substance and the volume of the flask.

(2) Indirect preparation method

Indirect preparation method, also known as calibration method, refers to the solution to be prepared into a solution similar to the required concentration, and then use the reference or standard solution to calibrate its accurate concentration.

Matters needing attention:
(1) The sample should be accurately weighed, and the amount should reach a certain value (generally more than 200mg), to reduce the relative error.
(2) Pay attention to the "quantitative transfer" operation, 100.0% of all transfer, there should be no loss.
(3) Pay attention to the purity of reagent water to meet the requirements, to avoid impurities.
(4) keep the bottle mouth tight when shaking well and pay attention to the tight sealing of the bottle stopper to avoid leakage loss. (scientific, 2011)
For the yellow box testing, the equipment is located at the test site and of course CA6460 are needed.

Wearing

You should have the following items with you in the laboratory:

1. **A shirt that covers the stomach, lower back, and upper arms, as well as approved safety eyewear**
2. **Long slacks (An acceptable, but not recommended, alternative is to wear shorts, a skirt, or a lab coat such that your knees are covered when you are sitting down.)**
3. **Shoes that cover the entire foot (Proper Laboratory Clothing, 2011).**

Wearing the following items to lab is not recommended:

1. **Mesh shirts**
2. **Contact glasses**
3. **Tank tops or cropped tees**
4. **Sandals, flip-flops, or other shoes that do not entirely cover your feet**
5. **Shorts or skirts that do not cover your knees when you are seated It is not acceptable to wear sandals with socks (Proper Laboratory Clothing, 2011).**

Planning

Before every test begin, a test plan which shows all kinds of information that are needed should be done and it should also contain the safety issue and executable.
Normally, a test plan contained: Aim, Hypothesis, Tools and devices needed, Actions, Expected Results, Actual results and Improvements.
By having a test planned and the approve of in-company mentor, the test can be executed.
(Kwekkeboom, 2019)

Test log

Test log should be recording during every test, by having a test log, the actual process has been done would be able to be evaluated and repeated by others.
Also, if there have any kinds of problem that might raise afterward the test, the evaluator can have the opportunity to review his or her test and find of the problem.

Test standard CA6460

The test standard of CA6460 can be find in Appendix chapter.

2.1.7 Pricing

The pricing of components and system is also significant and should not be ignored. To keep the main part of the report as brief as possible, further discussion about electrodes, housing shell, and electronics can be found in the appendix.

Chapter 3. Method

Chapters before providing some basic overview and related knowledge, besides of those In this chapter, method that used to accomplish this assignment will be introduce and discuss. Two of the potential researching method will be compare and choice of method will be make and explain.

3.1 Delft design method

Introduction of Delft method mentioned in appendix. See "Delft design"

3.2 V-model design

Figure 19 Process of V-model

V-model is a design methodology which originated published in 1986 by Paul Rook. It is used in software design at first, but it goes popular afterward and also be used in several engineering facilities. The key for the V-model is its way of breaking questions and making solutions based on test.(pr

In V-model design, a main problem which might be complex and difficult would be broken down into numbers of small pieces that are much easier to handle one after another. Every sub-components, sub-systems are going to be tested and validated. All the tests are planned before with logical test plan and the process of the test would be noted and making a test log. By having the test plan and test log, What is verified by the experiment will be more convincing and easier for other scholars to repeat and re-validate. (V-model in figure 20)

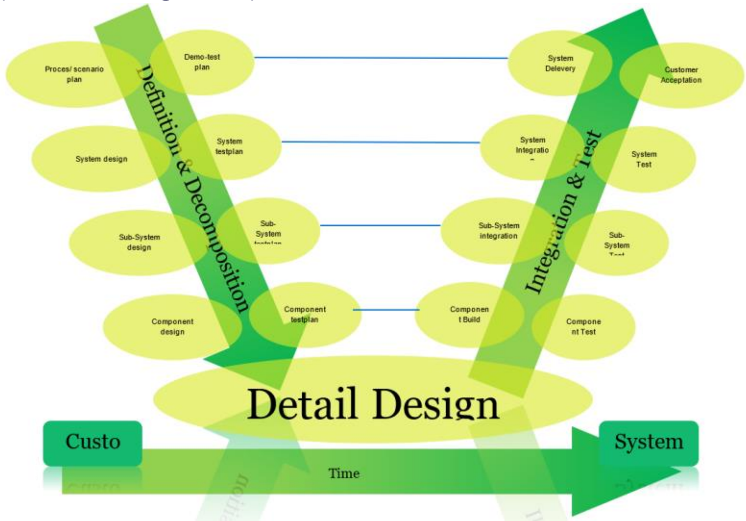


Figure 20 V-model layout (Haak, 2021)

Normally V-model divided the project into System, sub-system, component three parts, each part have their own design phase and integrate phase which are contained several required tests. The flow of order is design from big system to small components and integrate them from small components to one system, this process of the design makes up the shape of a "V". (Kwekkeboom, 2019)
Before the real work start, a demo part which can be used to prearrange and plan for all schedule and works is exist. This part is not only shown in the very beginning of the project but can also happened before every practical test.
Detailed plan and activity can be found in the roadmap, roadmap is a personal guidance of the usage of design methodology, by doing plan setup step by step, a doable and accurate schedule would be made. And by following the plan, the prototype would be finally succeed.
One significant point of this method is that although it is a perfect "V" shape of this overview, the time plan is now as "perfect" as this looks like. As engineer, failed and error are the "best friend" that can never get rid of. To get every plan in logic, it is wise to longer the time of integration. Integration phase is the part that most of failures and unexpected things happen. 4 months of time in total, integration phase have about 2 months of time.(shows in the appendix table 41 and figure 98)

3.3 Choice of the method

Different design methods have their own features and suitable for different kinds of design situation. It should be also considered that the requirements from client and time range also have big effect on the choosing of method.

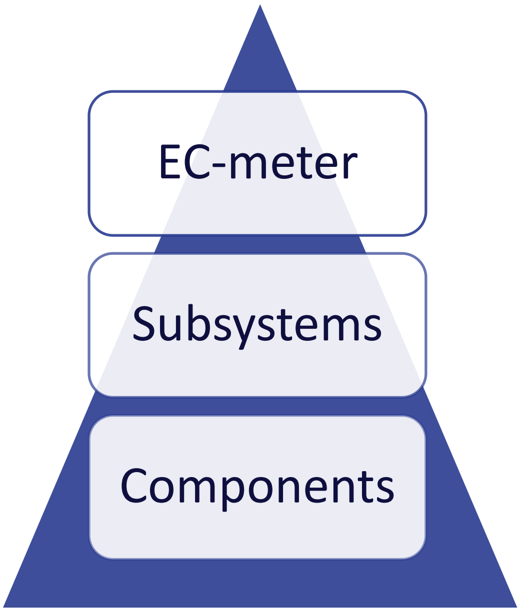


Figure 21 break down of EC-meter

Delft design is quite look into the part of innovation. It is a creativity-based design method which would takes a long time on designing and thinking. On the contrary, realization phase in delft method is not very detailed and clear. Compere with V-model, V-model is like a method which already have a clear direction of designing and spend most of the time of testing and realizing.

With the using of V-model, it would be easier on realizing an idea that already considered. But of course V-model also have phase in analyzing client's requirements. (Figure 21 shows three elements)

In this assignment of EC-meter design, the basic principle of the system is already decided and several requirement are noted from client. Thus, the project is more like to realization an idea of the EC-meter. From this perspective, it is more suitable for the method of V-model. So, the method choice for EC-meter assignment should be V-model. The time plan of the V-model implement will be mentioned in appendix by figures and gantt chart, also the reason for time planning will be mentioned.

Chapter 4. Result

4.1 System design

4.1.1 list of demands

Table 7 table of demand

Num	Requirement	Demand	Wish
1	EC meter should use 4-electrodes measuring method	√	
2	A high frequency AC power source is needed, from 400Hz to 3600Hz, around 800Hz is preference	√	
3	Have a temperature sensor is a good choice		√
4	Electronics cost for per product should be lower than 100€, not include the cost during the designing and electrodes.	√	
5	Material of electrodes should be as common as possible		√
6	Cost of electrodes should be as lower as possible, No certain prices limited		√
7	Design documents should be uploaded to google drive for continuous research	√	
8	Measuring range should be higher than 20mS/cm(2 electrodes commercial EC meter), 1000 mg chloride/liter(previous prototype)	√	
9	Higher sensitivity at high salt concentration		√
10	Better stability at higher salt concentration		√
11	Design the PCB board is better than using bread board as the platform for the prototype		√

From table 7, The list of demands shows the wish and requirements from client and the assignment, demands are defined by numbers and measurable values, wishes are more like a point that can go further on this direction.

4.1.2 System overview

System figure 65 above shows the basic interaction between user, environment, and the system. Environments have some disturb while the system working. And test area has a trigger type of interaction with measuring system. Table 29 below shows the detailed data forms in the communication. Table 30 shows the system description of the main system.
In real design the system looks like figure 72, left upper corner is the sensor module and right side is the processor module, four pin out downside of the graph is the interaction part with environment and test area.

4.1.3 Function overview

Processing from the requirements, the 4 electrodes EC meter contained some other functions divided from main function. Figure 66 shows the whole related function.

Powering function

4-electrodes EC measuring method need a power source which can provide certain voltage or current between two outside electrodes. There are two kinds of ways, one is AC voltage provider, which create a voltage different between two outside electrodes among two inside measuring electrodes. By measuring the current value going through the system resistance can be calculated. The other method is to provide AC current between electrodes, by measuring the voltage value resistance can also be calculated.
For both two methods, the AC source should provide square wave instead of sin or cos wave because square wave is much easier for measuring of current or voltage.
To create this high frequency square wave, a DAC is needed, but for functional test this kind of square wave can be provide by square wave generator in Dockwise and HZ lab.

Measuring function
Measuring function is the function that used to measuring the current or voltage between two inside electrodes. From previous development, it is proved that analog signal directly read by processor is not accurate as expect, so the best way to solve the problem is to use ADC outside of the processor.

Correction function
Correction functions are common in many area, for the EC meter, EC value at different temperature can tells the salt concentration of the liquid. This function normally realized by a temperature sensor.

4.1.4 Input & output diagram
This chapter shows a clear overview of input value and output value for the EC meter system. Also, the form and limits of the input and output value have been made in table for check.

Figure 26 shows the related input and output conditions and table 14 discussed about the values in detail.

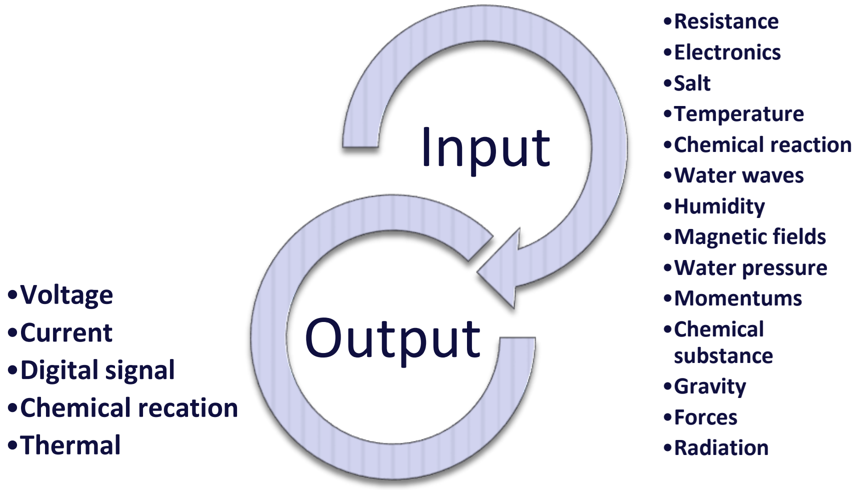


Figure 22 Input and output

4.2 Sub-system design

4.2.1 System division
To descript the system clearly and logically, a division of main system and functions are made, shown in figures in appendix.(See figure 71) The main system divided into four parts: power sub-system, measure sub-system, correction sub-system and process sub-system.
Shown in figure 71, main system divided into 4 sub-systems. These sub-systems will be introduced a little bit here and extended later in sub-system design chapter.
To have a relation between functions and sub-systems, figure 72 is made. Which sub-system contained what kind of functions are described in a visible way.

4.2.2 Sub-system overview
Sub-system overview contains a flow chart of the EC meter system divided by sub-systems. Data transmission and connection between different sub-systems are also shown in the figure 67.
From the figure 67, data interaction inside the system is described and all these communication are explained as measurable as possible in table 31.
After the overview of the sub-system, details for each sub-system will explained individually.

1. Power system overview
Figure 68 shows the principle of powering system, the main interaction is though electrodes. Noticed, this powering system is not used to powering the processor but powered by Arduino NANO (the processor), the processor will powered buy USB cable in this design but can be replaced by cells.
Table 32 list the signal details. A 4bleeder circuit are designed to control the output voltage.

2. Measuring system

Figure 69 described the structure of the measuring system, table 33 shows the detail of data communication in between. By using the measuring system, the nodes' voltage between three resistors can be detected.

3. Correcting system overview

Compare with measuring system, the correction system is simpler and clearer. This part is mainly about the use of temperature sensor, sub-system overview shows in figure 70 and data details explained in table 34. Figure 35 shows the "one line" communication method used in this sub-system.

4.2.3 Sub-system description

I. Powering system

Input	Symbols	Units	Min	Max		Output	Symbols	Units	Min	Max
Voltage	U	V	0	5	powering Sub-system	Voltage	U	V	0	
Current	I	A	0			Current	I	A	0	
Power	P	W	0			Power	P	W	0	
Analog signal	N/A	N/A	N/A	N/A		Digital signal	N/A	N/A	N/A	N/A
Digital signal	N/A	N/A	N/A	N/A						

table 8 Powering system description

This table shows the system description of powering system, some of the input environmental effect have been blanked from the main system description.

2. Measuring system

Input	Symbols	Units	Min	Max		Output	Symbols	Units	Min	Max
Resistance	R	Ω	0	99999999	Measuring Sub-system	Digital signal	N/A	N/A	N/A	N/A
Current	I	A	0	0.5						
Power	P	W	0	2.5						
Analog signal	N/A	N/A	N/A	N/A						
Digital signal	N/A	N/A	N/A	N/A						

table 9 Measuring system description

This table shows the system description of measuring system, some of the input environmental effect have been blanked from the main system description.

3. Correcting system

Input	Symbols	Units	Min	Max		Output	Symbols	Units	Min	Max
Temperature	T	℃	0	40	Measuring Sub-system	Digital signal	N/A	N/A	N/A	N/A
Voltage	U	V	0	5						

table 10 Correction system description

This table shows the system description of Correcting system, some of the input environmental effect have been blanked from the main system description.

4.3 Components design

4.3.1 AC source sub-system component design

I. Power source component

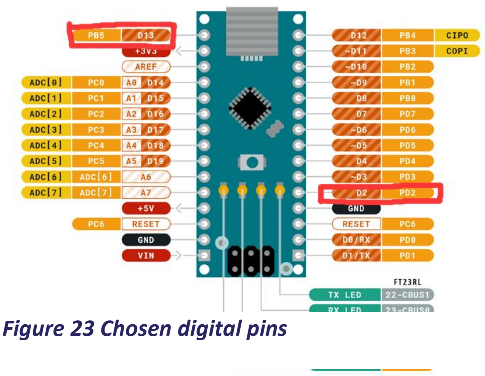


Figure 23 Chosen digital pins

The component that chosen to be as the power source is the Arduino NANO board which can provide 4.8V on digital pins and Analog pins.
Considered that the analog pins are not able to be used at high frequency, 2 digital pins are used in prototype. In the testing period D2 and D13 pins are chosen to test.
(see figure 23 NANO digital pins that been chosen)
another part of the powering system is the bleeder circuit, it is established by different number of resistors. By dividing the output voltage by 1/6 and 1/3, a 0.5V AC wave can be generated. In this situation, to divide the voltage at fixed ratio, four resistors are list: 510Ω, 100Ω, 200Ω. (see list in table 11)

Type	Quantity	photo
100 Ω	2	
510 Ω	1	
200 Ω	1	

table 11 List of resistors

4.3.2 Measuring sub-system component design & test-plan

I. Voltage sensor design

According to the principle of EC meter system, there are two values need to be detected if only use voltage sensor. One is the voltage of reference resistor; the other is the voltage of measuring liquid or resistance. To achieve the function of voltage detection, two sensors are available. They are ADS1015 and ADS1115, these two sensors are the same series which share a same software library and easy two use, the difference are working sample rate and accuracy. (See photos of ADS1X15 in figure 24 and 25)

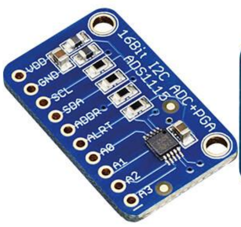


Figure 24 Adafruit ADS1015 (www.reichelt.nl, 2022)

Figure 25 Adafruit ADS1115 (www.reichelt.nl, 2022)

In this part of the system, accuracy is more important so ADS1115 is chosen to be test and use. To test its usage and accuracy in sub-system, a test-plan is made and executed in Appendix.

2. Current sensor

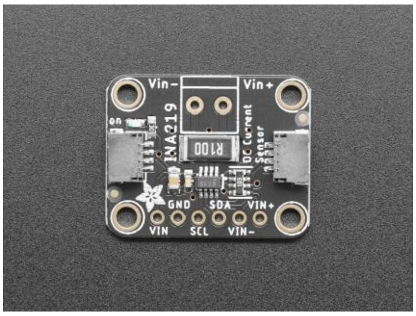


Figure 26 INA219 current sensor (adafruit, 2022)

Apart from voltage sensor, there also have a possible way by using the current sensor to detect the current value directly through the measuring liquid. But this method needs to use the voltage sensor and current sensor at the same time which means this might increase the complex of the system and higher the risk of failures and errors.
One accessible sensor recommended by my in-company mentor Mr. Goossen is INA219. To figure out if this component is fit to my system and have a clear view of its accuracy, a test-plan is made and executed. Details can be found in Appendix. (See figure 26 INA219)

4.3.3 Correcting sub-system component design

Figure 27 DS18B20 (ds18b20-temperature-sensor-wired, 2022)

Different from other two sub-system, the correction system is not as highly related as the main measuring action. In real measuring situation, using a temperature sensor is to record the liquid or resistor temperature at the moment of measuring action.(see figure 27 DS18B20)
The temperature needs to be record because EC value will be affect by temperature, this means same liquid will have different EC value at different temperature. This part is slightly out of the scope, so during this section the correction system will be design but not integrated into the whole final system. During the real use, this can be used to record the temperature manually.
The component is chosen by my in-company mentor, it is DS18B20.

4.4 Test-plan

4.4.1 component test-plan

To validate the functionality of components, component test-plan are made and mentioned in the chapter before. Several components test-plan are given in appendix: ADS1115, INA219, DS18B20.

4.4.2 sub-system test-plan

According to the system division, sub-systems are divided into three. Sub-systems' test-plan are also followed these and three tests are designed. By testing the powering system, measuring system, and correcting system, the usage of sub-systems is validated. To make the test-plan related with results and actions, every test-plan have its own content and result chapter. See in Appendix.

4.4.3 system test-plan

To make sure the final integrated system can work as expect, system test-plan is made and executed. This system does not include the temperature sub-system which will be mentioned later at sub-system integration chapter. See system test-plan in Appendix.

4.4.4 demo test-plan

Demonstration of the system is not completely the same as system test, demonstration need to be as clear and easy as possible and also need to show that the system is achieved the scope or requirement. See demo test-plan in Appendix.

4.5 Sub-system integration

The order of realizing the sub-system would be start from powering system, then, the integration of measuring system and whole system integrating and finally test the temperature sub-system.
The integration is not the last one because temperature correction sub-system is less complex than the measuring system. From the view of function, the measuring function is the core function which decided the successful of whole system. For temperature correction system, it is more on improve the accuracy and usage in different environments.

4.5.1 Powering sub-system

According to the design and test from previous student Yige Li and Pinqi Guo, they have proved that 555-timer circuit and Digital write function from Arduino have several drawbacks. For example, by using the analog output pin from Arduino, the frequency output would be limited by the type of the Arduino board, in their situation it is limited by 500Hz. So this is one of the problem that need to be solved.
By analyzing the reports from previous students, a list of demands is made below.(table 12)

Items	Demands
Frequency	The frequency of the AC square wave power source should be able to adjust from 1Hz to 3600Hz Should be able to work at the frequency from 800Hz to 900 Hz
Output voltage	The difference between high peek of the voltage and the low peek of the voltage should be lower than 200mV in absolute value The absolute voltage peek should be lower than 1000mV
Frequency error	The error between setting frequency and actual frequency should be lower than 5%

table 12 List of demands of sub-system

From the report of Mick van Eerd, it is recommended to use DDS or DAC to generate high frequency AC square wave. The report mentioned that the best frequency of AC square wave power source is around 820Hz.
During this project, by concerning about tests and designs that have done by previous students, three direction of researching are listed: Digital powering, analog powering, and DAC powering. Because of the limitation of frequency while use analog powering, this way is not suitable for this system. Compare with DAC method, using digital signal directly have a better response and easier to cooperatively work with measuring system.

Digital powering with outside bleeder circuit

Digital pins are most common and basic IO pins of Arduino, but it is not able to adjust its output voltage by software. So an outside circuit used to lower its output voltage is needed. Frequency adjust can be done by sofware.(See designed bleeder circuit in figure 28)
But one disadvantage that already found is that the output digital signal can only be 0 and 1 which represent 0V low level and 3.3~5V high level. Output voltage of Arduino NANO digital pin is about 3.72V with 1KΩ resistant, so to achieve the demand of 0.5V-0.8V voltage output those resistors used to create the bleeder circuit will be adjusted.

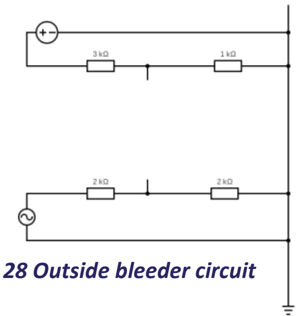


Figure 28 Outside bleeder circuit

Components list of powering integration:

Num	Amount	Name	Marks	Price
1	1	Arduino NANO	Main processor, one for all	€18,90
2	2	100Ω Resistor	Bleeder circuit parts	€0(€0.08/100)
3	1	680Ω Resistor	Bleeder circuit parts	€0(€0.03/100)
4	1	270Ω Resistor	Bleeder circuit parts	€0(€0.06/100)
5	1	PCB board	Basic board for powering test	€4/ piece
6	10	MM wires	For test executing	€0

table 13 Component list for sub-system

The list above contained the parts that needed for integrating the powering sub-system. “€0” on the list is because those parts are found in stock and do not need to purchase from another supplier. (See components list in table 13)

Test results for powering system

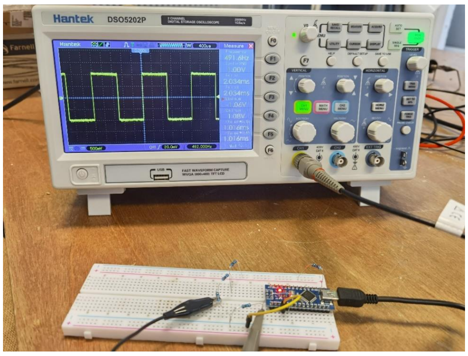


Figure 29 One of the test setup

The photo of test setup and outside circuit setup showing in the Figure 21 and 31. During the test reading from measuring and monitoring equipment is the way to record the data, thus, it is significant to think about the accuracy of the measuring tools. In this test, the measuring tool is an oscilloscope from “Hantek”. Type of this equipment is DS05202P. By checking the datasheet of this device, measuring range of 200MHz and sample rate of 1GS/s. Also there is a warmup process for this scope, after 20mins warmup it can work on the highest accurate situation. Discussed with Mr. Goossen, it is reliable to confirm the reading data as accurate and ignore its error.

4.5.2 measuring sub-system

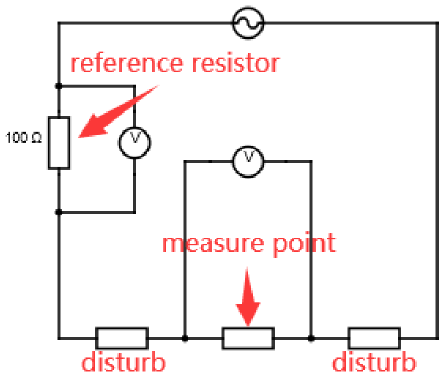


Figure 31 measuring circuit diagram

The EC value measuring is sort of resistance measuring, by calculate from resistance, EC value are clear. Thus the measuring of EC is able to transfer to the measuring of resistance of the liquid.
To measuring the resistance, two key values are necessary. One is the voltage of the target and the other is the current value going through the target. To detect the voltage on the measuring resistor, ADS1115 is one of the option. By using ADS1115 and another known resistor, the current in the circuit can also be calculate.
The test plan for measuring system test will be in appendix.

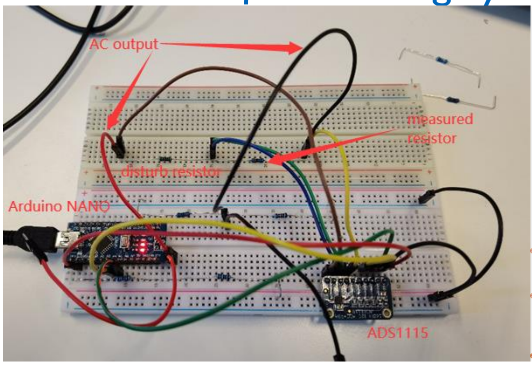
Component list for measuring system

Number	Amount	Name	Marks	Price
1	1	Arduino NANO	Main processor one for all	€18,90
2	1	Resistor 10Ω	Reference resistor	€0(€0.02/100)
3	1	ADS1115 voltage sensor	Main sensor	€8.95
4	1	PCB board	Basic board	€4
5	10	MM wires	Test executing use	€0

table 14 Component list for sub-system

The table above shows the parts that needed to build a measuring sub-system. Notice that the Arduino NANO is the same one with the powering system. “€0” means that these parts can be found at Dock do not need to purchase additional one. Price in bracket is the price to buy additional.(See table 15 components list)

Test results of measuring system



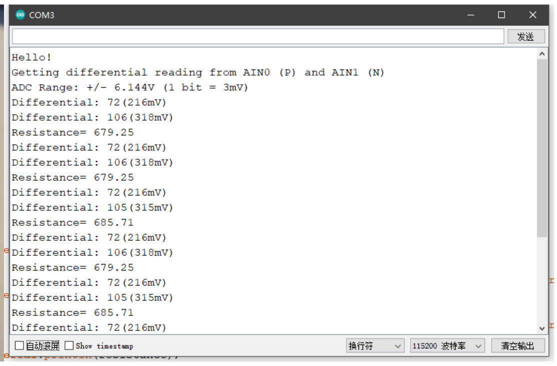
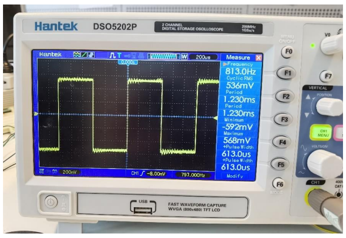


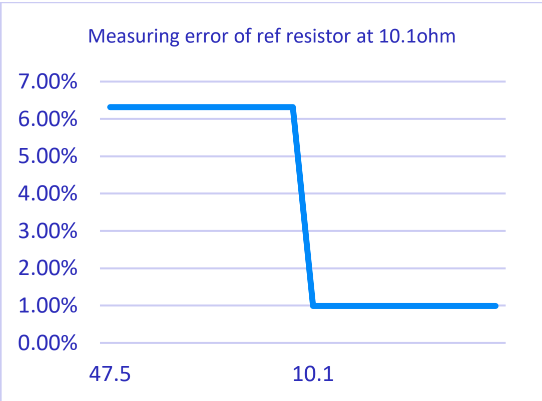
Figure 32 circuit setup(left)

Figure 33 Reading value from serial monitor (right)



From the test, AC square wave is detected by the scope on testing resistors' circuit.(see setup and readings in figure 32 33)
This proved that AC square wave source can be used on outside circuit. (see AC square in figure 34)

Figure 34 scope setup(left)



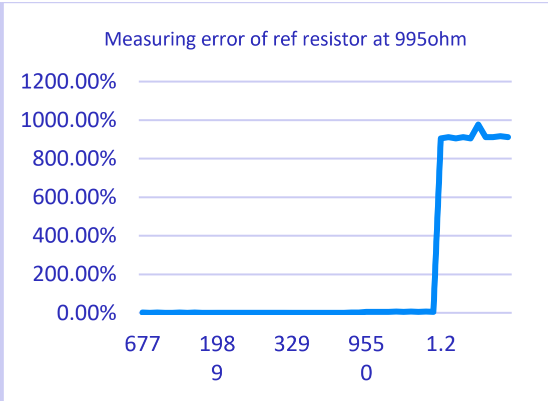
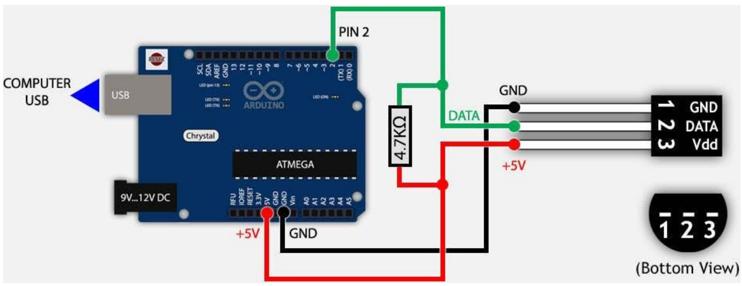


table 15 Error table result 1 on left

table 16 Error table result 2 on right

This two graph shows a roughly line of errors, the more reference resistor close to the measured resistor the more accurate result system can get.

4.5.3 Correcting sub-system



Correcting sub-system mainly use the sensor called DS18B20. This sensor has 3 wires, 2 of those are power wire and the other one is data line. It is using a unique one wire communication with processor. By established this circuit, the temperature value can be read by the processor and shows on the serial monitor.

Figure 35 One wire communication circuit

Component list for correcting system

Number	Amount	Name	Marks	Price
1	1	Arduino NANO	Main processor one for all	€18,90
2	1	Resistor 4.7KΩ	Circuit resistor	€0(€0.02/100)

3	1	DS18B20 temperature sensor	Main sensor, contained the long wire and steel shell	€0(€6.15)
4	10	MM wires	Test executing use	€0

table 17 component list for sub-system

The table above shows the parts that needed to build a correcting sub-system. Notice that the Arduino NANO is the same one with the powering system. "€0" means that these parts can be found at Dock do not need to purchase additional one. Price in bracket is the price to buy additional.

Test results

target	temp from measuring (℃)	temp from sensor (℃)	deviation (℃)	error(%)
1413μs/cm liquid	22.1	22	0.1	0.45%
indoor temperature air	22.7	23.06	0.36	1.59%
salt water	20.8	20.5	0.3	1.44%
indoor temperature air2	21.6	21.44	0.16	0.74%

According to the data collected from test above, the designed correction system can achieved an accuracy close to professional commercial temperature sensor. This result is meeting the requirement and able to be used during the test. (See test table in figure 36)

Figure 36 Temperature test table

4.6 System integration

System integration contained two parts of work, one is the combination of sub-systems and the other is the test of main system. During the combination of sub-systems, two of them are considered to integrated: Powering system and measuring system. When executing the test, correction sub-system can work individually to record the data.
The key point of the system integration is the main processor, by using the same processor, the frequency of the AC wave can be in sync with the measuring system.

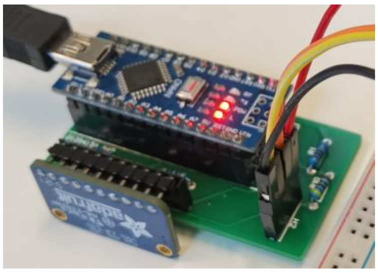


Figure 37 PCB piece of the integrated system(right)

Components list of main system

Number	Amount	Name	Marks	Price
1	1	Arduino NANO	Main processor one for all	€18,90
2	1	Resistor 10Ω	Reference resistor	€0(€0.02/100)
3	1	ADS1115 voltage sensor	Main sensor	€8.95
	1	PCB board	Basic board	€4
4	10	MM wires	Test executing use	€0
5	2	100Ω Resistor	Bleeder circuit parts	€0(€0.08/100)
6	1	680Ω Resistor	Bleeder circuit parts	€0(€0.03/100)
7	1	270Ω Resistor	Bleeder circuit parts	€0(€0.06/100)
8	1	Correcting sub-system	Optional	€0

table 18 Component list for system

The list form above did not shows the cost of labor. If consider about the labor, soldering takes 40mins (include the soldering on wires between electrodes and system), 3D printing of electrodes shell need 4 hours, program loading and functional test takes 20mins. In total, with all the components in stock, an assembly takes 5hours by one worker.

Risk list

In this section as an integrating of the final whole system, it is obvious that there has a huge possibility of failures happened. Failures may not only happened during the integrating but also will happened during the validating test. Thus, make a risk list is one possible way to avoid or predict failures as much as possible.

Num.	Items	Description
1	Electrodes waterproof	Not well waterproofed and test liquid overflow to the upper side of the electrodes
2	Electric field shielding	The test will affect by outside electric field
3	Wiring	Welding point over connect or opened
4	Short circuit	Short circuit happened and damaged the processor and sensor
5	Polarization	Using 4 electrodes AC method but still have polarization
6	Software failure	Software may meet problem and crashed
7	Electrodes damage	Polarization and Ionizing corrosion may permanently damage the electrode
8	Overload penetration	The electrodes shell may be penetrated by current and disabled or causing short circuit
9	Unknow effect from measuring area	The test may be affect by the space of test area, results on open area and lab area might have huge difference
10	Electrodes shell shaping problem	The shape of electrodes' shell may affect the result
11	Capacity affect	The capacity of liquid may affect the results

table 19 Risk list

System test

Tests introduce

The system test will focus on the real KCL liquid EC measuring, to cover all range in the scope, several solutions of KCL liquid are made. The original liquid is 1N KCL comes from HZ chemistry department, thanks to Mr. M.J. van den Berge (marcel.van.den.berge@hz.nl).
Four solutions of liquid are made, they are 1N, 0.5N, 0.1N, and 0.01N, each solution have 200ml store in sealable containers to prevent from volatilization and evaporation.

Test results

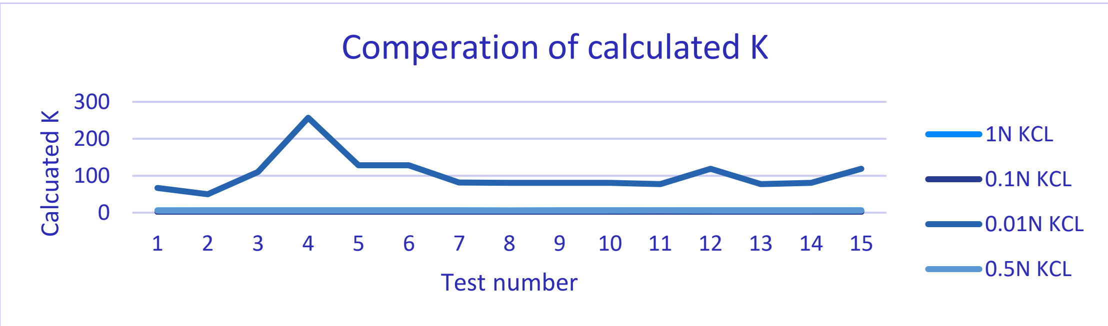


Figure 38 Results of system test

From the tests in different solution of liquid, it is found that the designed system can work on 1N to 0.1N solution range if the solution lower to 0.01N the system is not able to maintain stable operation. See figure above, the line chart shows the 15 times test K value on different solution. K value is the calculated scale between commercial result and measured 1/R, in the area of physics , K can be calculated by $(\frac{L}{A} * Compensation\ factor)$. If we transfer the 1N and 0.1N KCL into EC value, the measuring range is from 12.8246mS/cm to 108.62mS/cm at 25℃ (W.M.Haynes, 2010).

Chapter5. Discussion

Throughout the course of the project, three words can be used as title to discuss: Arrangement, design, and Proof.
First of all, “Arrangement”. During the researching period, V-model has been chosen as the design method. By following the step of V-model, problem has been decomposed and simplified, and milestones for the assignment also set. This part draws a clear time and structure sketch for the project.
Second one, “Design”. As the beginning of technical part, the design decided the limitation of the system. By learning from commercial equipment and previous senior’s design, the AC square wave sub-system achieved the requirements by an extremely easy way which brings the great reliability and stability. Also, by using Wenner method and other compensation methods, the measuring sub-system achieved a high accuracy when doing lab tests.
Finally, “Proof”. To have a clear view of the designed system, full range of tests are needed which can not only prove the functionality of the system but also point out short comes of the system. A system without any short comes is not exist, when implementing the tests, deviation of the system in different using situation are listed, besides the working range and potential affecting from environment are listed as the risk. By learning from the tests, more and more recommendations can be provided and the improving of the system will be easier in the future.

5.1 AC power sub-system

According to the error table extracted from the results table shows in table 17, by get rid of the data which can be identified as mistake, a positive correlation trend has been found between error rate and set frequency. The higher frequency it set, the larger error there will be. So it is wise to set the working frequency at around 800Hz.

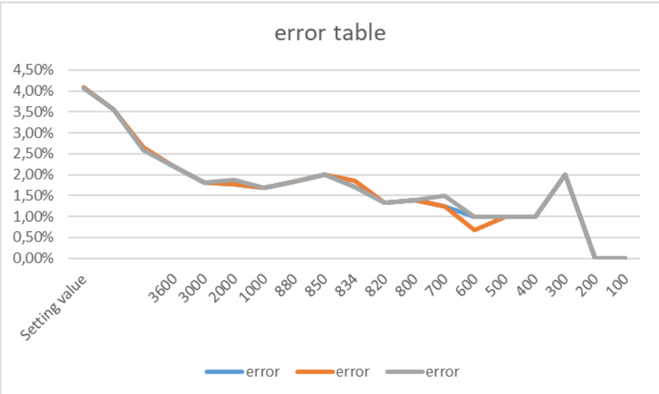


table 20 Table of the errors

Two related points might be effect by this error. The first one is the chemical reaction which is also mentioned before as “polarization”, the key reason for using AC square wave is to prevent the system from polarization, according to the report from Mike and user manual of CA6460 (known as “the yellow box”), it is proved that 800Hz is the best frequency for measuring. Thus, in the view of chemical concerned, this error is acceptable.
Another point is the error stack for the system, it is necessary to consider if the error in this sub-system will also multiply with the error comes from next sub-system. From the view of measuring system, the measuring chip ADS1115 is working at DC based power so the powering job is not the part for AC source, this means that there is no interact between them. During the action of measuring, the detecting process happened in a stable part of the wave shape which been defined by software(shown in figure 13), so the detecting always happened on high level or low level but not at the edge, therefore the frequency of the AC source is not a problem.

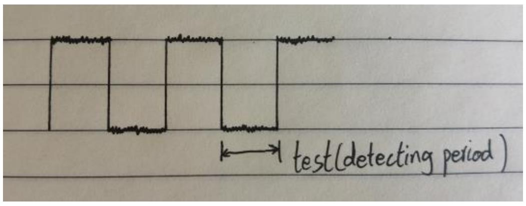


Figure 39 Measuring(detecting) period of ADS1115

All in all, the deviation of the real frequency in setting frequency will not highly influent the system accuracy.

5.2 Measuring sub-system

The error shows in the table above(table 19 and table 20) represent the deviation situation between the final measuring resistance results and actual resistance been measured by the multimeter.
In this process several errors may happened and multiplied together.
They are:

1. **Voltage detecting errors from ADS1115(unavoidable)**
2. **Measuring errors of resistance from multimeter(unavoidable)**
3. **Deviations between the reading value of resistors and actual resistance(unavoidable)**
4. **Resistance and poor contact of breadboard and test setup**

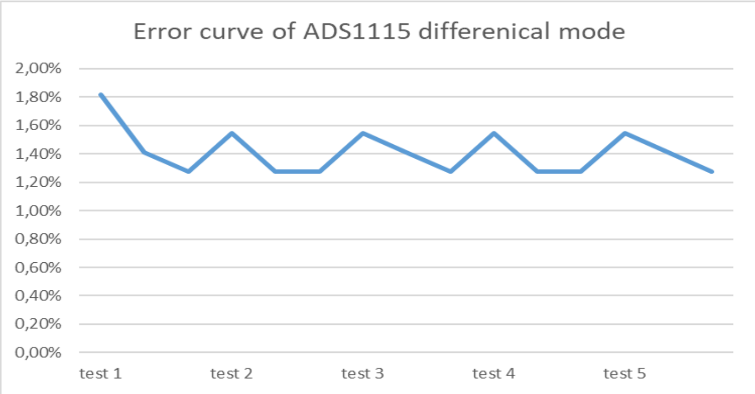


Figure 40 Error curve of ADS1115

Firstly, the error of ADS1115. According to the components test(test plan and results shown in the appendix) of ADS1115. Its error curve is drawn and considered(shown in the table below). From the curve we can find out that the average error is about 1.4% which is much higher than the final error results, if the errors are simply multiplied with each other the final deviation would be much higher than now. The reason for measuring system has a much lower error is because of the measuring method. Normally measuring method using voltage sensor and current sensor together, at this moment, error from voltage sensor and error from current sensor are separate and no relation which making their final error added and going higher. But the measuring method here is using only one voltage sensor and measuring two resistance together, use one known reference resistor to calculate another resistor to be measured. This means the value from reference resistor and the value from measuring resistor have a same deviation from same sensor. Thus the final deviation will be decreased by its calculation process. For example, if we defined reference value as “b”, measured value as “c” and there is an error of a% higher. Following the calculation:

$$actual\ result = \frac{c*(1+a\%)}{b*(1+a\%)} = \frac{c}{b}$$

$$ideal\ result = \frac{c}{b}$$

$$error = \frac{|actual\ result - ideal\ result|}{ideal\ result} = \frac{c/b}{c/b} = 0$$

We can delightedly found that the error itself has been eliminated. This explained why the final results’ errors are lower than expected.

Besides, from the error curve of final results, we can find that the error has a firmly positive correlation with the difference between the resistance of reference resistor and measured resistor. In other words, the larger difference between reference resistor and measuring resistor, the bigger error will be caused. But from the calculation, the value difference is not influent the error at sensor level at all, this also proved that the final error is not related with sensor’s error itself.

Thus, the final error can be explained as caused by multimeter’s reading error and contacting problems inside of the test setup(mainly from breadboard and jumping wires). Reading errors from multimeter is unavoidable but can be decreased by using different type of meter getting average value. Errors inside of the setup cannot be fixed also but using PCB for prototype will fix this in a large extent.

5.3 Correcting sub-system

During the repeat of test, it is found that the error between commercial sensor and designed system would getting lower over time. This means that the longer measuring time the higher accuracy it has. From the view of heat transfer, this time delay mainly caused by the sensor probes’ material, the commercial one using expensive steel which performs better than normal stainless steel.

5.4 Integrated main system

From the figure on the left, Ks value calculated from test result are listed, this is the measuring value calculated by ideal value. Ideal EC value comes from “Handbook of Chemistry and Physics”. This Ks value means the accurate constant:

$(\frac{L}{A} * Compensation\ factor)$ At the solution of 1N this value is around 5.4±0.1; At 0.5N this value is around 4.8±0.1; At 0.1N this value is around 1.7±0.1.
Because of the same electrodes being used in the test, L/A value should be a constant, if compensation factor is also a constant, then the Ks should be a constant too, which is not match the tests' results. This means that the compensation factor is not a constant and it is related to the liquid solution but not a linear correlation.

From the risk list in table 31, this compensation factor could be affected by these :

1. **Liquid capacity effect**
2. **Electrodes shaping effect**

Among them, liquid capacity effect has the highest possibility considered that this system is using AC power source. The other possibility is the shape of electrodes' shell, the shape of the shell, such as small gapes between electrodes or ventilation holes on the top may affect the electromagnetic shielding capability of the shell itself or affect the capacity inside.

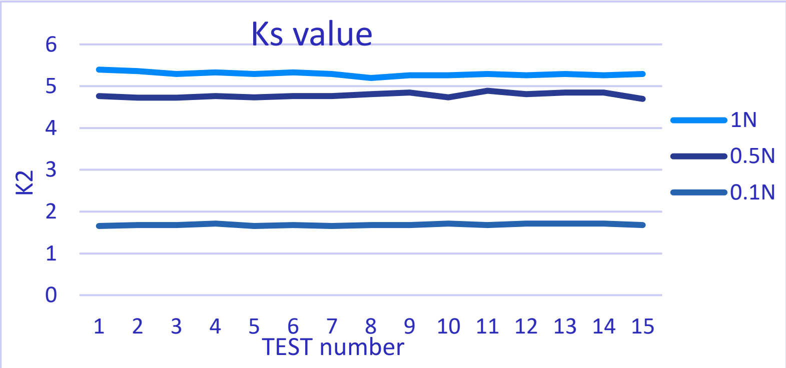


Figure 41 Calculated Ks value

Chapter6. Conclusions, recommendations

6.1 Conclusions from tests

6.1.1 AC power sub-system

By following the test, working frequency around 800Hz(+-50Hz) is achievable and stable. Operating deviation is lower than 3% which is acceptable. Next section will analyze the deviation from where it happened and how it influences the system.

6.1.2 Measuring sub-system

The measuring setup is correct and functionally doable by following the designed circuit.
ADS1115 is suitable in error range for this sub-system. The more ref-resistor's resistance close to the measured resistance, the less measuring error will shows

6.1.3 Correcting sub-system

From the test results, it can be found that the designed system has a quick response on temperature measuring. Considered that the designed system has only no more than 2% of error compare with the commercial lab level temperature sensor, the correction sub-system passed the test and achieved the requirement. This sub-system can be use in real measuring.

6.1.4 Integrated main system

From the outcome of several tests, it is proved that the designed system can achieved lower than 10% of deviation during resistance measuring, but in liquid measuring the effect of capacity still need to be eliminate and accurate K constant need to be optimized but capacity compensation.

The stable measuring data proved that the system could work at the range from 12.8246mS/cm to more than 108.62mS/cm at 25℃, which is far beyond the requirement of 20mS/cm. The only not stable range is from 0mS/cm to 12mS/cm, this can be solved by increasing the resistance of reference resistor.

6.2 Answer to main question

What is the design of 4 poles EC meter which have a larger working range(more than 0-20mS/cm) and higher accuracy(lower than 10% error) by using AC power source and V-model design methodology?

Answer: The designed prototype of 4-electrodes EC meter consists of 800Hz AC power source and 4 probes voltage sensor, validated by V-model design method and real liquid tests.

6.3 Answer to sub-questions

1. What kind of system is suitable for 4-electrodes EC-meter to achieve its measuring function on larger working range and higher accuracy?

Answer: A 800Hz Wenner method 4-electrodes sensor system is suitable for this project.

2. What is the design of system description of 4-electrodes EC meter?

Answer: The design of the system and description can be found in chapter 4.1.

3. What is the design of sub-system description of 4-electrodes EC meter?

Answer: The design of sub-systems and their description can be found in chapter 4.2.

4. What is the design of test plan for 4-electrodes EC meter?

Answer: The test plan for this assignment can be found in chapter 4.4.

5. What is the validation of the working range and measuring accuracy of the 4-electrodes EC-meter in lab and presenting room?

Answer: The validation of working range will be done at lab because of the liquid sample and longer measuring time required, the measuring accuracy can be reproduced in presenting room by measuring the resistors.

6. What are the test results and data analysis of 4 electrodes EC meter?

Answer: The test results and analysis can be found in both chapter 4.5 and chapter 5, detailed original data can be found in Appendix of test plan.

6.4 Recommendations to further research

6.4.1 Power system

As the MFM EC meter is a continuous assignment, this designed system also absorbed lots of recommendation and suggestion from previous work. According to Yige Li's report (Li, thesis report_Yige Li_2019-06-11, 2019) the power source can be improved by a better shape square wave and adjustable frequency is strongly recommended. The new designed 4-electrodes EC meter using an adjustable AC square wave source which need to match with the voltage sensor by software control, this solution making the system have a large range of adjustable frequency and good shape of square wave. However, the trigger of voltage sensor ais controlled by square waves' cycle counting, for example one detect of voltage per 800 cycles of square wave. I recommend improving this part by cutting off the relation between cycles and sensor trigger, it is wise to synchronize the AC frequency with sensor's detecting frequency. By doing this, the system can gathered more data in a shorter time and by processing these data the error of the system can be reduced.

6.4.2 Measuring system

The measuring system is accurate enough for not, but it is not able to synchronize with AC source's frequency. My recommendation for this part is to find a software way to synchronize the sensor or to find another sensor. For the type of the sensor, voltage sensor has a much higher accuracy compare with the current sensor.

6.4.3 Correcting system

Temperature correcting system is validated as functional, during this project, because the commercial EC meter already have a temperature sensor, the designed correcting system do not been used in test. I recommend integrating that part into the PCB broad with can make the whole system stable and smart on size.

Chapter 7. References

adafruit. (2022, 3 1). *product*. Retrieved from www.adafruit.com: https://www.adafruit.com/product/904

arduino. (2021, 12 20). Retrieved from Github: https://github.com/arduino/Arduino

Ardunio. (2018, 2 5). Retrieved from arduni.cc: https://www.arduino.cc/en/Guide/Introduction

C.A. 6460 or C.A. 6462 User manul. (2021, 2 1).

Chauvin-arnoux. (2001, 12). chauvin-arnoux-c-a-6460-earth-earth-resistance-tester-p01126501-user-manual.

cole-parmer. (2020, 3 5). Retrieved from coleparmer.com: https://www.coleparmer.com/tech-article/conductivity#:~:text=The%20principle%20by%20which%20instruments,through%20the%20solution%20is%20measured.

D, C. (2020, 8 20). *how-much-does-a-pcb-cost-factors-that-will-affect-the-price*. Retrieved from svtronics.com: https://svtronics.com/blog/how-much-does-a-pcb-cost-factors-that-will-affect-the-price/#:~:text=In%20general%2C%20the%20cost%20to,and%20type%20of%20material%20used.

ds18b20-temperature-sensor-wired. (2022, 4 5). Retrieved from pcboard.ca: https://www.pcboard.ca/ds18b20-temperature-sensor-wired

Du, F. (2020). *Final Report Hydrogen.*

Du, F. (2021). Research proposal_FeifanDu_V5_20210318.

Endress+Hauser. (2016, 4 26). Four-electrode conductivity measurement.

Farnell. (2022, 2 25). Retrieved from farnell.com: https://nl.farnell.com/en-NL/search?st=ec%20sensor

Farnell. (2022, 2 25). Retrieved from farnell.com: https://nl.farnell.com/en-NL/c/embedded-computers-education-maker-boards/arduino/embedded-development-kits-arduino

GLOBE. (2014). *Electrical Conductivity protocol.*

Goossen, J. (2022, 2 14). 2022_thesis project MFM 4-electrodes EC-meter. Vlissingen, Zeeland, Netherlands.

Guide/introduction. (2018, 2 5). Retrieved from arduino.cc: https://www.arduino.cc/en/Guide/Introduction

Guo, P. (2021). *2021-06-11-Thesis report Pinqi Guo.*

Haak, W. (2021). *ENG-MET-Syst-meth-B-2021-09-13-WHk.* Vlisssingen: HZ University.

Hoog, W. v. (2010). *Delft design guide.* Delft: Faculteit Industrieel Ontwerpen.

Jagt, W. v. (2019). *Engineering dsign methodology.* HZ university of applied sciences.

Kester, R. L. (2016, 11). Fully Automatic Self-Calibrated Conductivity Measurement System. Retrieved from AnalogDialogue: https://www.analog.com/cn/analog-dialogue/articles/fully-automatic-self-calibrated-conductivity-measurement-system.html#:~:text=%E7%94%B5%E5%AF%BC%E7%8E%87%E6%B5%8B%E9%87%8F%E7%94%B5%E8%B7%AF%E9%80%9A%E8%BF%87,%E5%A6%82%E5%9B%BE1%E6%89%80%E7%A4%BA%E3%80%8

Kester, R. L. (n.d.). *fully-automatic-self-calibrated-conductivity-measurement-system*. Retrieved from www.analog.com: https://www.analog.com/cn/analog-dialogue/articles/fully-automatic-self-calibrated-conductivity-measurement-system.html

Kwekkeboom, G. (2019). *THE ENGINEER'S GUIDE TO THE V-MODEL.* Driewegen: Pumbo.nl.

Li, Y. (2019). *thesis report_Yige Li_2019-06-11.* Waterschap MFM.

Li, Y. (2019). *thesis report_Yige Li_2019-06-11.*

LINECARD - ARDUINO. (2022, 2 14). Retrieved from TEM electronic components: https://www.tme.eu/nl/linecard/p,arduino_881/

MFM EC-meter. (2022, 2 15). Retrieved from Multiflexmeter: https://www.multiflexmeter.nl/logboek/multiflexmeter-ec/

Multiflexmeter. (2022). *2022_thesis project MFM 4-electrodes EC-meter.*

multiflexmeter-ec. (2021). Retrieved from https://www.multiflexmeter.nl/logboek/multiflexmeter-ec/: https://https://www.multiflexmeter.nl/logboek/multiflexmeter-ec//logboek/multiflexmeter-ec/

Netherlands Labour Costs. (2021). Retrieved from Trading economics.

Proper Laboratory Clothing. (2011). Retrieved from chemed.chem.purdue.edu: https://chemed.chem.purdue.edu/genchem/lab/safety/clothing.html

Raspberry Pi. (2022, 2 15). Retrieved from Raspberry PI/news: https://www.raspberrypi.com/
Raspberry pi fundation. (2022, 2 15). Retrieved from raspberry pi website: https://www.raspberrypi.org/about/
scientific, F. (2011). *LaboratorySolutionPreparation.*
W.M.Haynes. (2010). *CRC Handbook of Chemistry and Physics, 91th Edition.* CRC Press.
what-is-conductivity-cell-constant. (2017, 2 24). Retrieved from iccontrols.com: https://iccontrols.com/faq-items/what-is-conductivity-cell-constant/#:~:text=The%20cell%20constant%20is%20a,square%20plates%201%20cm%20apart.
www.reichelt.nl. (2022, 3 4). Retrieved from rechelt elektronik: https://www.reichelt.nl/nl/nl/ontwikkelaarsborden-a-d-versterkerkaart-16-bit-ads1115-debo-amp-16bit-p235500.html?PROVID=2809&gclid=Cj0KCQjwpcOTBhCZARIsAEAYLuWkrwT352VaBNEGe2WvNq_XrGDcVgY9kcNRn3Tl0i2DSobFDthDQ_8aAhEqEALw_wcB

Appendix:

Content of figure:

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Arduino platform

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Arduino IDE

Arduino IDE (integrated development environment), An application that can working on multiple operation systems is developed by Java programming language. The application can be used to program the software which need to operate on Arduino board. (Du, Research proposal_FeifanDu_V5_20210318, 2021)

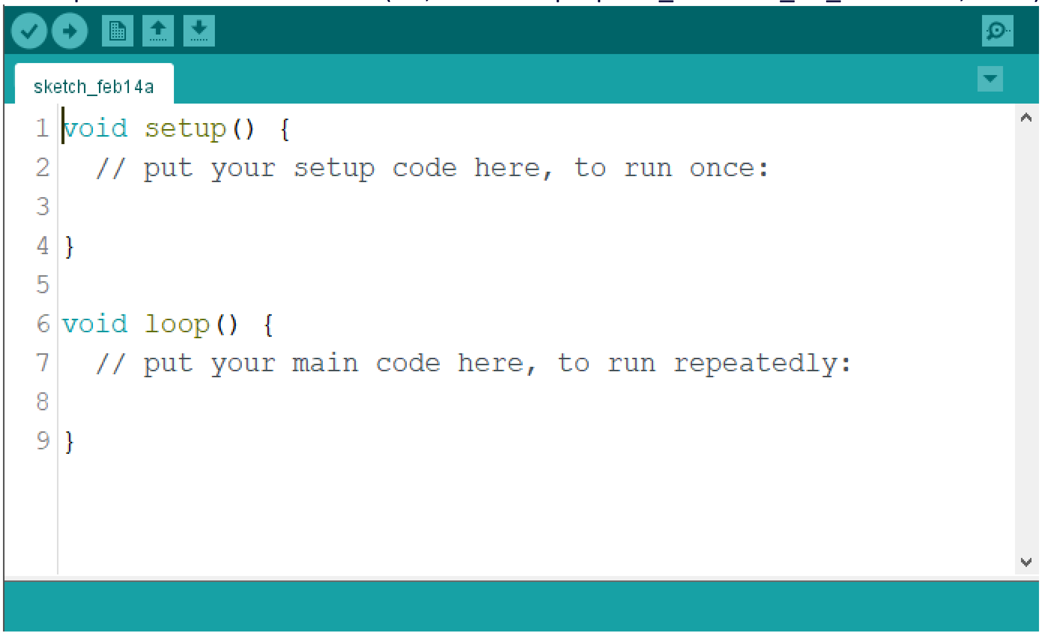


Figure 42 Arduino IDE 1.8 UI (Ardunio, 2018)

According to the description from official website, Arduino IDE contain the function of text cutting and pasting, searching and replacement, automatic indenting, brace matching, and syntax highlighting. (see Arduino IDE in figure 41) (arduino, 2021)

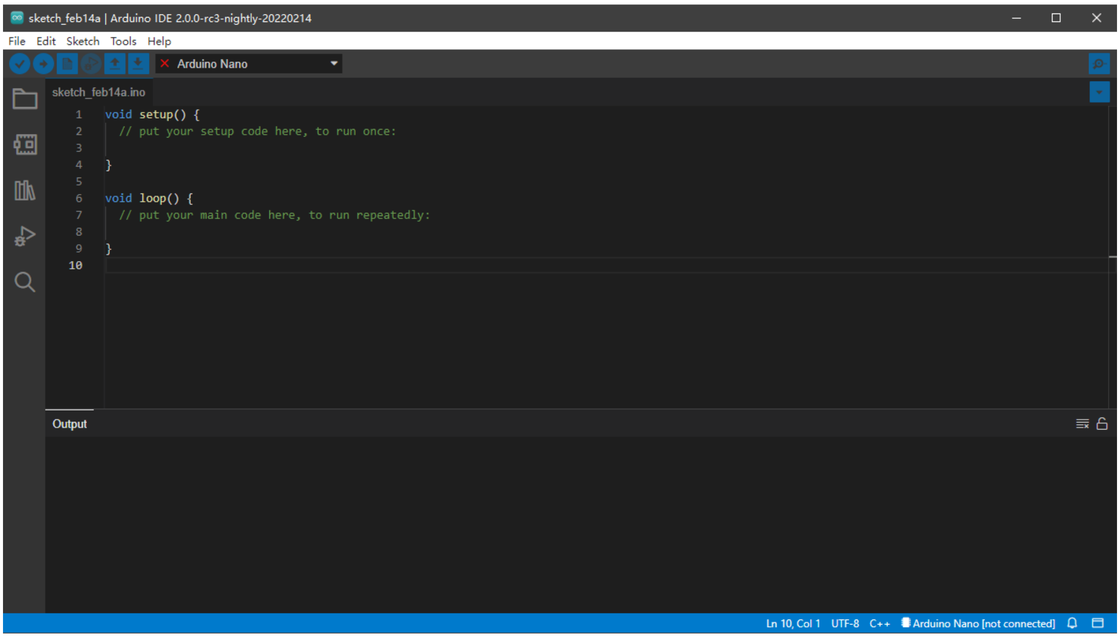


Figure 43 Arduino 2.0 UI

Program for Arduino hardware normally can be created by any kinds of programming language, with compiler the text-based program would be translated into binary machine code command.(see figure 42 Arduino IDE 2.0)

When programming on Arduino IDE, using programming language is C/C++ language, the debug function can be implemented to check for the code.

Hardware

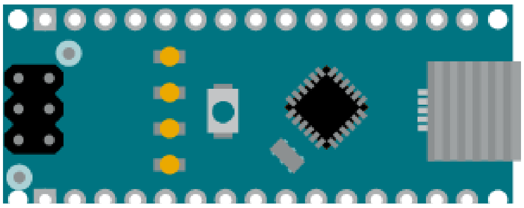


Figure 44 Arduino NANO (Ardunio, 2018)

Arduino nano is one of the classic board design for bread board. It is the smallest board among similar product, it has the shortest dimension with the feature of connecting Mini-B USB.(see figure 43 Arduino NANO and figure 44 its features)

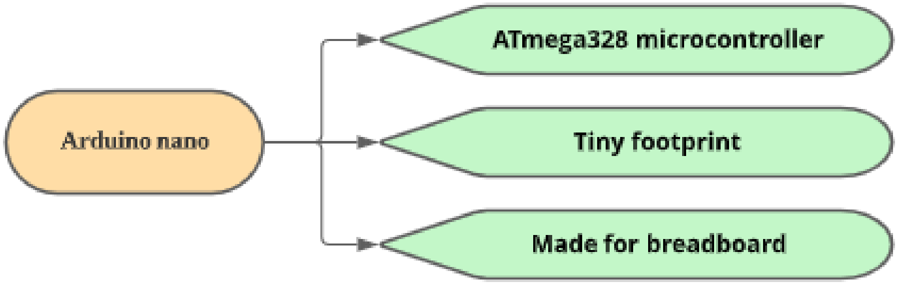


Figure 45 Arduino nano features

It is one of the oldest type, (you can find detailed information in table 21 and table 22) similar with Arduino Duemilanove but used on breadboard, nano series also contain a network support version "nano 33 IoT" and sensor equipped version "nano 33 BLE sense"

Board	**Name**	Arduino® Nano
	SKU	A000005
Microcontroller	ATmega328	
USB connector	Mini-B USB	
Communication	**UART**	Yes
	I2C	Yes
	SPI	Yes
Power	**I/O Voltage**	5V
	Input voltage (nominal)	7-12V
	DC Current per I/O Pin	20 mA
Clock speed	**Processor**	ATmega328 16 MHz
Memory	**ATmega328P**	2KB SRAM, 32KB flash 1KB EEPROM
Dimensions	**Weight**	5gr
	Width	18 mm
	Length	45 mm

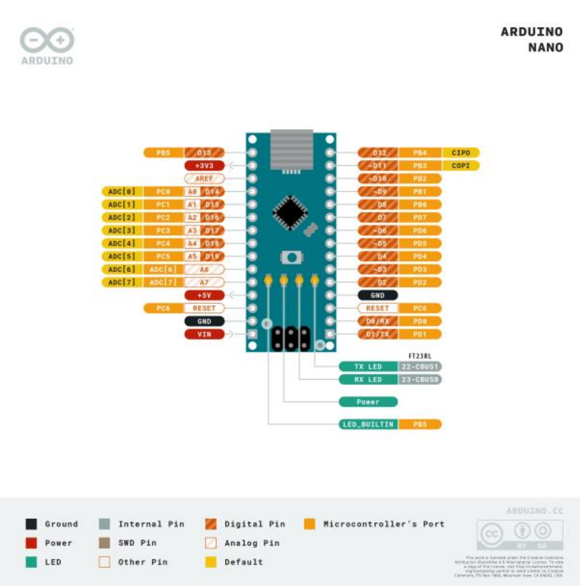


table 21 Technical specifications of Arduino nano (Ardunio, 2018)

table 22 I/O diagram of Arduino NANO (Ardunio, 2018)

Raspberry PI platform

Hardware

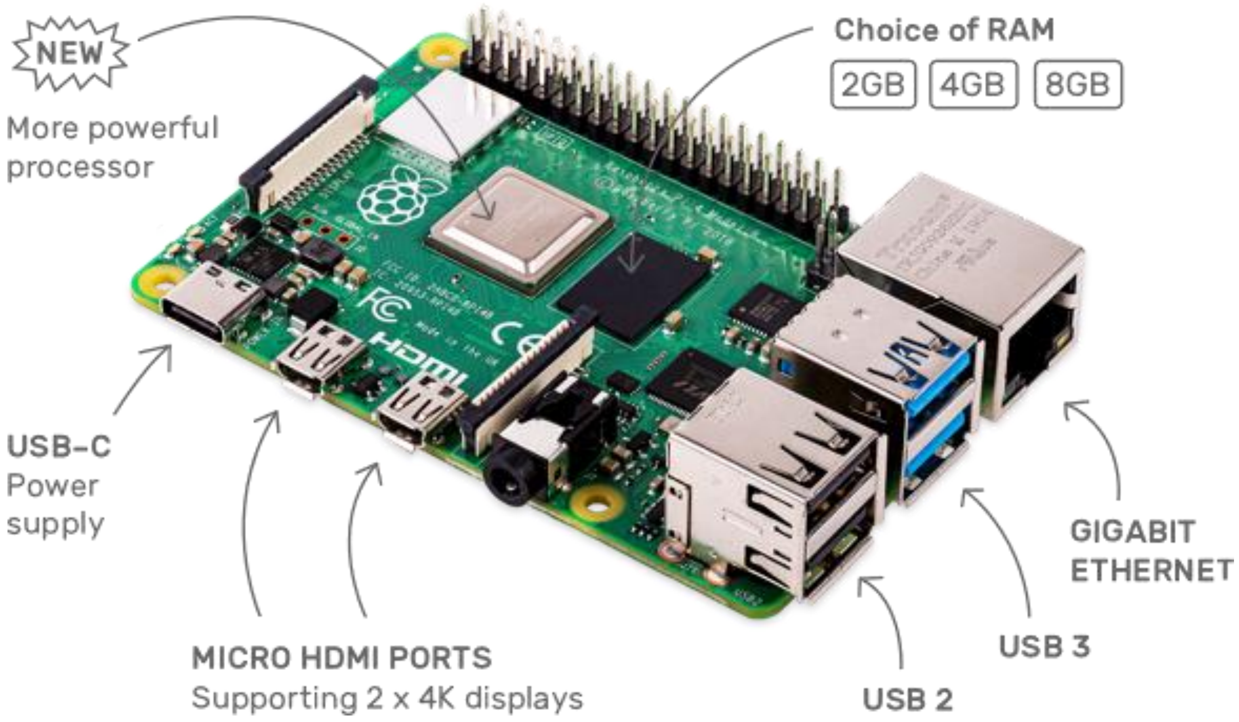
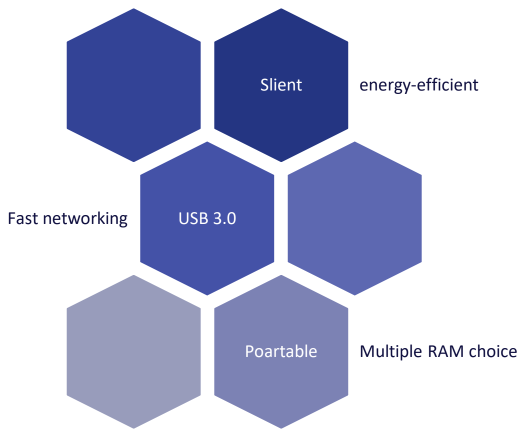


Figure 46 Raspberry Pi 4B (Raspberry Pi, 2022)



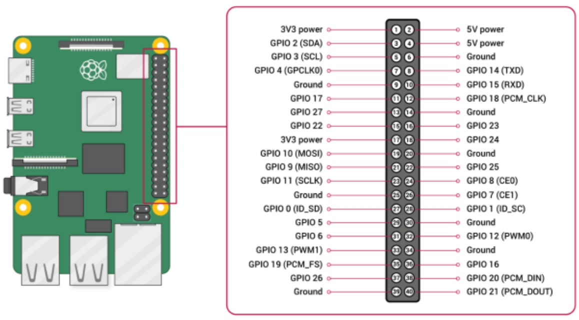


table 23 I/O pins for Raspberry (Raspberry Pi, 2022)

Figure 47 Advantage of raspberry Pi

Raspberry Pi has a large number of devices in different series. (see advantages of raspberry pi in figure 46 and I/O pins in table 23)One of the significant point that need to be considered is the Raspberry Pi Zero series have same features as Raspberry 4 platform but have a smaller size. This means by using zero series in practical prototype might be able to lower the size of the system. (Raspberry Pi, 2022)
(back to main article)

Test standard CA6460

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Implementation:

Connect the cords to the equipment using the forked terminals and the terminal colors.

Set the stakes at the ends and pay out the cords.
Using the alligator clips, attach the cords to the stakes.
Return to the measurement equipment, press the pushbutton, and read the results.

Earth resistance testing:

It is best to use the "62 percent" method to calculate earth resistance (method using two stakes). The earth Kit components are required for this measurement (measuring figure in figure 47).

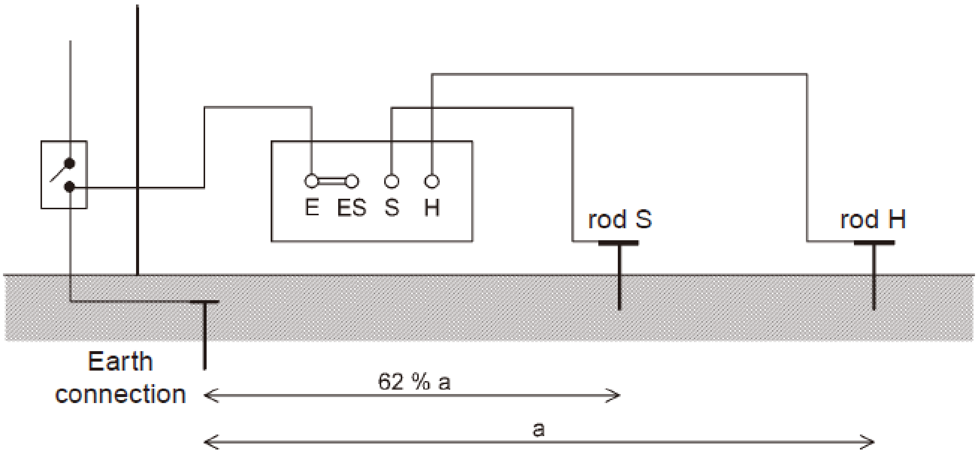

Figure 48 Earth resistance measurement (C.A. 6460 or C.A. 6462 User manul, 2021)

Disconnect the installation power supply from the earth by opening the ground terminal bar:

1. Using the corresponding terminal bar, short-circuit terminals E and ES and connect them to the earth point to be measured.
2. Drive rod H as far into the ground as possible at a distance "a" from the earth to be measured.
It should be noted that the greater the depth of the earth, the greater this distance should be (larger area of influence). It is preferable if the distance "a" is greater than 25 m.
3. Insert rod S into the ground at a distance of 62 percent of "a" from the earth connection E and rod H. earth connection rod S rod H 24
4. Using the leads, connect the rods to their respective instrument terminals.
5. Hold down the button until the measurement appears. Check that none of the three indicators are flashing, and if they are, check the setup and start measuring again.

Measuring check:

6. Take note of the previously obtained measurement value.
7. Repeat a measurement a few seconds later.
8. Move rod S toward H for a distance equal to 10% of "a." Take a measurement and make a note of the outcome.
9. From the starting point, move the rod S toward E for a distance of 10% of "a." Take a measurement and make a note of the outcome. If the magnitudes of the three measurements are the same, the measurement is correct. Otherwise, increase "a" and restart the operation.

Measurement of earth resistivity:

This measurement is used to select the best location and shape of the earth point before it is built, if possible.
This measurement is made using the WENNER method, which is described further below. It necessitates the use of the resistivity kit's components.
1. Check that the terminal bar is disconnected between the terminals E and ES.
2. Set out the four rods in a straight line at a constant interval “a”, rod E rod ES rod S rod H 25
3. Connect the rods to their respective terminals on the instrument, using the leads.
4. Press the Ä button until the measurement is displayed.
Make sure that none of the three indicators is flashing, otherwise check the setup (see § 3.5 Fault signaling) and start measuring again.

5. Make a note of the measured resistance R.
6. The ground resistivity at point O is obtained by calculation:
r = 2p x R x a (with r in Wm, R in W and a in meters)

Coupling measuring:

The coupling resistance between two earth points can be determined using this measurement. For example, consider the distance between the neutral earth point and the ground earth point (EDF distribution).(schematic shows in figure 48)

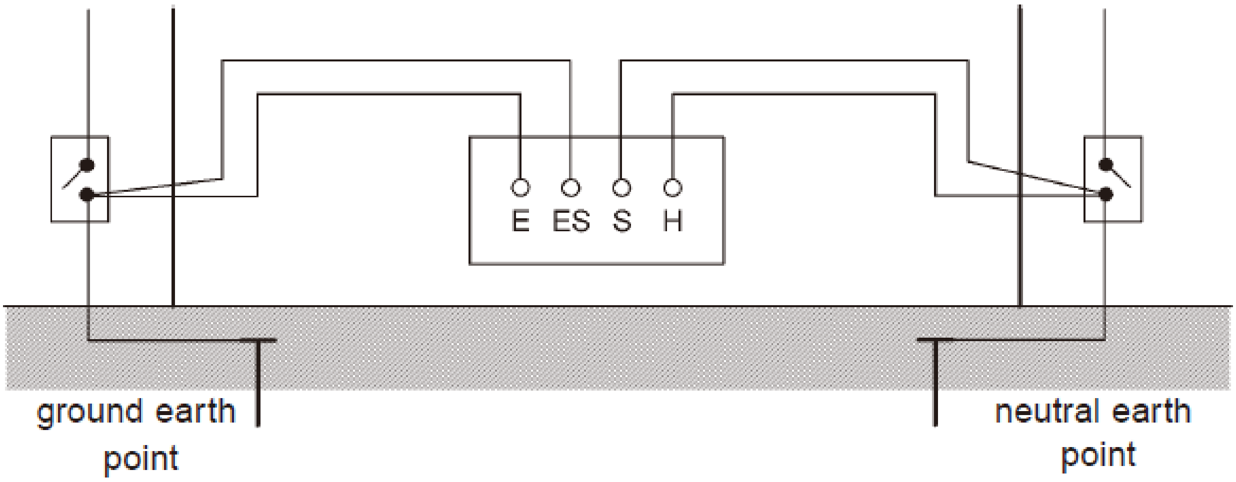

Figure 49 Measurement of coupling (C.A. 6460 or C.A. 6462 User manul, 2021)

Reference condition

The table below shows the reference condition value of CA6460 (table 24).

Influence quantities	Reference values
Temperature	23°C ±3 K
Relative humidity	45 to 55% HR
Supply voltage	9.5 V ±0.2 V
Auxiliary resistances RH, RS, RES and RE	zero
Spurious voltages (Ac and DC)	zero
Serial inductances	zero
Electrical field	< 1 V/m
Magnetic field	< 40 A/m

table 24 Reference condition value

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Electrodes' price

(back to main article)

Why do the material used by electrode needs to be considered?

The surface smooth level of the electrodes has a huge effect to the measuring result EC value. Surface smooth level could be changed when there is a scratch or impact on the electrode, any kind of different metal on the surface would also affect the measuring of the EC value. Thus, choosing a suitable electrode is quite significant to the EC meter system. However, a suitable material is not always common on the market and finding a suitable material might cost much more than purchase a common metal electrode.

Figure 53 commercial electrode

Figure 50 Europe plug that used as electrodes

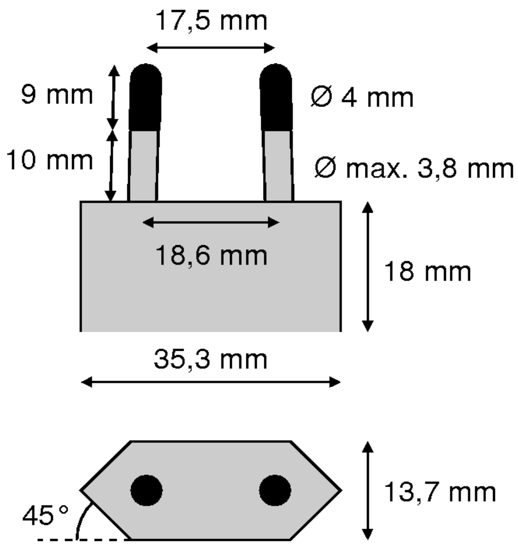


Figure 52 Size of Europe plugs

Figure 51 Plugs MFM EC meter (multiflexmeter-ec, 2021)

During the project before, Europe plugs also been used as electrodes because of its cheap and stability.(see figure 49 50 and 51) This is also a mature choice for this assignment. One different is that this assignment needs a four-electrodes which means several modifications are needed. (see figure 52)

Also another point is that by using standard Euro plugs, the separation distance of electrodes can also be fixed by a setting value. (back to main article)

Housing shell price

The plastic housing shell is already be used in many other project in waterschap, it is also a good idea to make massive production. But for this project using 3D printer to print shell prototype is more suitable for modification and improve. Also during the testing and adjustment it is easier to wiring and repairing without using shell. (See examples of housing shells in figure 53)

3D printer is a very easy method to design, by drawing a 3D model, parts and the integrating can be test not only on PC but also on real printed part.

What need to be considered is the printer’s accuracy and its resolution. Some of the printers that do not have enough accuracy may not be able to print small parts.

Figure 54 Current housing shell

Electronics price

Common electronics are well used in different kinds of MFM products, some of common components usually not very expensive. However, when comes to chips sensors and processors, the cost would be much higher. Detailed information shown in Appendix “Pricing of parts and labors”.
All above are the focus of the theoretical framework, readers can find some of the details that not shown in this chapte. (back to main article)

Pricing for parts and labor

Manufacturer Part No	Order Code	Description / Manufacturer	Availability	Price For	Price	Quantity
EC 30 25 TB APL	7113249 Data Sheet	Capacitive Proximity Sensor, Type EC, M30, TRIPLESHIELD™, 25 mm, SCR, 20 to 265 Vac, Pre-Wired CARLO GAVAZZI	50 In stock	Each	1+ €261.94 5+ €256.70 10+ €251.46	1 Add Min: 1 Mult: 1
EC 30 16 TB APL	7113250 Data Sheet	Capacitive Proximity Sensor, Type EC, M30, TRIPLESHIELD™, 16 mm, SCR, 20 to 265 Vac, Pre-Wired CARLO GAVAZZI	2 In stock	Each	1+ €94.70 5+ €92.81 10+ €90.91	1 Add Min: 1 Mult: 1
EC 55 25 PP AP	7114953 Data Sheet RoHS	Capacitive Proximity Sensor, Type EC 5525, TRIPLESHIELD™, 25 mm, PNP, 10 to 40 Vdc, Pre-Wired CARLO GAVAZZI	3 In stock	Each	1+ €73.62 5+ €72.15 10+ €70.68	1 Add Min: 1 Mult: 1
ECS300	3812389 New product Data Sheet RoHS	Solar Cell, Indoor, 8 Cells, 3 V, -20 °C to 65 °C, 35 x 12.8 x 1.1 mm ENOCEAN Best Seller	990 In stock	Each	1+ €3.68 10+ €3.10 25+ €2.93	1 Add Min: 1 Mult: 1

Figure 55 price list of some sensors (Farnell, 2022)

For processor-based electronics, by searching from component websites, Embedded Daughter Boards & Modules for AVR normally cost from 10€ to 70€. Development board for Arduino cost from 20€ to 100€. For processor, if only purchase for AVR or other processor chips itself, it would be cheaper than buy a whole development board. However it would also make it difficult to functionally design the prototype. Further going, when there is a microcomputer which is based on Arduino or Raspberry Pi, the cost would also going very high. (back to main article)

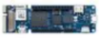
Manufacturer Part No	Order Code	Description / Manufacturer	Availability	Price For	Price	Quantity
ABX00011 	2830992 Data Sheet RoHS	Development Board, Arduino MKR1000 With Mounted Pin Headers ARDUINO Best Seller	146 In stock	Each	1+ €25.27	1 Add Min: 1 Mult: 1
ABX00017 	2851778 Data Sheet RoHS	Development Board, Arduino MKR WAN 1300, Arduino Zero with LoRaWAN, IoT Development ARDUINO Best Seller	433 In stock	Each	1+ €34.20	1 Add Min: 1 Mult: 1
ABX00019 	2917565 Data Sheet RoHS	Development Board, Arduino MKR NB 1500 Shield, Narrow Band IoT, LTE CAT M1 Compatible ARDUINO Best Seller	375 In stock	Each	1+ €69.72	1 Add Min: 1 Mult: 1
ABX00022 	2917571 Data Sheet RoHS	Development Board, Arduino MKR VIDOR 4000 Shield, Configurable Controller Board ARDUINO Best Seller	133 In stock	Each	1+ €47.91	1 Add Min: 1 Mult: 1

Figure 56 Development board for Arduino (Farnell, 2022)

M50-300054 5 	1022299 RoHS	PCB Receptacle, Vertical, Board-to-Board, 1.27 mm, 2 Rows, 10 Contacts, Through Hole Mount HARWIN Best Seller	3,263 In stock	Each	1+ €1.68 10+ €1.30 100+ €1.19 500+ €1.08 1000+ €0.929 More Pricing...
6130062182 1 	2827894 Data Sheet RoHS	PCB Receptacle, Board-to-Board, 2.54 mm, 2 Rows, 6 Contacts, Through Hole Mount, WR-PHD WURTH ELEKTRONIK Best Seller	23 In stock	Each	10+ €0.39 100+ €0.321 500+ €0.308 1000+ €0.276 2500+ €0.233 More Pricing...
2212S-09SG -85 	2847198 Data Sheet RoHS	PCB Receptacle, Board-to-Board, 2.54 mm, 1 Rows, 9 Contacts, Through Hole Mount MULTICOMP PRO Best Seller	8,932 In stock	Each	5+ €0.285 50+ €0.212 150+ €0.182 250+ €0.15
M20-782364 6 	3225933 RoHS	PCB Receptacle, Board-to-Board, 2.54 mm, 1 Rows, 36 Contacts, Through Hole Mount, M20 HARWIN Best Seller	191 In stock	Each	1+ €2.91 10+ €2.33 100+ €2.16 250+ €1.98 500+ €1.69 More Pricing...

table 25 Plugs prices

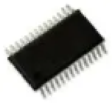
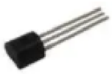
TC74A3-5.0 VAT 	1627189 Data Sheet RoHS	Temperature Sensor IC, Voltage, ± 2°C, -40 °C, +125 °C, TO-220, 5 Pins MICROCHIP Best Seller	143 In stock	Each	1+ €1.53 25+ €1.28 100+ €1.17
KTY81/110,112 	2066195 Data Sheet RoHS	Temperature Sensor IC, Analogue, -55 °C, +150 °C, SOD-70, 2 Pins NXP Best Seller	71,132 In stock	Each	1+ €1.98 10+ €1.20 50+ €1.10 100+ €0.99
LM87CIMT/NOPB . 	1286932 RoHS	Temperature Sensor IC, Voltage, ± 3°C, -40 °C, +125 °C, TSSOP, 24 Pins TEXAS INSTRUMENTS Best Seller	2,491 In stock	Each	1+ €9.90 10+ €7.82 25+ €6.96 50+ €6.44 100+ €5.35
KTY82/110,215 	2066190 Data Sheet RoHS	Temperature Sensor IC, Analogue, ± 3.02°C to ± 8.55°C, -55 °C, +150 °C, SOT-23, 3 Pins NXP Best Seller	18,646 In stock	Each (Supplied on Cut Tape) Cut Tape Packaging Options	1+ €1.46 10+ €0.891 50+ €0.813 100+ €0.735
LM135Z 	1750200 Data Sheet RoHS Date/Lot Code	Temperature Sensor IC, Linear, ± 1°C, -55 °C, 150 °C, TO-92, 3 Pins STMICROELECTRONICS Best Seller	365 In stock	Each	5+ €4.33 10+ €3.68 100+ €3.07 500+ €3.01
TSIC 506F TO92 	2191826 Data Sheet RoHS	Temperature Sensor IC, TSic™ 506F Series, TO92. Digital Output, -10 to 60°C, 3 to 5.5 Vdc IST INNOVATIVE SENSOR TECHNOLOGY	1,755 In stock	Each	1+ €13.15 5+ €11.18 10+ €10.40 20+ €9.94 50+ €8.94

table 26 price list of IR temperature sensors

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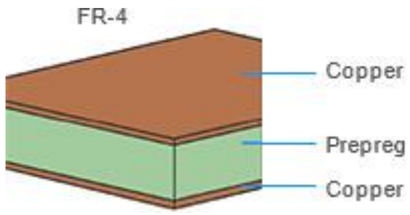
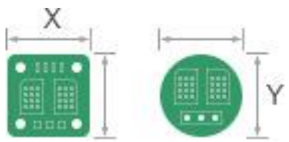
PCB order

Features	Capability	Notes	Patterns
Layer count	1,2,4,6 layers	The number of copper layers in the board.	
Controlled Impedance	4/6-layer, default layer stack-up	[Controlled Impedance PCB Layer StackupJLCPCB Impedance Calculator]()	
Material	FR-4	FR-4 Standard Tg 130-140/ Tg 155	
Dielectric constant	4.5(double-sided PCB)	7628 Prepreg 4.6 2313 Prepreg 4.05 2116 Prepreg 4.25	
Max. Dimension	400x500mm	The maximum dimension JLCPCB can accept	
Dimension Tolerance	±0.2mm	±0.2mm for CNC routing, and ±0.4mm for V-scoring	
Board Thickness	0.4/0.6/0.8/1.0/1.2/1.6/2.0mm	The thickness of finished board.	

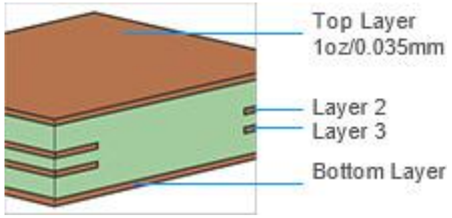
Thickness Tolerance (Thickness≥1.0mm)	± 10%	e.g. For the 1.6mm board thickness, the finished board thickness ranges from 1.44mm(T-1.6×10%) to 1.76mm(T+1.6×10%)	
Thickness Tolerance (Thickness<1.0mm)	± 0.1mm	e.g. For the 0.8mm board thickness, the finished board thickness ranges from 0.7mm(T-0.1) to 0.9mm(T+0.1).	
Finished Outer Layer Copper	1 oz/2 oz (35um/70um)	Finished copper weight of outer layer is 1oz or 2oz.	
Finished Inner Layer Copper	0.5 oz (17.5um)	Finished copper weight of inner layer is 0.5oz by default.	

table 27 Table of PCB ordering

(back to main article)

Labor price

During the real mass production, labor price is part of the cost of the product, average assembly time or production time also effect the total cost of a product.

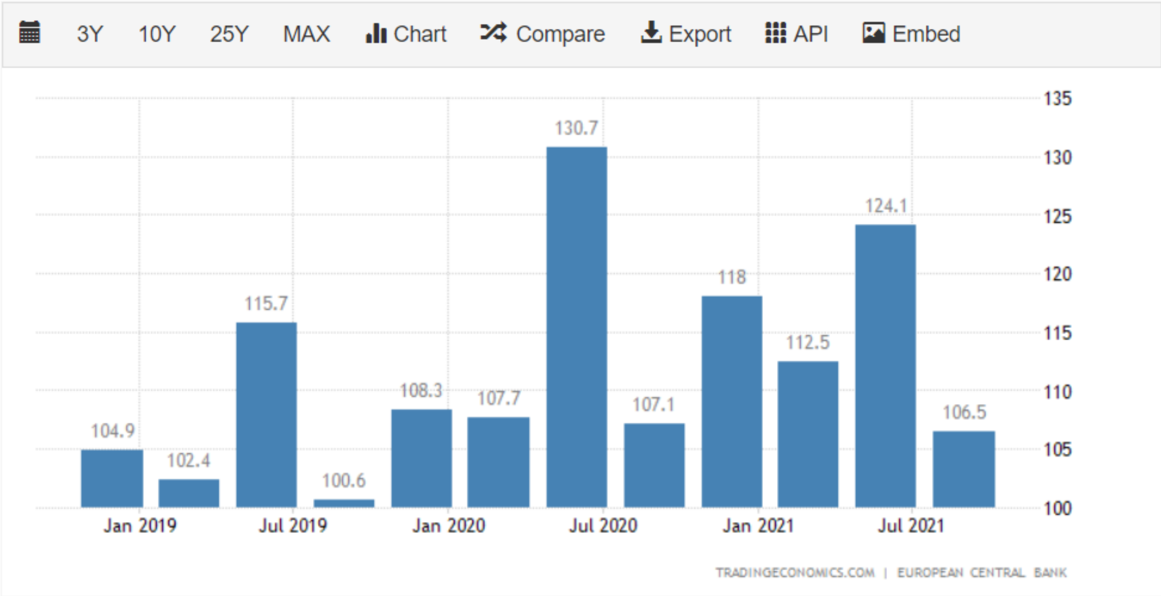


Figure 57 Netherlands - Labor cost index

According to the Europe central bank: “Labor Costs in Netherlands decreased to 106.50 points in the third quarter of 2021 from 124.10 points in the second quarter of 2021.” (Netherlands Labour Costs, 2021)

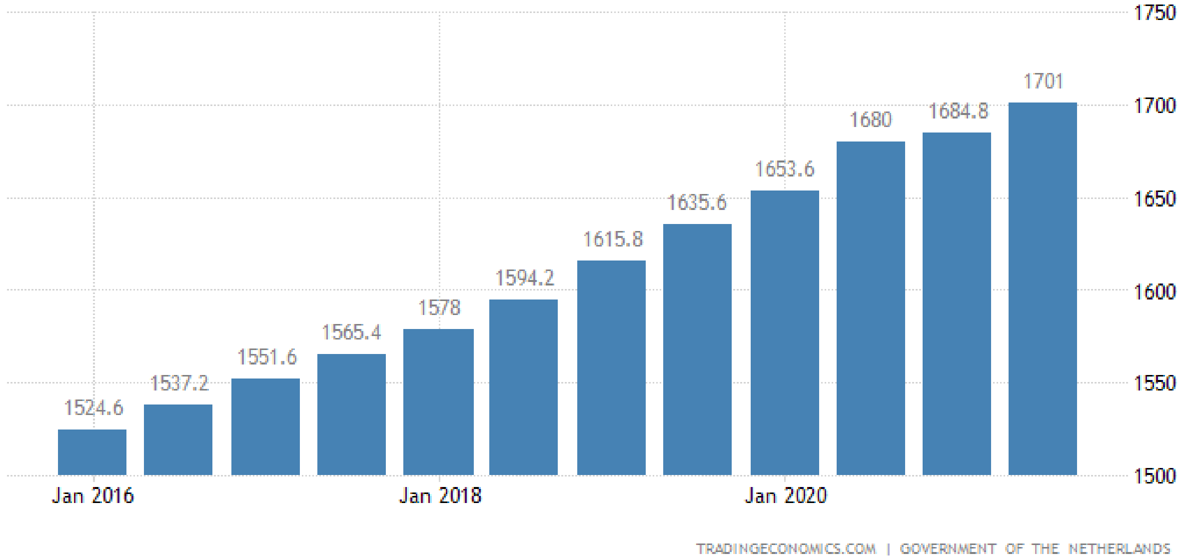


Figure 58 Netherlands Gross Minimum Monthly Wage

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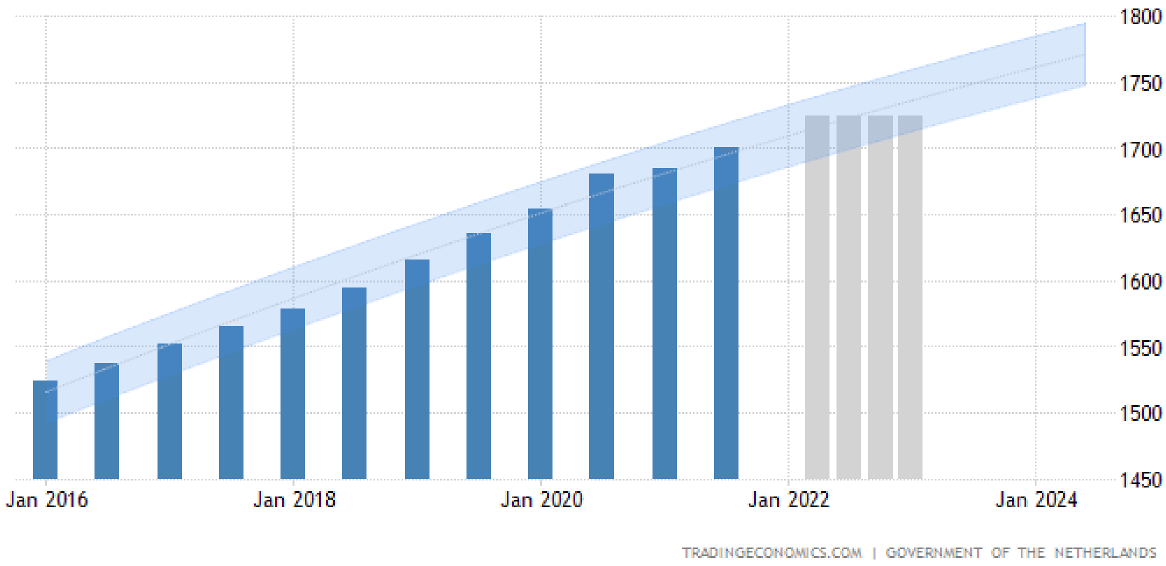

Figure 59 forecast figure (Netherlands Labour Costs, 2021)

Labor reducing

It is a significant point to considered about the labor costs during the whole design process, once the design is fixed, it will be difficult to reducing the labor costs during the producing. Labor cost in Europe is much expensive than the same working in China, thus the importance of reducing labor become necessary. The labor costs for this project can be analyzed by the points below:

1. **Labor costs during the design**
2. **Labor costs during the supply chain**
3. **Labor costs during the assembly**

First part, labor costs during the design period. The first pricing come into mind is the developer's labor costs. Considered that developers are the writer of this thesis, this project can ignore this part of the labor costs because this project is also a study-based assignment. The other parts contained the daily costs of the dockwise, but this part of the costs is not highly related to only this assignment.

Second one, labor costs during the supply chain. The supply chain contained several related electronics supplier and companies. The Labor pricing of producing the standard devices is normally contained in its sell price, so this is no way to reduce it by this side. But what can be reduced is the customization product and the logistic plan. By ordering devices from near by supplier rather than those supplier overseas normally make the costs lower, but there still have the situation that local supplier are not able to produce or provide. Customization product, for example PCBs, by designing the PCB in a producing-friendly way makes the costs of the PCB much lower than a complex solution. This part will also be discussed in the chapter of "PCB cost"

Last one, assembly costs, assembly is the last process of products which are going to market. In some situation, a product that are difficult to assembly will lead to an extremely high labor costs. The easiest way to solve this problem is to make the integrating of the system clear and simple, use as less parts as possible. So this is what need to be considered during the developing.

Additional section is the control part, during the sub-system design and system design, some of the work need to be done by microchips or processors, to avoid waste of hash rate it is wise to use only one main processor and make the use of all IO pins.

Costs of PCB

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Type of PCB material

One of the significant effect to the cost of PCB is its material, PCBs are made out of different type of materials such as fiberglass, polymer inks, and solder. The type of materials that chosen will affect the physical capacity of PCB. Some of PCB that have certain requirement also use gold and silver as part of the material.

PCB Size and the Number of Layers

The size of PCBs for sure also affect to the price, the bigger the more expensive. And number of layers also represent the difficulty of producing. bigger boards and boards with several layers take more time to manufacture.

Size of Board Holes

Holes are using to connect different layers in PCB, the accurate of holes also affect to costs.

Labor costs

Producing PCBs is an expensive endeavor because the work is done by skilled professionals. They must use automated machinery designed specifically for PCB production. Labor costs influence the cost of producing a PCB, and no one wants inexperienced workers producing these critical components for complex electronic devices. It is preferable to pay a fair wage to employees who construct high-quality boards the first time rather than paying to have them constructed twice by mediocre employees. (D, 2020).

Expected Turnaround Time

Some manufacturers create PCBs with a quick turn-around time. Manufacturers will charge more if they are asked to produce PCBs quickly. Manufacturers frequently have to put other orders on hold in order to complete another order quickly. The increased price will cover the cost of holding other orders.
If you want to save money, place your order as soon as possible. This allows your manufacturer to complete the order without having to pay overtime or higher shipping costs to get parts. (D, 2020).

Quantity of PCB in the Order

Prototype of PCB normally is not cheap, but if using massive producing the costs will drop.

Technology Used in PCBs

Technology used to produce PCB also affect to costs. Two method are normally in use: Surface-mount or through-hole technology is used. Surface-mount technology is the less expensive of the two because it employs more automation, which necessitates fewer manpower and lower employee costs.

Packaging Costs

Fragile electronics components' transportation is expensive. If the order contained those items, the costs for shipping will increase.

General costs

In general, the cost of producing a PCB ranges from $10 to $50 per board. The manufacturer will determine the final price, which may be higher or lower depending on the components, size, and type of material used. Smaller boards can sometimes be more expensive because they require more labor hours to get components working properly, especially if the board has to power a smartphone or other small, complicated device. (D, 2020).
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Method time plan:

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Reason for time plan

It is easy to find from the time figure that the second part of the graph are much longer than the first designing phase. According to the V-model logic, the most part of the actual practice work happened during the integration phase, so this is the part that more and more errors and problems will jump out. It is wise to be prepared in advance, this can also give enough time to fix all the problem or choose another solution.

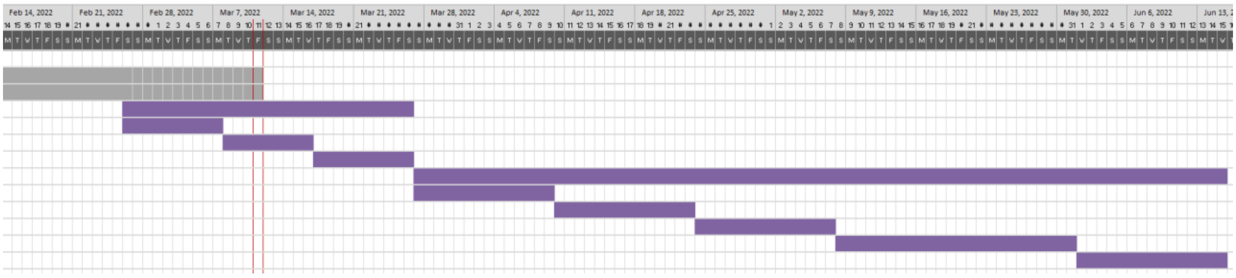

Figure 60 gantt chart

MFM 4-electrodes EC-meter

Waterschap Scheldestromen multiflexmeter

Jos Goossen

Project Start:	Mon, 2/7/2022
Today:	Fri, 3/18/2022
Display Week:	1

TASK	ASSIGNED TO	PROGRESS	START	END
Phase 1 Research proposal	**Haobo Guo**	217%	2/7/22	2/25/22
Research proposal		217%	2/7/22	2/25/22
Phase 2 Design phase	**Haobo Guo**		2/26/22	3/26/22
system design		222%	2/26/22	3/7/22
subsystem design		125%	3/8/22	3/16/22
components design		11%	3/17/22	3/26/22
Phase 3 Integration phase	**Haobo Guo**		3/27/22	6/15/22
Satrting test integration		-69%	3/27/22	4/9/22
components integration		-177%	4/10/22	4/23/22
subsystem integration		-285%	4/24/22	5/7/22
system design intergration		-222%	5/8/22	5/31/22
Phase 4 Demon & Reporting phase	**Haobo Guo**		6/1/22	6/15/22
Reporting and documenting		-536%	6/1/22	6/15/22

Table 28 Time schedule

Roadmap of two method

Engineering Roadmap

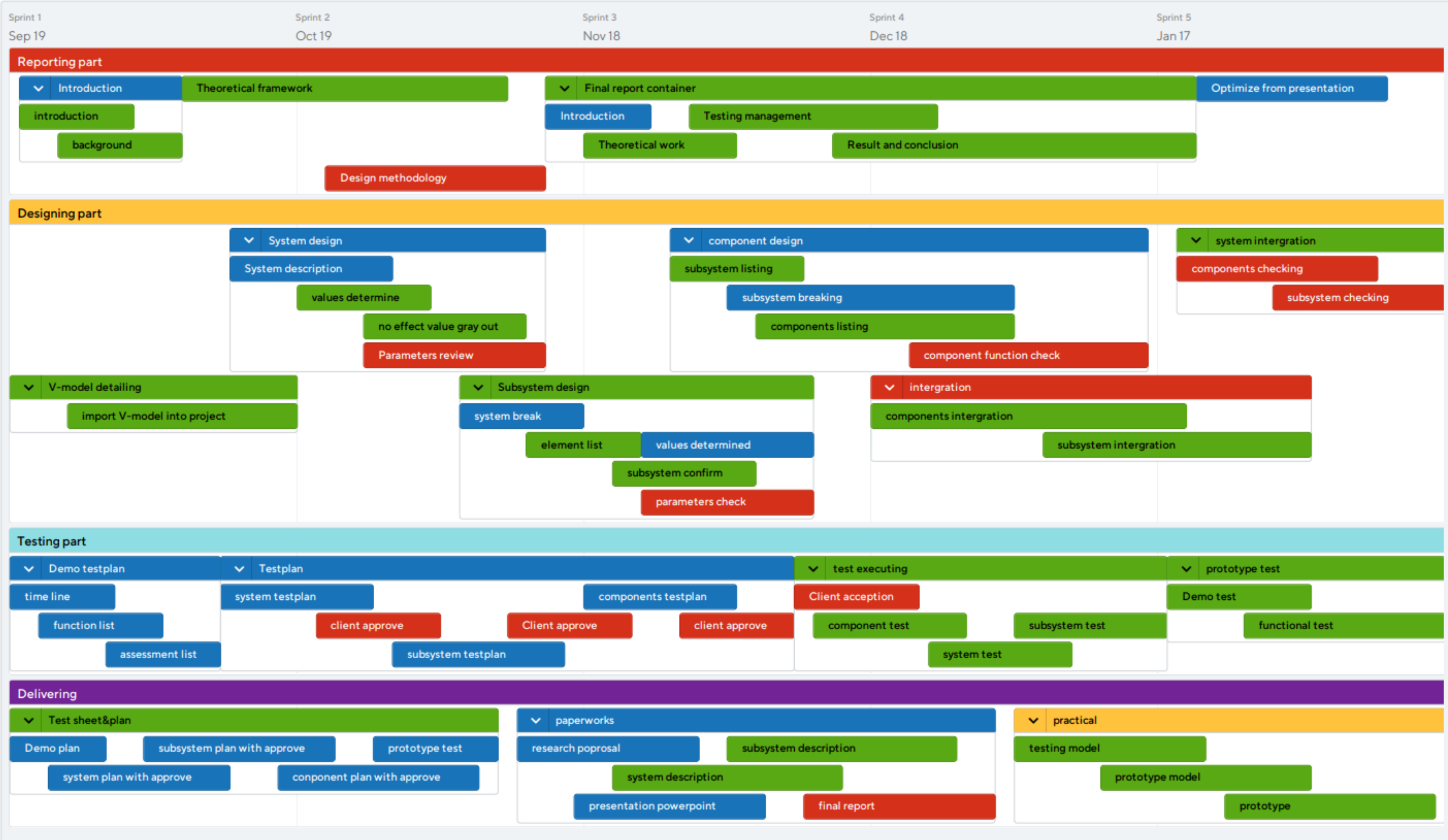

Figure 61 V-model design roadmap

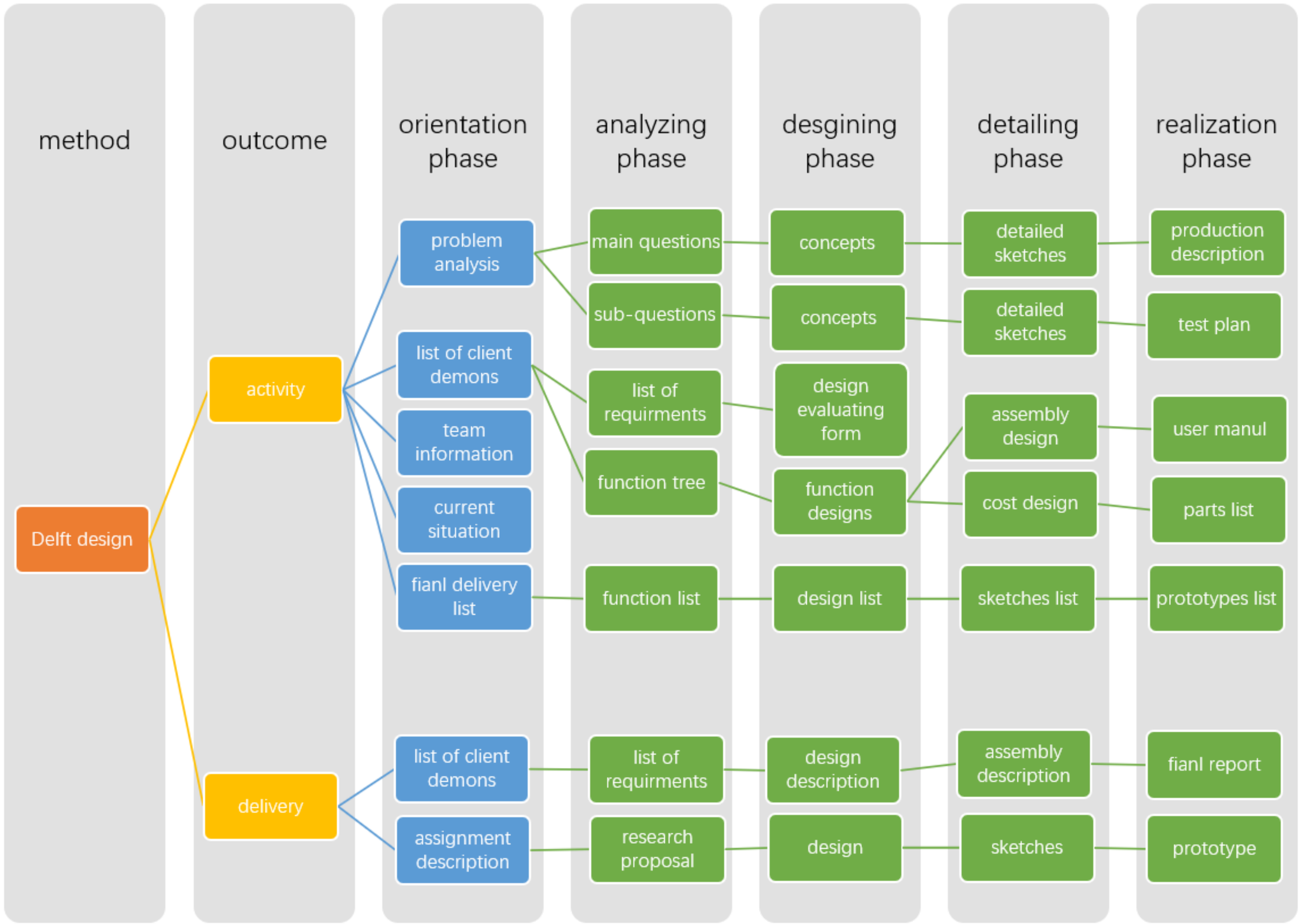

Figure 62 Delft design roadmap

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Delft design method

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Delft design process is a design method developed by Delft University which can be used for consumer design and engineering design. The whole process can be divided into two main parts, one is development part and the other is realization part. Development parts contain the concept designing which will roll out the general or specific idea of a product or project. (Jagt, 2019)

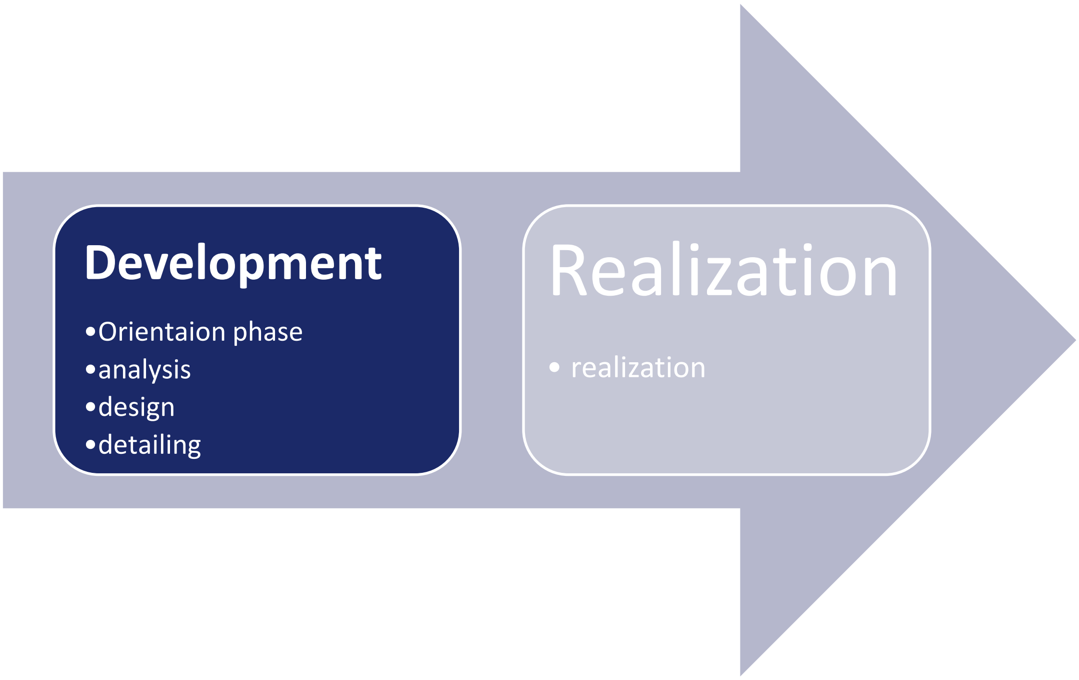

Figure 63 Overview of delft design

By using the delft design, the process of designing can be combined with innovation and become easier for team to technically achieve the design.
The first part of delft design, development, consist by 4 phases, each of them have unique meaning and delivery. Phase one is orientation phase, this phase focus on making it clear on design problem. Designers need to make an accurate problem description which can present the customer’s requirements correctly.

Second phase is analysis phase, it is a deeper process of the described question, designers need to analyze the difficulties and find as much possible solutions as possible. (Hoog, 2010)

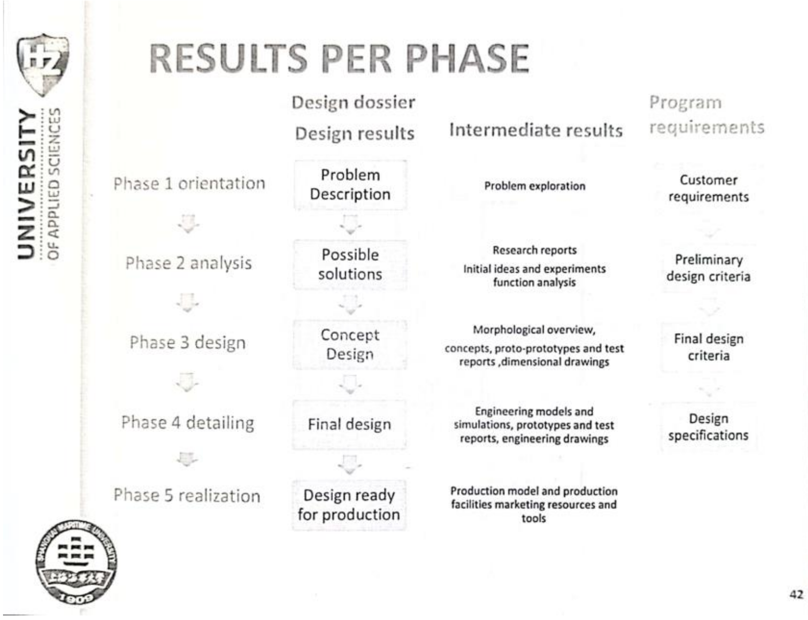

Figure 64 activities and delivery

Once the analysis is done, the third phase where designers begin their design can be started. In this phase, concept need to be roll out and final design criteria need to be provided. After that, in phase four, a detailed concept can be present and waiting for realization.

Four phases above make up the development part in delft design method.

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System & sub-system overview

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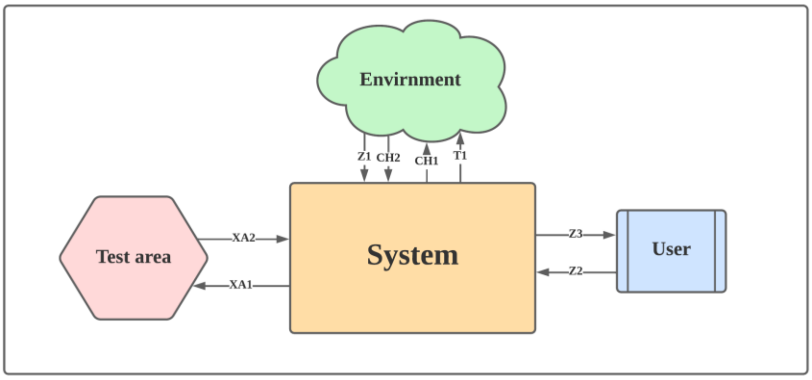


Figure 65 System flow chart

Table 29 Symbols table

Item	Value type	units	max value	min value
Z1	Physical impact	N/A	N/A	N/A
Z2	Digital signal	N/A	N/A	N/A

Z3	Digital signal	N/A	N/A	N/A
XA1	Analog signal	V	1V	-1V
XA2	Analog signal	mA	10mA	-10mA
CH1	Chemical reaction	N/A	N/A	N/A
CH2	Chemical reaction	N/A	N/A	N/A
T1	Thermal transfer	W	N/A	N/A

input	Symbol	unit	Min	Max	main system	output	Symbol	unit	Min	Max
Resistance	R	Ω	0	5000		Voltage	U	V	0	1
Electronics	N/A	N/A	N/A	N/A		Current	I	A	0	0.5
Salt	Salinity	g/L	0.01	35		Digital signal	N/A	N/A	0	1
Temperature	T	℃	20	30		Chemical recation	N/A	N/A	0	1
Chemical reaction	N/A	N/A	N/A	N/A		Thermal	KT	J	N/A	N/A
Water waves	N/A	N/A	N/A	N/A		EC value	σ	mS/cm	0.01	99
Humidity	N/A	N/A	N/A	N/A						
Magnetic fields	B	Tesla	N/A	N/A						
Water pressure	P	Kpa	0.00001	10						
Momentums	p	kg•m/s	N/A	N/A						
Chemical substance	N/A	N/A	N/A	N/A						
Gravity	G	m/s^2	9.7	9.9						
Forces	F	N	N/A	N/A						
Radiation	R	Gy	N/A	N/A						

Table 30 Table of input and output

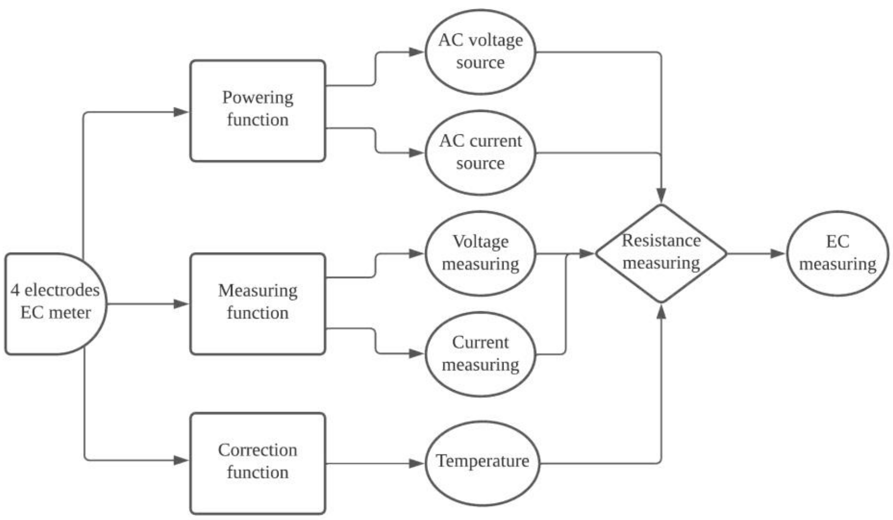


Figure 66 Function tree for EC meter system

(back to main report)

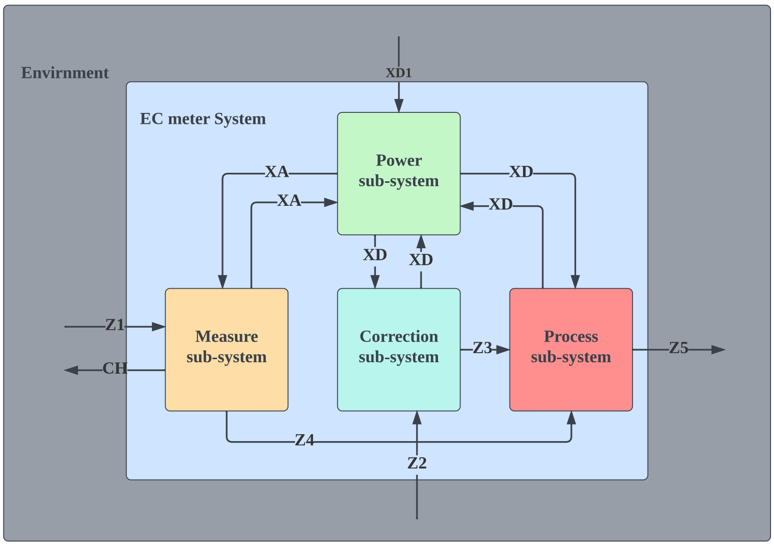


Figure 67 Flow chart of sub-system

INTERACTION			SYMBOL	MINIMUM	MAXIMUM	UNIT
Z	Z1	Voltage	U	-1,00	1,00	V
		Current	I	-10,00	10,00	mA
	Z2	Heat	T	0,00	50,00	℃
	Z3	Digital signal	byte	0	1	0/1
	Z4	Digital signal	byte	0	1	0/1
	Z5	Data output	#	\	\	\
XD	XD	DC signal	U	0,00	3.3	V
	XD1	DC signal	U	3.3	5.0	V
XA	XA	AC signal	U	\	\	\
CH	CH	Chemical reaction	\	\	\	\

table 31 table of limits

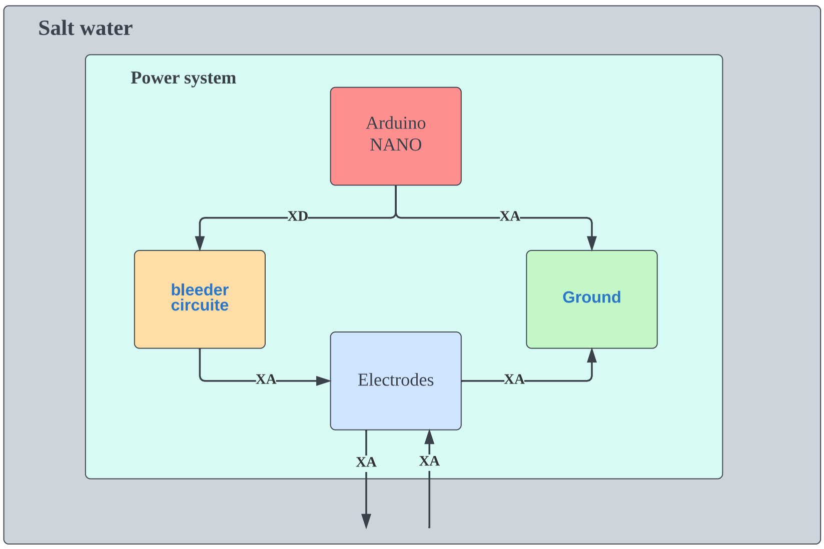


Figure 68 Overview of power system

INTERACTION		SYMBOL	MINIMUM	MAXIMUM	UNIT
XD	Digital signal	U	0	5	V
XA	Analog signal	U	-1	1	V

table 32 table of signals

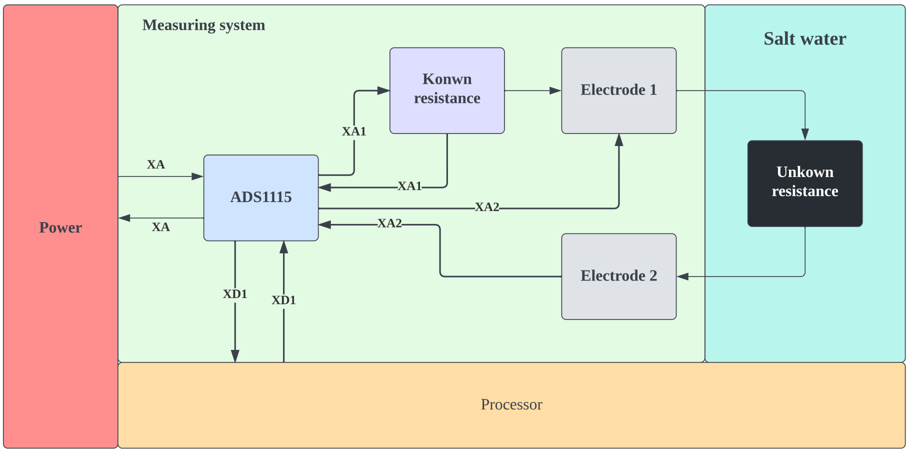


Figure 69 System overview of measuring system

INTERACTION			SYMBOL	MINIMUM	MAXIMUM	UNIT
XA	XA	Voltage	U	-1,00	1,00	V
	XA1	Potential	U	-1,00	1,00	V
	XA2	Potential	U	-1,00	1,00	V
XD	XD	DC signal	U	0,00	3.3	V
	XD1	DC signal	U	0,00	3.4	V

table 33 Table of signals

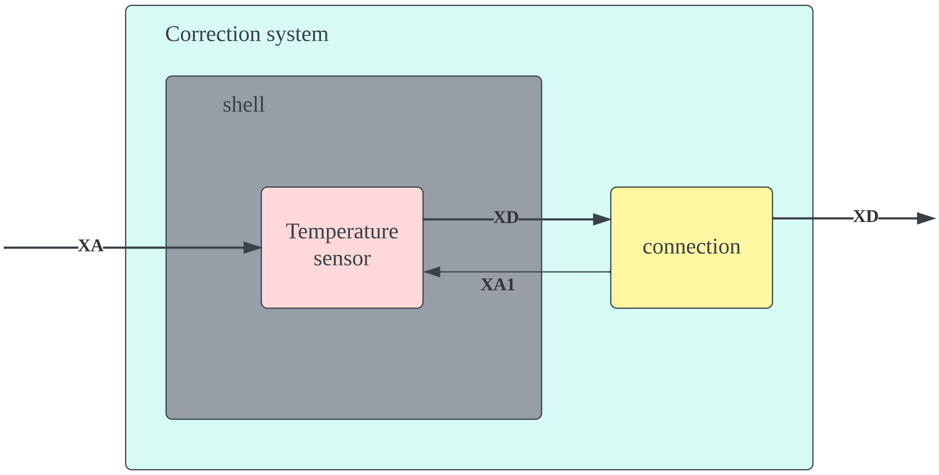


Figure 70 Correction system overview

INTERACTION			SYMBOL	MINIMUM	MAXIMUM	UNIT
XA	XA	Thermal	T	0	40	℃
	XA1	voltage	U	0	5	V
XD	XD	DC signal	U	0,00	3.3	V

table 34 Table of signals

System & sub-system design

(back to main report)

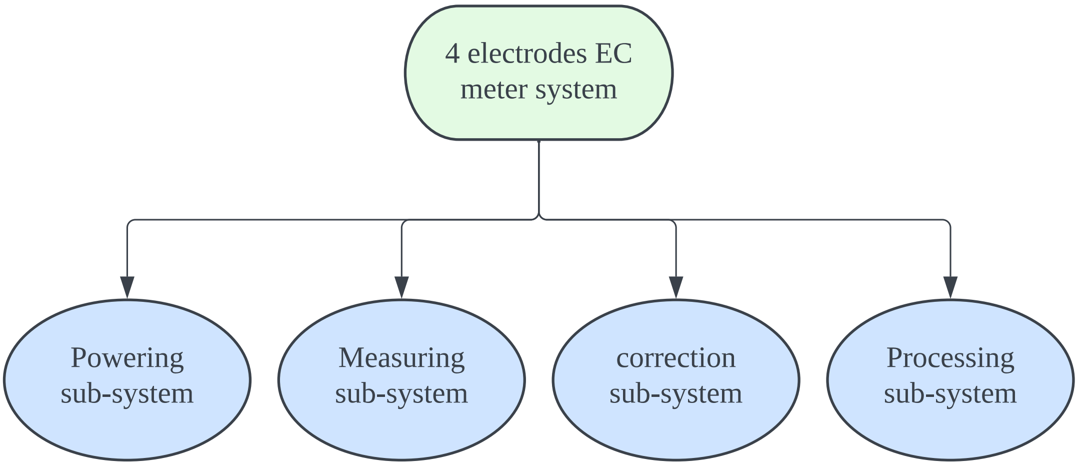


Figure 71 System division

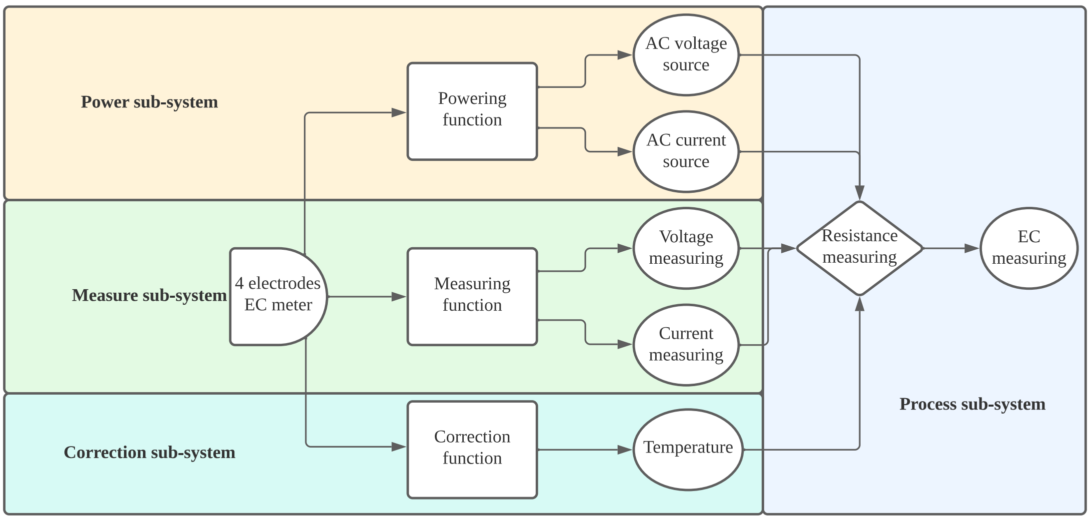


Figure 72 System division with function tree

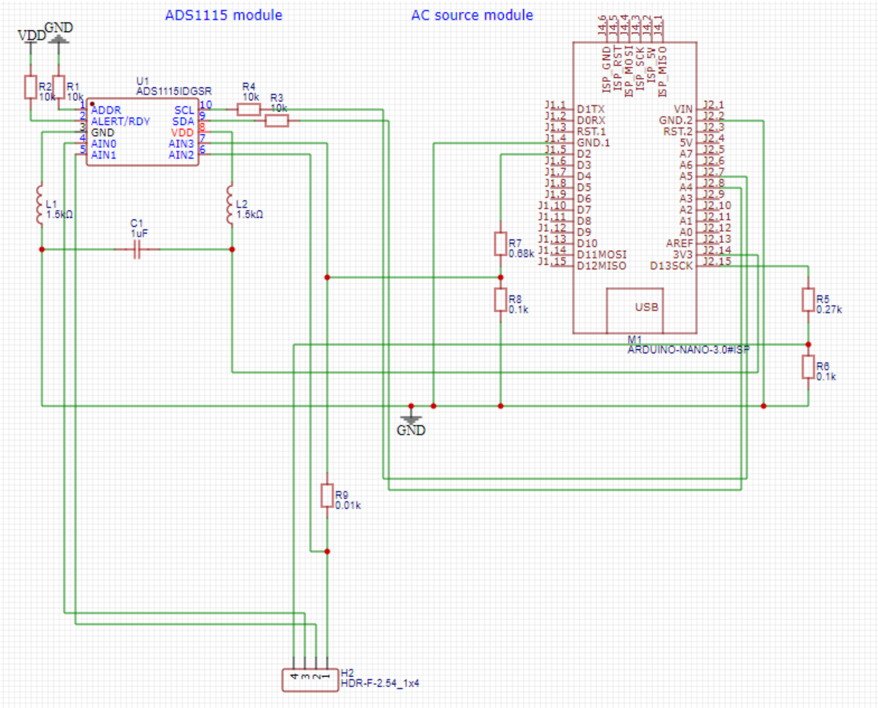


Figure 73 system circuit

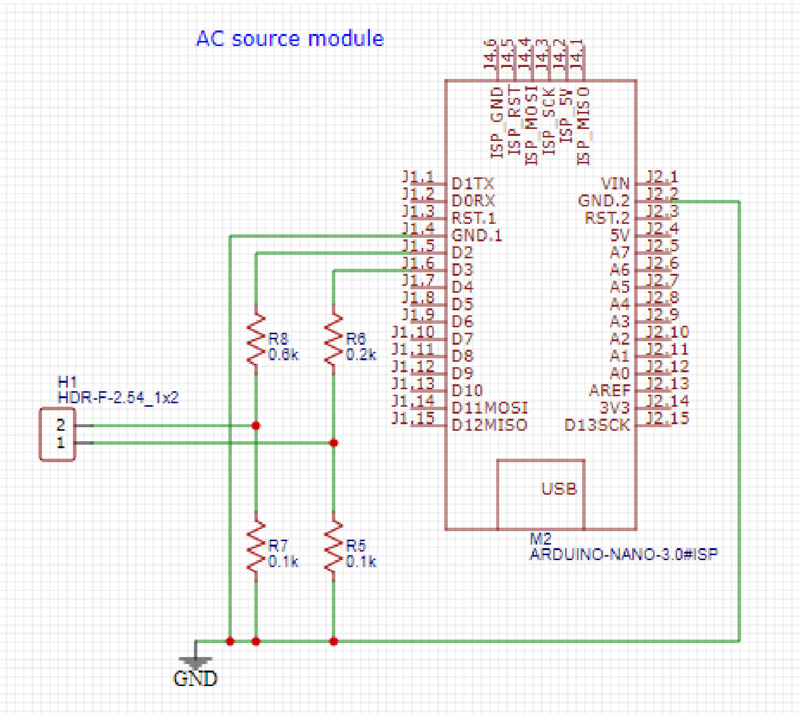


Figure 74 Power system circuit

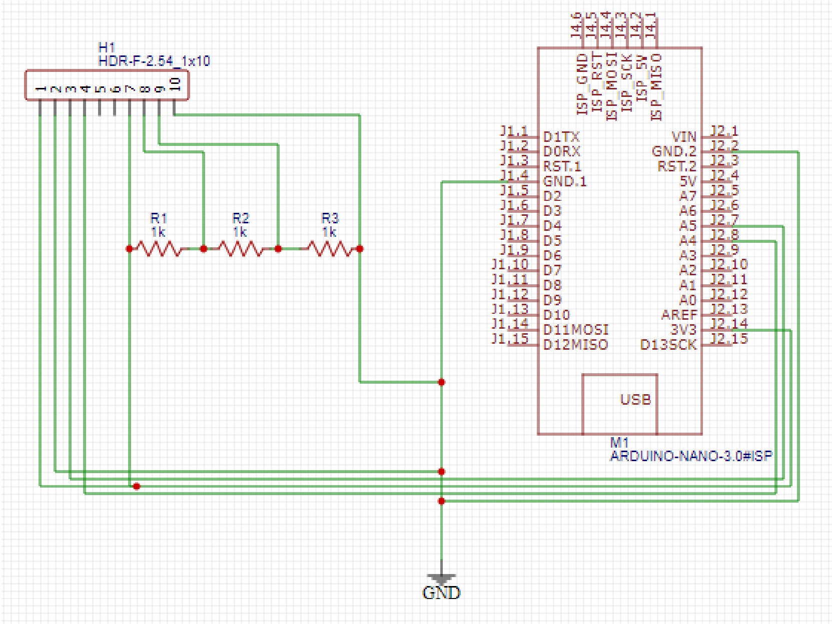


Figure 75 Measuring system test circuit

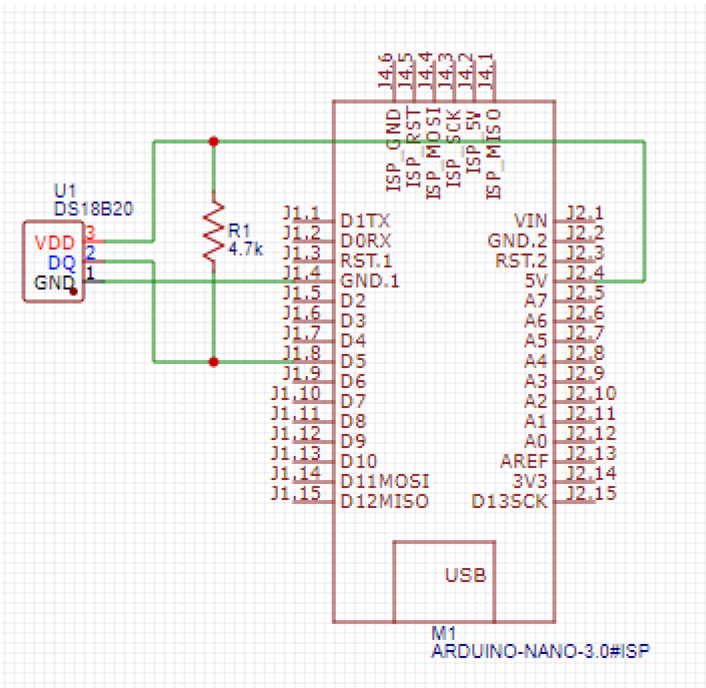


Figure 76 Correcting system circuit

Test-plans

ADS1115 ADC component Test plan

Contents

Chapter1. test-plan

1.1 Aim

This test is aiming to check the function and capability of ADC chip and its communication with Arduino processor.
Function needs to be check:
1. Single ended input
2. Differential

1.2 Hypothesis

If the circuit is connect correctly and ADC chip is working well, the processor should be able to receive the data of senso value(voltage value in this situation) by I2C communication through A4 and A5 pins from NANO. Both for the single and differential function should working well.

1.3 Tools and devices needed

Tool/Device	Description
PC laptop	Use to coding and doing paper works
Arduino NANO	Using to debug and as main platform
Bread board with wires	Test base hardware outside platform
oscilloscope	Using to monitor the voltage level
Resistors 1KΩ*3	Protect circuit and create voltage difference
multimeter	Checking electric potential and current
Software	Description
Arduino IDE	Main coding platform

1.4 Variables

results	The reading value from ADC chip

1.5 Actions

1. Connected Arduino NANO on the bread broad.
2. Connect power and GND pins between ADS1115 and Arduino NANO
3. Connect I2C communication pins between ADS1115 and NANO
4. Connect resistors and oscilloscope
5. Load the program to NANO
6. Read the data from oscilloscope
7. Read the data from serial monitor
8. Type the data into excel for record and process

1.6 Test setup:

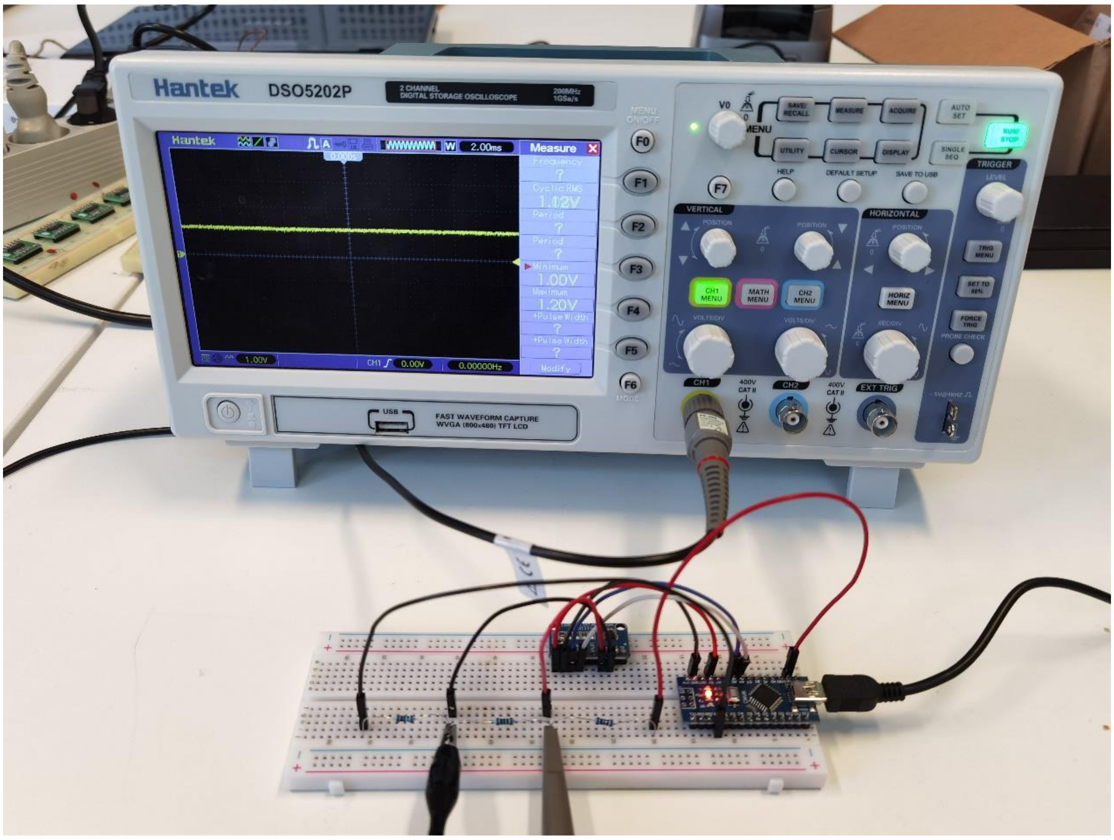
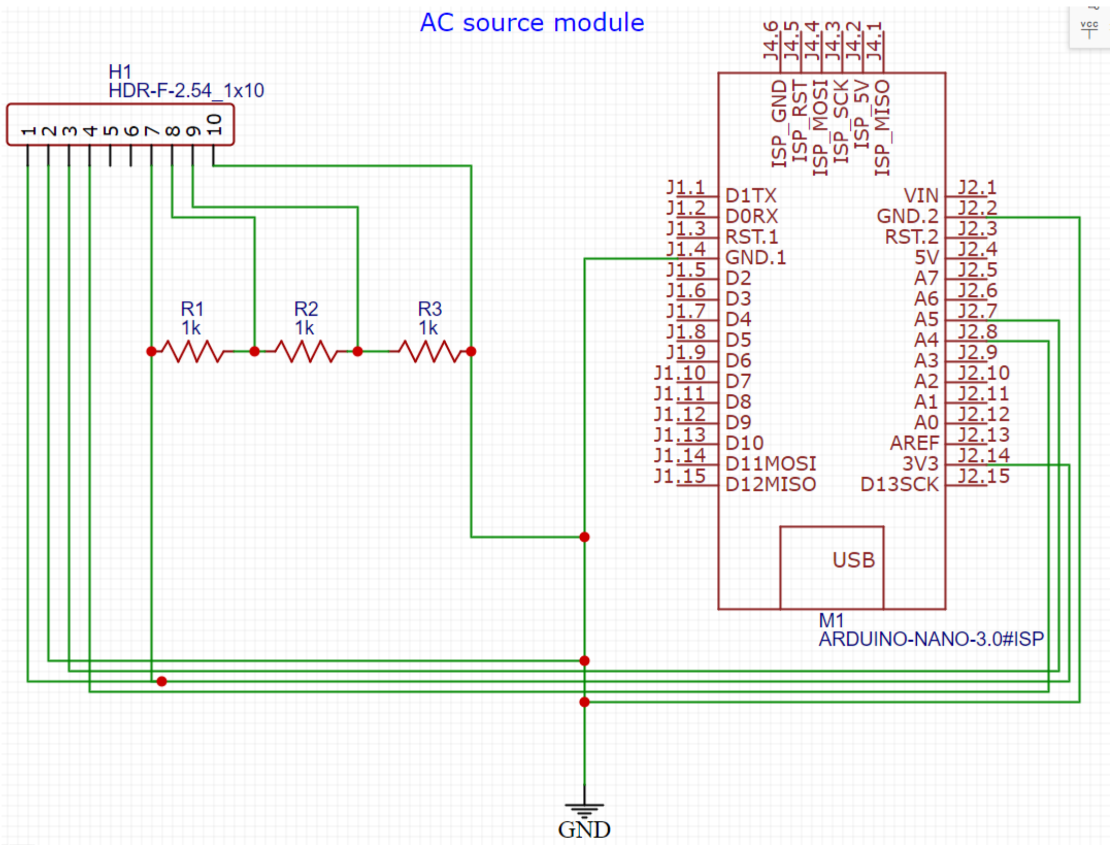


Figure 77 Test setup

1.7 Circuit diagram



Single ended input diagram

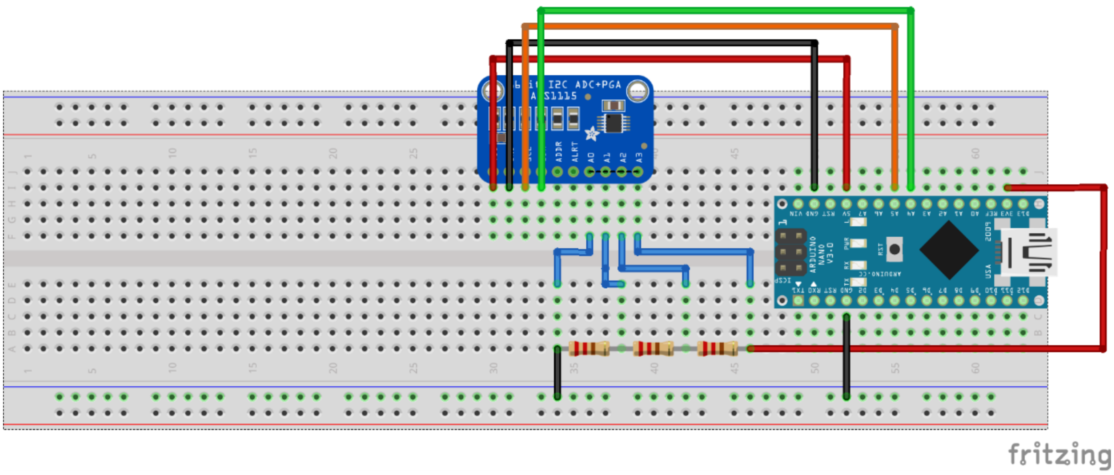


Figure 78 Single Ended Connections:

Differential input diagram

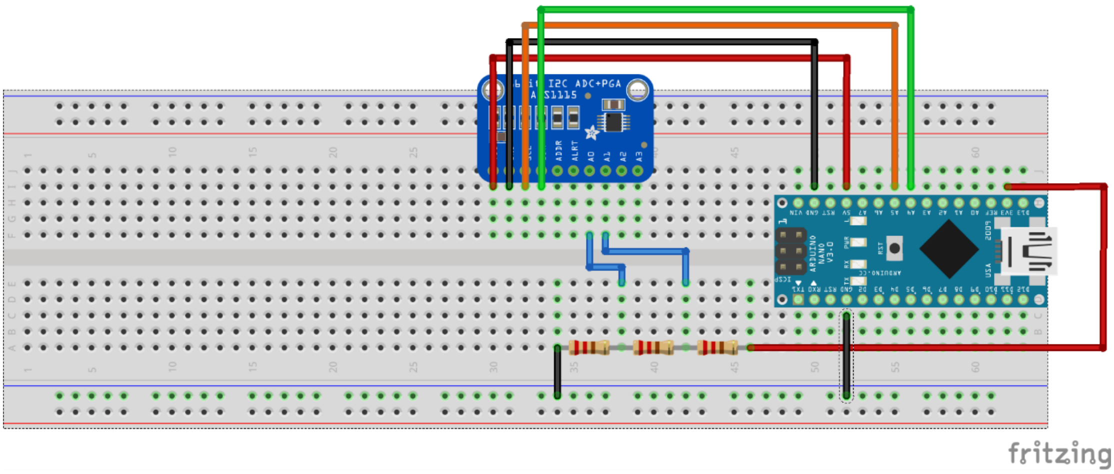


Figure 79 Differential input diagram

Schematic

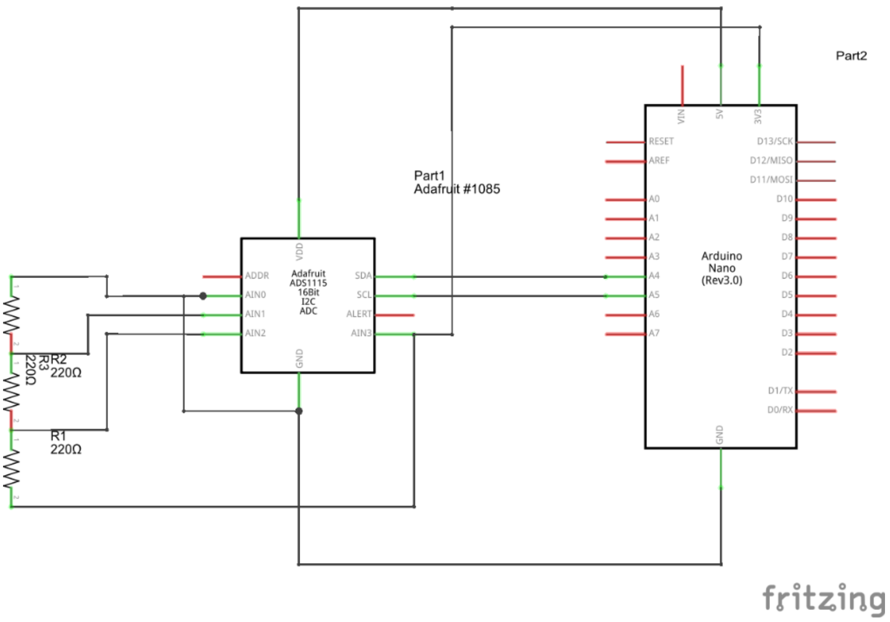


Figure 80 Schematic of test setup

1.8 Code

1. Single read testing code

```
#include <Wire.h>
#include <Adafruit_ADS1X15.h>
```

```
Adafruit_ADS1015 ads1015;
void setup(void)
{
  Serial.begin(9600);
  Serial.println("Hello!");

  Serial.println("Getting single-ended readings from AIN0..3");
  Serial.println("ADC Range: +/- 6.144V (1 bit = 3mV)");
  ads1015.begin();
}

void loop(void)
{
  int16_t adc0, adc1, adc2, adc3;

  adc0 = ads1015.readADC_SingleEnded(0);
  adc1 = ads1015.readADC_SingleEnded(1);
  adc2 = ads1015.readADC_SingleEnded(2);
  adc3 = ads1015.readADC_SingleEnded(3);
  Serial.print("AIN0:                                              ");
Serial.print(adc0);Serial.print("(");Serial.print(adc0*3);Serial.println("mV)");
  Serial.print("AIN1:                                              ");
Serial.print(adc1);Serial.print("(");Serial.print(adc1*3);Serial.println("mV)");
  Serial.print("AIN2:                                              ");
Serial.print(adc2);Serial.print("(");Serial.print(adc2*3);Serial.println("mV)");
  Serial.print("AIN3:                                              ");
Serial.print(adc3);Serial.print("(");Serial.print(adc3*3);Serial.println("mV)");
  Serial.println(" ");

  delay(1000);
        }
```

2. Differential reading code

```
#include <Wire.h>
#include <Adafruit_ADS1X15.h>

Adafruit_ADS1015 ads1015;

void setup(void)
{
  Serial.begin(9600);
  Serial.println("Hello!");
```

```
  Serial.println("Getting differential reading from AIN0 (P) and AIN1 (N)");
  Serial.println("ADC Range: +/- 6.144V (1 bit = 3mV)");
  ads1015.begin();
}

void loop(void)
{
  int16_t results;

  results = ads1015.readADC_Differential_0_1();
  Serial.print("Differential: "); Serial.print(results); Serial.print("("); Serial.print(results
* 3); Serial.println("mV)");

  delay(1000);
}
```

1.9 Expected Results

By using three 1KΩ resistors, the output voltage from Arduino NANO should be divided equally, by connect to different pins on resistor.

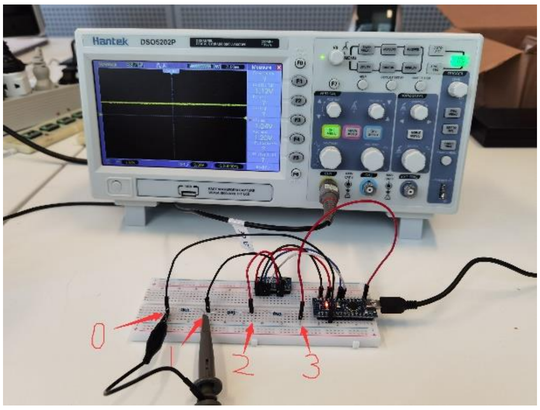


Figure 81 number of test pins

During the single point test A0, A1, A2, A3 pins on ADS1115 will connect to 0 1 2 3 (shown in picture) in order. By monitoring the data, A0 should be able to read the 0mV, A1 should read 1.1V, A2 should read 2.2V, A3 should read 3.3V.

During the differential test, A0 connect to 0 and A1 connect to 1 2 3 respectively. 0-1 should read out 1.1V, 0-2 should read 2.2V and 0-3 should read 3.3V.
If connect A1 with 0 and connect A0 with 1 2 3 respectively the result should be negative.
When all the data have been gathered, analyze their error rate, if the deviation is less than 3% compare with the data read from scope this component can be defined as pass the test.

Chapter2. Tests execute & Results

2.1 Scope data reading & Serial monitor data reading

The test contained single pin reading and differential voltage reading.

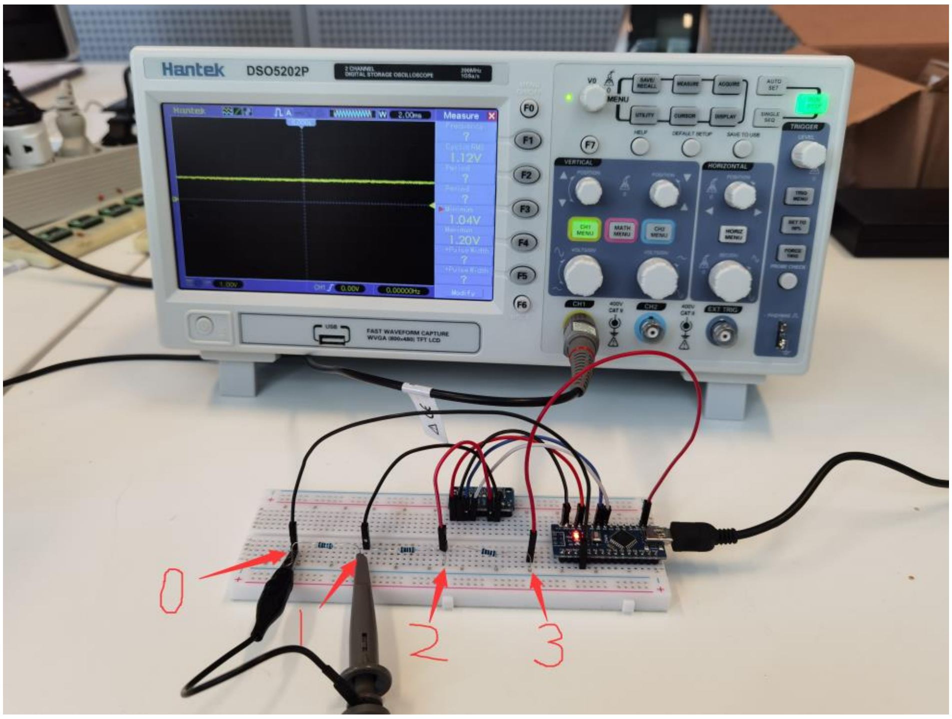
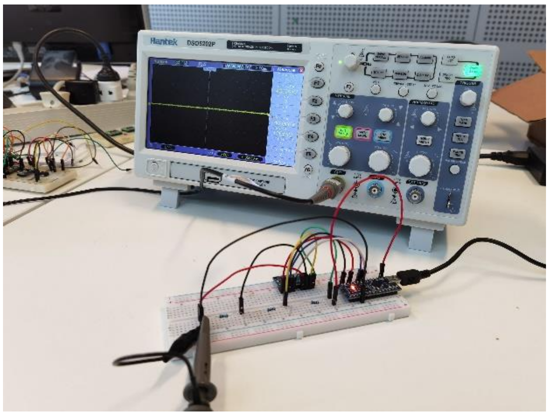
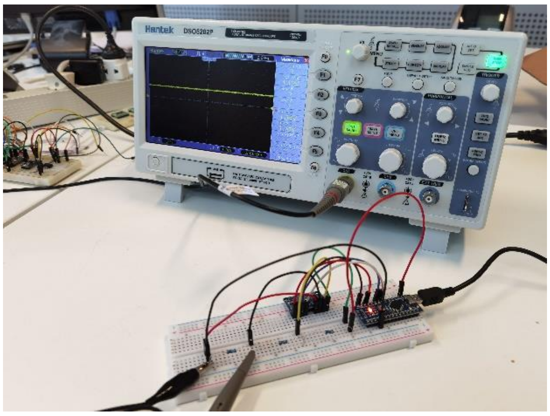
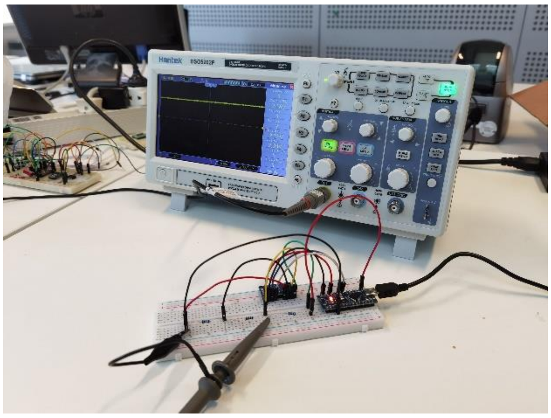


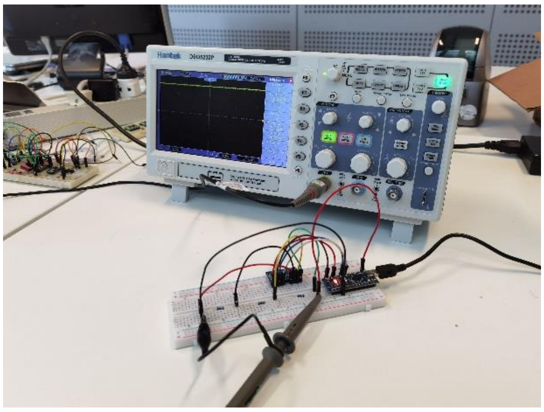
Figure 82 Number of pins

1. Single point test results









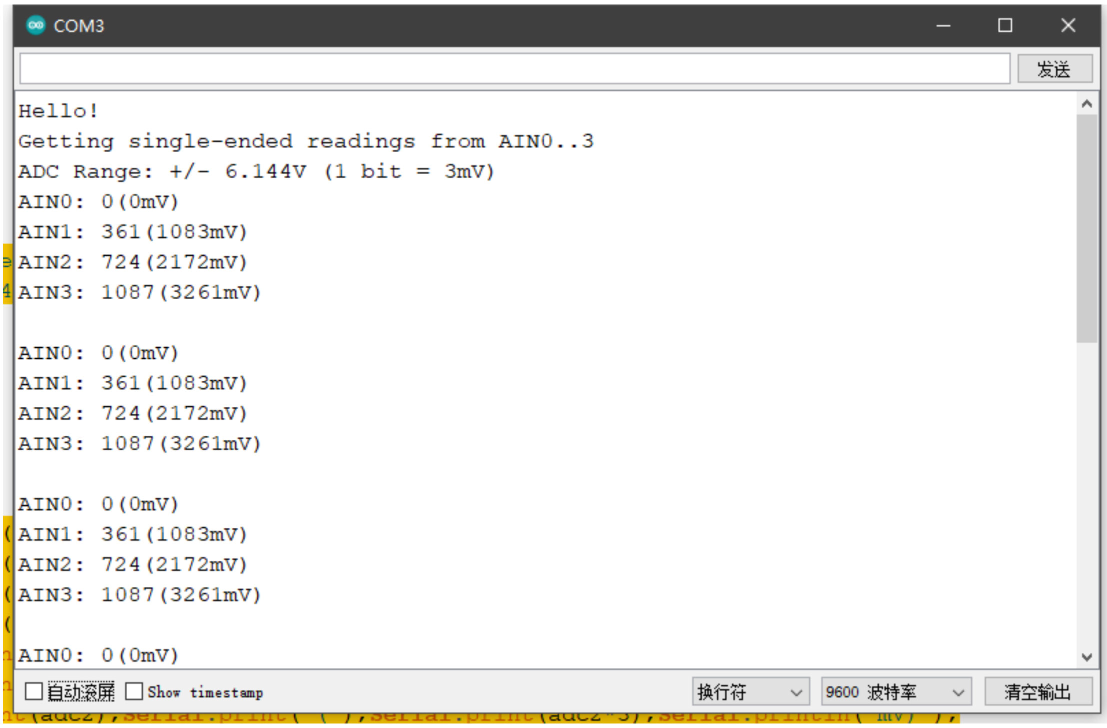


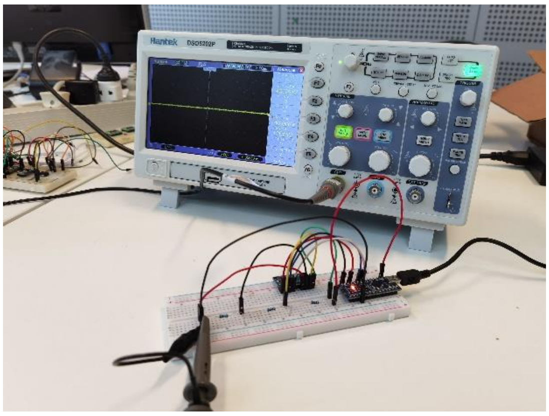
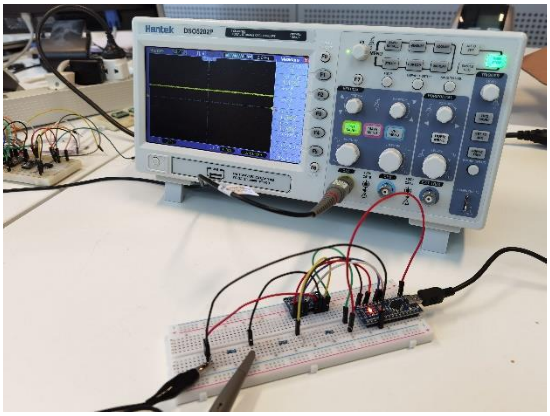
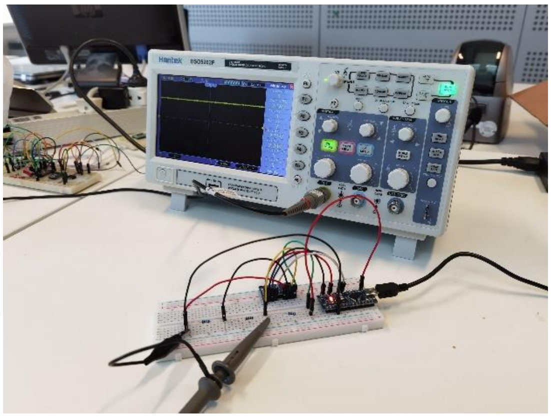
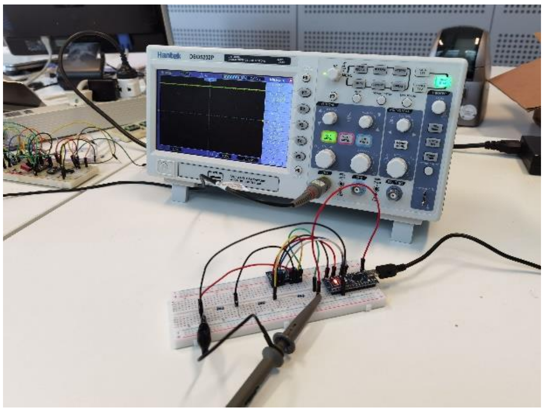
Figure 83 Reading value from ADS1115

turns	ADS1115Pin	connect pin	ideal result(mV)	actual result(mV)	error(%)
test 1	AD0	0	0	0	0,00%

	AD1	1	1100	1083	1,55%
	AD2	2	2200	2172	1,27%
	AD3	3	3300	3261	1,18%
test 2	AD0	0	0	0	0,00%
	AD1	1	1100	1083	1,55%
	AD2	2	2200	2172	1,27%
	AD3	3	3300	3261	1,18%
test 3	AD0	0	0	0	0,00%
	AD1	1	1100	1083	1,55%
	AD2	2	2200	2172	1,27%
	AD3	3	3300	3261	1,18%
test 4	AD0	0	0	0	0,00%
	AD1	1	1100	1083	1,55%
	AD2	2	2200	2172	1,27%
	AD3	3	3300	3261	1,18%
test 5	AD0	0	0	0	0,00%
	AD1	1	1100	1083	1,55%
	AD2	2	2200	2172	1,27%
	AD3	3	3300	3261	1,18%

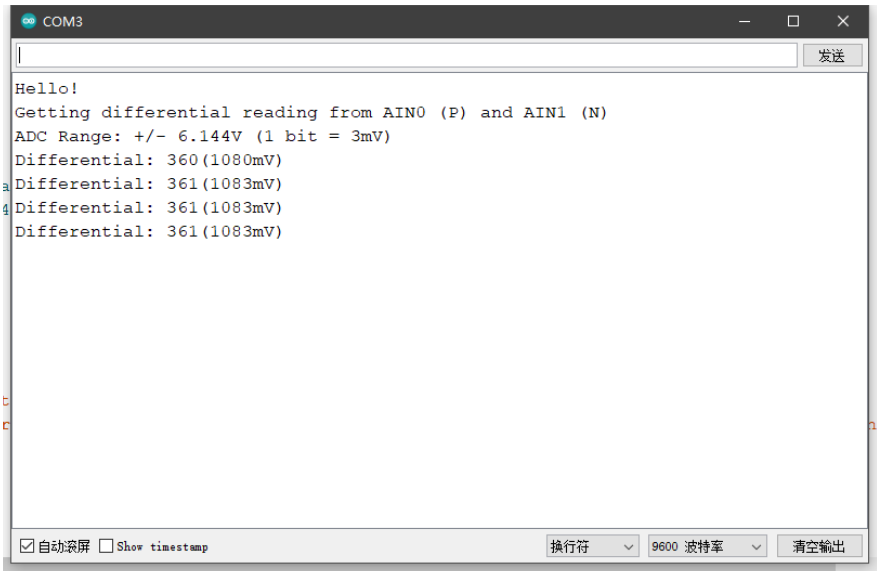
table 35 test result single mode

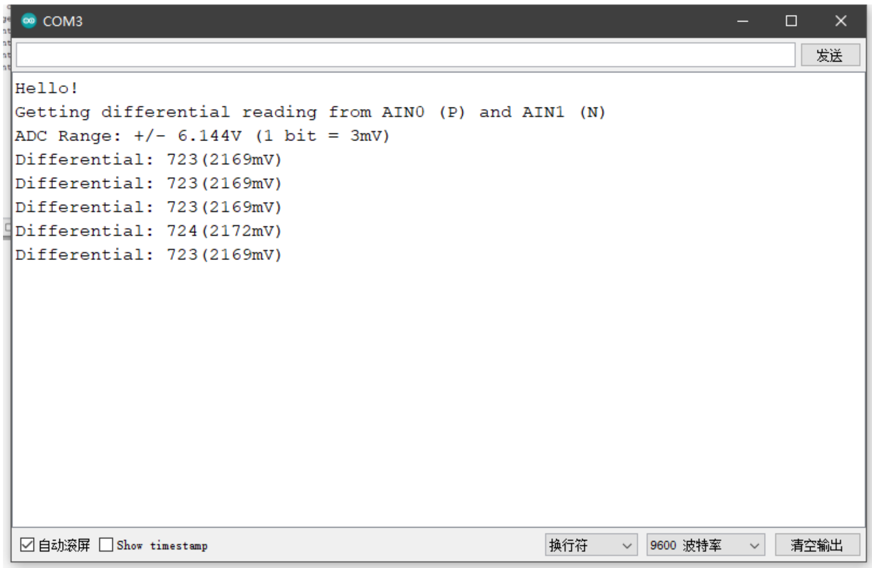
2. Differential measuring

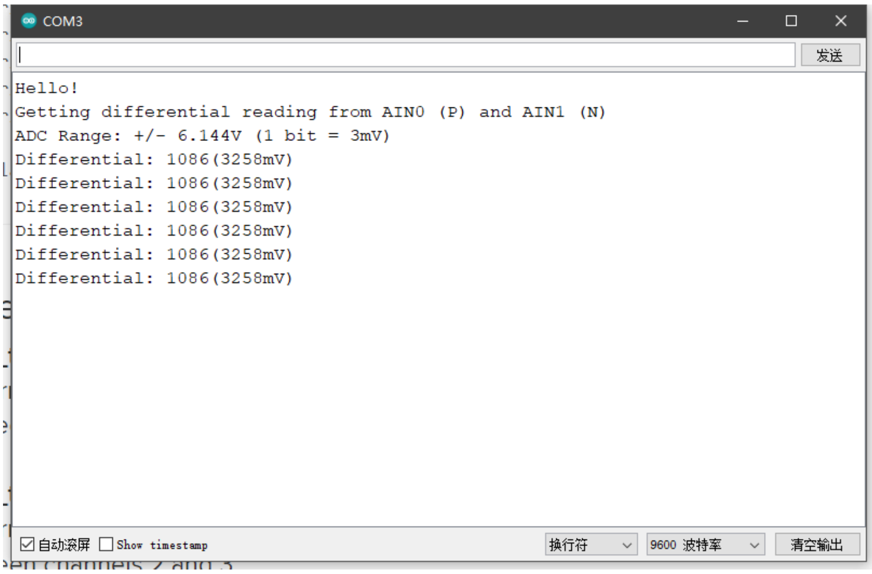





turns	ADS1115Pin	connect pin	ideal result(mV)	actual result(mV)	error(%)
test 1	AD0-1	0-1	1100	1080	0,00%
	AD0-1	0-2	2200	2169	1,41%
	AD0-1	0-3	3300	3258	1,27%
test 2	AD0-1	0-1	1100	1083	0,00%
	AD0-1	0-2	2200	2172	1,27%
	AD0-1	0-3	3300	3258	1,27%
test 3	AD0-1	0-1	1100	1083	0,00%
	AD0-1	0-2	2200	2169	1,41%
	AD0-1	0-3	3300	3258	1,27%
test 4	AD0-1	0-1	1100	1083	0,00%
	AD0-1	0-2	2200	2172	1,27%
	AD0-1	0-3	3300	3258	1,27%
test 5	AD0-1	0-1	1100	1083	0,00%
	AD0-1	0-2	2200	2169	1,41%
	AD0-1	0-3	3300	3258	1,27%

table 36 test results of differential mode


COM3
发送
Hello!
Getting differential reading from AIN0 (P) and AIN1 (N)
ADC Range: +/- 6.144V (1 bit = 3mV)
Differential: 360(1080mV)
Differential: 361(1083mV)
Differential: 361(1083mV)
Differential: 361(1083mV)
自动滚屏
Show timestamp
换行符
9600 波特率
清空输出


COM3
发送
Hello!
Getting differential reading from AIN0 (P) and AIN1 (N)
ADC Range: +/- 6.144V (1 bit = 3mV)
Differential: 723(2169mV)
Differential: 723(2169mV)
Differential: 723(2169mV)
Differential: 724(2172mV)
Differential: 723(2169mV)
自动滚屏
Show timestamp
换行符
9600 波特率
清空输出


COM3
发送
Hello!
Getting differential reading from AIN0 (P) and AIN1 (N)
ADC Range: +/- 6.144V (1 bit = 3mV)
Differential: 1086(3258mV)
Differential: 1086(3258mV)
Differential: 1086(3258mV)
Differential: 1086(3258mV)
Differential: 1086(3258mV)
Differential: 1086(3258mV)
自动滚屏
Show timestamp
换行符
9600 波特率
清空输出

2.2 Conclusion of the test

During the test, deviation percentage of single mode working is around 0% to 1.7% which less than 3% and achieved the expectation.
Differential mode working deviation is around 0% to 1.3% which also satisfied the expectation.
ADS1115 passed the test, this mean ADS1115 can be used as one of the critical component in EC meter system.

INA219 component Test plan

Contents

Chapter1. Test-plan

1.1 Aim

This test aim to validate the functionality of the INA219 chips.

1.2 Hypothesis

If circuit connect correctly, INA219 chip should be able to detect the current going through the chip.

1.3 Tools and devices needed

Tool/Device	Description
PC laptop	Use to coding and doing paper works
Arduino NANO	Using to debug and as main platform
Bread board with wires	Test base hardware outside platform
oscilloscope	Using to monitor the voltage level
Resistors 1KΩ*3	Protect circuit and create voltage difference
multimeter	Checking electric potential and current
INA219	Sensor chip of current
• Software	• Description
• Arduino IDE	• Main coding platform

1.4 Variables

results	The reading value from ADC chip

1.5 Actions

1. Connected Arduino NANO on the bread broad.
2. Connect power and GND pins between INA219 and Arduino NANO
3. Connect I2C communication pins between INA219 and NANO
4. Connect resistors and oscilloscope
5. Load the program to NANO
6. Recording data from oscilloscope
7. Read the data from serial monitor
8. Type in all the data into excel and process

1.6 Test setup:

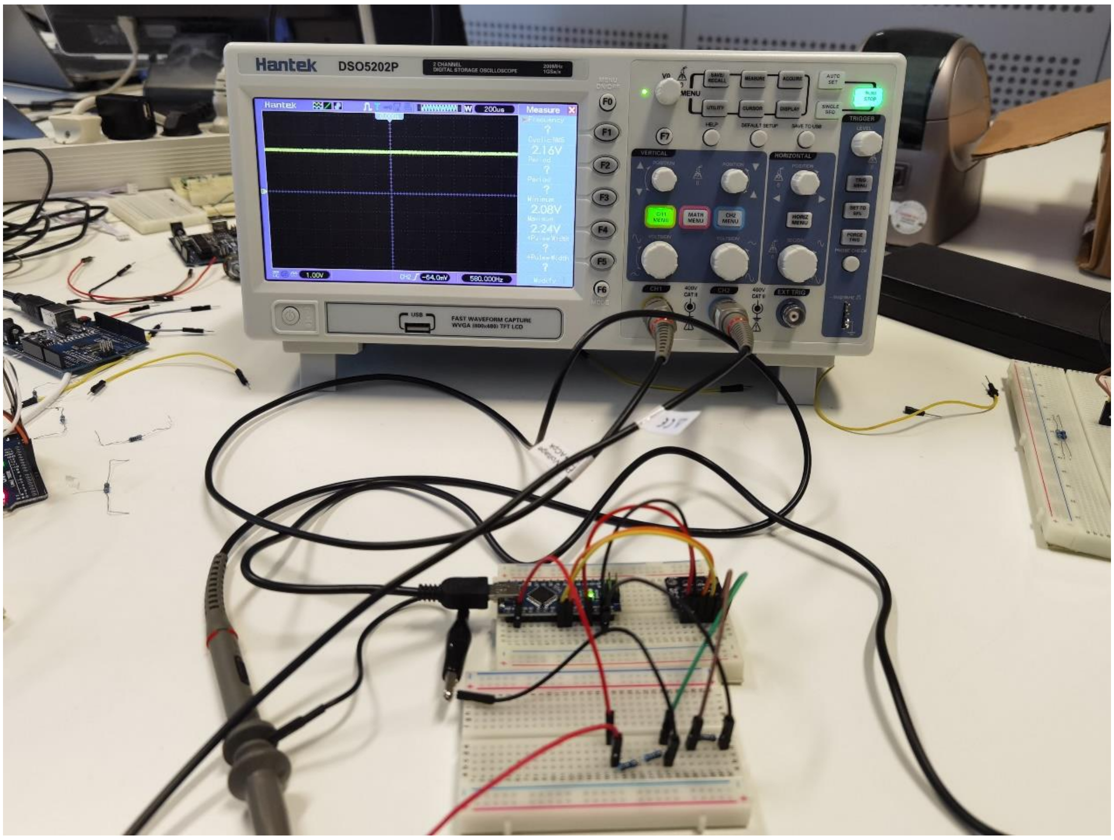


Figure 84 Test setup

1.7 Circuit diagram

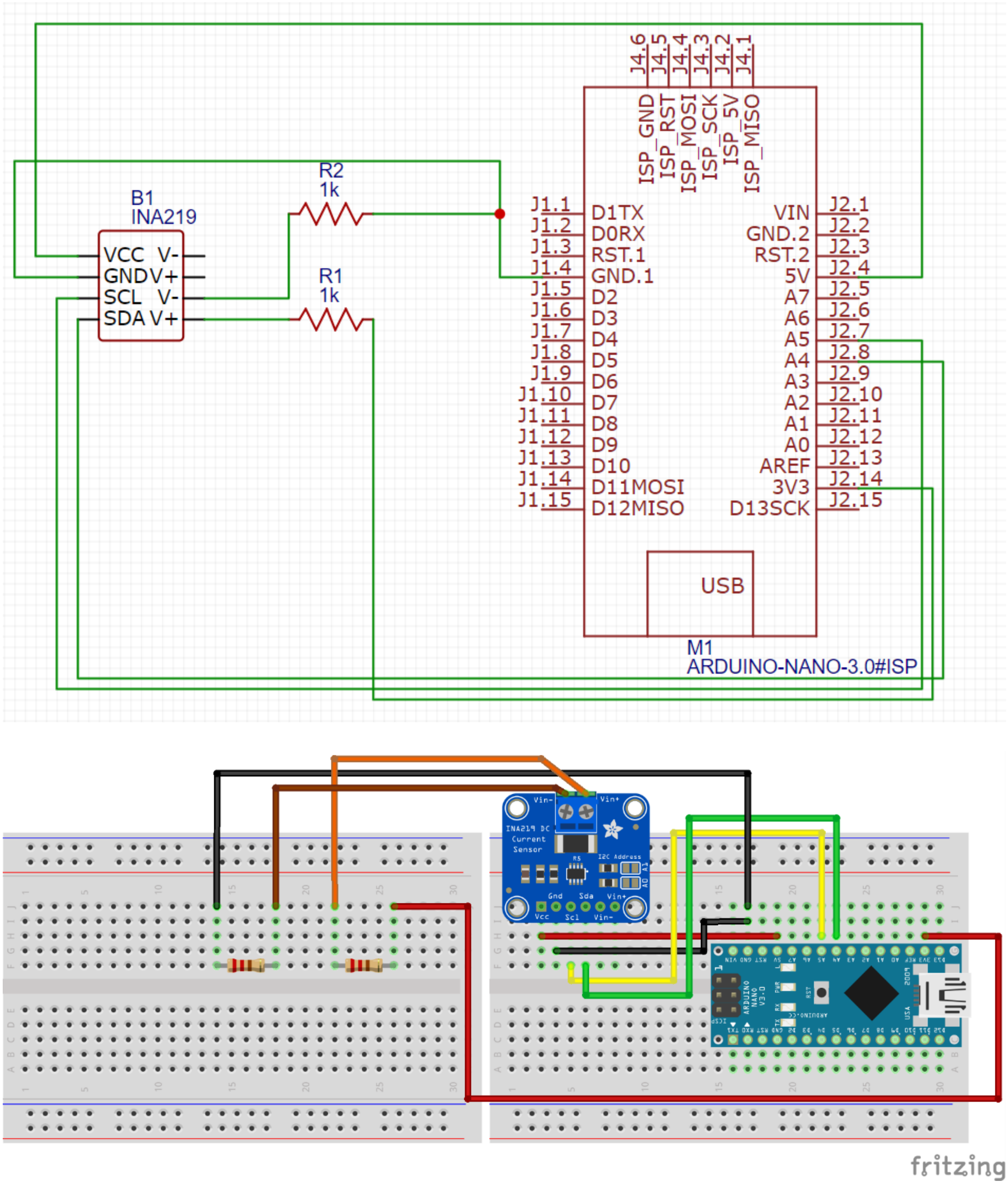


Figure 85 Diagram of circuit

1.8 Code

```
#include <Wire.h>
#include <Adafruit_INA219.h>
```

```
Adafruit_INA219 ina219;


void setup(void)
{
  Serial.begin(115200);
  while (!Serial) {
      // will pause Zero, Leonardo, etc until serial console opens
      delay(1);
  }

  uint32_t currentFrequency;

  Serial.println("Hello!");

  // Initialize the INA219.
  // By default the initialization will use the largest range (32V, 2A).  However
  // you can call a setCalibration function to change this range (see comments).
  if (! ina219.begin()) {
    Serial.println("Failed to find INA219 chip");
    while (1) { delay(10); }
  }
  // To use a slightly lower 32V, 1A range (higher precision on amps):
  //ina219.setCalibration_32V_1A();
  // Or to use a lower 16V, 400mA range (higher precision on volts and amps):
  //ina219.setCalibration_16V_400mA();

  Serial.println("Measuring voltage and current with INA219 ...");
}

void loop(void)
{
  float shuntvoltage = 0;
  float busvoltage = 0;
  float current_mA = 0;
  float loadvoltage = 0;
  float power_mW = 0;

  shuntvoltage = ina219.getShuntVoltage_mV();
  busvoltage = ina219.getBusVoltage_V();
  current_mA = ina219.getCurrent_mA();
```

```
  power_mW = ina219.getPower_mW();
  loadvoltage = busvoltage + (shuntvoltage / 1000);

  Serial.print("Bus Voltage:   "); Serial.print(busvoltage); Serial.println(" V");
  Serial.print("Shunt Voltage: "); Serial.print(shuntvoltage); Serial.println(" mV");
  Serial.print("Load Voltage:  "); Serial.print(loadvoltage); Serial.println(" V");
  Serial.print("Current:       "); Serial.print(current_mA); Serial.println(" mA");
  Serial.print("Power:         "); Serial.print(power_mW); Serial.println(" mW");
  Serial.print("Resistance:         ");     Serial.print(busvoltage/current_mA*1000);
Serial.println(" ohm");
  Serial.println("");

  delay(2000);
}
```

1.9 Expected Results

The INA219 detected the target current and other values, print them on the serial monitor. From reading the data and process it, if the deviation of the results lower than 3%, INA219 can be defined as pass the test. Otherwise failed.

Chapter2. Tests execute & results

2.1 Reading data from serial monitor

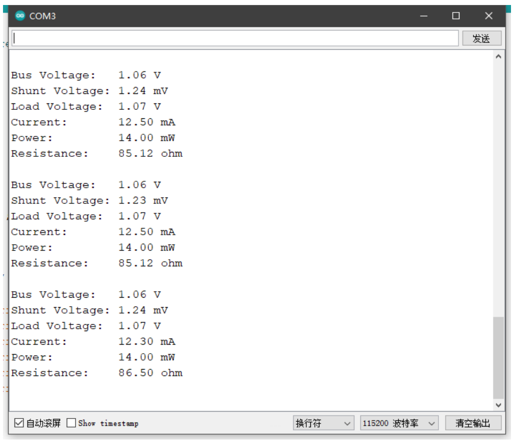


Figure 86 RESULT

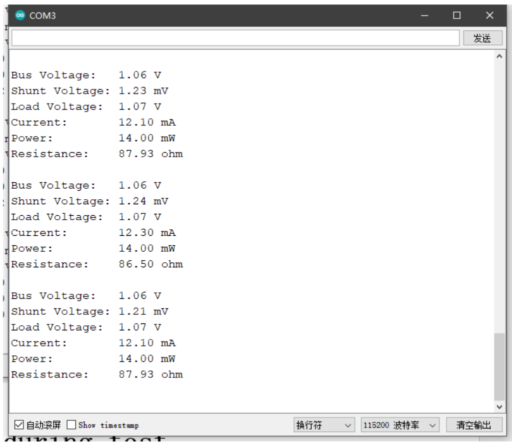


Figure 87 RESULTS

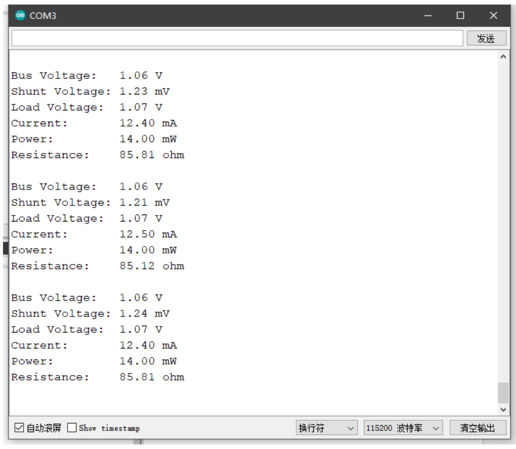


Figure 88 RESULTS

2.2 Data collected in excel

test	resistance measured (ohm)	resistance set (ohm)	error
1	85,44	100,00	14,56%
2	85,81		14,19%
3	85,81		14,19%
4	88,26		11,74%
5	86,13		13,87%
6	86,83		13,17%
7	87,93		12,07%
8	85,44		14,56%
9	86,50		13,50%
10	264,74	330,00	19,78%
11	261,30		20,82%
12	267,73		18,87%
13	264,74		19,78%
14	261,30		20,82%
15	268,27		18,71%
16	276,78		16,13%
17	260,78		20,98%
18	268,27		18,71%
19	1057,14	2000,00	47,14%
20	1019,31		49,03%
21	1096,30		45,19%
22	1136,92		43,15%
23	1138,46		43,08%
24	1138,46		43,08%
25	1019,31		49,03%
26	1057,30		47,14%
27	1057,14		47,14%

Figure 89 results

2.3 Conclusion

From the test data collected in excel, it is found that the deviation is getting higher and higher when testing resistance goes higher. Error percentages are far more than 3%'s setting standard. INA219 failed the test, this means using INA 219 as a critical components in EC meter system is not acceptable.

AC square wave Test plan

Contents

Chapter1. Test-plan

1.1 Aim

The test is aiming to validate the possibility of using processor to generate AC square wave at the frequency of 800Hz.

1.2 Hypothesis

If the outside circuit is designed correct, the power sub-system should be able to create an AC square voltage wave of 1V~-1V, frequency from 400Hz to 1200Hz.

1.3 Tools and devices needed

Tool/Device	Description
PC laptop	Use to coding and doing paper works
Arduino NANO	Using to debug and as main platform
Bread board with wires	Test base hardware outside platform
oscilloscope	Using to monitor the output wave
Resistors	Create the outside circuit 1kΩ
multimeter	Checking electric potential and current
1. Software	2. Description
3. Arduino IDE	4. Main coding platform

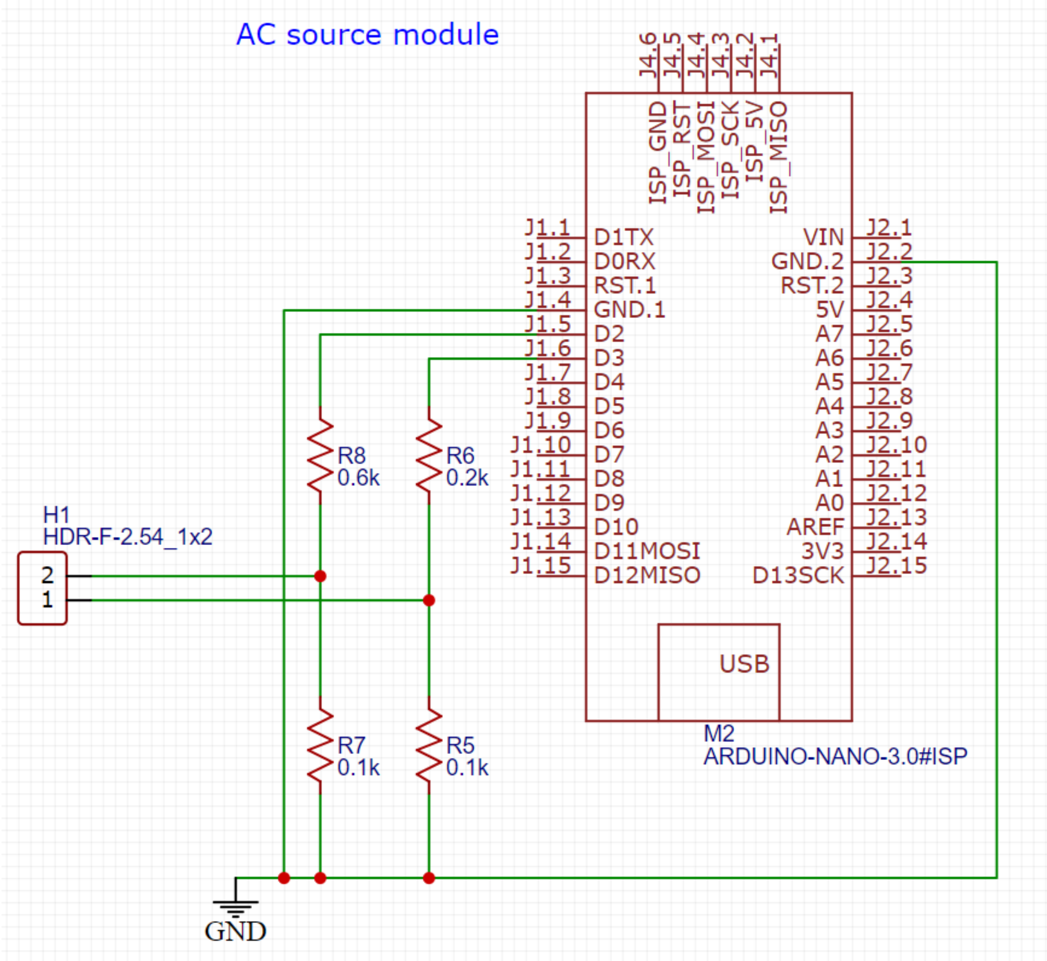
1.4 Variables

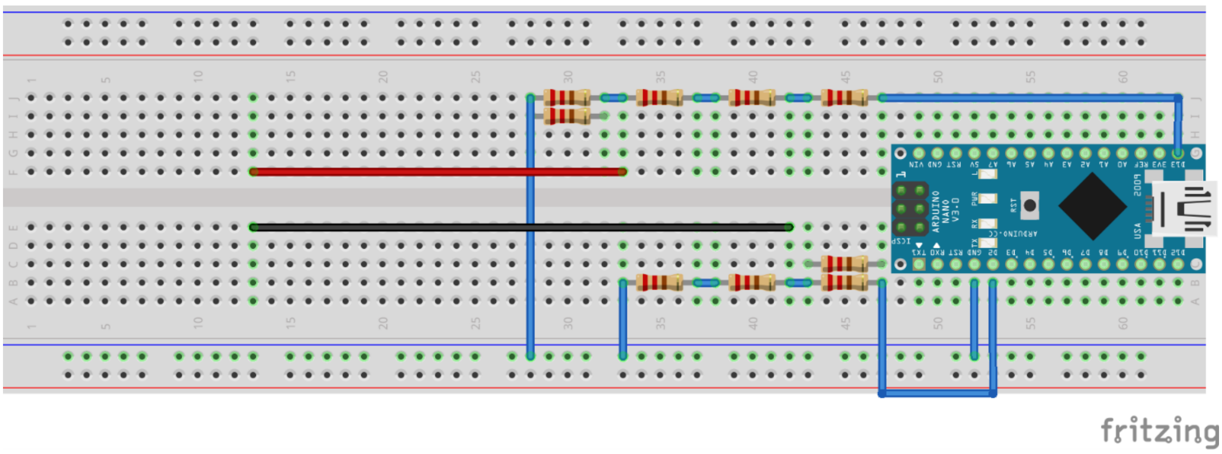
frequency	Setting frequency of AC square wave
delayTime	Actual real delay time

1.5 Actions

1. Connected Arduino NANO on the bread broad.
2. Use USB cable to connect the NANO with PC
3. Check NANO using “blink” code
4. Connect resistors and oscilloscope
5. Load the program to NANO
6. Reading data from oscilloscope
7. Type the data in excel

1.6 Circuit diagram





1.7 Code

```
int frequency = 500; //Set frequency in Hertz
double delayTime = 1000 / (frequency * 2);

void setup()
{
pinMode(13, OUTPUT);
pinMode(2, OUTPUT);
}

void loop()
{
 digitalWrite(13, HIGH);
 digitalWrite(2, LOW);
 delay(delayTime);
 digitalWrite(2, HIGH);
 delay(delayTime);
}
```

1.8 Expected Results

If the oscilloscope directly connects to the output pin of the processor, a DC square wave will be captured and the frequency should be equal to the setting value.
If connect the oscilloscope on two AC output circuit nodes, an AC square wave should be captured and the frequency should also equal to the setting value.
Desired frequency output is 820Hz. The acceptable deviation is 5%.

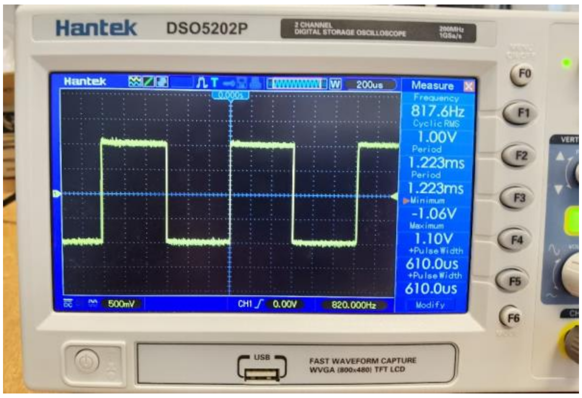


table 37 820 Hz output AC square wave

Chapter2. Test executing & results

2.1 Reading from scope

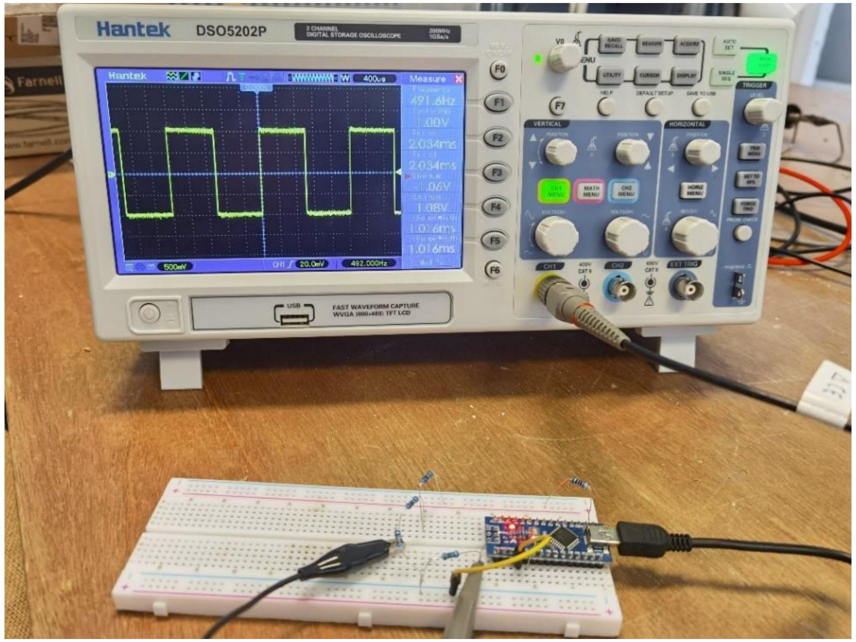


Figure 91 test setup

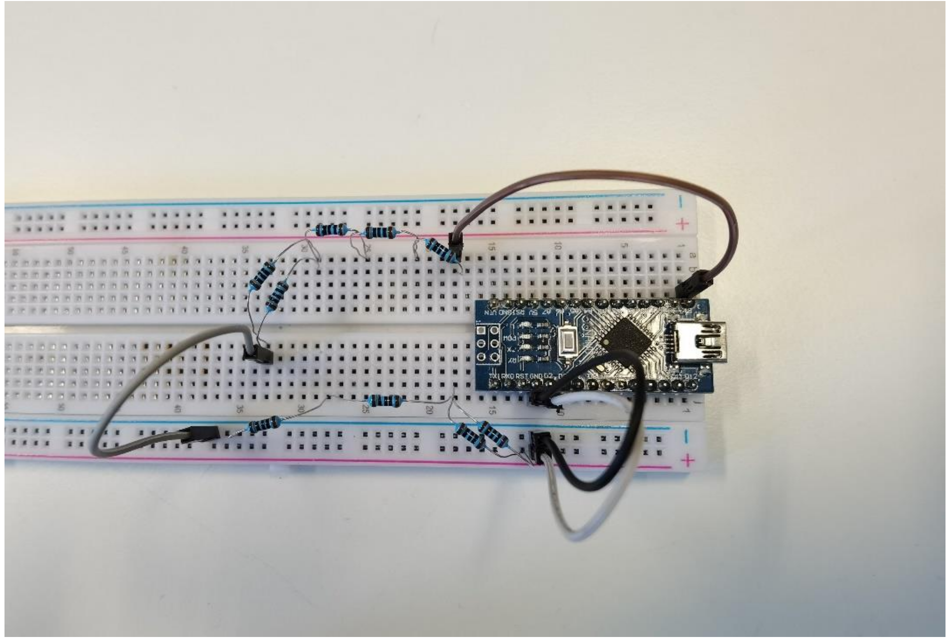


Figure 90 improved test setup

2.2 Data made into table

Setting value	measuring value								
	1st measuring			2nd measuring			3rd measuring		
	measuring voltage(mV)	measuring frequency(Hz)	error	measuring voltage(mV)	measuring frequency(Hz)	error	measuring voltage(mV)	measuring frequency(Hz)	error
3600	-960/820	3454	4,06%	-960/820	3453	4,08%	-960/820	3453	4,08%
3000	-940/800	2893	3,57%	-940/800	2893	3,57%	-940/800	2893	3,57%
2000	-940/800	1948	2,60%	-940/800	1947	2,65%	-940/800	1948	2,60%
1000	-960/820	978	2,20%	-960/820	978	2,20%	-960/820	978	2,20%
880	-960/820	864	1,82%	-980/820	864	1,82%	-980/820	864	1,82%
850	-940/820	834	1,88%	-940/820	835	1,76%	-940/820	835	1,76%
834	-940/800	820	1,68%	-940/800	820	1,68%	-940/800	820	1,68%
820	-920/840	805	1,83%	-920/840	805	1,83%	-920/840	805	1,83%
800	-960/820	784	2,00%	-960/820	784	2,00%	-960/820	784	2,00%
700	-960/780	688	1,71%	-960/780	687	1,86%	-960/780	688	1,71%
600	-980/760	592	1,33%	-960/760	592	1,33%	-980/760	592	1,33%
500	-980/760	493	1,40%	-980/760	493	1,40%	-980/760	493	1,40%
400	-980/760	394	1,50%	-980/780	395	1,25%	-980/760	395	1,25%
300	-1000/760	297	1,00%	-1000/760	298	0,67%	-1000/760	297	1,00%
200	-1000/780	198	1,00%	-980/760	198	1,00%	-1000/760	198	1,00%
100	-1000/780	99	1,00%	-1020/780	99	1,00%	-1020/780	99	1,00%
50	-980/760	49	2,00%	-980/760	49	2,00%	-980/760	49	2,00%
10	-980/740	10	0,00%	-980/740	10	0,00%	-980/740	10	0,00%
1	-960/740	1	0,00%	-960/740	1	0,00%	-960/740	1	0,00%

table 38 Result of the tests

2.3 Line chart extracted

output voltage of Arduino NANO digital pin is about 3.72V with 1KΩ resistant

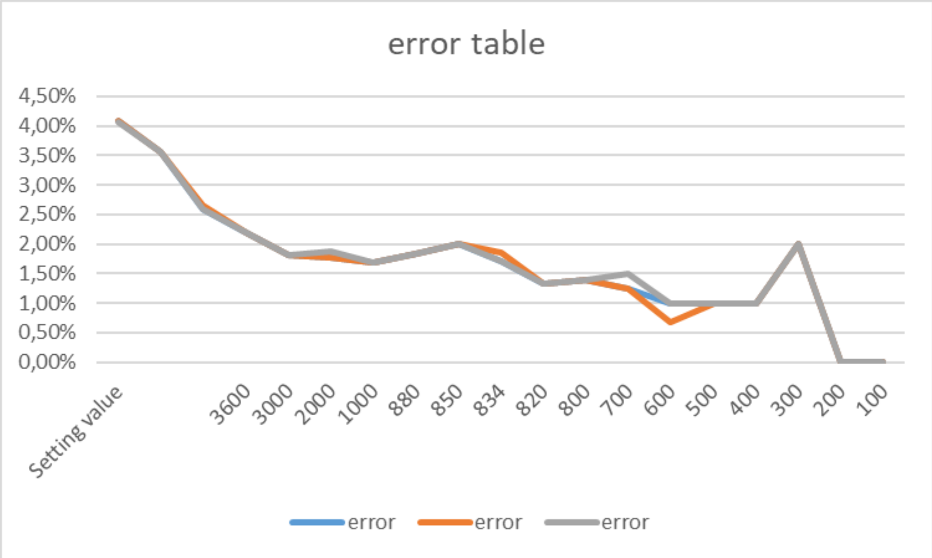


table 39 Table of the errors

2.4 Drawbacks during test

5. When using “delayMicroseconds” function in program the error going extremely high at low frequency (lower than 100Hz)
6. When using “delay” function in program the error going extremely high at high frequency (higher than 500Hz)
7. Limited by the testing setup, 6 resistors are used, it can be limit in 4

2.5 Improvements made

1. Add if statement to improve the performance of the program
2. Use different kind of delay function

2.6 Improved code

```
int frequency = 80; //Set frequency in Hertz
double delayTime = 1000000 / (frequency * 2);
double delayseconds = 1000/(frequency * 2);
```

```
void setup()
{
pinMode(13, OUTPUT);
pinMode(2, OUTPUT);
}

void loop()
{
 double T = 0;
 digitalWrite(13, HIGH);
 if (frequency>=100)
  {
   T = delayTime;
   digitalWrite(2, LOW);
   delayMicroseconds(T);
   digitalWrite(2, HIGH);
   delayMicroseconds(T);
  }
 else
 {
   T = delayseconds;
   digitalWrite(2, LOW);
   delay(T);
   digitalWrite(2, HIGH);
   delay(T);
 }
}
```

2.7 Conclusion

According to the test result, this AC square wave have a deviation less than 5% and the wave shape is stable which meet the expectation. Therefore, the test defined as pass, and this sub-system is able to be used in system.

Measuring system Test plan

Contents

Chapter1. Test-plan

1.1 Aim

This test is focus on validate the functional ability of measuring system cooperating with powering system. By doing this test, the measuring capability will be proved.

1.2 Hypothesis

If the circuit connected correctly, AC square wave should be able to be detected and the measuring component ADS1115 should be able to measure both of the voltage of two resistors(one resistor is known as 1000Ω) and calculate out one of the unknow resistance.

1.3 Tools and devices needed

Tool/Device	Description

PC laptop	Use to coding and doing paper works
Arduino NANO	Using to debug and as main platform
Bread board with wires	Test base hardware outside platform
oscilloscope	Using to monitor the voltage level
Resistors 1KΩ*1	Reference resistor
Resistors 680Ω*1	Measuring resistor
Resistors 2000Ω*1	Measuring resistor
Resistors 330Ω*1	Measuring resistor
multimeter	Checking electric potential and current
• Software	• Description
• Arduino IDE	• Main coding platform

1.4 Variables

Results1/a	The reading voltage from measuring resistor
Results2/b	The reading voltage from reference resistor
Frequency	Set frequency of AC source

1.5 Actions

1. Connected Arduino NANO on the bread broad.
2. Connect I2C communication pins between ADS1115 and NANO
3. Connect AC square wave circuit
4. Connect power and GND pins between ADS1115 and AC circuit
5. Load the program to NANO
6. Recording data from oscilloscope
7. Reading data from the serial monitor
8. Type the data into excel and calculate the deviation

1.6 Test setup:

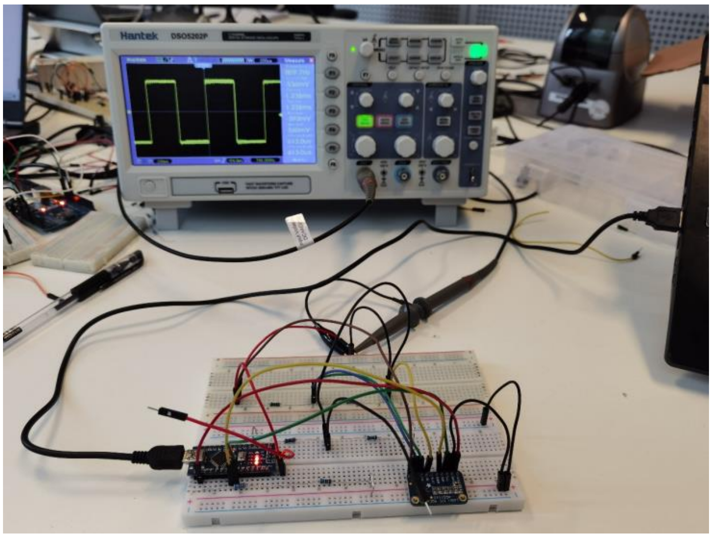
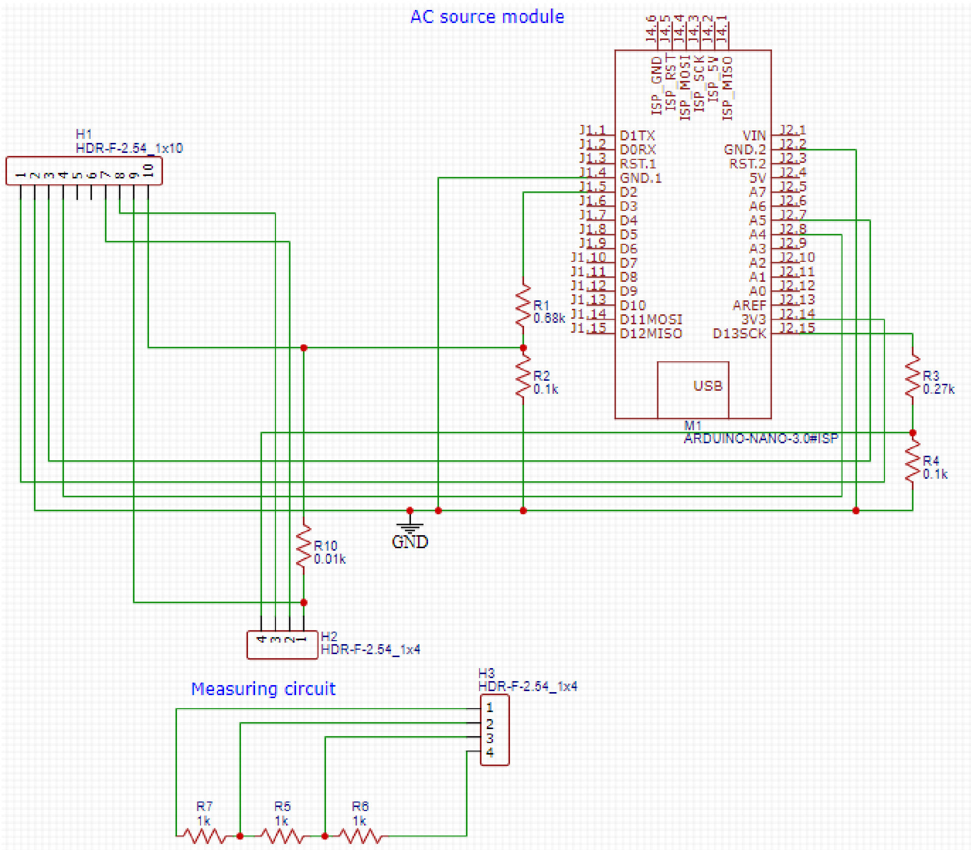


Figure 92 test setup

1.7 Circuit diagram



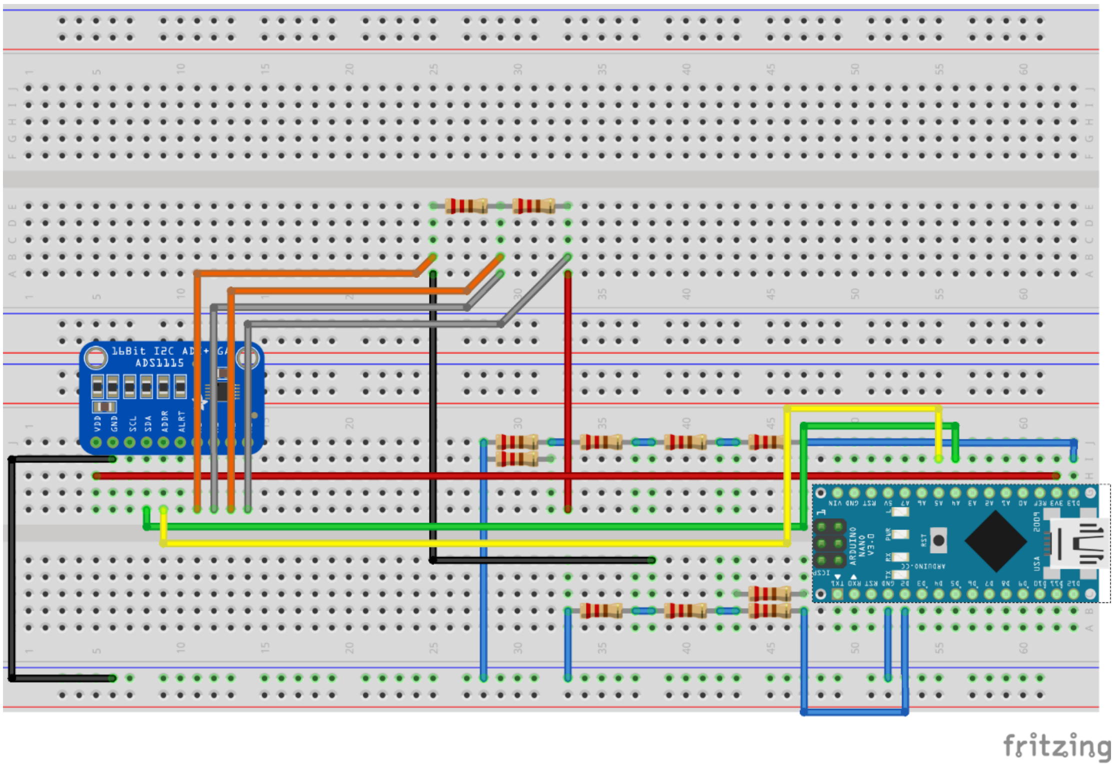


Figure 93 circuit diagram

1.8 Code

```
#include <Wire.h>
#include <Adafruit_ADS1X15.h>
int frequency = 834; //Set frequency in Hertz
double delayTime = 1000000 / (frequency * 2);
double delayseconds = 1000/(frequency * 2);
Adafruit_ADS1015 ads1015;
double n = 0;

void setup(void)
{
  pinMode(13, OUTPUT);
  pinMode(2, OUTPUT);
  Serial.begin(115200);
  Serial.println("Hello!");

  Serial.println("Getting differential reading from AIN0 (P) and AIN1 (N)");
  Serial.println("ADC Range: +/- 6.144V (1 bit = 3mV)");
  ads1015.begin();
```

```
}

void loop(void)
{
 int16_t results1;
 int16_t results2;
 double T = 0;
 double resistance = 0,a=0,b=0;
 digitalWrite(13, HIGH);
if (frequency>=100)
 {
  T = delayTime;
  digitalWrite(2, LOW);
  delayMicroseconds(T);
  digitalWrite(2, HIGH);
  delayMicroseconds(T);
  }
else
{
 T = delayseconds;
 digitalWrite(2, LOW);
 delay(T);
 digitalWrite(2, HIGH);
 delay(T);
}
n=n+1;
if (n>=850)
{
 n=0;
 results1 = ads1015.readADC_Differential_0_1();
 a=results1;
 Serial.print("Differential: "); Serial.print(results1); Serial.print("(");
Serial.print(results1 * 3); Serial.println("mV)");
 results2 = ads1015.readADC_Differential_2_3();
 b=results2;
 Serial.print("Differential: "); Serial.print(results2); Serial.print("(");
Serial.print(results2 * 3); Serial.println("mV)");
 resistance = (a/b) * 1000;
 Serial.print("Resistance= "); Serial.println(resistance);
}
}
```

1.9 Expected Results

By successfully setup the test, AC square wave should be able to correctly detect by scope. ADS1115 should be able to read both two resistor's voltage and shows on the serial monitor. Unknown resistor's resistance should be able to be calculated and also shows on the serial monitor. The error of the resistance should be lower than 10%.

Thus, if the deviation of the measuring of resistance is less than 10% compare with the commercial measuring tools then the sub-system can be seem as pass, otherwise it will be admit as failed and other sub-system need to be made.

Chapter2. Test executing & results

2.1 Reading from scope

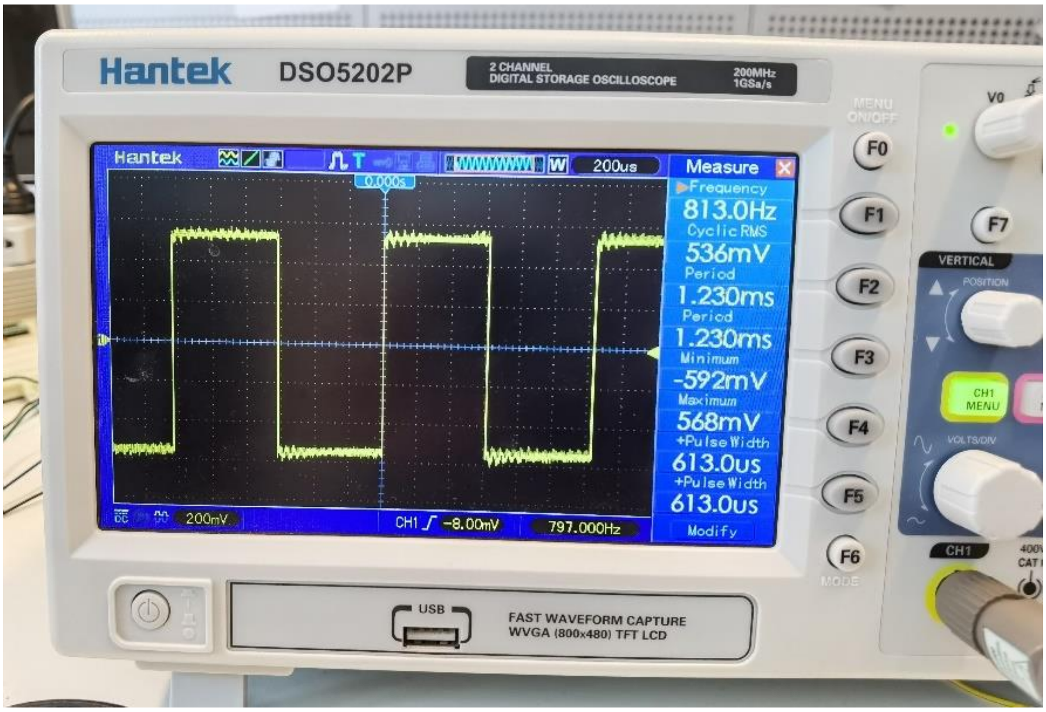


Figure 94 scope setup

From the test, AC square wave is detected by the scope on testing resistors' circuit. This proved that AC square wave source can be used on outside circuit.

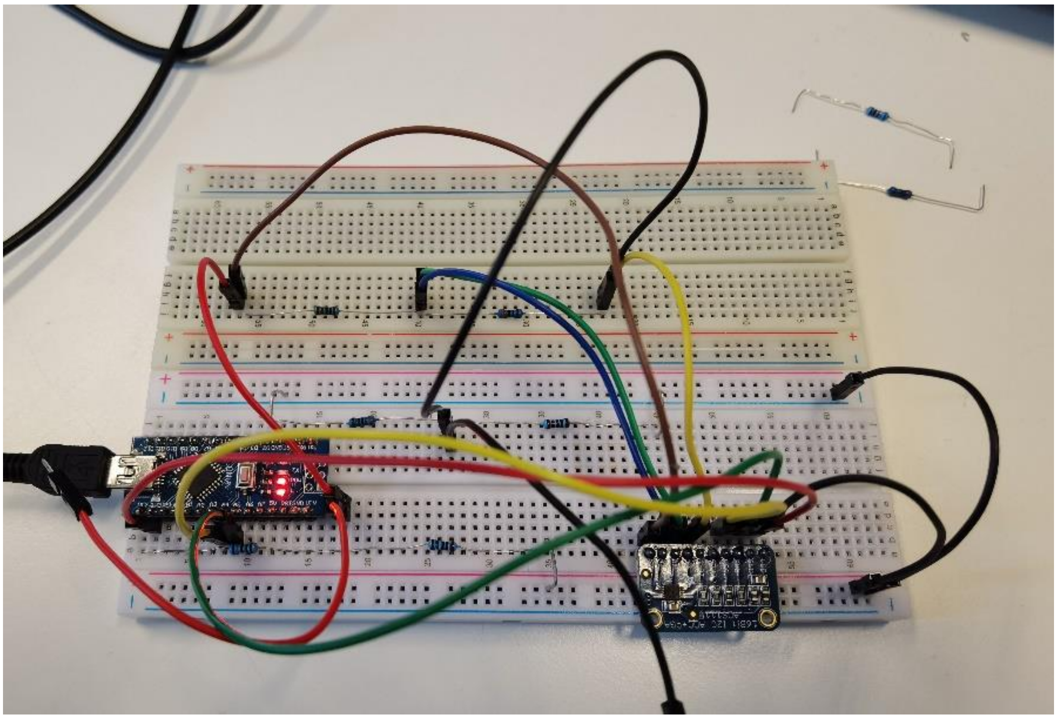


Figure 95 circuit setup

2.2 Reading from serial monitor

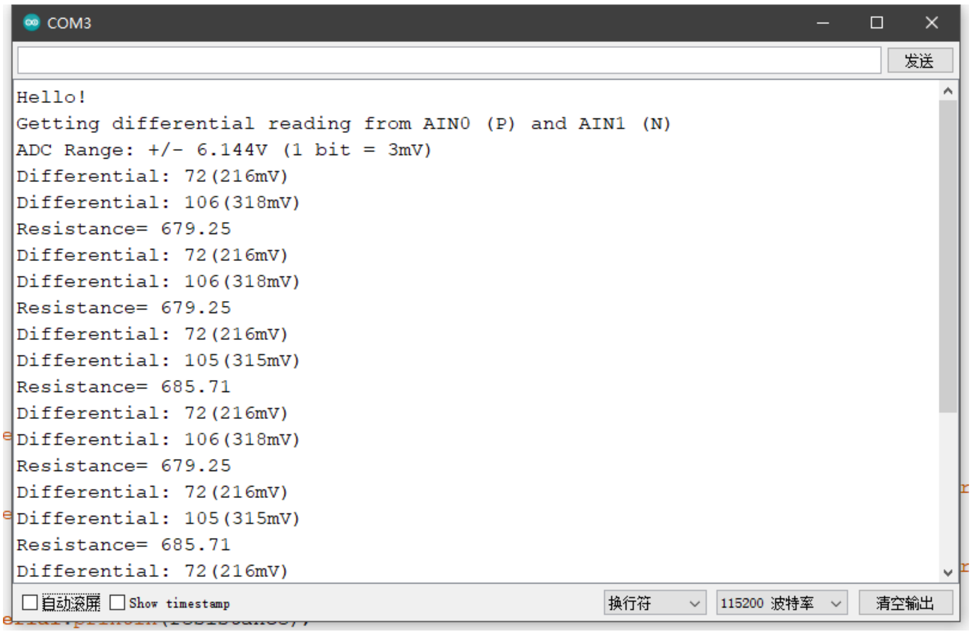


Figure 96 Reading value from serial monitor

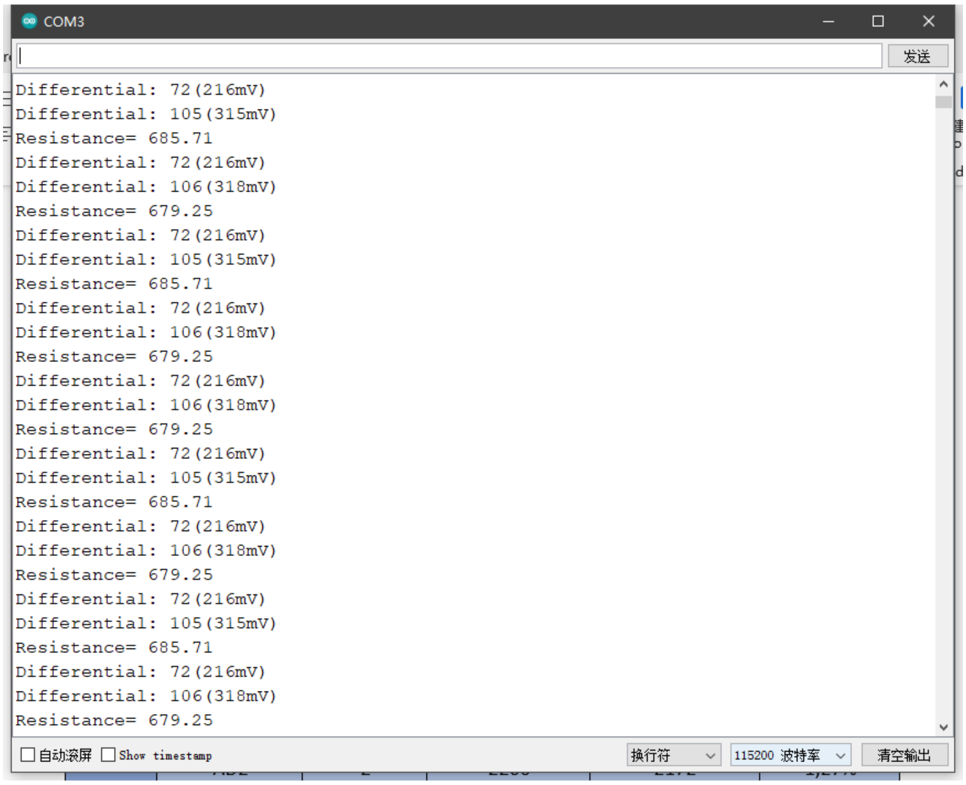


Figure 97 Reading value from ADS1115

2.3 Type into excel

From the table below, you can see the processed test data.

The first left row is the reference resistor used, here used two the first one is labeled as 1000ohm and measured by commercial multimeter as 995ohm. The second resistor is labeled as 10ohm and measured as 10.1ohm. By use two different types of multimeter's measuring these value is the same and can be admit as accurate according to in-company mentor.

The test power frequency has been set as 835Hz(±2Hz). During the test, from the left fourth row's data we found a part of frequency loss in real use, but this is not affect the test and real use.

ref resistor	test	set frequency(Hz)	frequency (Hz)	frequency error	voltage measure(mV)	voltage ref(mV)	measure resistance(Ω)	set resistance(Ω)	resistance error
995	1	834	813	2,52%	216	315	682,29	677	0,78%
	2		814	2,40%	216	318	675,85		0,17%
	3		813	2,52%	216	315	682,29		0,78%
	4		813	2,52%	216	318	675,85		0,17%
	5		812	2,64%	216	318	675,85		0,17%
	6		813	2,52%	216	315	682,29		0,78%
	7		812	2,64%	216	318	675,85		0,17%
	8		812	2,64%	216	315	682,29		0,78%
	9		812	2,64%	216	318	675,85		0,17%
	10		812	2,64%	216	318	675,85		0,17%
	11	834	813	2,52%	360	180	1990,00	1989	0,05%
	12		814	2,40%	360	180	1990,00		0,05%
	13		813	2,52%	360	180	1990,00		0,05%
	14		813	2,52%	360	180	1990,00		0,05%
	15		812	2,64%	360	180	1990,00		0,05%
	16		813	2,52%	360	180	1990,00		0,05%
	17		812	2,64%	360	180	1990,00		0,05%
	18		812	2,64%	360	180	1990,00		0,05%
	19		812	2,64%	360	180	1990,00		0,05%
	20		812	2,64%	360	180	1990,00		0,05%
	21	834	813	2,52%	144	438	327,12	329	0,57%
	22		814	2,40%	144	438	327,12		0,57%
	23		813	2,52%	144	438	327,12		0,57%
	24		813	2,52%	144	438	327,12		0,57%
	25		812	2,64%	144	438	327,12		0,57%
	26		813	2,52%	144	438	327,12		0,57%
	27		812	2,64%	144	438	327,12		0,57%
	28		812	2,64%	144	438	327,12		0,57%
	29		812	2,64%	144	441	324,90		1,25%
	30		812	2,64%	144	441	324,90		1,25%
	31	835	811	2,76%	172	17	10067,06	9550	5,41%
	32		813	2,52%	172	17	10067,06		5,41%
	33		813	2,52%	172	17	10067,06		5,41%
	34		813	2,52%	172	17	10067,06		5,41%
	35		812	2,64%	173	17	10125,59		6,03%
	36		812	2,64%	172	17	10067,06		5,41%
	37		813	2,52%	173	17	10125,59		6,03%
	38		812	2,64%	172	17	10067,06		5,41%
	39		812	2,64%	173	17	10125,59		6,03%
	40		812	2,64%	172	17	10067,06		5,41%
	41	835	813	2,52%	6	495	12,06	1,2	905,05%
	42		813	2,52%	6	492	12,13		911,18%
	43		813	2,52%	6	495	12,06		905,05%
	44		813	2,52%	6	492	12,13		911,18%
	45		811	2,76%	6	495	12,06		905,05%
	46		811	2,76%	6	462	12,92		976,84%
	47		811	2,76%	6	492	12,13		911,18%
	48		812	2,64%	6	492	12,13		911,18%
	49		813	2,52%	6	489	12,21		917,38%
	50		812	2,64%	6	492	12,13		911,18%
	51		813	2,52%	120	24	50,50		6,32%

10.1	51	836	813	2,52%	120	24	50,50	47,5	6,32%
	52		813	2,52%	120	24	50,50		6,32%
	53		813	2,52%	120	24	50,50		6,32%
	54		813	2,52%	120	24	50,50		6,32%
	55		813	2,52%	120	24	50,50		6,32%
	56		813	2,52%	120	24	50,50		6,32%
	57		812	2,64%	120	24	50,50		6,32%
	58		812	2,64%	120	24	50,50		6,32%
	59		812	2,64%	120	24	50,50		6,32%
	60		812	2,64%	120	24	50,50		6,32%
	61	837	812	2,64%	30	30	10,20	10,1	0,99%
	62		812	2,64%	30	30	10,20		0,99%
	63		812	2,64%	30	30	10,20		0,99%
	64		812	2,64%	30	30	10,20		0,99%
	65		812	2,64%	30	30	10,20		0,99%
	66		813	2,52%	30	30	10,20		0,99%
	67		813	2,52%	30	30	10,20		0,99%
	68		813	2,52%	30	30	10,20		0,99%
	69		813	2,52%	30	30	10,20		0,99%
	70		813	2,52%	30	30	10,20		0,99%

Two middle of the rows measuring voltage and reference voltage are the value detected by the ADS1115 which also used to calculate the resistance. The right third row “measured resistance” is the resistance calculated by the detected voltage. By comparing this value with the actual simulating resistor’s resistance, the deviation can be found and error rate can be calculate as the right first row. Noticed the right second row is the measured value by two multimeter of the resistors, their label values are 680ohm, 2000ohm, 330ohm, 10Kohm, 0ohm, 50ohm and 10ohm.

2.4 conclusion of the test

According to the data above and compare with the expectations before, this outcomes are achieved the expectation and this test is passed. This means the sub-system is functional to the system.

Correcting system Test plan

Contents

Chapter1. Test-plan

1.1 Aim

This test is focus on validate the usability of temperature sensor.

1.2 Hypothesis

If the circuit connected correctly, the Arduino should be able to read the temperature value from DS18B20

1.3 Tools and devices needed

Tool/Device	Description
PC laptop	Use to coding and doing paper works
Arduino NANO	Using to debug and as main platform
Bread board with wires	Test base hardware outside platform
oscilloscope	Using to monitor the voltage level
Resistors 4.7KΩ*1	Functional resistor
multimeter	Checking electric potential and current
Software	Description
Arduino IDE	Main coding platform

1.4 Variables

PT	The reading value from sensor

1.5 Actions

1. Connected Arduino NANO on the bread broad.
2. Connect 3 wires between sensor and Arduino.
3. Upload the software to Arduino.
4. Recording data from oscilloscope
5. Record the data in excel

1.6 Test setup:

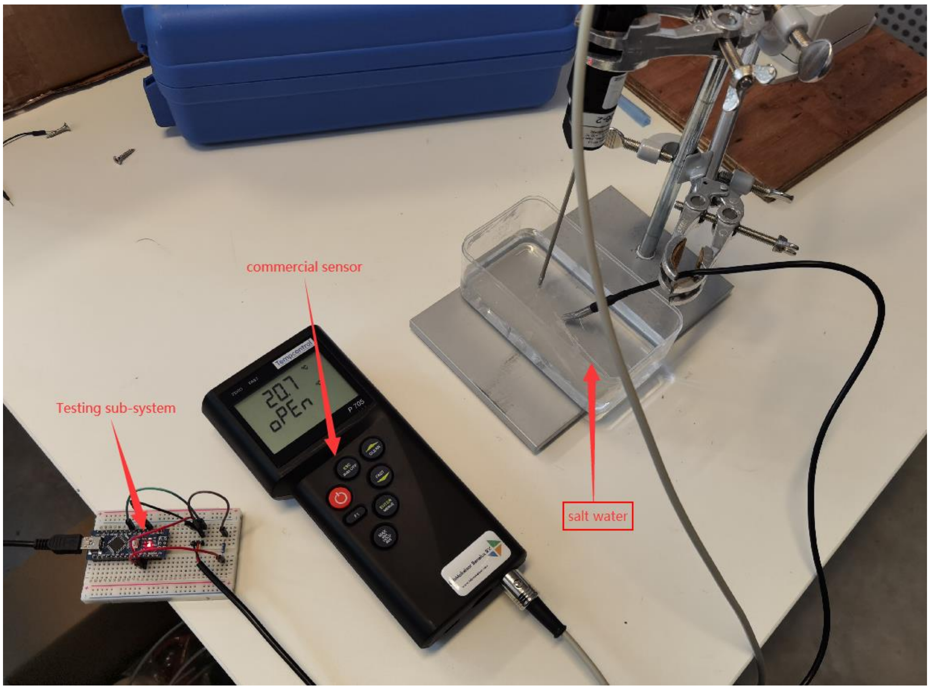


Figure 98 Correcting system setup

1.7 Circuit diagram

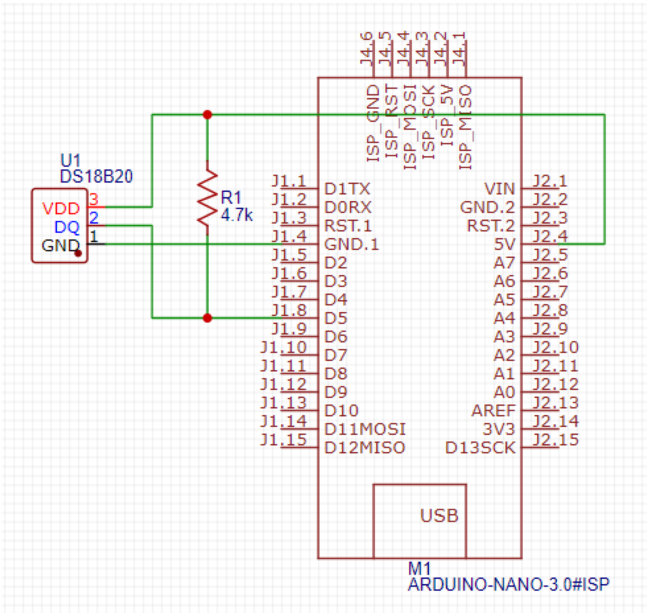


Figure 99 Circuit diagram

1.8 Code

```
#include <OneWire.h>
#include <DallasTemperature.h>
#define ONE_WIRE_BUS 5
OneWire oneWire(ONE_WIRE_BUS);
DallasTemperature sensors(&oneWire);

void setup(void)
{
 Serial.begin(115200);
 Serial.println("Dallas Temperature IC Control Library Demo");
 sensors.begin();
}
void loop(void)
{
 sensors.requestTemperatures();
 Serial.print("Temperature is: ");
 Serial.println(sensors.getTempCByIndex(0));
 delay(1000);
}
```

1.9 Expected Results

By successfully setup the test, temperature sensor should be able to read the temperature and send the value to Arduino when needed. If the temperature detected from sensor have a deviation less than 5% compare with commercial temperature sensor, the sub-system can be defined as pass.

Chapter2. Executing & results

2.1 Reading from serial monitor & commercial meter

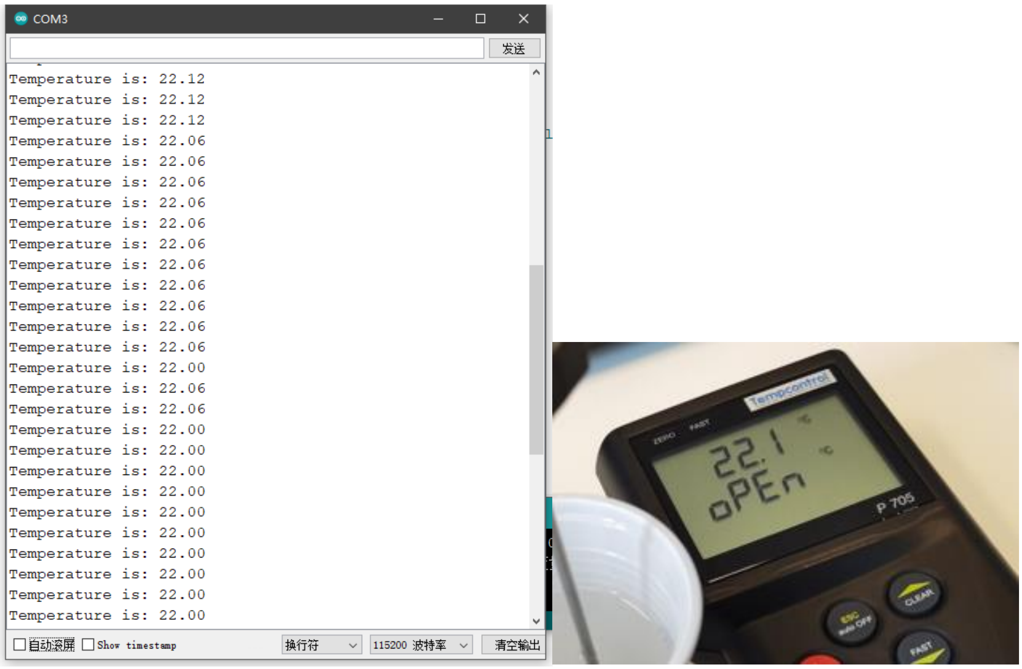


Figure 100 first test

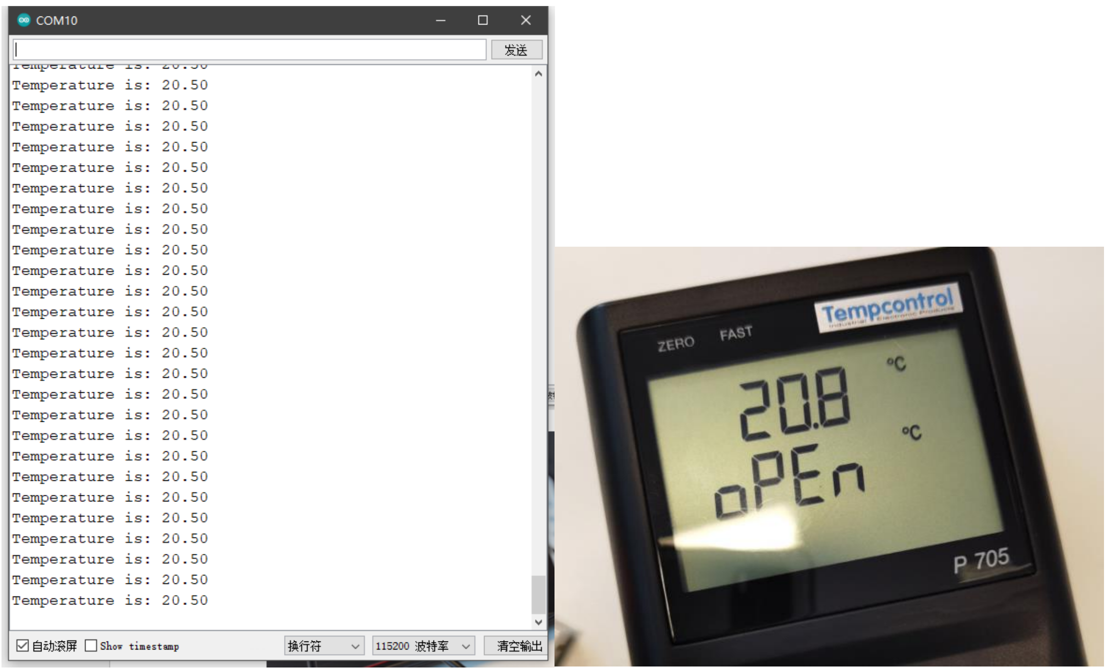


Figure 101 second test

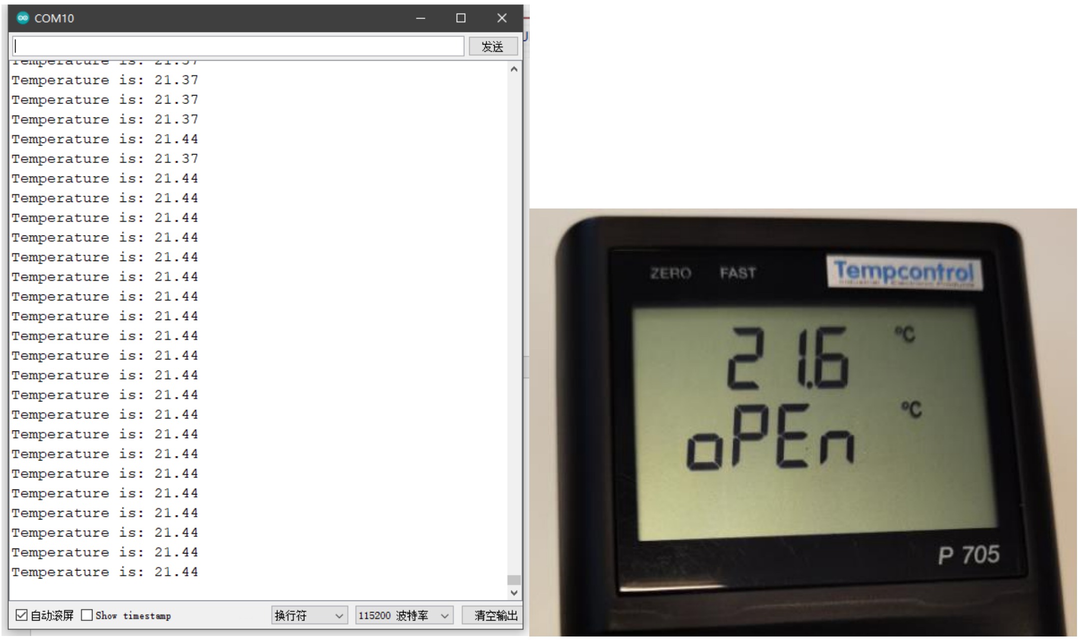


Figure 102 fourth test

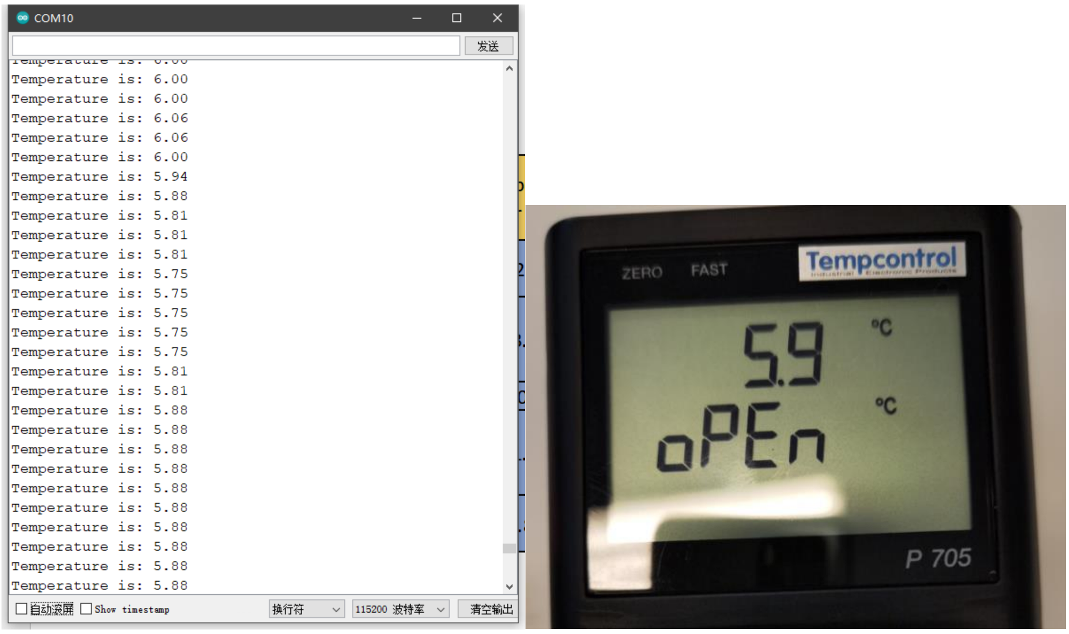


Figure 103 Fifth test

2.2 Data table

target	temp from measuring (℃)	temp from sensor (℃)	deviation	error
1413μs/cm liquid	22.1	22	0.1	0.45%
indoor temperature air	22.7	23.06	0.36	1.59%
salt water	20.8	20.5	0.3	1.44%
indoor temperature air2	21.6	21.44	0.16	0.74%
cold water from fridge	5.9	5.88	0.02	0.34%

table 40 Data in table

2.3 Conclusion

To make the test covered as large area as possible, different kinds of liquids and air have been tested. Second row of the table shows the reading temperature from commercial sensor and the third row shows the reading value from tested sub-system. By analyze their deviation, the percentage of error are listed. From the result, it is proved that the deviation is less than 5% which means this is acceptable for the system. Thus, the test can be defined as pass.

System Test plan (lab simulate condition)

Contents

Chapter1. Test-plan

1.1 Aim

This test is aiming to validate the functionality of whole system on PCB contain the electrodes and temperature sensor.

1.2 Hypothesis

If the software and Arduino board working well on PCB, the system should have the function of resistance(transfer to EC value) detecting. Not only can detecting the known resistor but can also detect the resistance in target liquid.
This test should be able to show that the system is able to achieve the measuring range from 0-40ms/cm. And the accuracy of the system should be good enough and has an error less than 10% compare with the commercial EC meter.

1.3 Tools and devices needed

Tool/Device	Description
PC laptop	Use to coding and doing paper works
Arduino NANO	Using to debug and as main platform
Finished PCB	Circuit that designed for the system
oscilloscope	Using to monitor the voltage level
Commercial EC meter	A commercial EC meter which has a high accuracy
Several resistors	Reference resistor and test resistors on different resistance
multimeter	Checking electric potential and current
Software	Description
Arduino IDE	Main coding platform

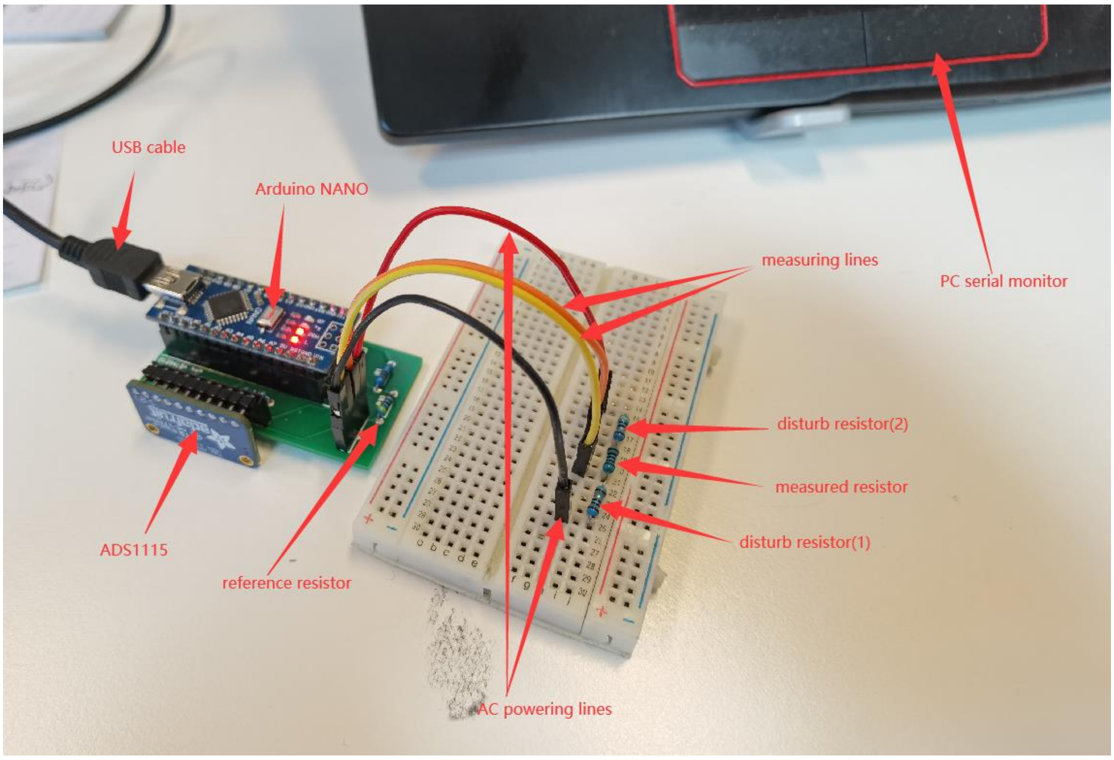
1.4 Variables

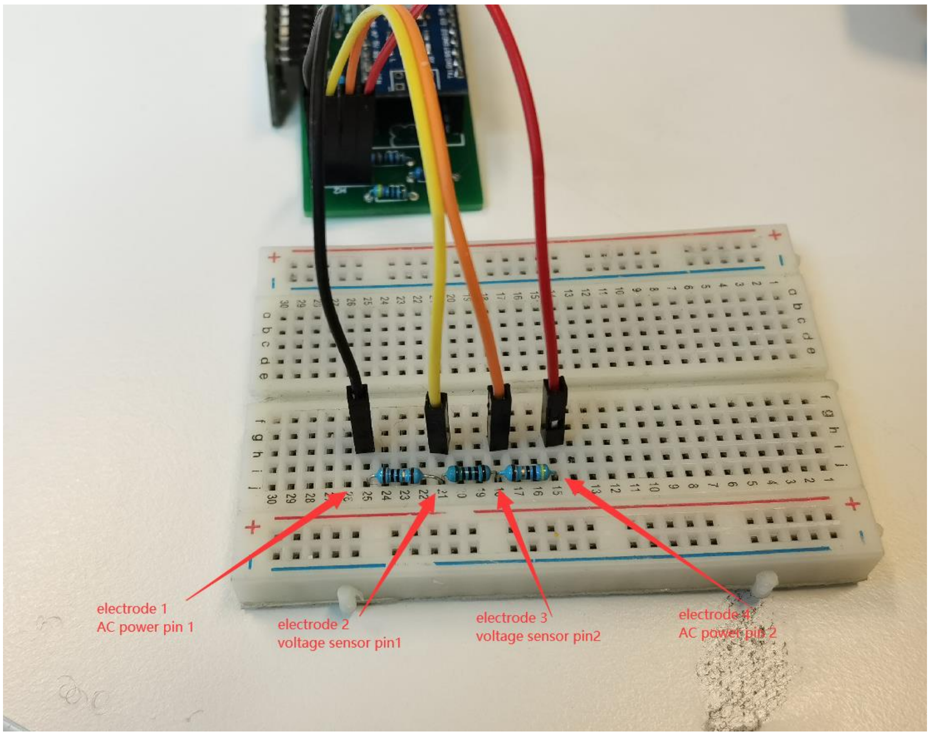
Voltage differential(1)	The reading voltage from measuring resistor
Voltage differential(2)	The reading voltage from reference resistor
Resistance	Measuring resistance calculated from detected voltages
EC value	Calculated EC value from measured voltages

1.5 Actions:

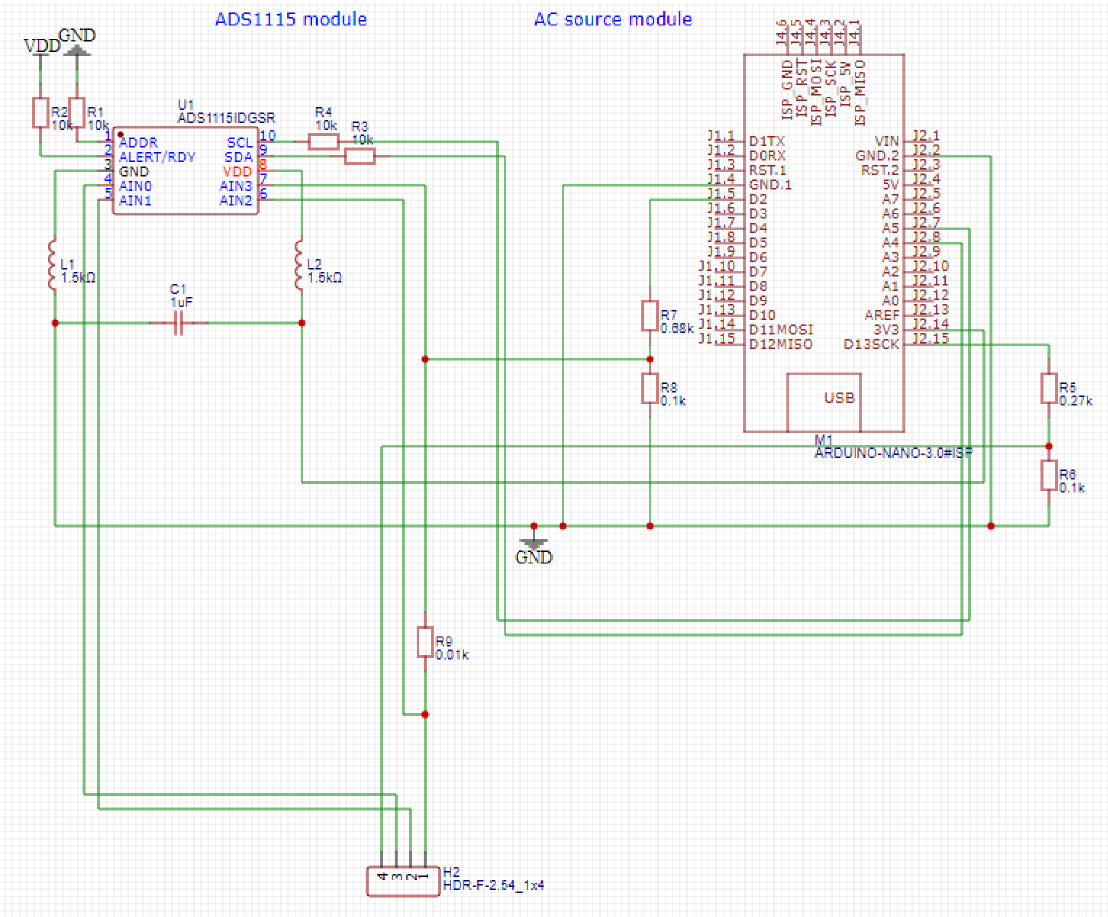
1. Assembly the PCB
2. Load the software into Arduino NANO
3. Plug in Arduino NANO and ADS1115
4. Plug in electrodes
5. Test on the resistors for several times and record data
6. Use multimeter to measure the resistor and record the data
7. Compere the system reading data with multimeter reading data
8. Type all data into excel

1.6 Test setup:





1.7 Circuit diagram



1.8 Code

```
#include <Wire.h>
#include <Adafruit_ADS1X15.h>
int frequency = 834; //Set frequency in Hertz
double delayTime = 1000000 / (frequency * 2);
double delayseconds = 1000/(frequency * 2);
Adafruit_ADS1115 ads1115;
double n = 0;
float refR = 10;

void setup(void)
{
  pinMode(13, OUTPUT);
```

```
  pinMode(2, OUTPUT);
  Serial.begin(115200);
  Serial.println("Hello!");

  Serial.println("Getting differential reading from AIN0 (P) and AIN1 (N)");
  Serial.println("ADC Range: +/- 6.144V (1 bit = 0.188mV) ");

  ads1115.begin();
}

void loop(void)
{
  int16_t results1;
  int16_t results2;
  double T = 0;
  double resistance = 0,a=0,b=0;
  digitalWrite(13, HIGH);
 if (frequency>=100)
  {
   T = delayTime;
   digitalWrite(2, LOW);
   delayMicroseconds(T);
   digitalWrite(2, HIGH);
   delayMicroseconds(T);
   }
 else
 {
  T = delayseconds;
  digitalWrite(2, LOW);
  delay(T);
  digitalWrite(2, HIGH);
  delay(T);
 }
 n=n+1;
 if (n>=850)
 {
  n=0;
  results1 = ads1115.readADC_Differential_0_1();
  a=abs(results1);
  Serial.print("Differential: "); Serial.print(results1); Serial.print("(");
Serial.print(results1 * 0.188); Serial.println("mV)");
  results2 = ads1115.readADC_Differential_2_3();
```

```
 b=abs(results2);
 Serial.print("Differential:          ");          Serial.print(results2);          Serial.print("(");
Serial.print(results2 * 0.188); Serial.println("mV)");
 resistance = (a/b) * refR;
 Serial.print("Resistance= "); Serial.println(resistance);
 }
}
```

1.9 Expected Results

During the test, different values of measured resistors and disturb resistors will be test. The expectation is the change of disturb resistor will not affect to the measuring of the measured resistor. Measured value should have a deviation with the multimeter reading less than 5% (10% required from client). If the measuring range of the resistor from 0.5Ω to 2KΩ all meet the expectation, then this system can be defined as pass the test.

Chapter2.

2.1 Actual results

Reference resistor (Ω)	Test group	Test number	Disturb resistor 1 (Ω)	Disturb resistor 2 (Ω)	measured resistor (Ω)	Reading value low from system (Ω)	Reading value high from system (Ω)	Average value from system (Ω)	Deviation (Ω)	Percentage	Percentage of floating
47.3	1	1	**10.1**	**47.5**	0.5	0.51	0.51	0.51	0.01	2.00%	0.00%
		2	**47.5**	**10.1**	0.5	0.54	0.54	0.54	0.04	8.00%	0.00%
		3	**10.1**	**47.5**	47.2	46.86	47.3	47.08	0.12	0.25%	0.93%
		4	**47.5**	**10.1**	47.3	47.18	47.3	47.24	0.06	0.13%	0.25%
		5	**10.1**	**47.5**	100.1	99.99	100.13	100.06	0.04	0.04%	0.14%
		6	**47.5**	**10.1**	100.1	99.93	100.22	100.075	0.025	0.02%	0.29%
		7	**10.1**	**47.5**	220.4	220.02	220.73	220.375	0.025	0.01%	0.32%
		8	**47.5**	**10.1**	220.4	219.86	220.44	220.15	0.25	0.11%	0.26%
		9	**10.1**	**47.5**	330	329.81	331.32	330.565	0.565	0.17%	0.46%
		10	**47.5**	**10.1**	330	330.88	331.1	330.99	0.99	0.30%	0.07%
		11	**10.1**	**47.5**	463	463.75	466.09	464.92	1.92	0.41%	0.51%
		12	**47.5**	**10.1**	463	464.11	464.38	464.245	1.245	0.27%	0.06%
		13	**10.1**	**47.5**	506	505.36	506.47	505.915	0.085	0.02%	0.22%
		14	**47.5**	**10.1**	506	505.92	508.61	507.265	1.265	0.25%	0.53%
		15	**10.1**	**47.5**	680	679.89	684.48	682.185	2.185	0.32%	0.68%
		16	**47.5**	**10.1**	680	679.09	683.3	681.195	1.195	0.18%	0.62%
		17	**10.1**	**47.5**	997	999.21	1001.49	1000.35	3.35	0.34%	0.23%
		18	**47.5**	**10.1**	997	994.66	1007.54	1001.1	4.1	0.41%	1.29%
		19	**10.1**	**47.5**	1494	1490.27	1491.53	1490.9	3.1	0.21%	0.08%
		20	**47.5**	**10.1**	1494	1489.29	1507.6	1498.445	4.445	0.30%	1.23%
		21	**10.1**	**47.5**	2041	2022.49	2058.16	2040.325	0.675	0.03%	1.75%
		22	**47.5**	**10.1**	2041	2037.34	2059.24	2048.29	7.29	0.36%	1.07%
		23	**10.1**	**47.5**	5080	4991.1	5006.23	4998.665	81.335	1.60%	0.30%
		24	**47.5**	**10.1**	5080	4981.64	5206.94	5094.29	14.29	0.28%	4.44%
		25	**10.1**	**47.5**	6740	6637.77	7050.48	6844.125	104.125	1.54%	6.12%
		26	**47.5**	**10.1**	6740	6645.6	7050.48	6848.04	108.04	1.60%	6.01%
		27	**10.1**	**47.5**	9990	10031.54	10063.08	10047.31	57.31	0.57%	0.32%
		28	**47.5**	**10.1**	9990	10047.31	10059.13	10053.22	63.22	0.63%	0.12%
		29	**10.1**	**47.5**	19060	20386.3	20394.18	20390.24	1330.24	6.98%	0.04%
		30	**47.5**	**10.1**	19060	20386.3	20409.95	20398.125	1338.125	7.02%	0.12%
47.3	2	31	**100.7**	**470**	0.6	0.55	0.55	0.55	0.05	8.33%	0.00%
		32	**470**	**100.7**	0.6	0.55	0.55	0.55	0.05	8.33%	0.00%
		33	**100.7**	**470**	47.5	47.3	47.3	47.3	0.27	0.27%	0.00%
		34	**470**	**100.7**	47.5	47	47.3	47.15	0.11	0.11%	0.63%
		35	**100.7**	**470**	100.2	99.43	100.43	99.93	1.01	0.46%	1.00%
		36	**470**	**100.7**	100.2	99.75	100.43	100.09	0.95	0.43%	0.68%

		37	**100.7**	**470**	220.4	220.73	222.09	221.41	1.715	0.52%	0.62%
		38	**470**	**100.7**	220.4	219.27	219.63	219.45	0.9	0.27%	0.16%
		39	**100.7**	**470**	330	330.29	333.14	331.715	0.57	0.12%	0.86%
		40	**470**	**100.7**	330	329.48	332.32	330.9	1.415	0.30%	0.86%
		41	**100.7**	**470**	466	466.11	467.03	466.57	0.28	0.06%	0.20%
		42	**470**	**100.7**	466	463.9	465.27	464.585	3.96	0.78%	0.29%
		43	**100.7**	**470**	506	504.38	507.06	505.72	0.46	0.07%	0.53%
		44	**470**	**100.7**	506	507.19	512.73	509.96	1.795	0.26%	1.09%
		45	**100.7**	**470**	681	677.61	685.31	681.46	3.86	0.39%	1.13%
		46	**470**	**100.7**	681	678.14	680.27	679.205	4.66	0.47%	0.31%
		47	**100.7**	**470**	993	995.24	998.48	996.86	2.295	0.15%	0.33%
		48	**470**	**100.7**	993	994.14	1001.18	997.66	2.88	0.19%	0.71%
		49	**100.7**	**470**	1491	1487.05	1490.36	1488.705	5.555	0.27%	0.22%
		50	**470**	**100.7**	1491	1482.07	1494.17	1488.12	16.715	0.82%	0.81%
		51	**100.7**	**470**	2034	2036.98	2042.13	2039.555	64.85	1.28%	0.25%
		52	**470**	**100.7**	2034	2044.41	2057.02	2050.715	72.375	1.43%	0.62%
		53	**100.7**	**470**	5050	5106.25	5123.45	5114.85	172.935	2.59%	0.34%
		54	**470**	**100.7**	5050	5119.15	5125.6	5122.375	184.065	2.76%	0.13%
		55	**100.7**	**470**	6680	6847.37	6858.5	6852.935	171.25	1.73%	0.17%
		56	**470**	**100.7**	6680	6861.28	6866.85	6864.065	151.54	1.53%	0.08%
		57	**100.7**	**470**	9880	10043.37	10059.13	10051.25	593.33	2.97%	0.16%
		58	**470**	**100.7**	9880	10027.6	10035.48	10031.54	578.69	2.90%	0.08%
		59	**100.7**	**470**	19970	17886.16	20867.18	19376.67	593.33	2.97%	14.93%
		60	**470**	**100.7**	19970	17899.67	20882.95	19391.31	578.69	2.90%	14.94%

Figure 104 Test group 1 and 2

Reference resistor (Ω)	Test group	Test number	Disturb resistor 1 (Ω)	Disturb resistor 2 (Ω)	measured resistor (Ω)	Reading value low from system (Ω)	Reading value high from system (Ω)	Average value from system (Ω)	Deviation (Ω)	Percentage	Percentage of floating
5.1	3	61	**10.2**	**47.5**	0.5	0.61	0.62	0.615	0.115	23.00%	2.00%
		62	**47.5**	**10.2**	0.5	0.59	0.61	0.6	0.1	20.00%	4.00%
		63	**10.2**	**47.5**	1.1	0.97	1.07	1.02	0.08	7.27%	9.09%
		64	**47.5**	**10.2**	1.1	0.97	1.05	1.01	0.09	8.18%	7.27%
		65	**10.2**	**47.5**	2.1	2.15	2.24	2.195	0.095	4.52%	4.29%
		66	**47.5**	**10.2**	2.1	2.15	2.25	2.2	0.1	4.76%	4.76%
		67	**10.2**	**47.5**	5.1	5.27	5.45	5.36	0.26	5.10%	3.53%
		68	**47.5**	**10.2**	5.1	5.27	5.36	5.315	0.215	4.22%	1.76%
		69	**10.2**	**47.5**	10.1	10.29	10.47	10.38	0.28	2.77%	1.78%
		70	**47.5**	**10.2**	10.1	10.37	10.64	10.505	0.405	4.01%	2.67%
		71	**10.2**	**47.5**	47.4	47.9	48.1	48	0.6	1.27%	0.42%
		72	**47.5**	**10.2**	47.4	47.9	48.2	48.05	0.65	1.37%	0.63%
		73	**10.2**	**47.5**	100.7	100.46	102.49	101.475	0.775	0.77%	2.02%
		74	**47.5**	**10.2**	100.7	99.65	102.45	101.05	0.35	0.35%	2.78%
		75	**10.2**	**47.5**	469	466.65	472.51	469.58	0.58	0.12%	1.25%
		76	**47.5**	**10.2**	469	465.38	467.16	466.27	2.73	0.58%	0.38%

		77	**10.2**	**47.5**	681	673.2	679.32	676.26	4.74	0.70%	0.90%
		78	**47.5**	**10.2**	681	683.4	688.5	685.95	4.95	0.73%	0.75%
		79	**10.2**	**47.5**	995	962.2	1059.41	1010.805	15.805	1.59%	9.77%
		80	**47.5**	**10.2**	995	961.35	1057.55	1009.45	14.45	1.45%	9.67%
		81	**10.2**	**47.5**	1995	1850.57	2168.35	2009.46	14.46	0.72%	15.93%
		82	**47.5**	**10.2**	1995	1851.3	2175.15	2013.225	18.225	0.91%	16.23%
		83	**10.2**	**47.5**	4690	4593.4	4624	4608.7	81.3	1.73%	0.65%
		84	**47.5**	**10.2**	4690	4590	4620.6	4605.3	84.7	1.81%	0.65%
		85	**10.2**	**47.5**	9870	7063	14178	10620.5	750.5	7.60%	72.09%
		86	**47.5**	**10.2**	9870	7027	14132	10579.5	709.5	7.19%	71.99%
		87	**10.2**	**47.5**	199600	14229	14315	14272	185328	92.85%	0.04%
		88	**47.5**	**10.2**	199600	14208	14320	14264	185336	92.85%	0.06%
		89	**10.2**	**47.5**	476000	inf	inf	#DIV/0!	#DIV/0!	#DIV/0!	#VALUE!
		90	**47.5**	**10.2**	476000	inf	inf	#DIV/0!	#DIV/0!	#DIV/0!	#VALUE!
5.1	4	91	**100.7**	**470**	0.6	0.49	0.51	0.5	0.1	16.67%	3.33%
		92	**470**	**100.7**	0.6	0.49	0.51	0.5	0.1	16.67%	3.33%
		93	**100.7**	**470**	1.1	0.97	1.02	0.995	0.105	9.55%	4.55%
		94	**470**	**100.7**	1.1	0.97	1.02	0.995	0.105	9.55%	4.55%
		95	**100.7**	**470**	2.1	1.94	2.04	1.99	0.11	5.24%	4.76%
		96	**470**	**100.7**	2.1	1.91	2.04	1.975	0.125	5.95%	6.19%
		97	**100.7**	**470**	5.2	5.1	5.38	5.24	0.04	0.77%	5.38%
		98	**470**	**100.7**	5.2	5.1	5.1	5.1	0.1	1.92%	0.00%
		99	**100.7**	**470**	10.2	10.2	10.46	10.33	0.13	1.27%	2.55%
		100	**470**	**100.7**	10.2	10.2	10.46	10.33	0.13	1.27%	2.55%
		101	**100.7**	**470**	47.6	46.15	48.58	47.365	0.235	0.49%	5.11%
		102	**470**	**100.7**	47.6	46.41	48.85	47.63	0.03	0.06%	5.13%
		103	**100.7**	**470**	100.5	100.02	100.3	100.16	0.34	0.34%	0.28%
		104	**470**	**100.7**	100.5	100.02	100.3	100.16	0.34	0.34%	0.28%
		105	**100.7**	**470**	151.3	150.6	152.7	151.65	0.35	0.23%	1.39%
		106	**470**	**100.7**	151.3	152.1	152.7	152.4	1.1	0.73%	0.40%
		107	**100.7**	**470**	220.6	218.98	219.94	219.46	1.14	0.52%	0.44%
		108	**470**	**100.7**	220.6	218.66	219.3	218.98	1.62	0.73%	0.29%
		109	**100.7**	**470**	469	455.68	495.13	475.405	6.405	1.37%	8.41%
		110	**470**	**100.7**	469	456.65	493.52	475.085	6.085	1.30%	7.86%
		111	**100.7**	**470**	683	666.71	731.85	699.28	16.28	2.38%	9.54%
		112	**470**	**100.7**	683	665.78	668.1	666.94	16.06	2.35%	0.34%
		113	**100.7**	**470**	995	997.33	1123.91	1060.62	65.62	6.59%	12.72%
		114	**470**	**100.7**	995	969.57	1092.67	1031.12	36.12	3.63%	12.37%
		115	**100.7**	**470**	6780	6864.6	6877.35	6870.975	90.975	1.34%	0.19%
		116	**470**	**100.7**	6780	6856.95	6874.8	6865.875	85.875	1.27%	0.26%
		117	**100.7**	**470**	98700	7055.85	14142.3	10599.075	88100.925	89.26%	7.18%
		118	**470**	**100.7**	98700	7104.3	14213.7	10659	88041	89.20%	7.20%
		119	**100.7**	**470**	19950	14616.6	14647.2	14631.9	5318.1	26.66%	0.15%
		120	**470**	**100.7**	19950	14601.3	14647.2	14624.25	5325.75	26.70%	0.23%

Figure 105 Test group 3 and 4

2.2 Conclusion

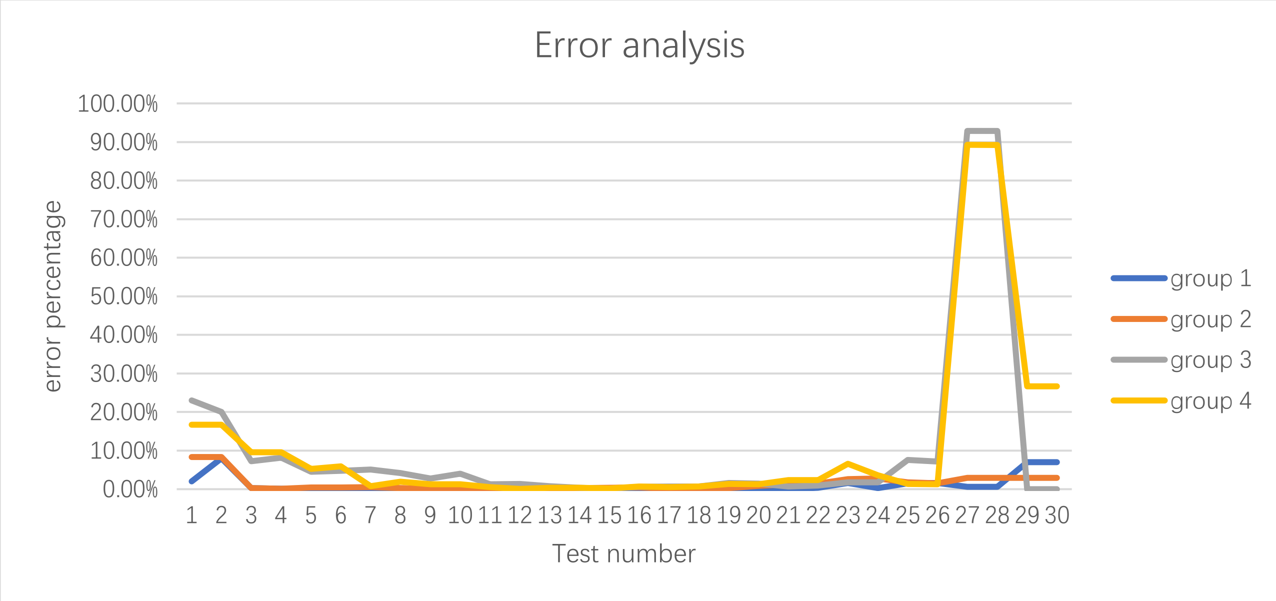


Figure 106 Processed results

The resistance in EC liquid normally from 10ohm to 1kohm. in the figure above, the system can working in good condition at that range. During this period, the error of the system is lower than 5% which achieved the target of 10%. It can be define as pass the error rate test.

System Test plan (In real given EC liquid)

Contents

Chapter1. Test-plan

1.1 Aim

This test is aiming to validate the functionality of whole system on PCB contain the electrodes and temperature sensor. Test should be in the real liquid environment but not simulating resistors.

1.2 Hypothesis

If the software and Arduino board working well on PCB, the system should have the function of resistance(transfer to EC value) detecting. Not only can detecting the known resistor but can also detect the resistance in target liquid.
This test should be able to show that the system is able to achieve the measuring range from 0-40ms/cm. And the accuracy of the system should be good enough and has an error less than 10% compare with the commercial EC meter or with the calculated idea EC value.

1.3 Tools and devices needed

Tool/Device	Description
PC laptop	Use to coding and doing paper works
Arduino NANO	Using to debug and as main platform
Finished PCB	Circuit that designed for the system
oscilloscope	Using to monitor the voltage level
Commercial EC meter	A commercial EC meter which has a high accuracy
Several resistors	Reference resistor and test resistors on different resistance
multimeter	Checking electric potential and current
Software	Description
Arduino IDE	Main coding platform
Samples	Description
1N KCL liquid	1N solution KCL liquid which have a known EC value
0.1N KCL liquid	0.1N solution KCL liquid which have a known EC value
0.01N KCL liquid	0.01N solution KCL liquid which have a known EC value

1.4 Variables

Voltage	The reading voltage from measuring resistor

differential(1)	
Voltage differential(2)	The reading voltage from reference resistor
Resistance	Measuring resistance calculated from detected voltages
EC value	Calculated EC value from measured voltages

1.5 Actions:

1. Assembly the PCB
2. Load the software into Arduino NANO
3. Plug in Arduino NANO and ADS1115
4. Plug in electrodes
5. Make enough testing liquid with known solution and volume
6. Test in the known different EC-value liquids for several times and type the data in to excel table
7. Analyze the data recorded and making conclusion and recommendation

1.6 Test setup:

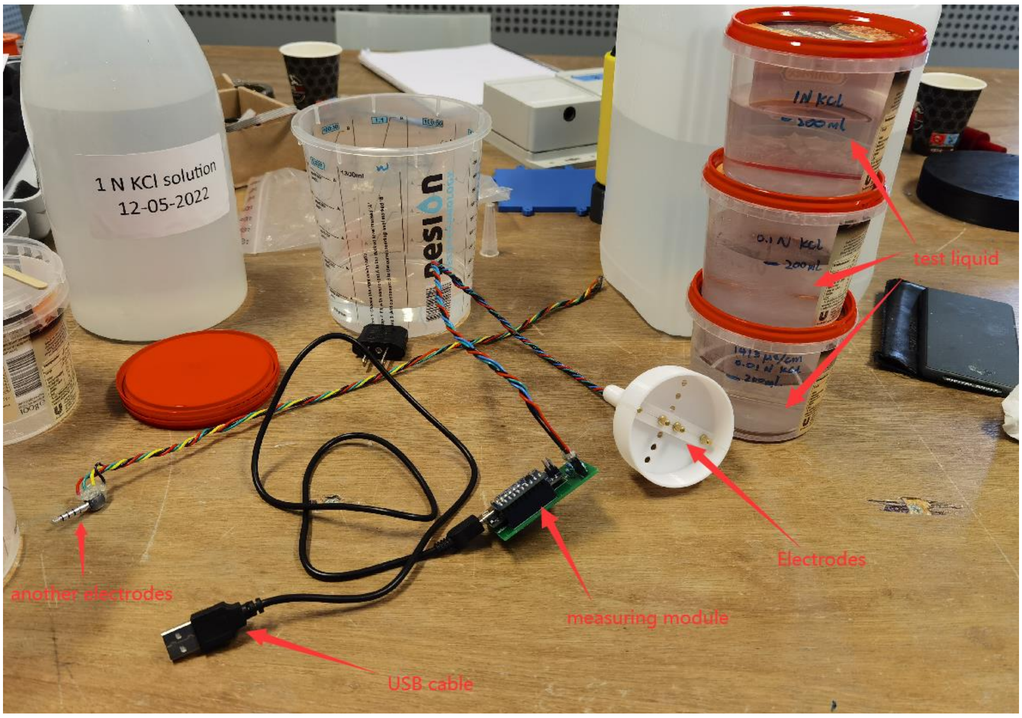
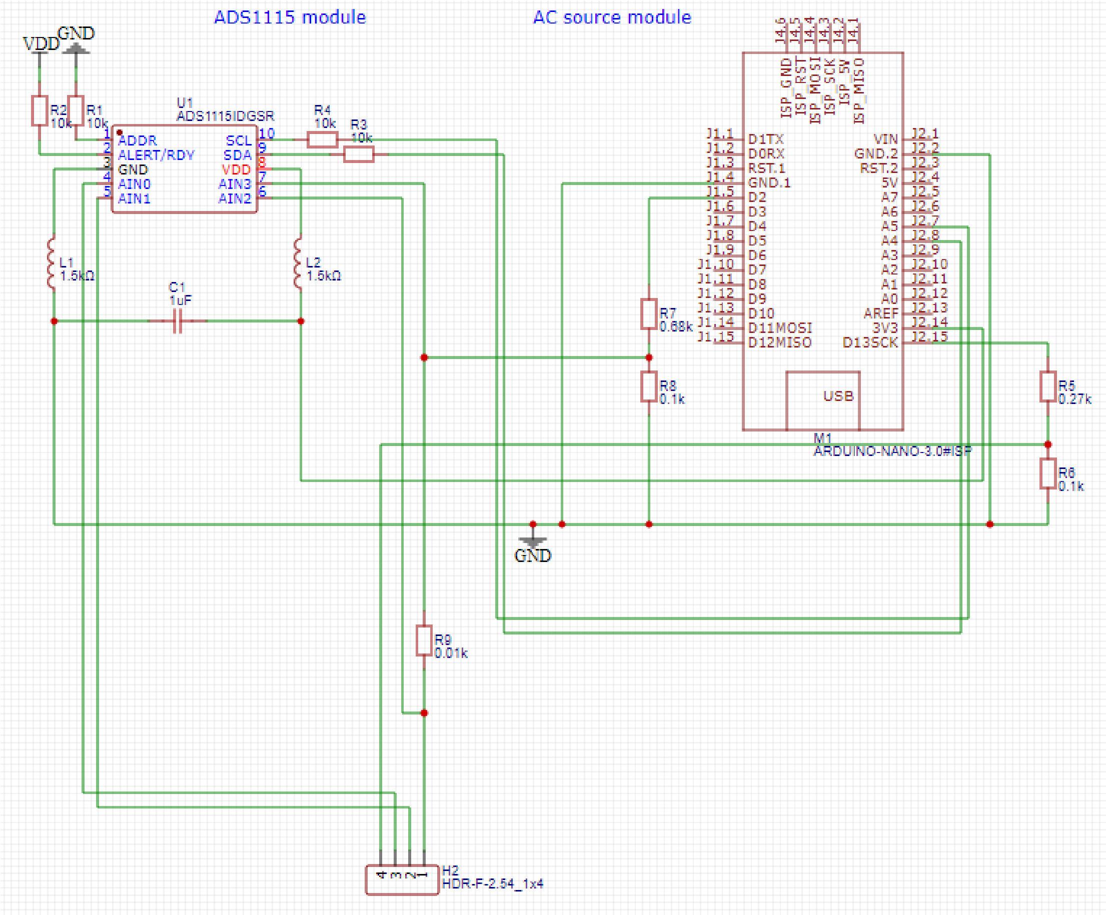


Figure 107 Test setup

1.7 Circuit diagram



1.8 Code

```
#include <Wire.h>
#include <Adafruit_ADS1X15.h>
int frequency = 834; //Set frequency in Hertz
double delayTime = 1000000 / (frequency * 2);
double delayseconds = 1000/(frequency * 2);
Adafruit_ADS1115 ads1115;
double n = 0;
float refR = 10;

void setup(void)
{
  pinMode(13, OUTPUT);
  pinMode(2, OUTPUT);
  Serial.begin(115200);
  Serial.println("Hello!");

  Serial.println("Getting differential reading from AIN0 (P) and AIN1 (N)");
  Serial.println("ADC Range: +/- 6.144V (1 bit = 0.188mV) ");

  ads1115.begin();
}

void loop(void)
{
  int16_t results1;
```

```
 int16_t results2;
 double T = 0;
 double resistance = 0,a=0,b=0;
 digitalWrite(13, HIGH);
if (frequency>=100)
 {
  T = delayTime;
  digitalWrite(2, LOW);
  delayMicroseconds(T);
  digitalWrite(2, HIGH);
  delayMicroseconds(T);
  }
else
{
 T = delayseconds;
 digitalWrite(2, LOW);
 delay(T);
 digitalWrite(2, HIGH);
 delay(T);
}
n=n+1;
if (n>=850)
{
 n=0;
 results1 = ads1115.readADC_Differential_0_1();
 a=abs(results1);
 Serial.print("Differential: "); Serial.print(results1); Serial.print("("); Serial.print(results1 * 0.188); Serial.println("mV)");
 results2 = ads1115.readADC_Differential_2_3();
 b=abs(results2);
 Serial.print("Differential: "); Serial.print(results2); Serial.print("("); Serial.print(results2 * 0.188); Serial.println("mV)");
 resistance = (a/b) * refR;
 Serial.print("Resistance= "); Serial.println(resistance);
}
}
```

1.9 Expected Results

If all process going well the system should be able to detect all the resistance and EC values shown on the serial monitor. Results compare with the accurate value should have a deviation less than 10%. If the deviation with the commercial meter is less than 10% at the same temperature and same liquid, the accuracy of the system can be defined as pass. If the working range could be larger than 20mS/cm to 0mS/cm, the working range of the system can be defined as pass.

Chapter2.

2.1 Actual results

1N KCL Solution	Test 1													Temp: 21.0 ℃		Average
Measuring time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Resistance R	53.41	53.06	52.39	52.72	52.39	52.72	52.39	51.42	52.05	52.05	52.72	52.05	52.39	52.05	52.39	52.415
1/R × 1000	18.724	18.854	19.089	18.967	19.089	18.967	19.089	19.447	19.21	19.21	19.089	19.21	19.089	19.21	19.089	19.08886
Commercial EC (ms/cm)	115.3	115.2	115.2	115.2	115.1	115.1	115.1	115	115	115	115	115	115	114.9	114.9	115.0667
Calculated K (L/A)	6.157872	6.110109	6.034889	6.073707	6.029651	6.068435	6.029651	5.913509	5.986465	5.986465	6.024412	5.986465	6.024412	5.98126	6.019173	6.028432
Calculated K2 (L/A)	5.397351	5.360136	5.294148	5.328202	5.294148	5.328202	5.294148	5.196688	5.260802	5.260802	5.294148	5.260802	5.294148	5.260802	5.294148	
	0.876496	0.877257	0.877257	0.877257	0.878019	0.878019	0.878019	0.878783	0.878783	0.878783	0.878783	0.878783	0.878783	0.879547	0.879547	
0.5 N KCL solution	Test 2													Temp: 21.2℃		Average
Measuring time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Resistance R	86.77	86.08	86.08	86.77	86.2	86.77	86.77	87.56	88.26	86.2	89.07	87.56	88.26	88.26	85.53	87.076
1/R × 1000	11.525	11.616	11.616	11.525	11.601	11.525	11.525	11.42	11.329	11.601	11.227	11.42	11.329	11.329	11.692	11.48533
Commercial EC (ms/cm)	63.6	63.5	63.5	63.5	63.4	63.4	63.4	63.3	63.3	63.2	63.2	63.2	63.2	63.2	63.2	63.34
Calculated K (L/A)	5.518438	5.466598	5.466598	5.509761	5.465046	5.501085	5.501085	5.542907	5.58743	5.447806	5.629287	5.534151	5.578604	5.578604	5.405405	5.51552
Calculated K2 (L/A)	4.764347	4.727023	4.727023	4.764347	4.733135	4.764347	4.764347	4.808152	4.846774	4.733135	4.890808	4.808152	4.846774	4.846774	4.696297	
	1.588994	1.591496	1.591496	1.591496	1.594006	1.594006	1.594006	1.596524	1.596524	1.599051	1.599051	1.599051	1.599051	1.599051	1.599051	
0.1N KCL Solution	Test 3													Temp: 21.2 ℃		Average
Measuring time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Resistance R	139.63	141.6	141.6	144.43	139.63	141.6	139.63	141.6	141.6	144.43	141.6	144.43	144.43	144.43	7062142	470942.1
1/R × 1000	7.161	7.062	7.062	6.923	7.161	7.062	7.161	7.062	7.062	6.923	7.062	6.923	6.923	6.923	7.062	7.035467
Commercial EC (ms/cm)	13.38	13.37	13.37	13.37	13.37	13.36	13.36	13.36	13.36	13.36	13.36	13.36	13.36	13.36	13.35	13.36333
Calculated K (L/A)	1.868454	1.893231	1.893231	1.931244	1.867058	1.891815	1.865661	1.891815	1.891815	1.929799	1.891815	1.929799	1.929799	1.929799	1.890399	1.899716
Calculated K2 (L/A)	1.655864	1.679077	1.679077	1.712789	1.655864	1.679077	1.655864	1.679077	1.679077	1.712789	1.679077	1.712789	1.712789	1.712789	1.679077	
0.01N KCL Solution	Test 4													Temp: 21.3 ℃		Average
Measuring time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Resistance R	42393	32171	70611	151051	78685	52456	51888	52423	51754	50985	49915	74823	49882	50250	73168	62163.67
1/R × 1000	0.023	0.031	0.014	0.006	0.012	0.012	0.019	0.019	0.019	0.019	0.02	0.013	0.02	0.019	0.013	0.017267
Commercial EC (ms/cm)	1.542	1.542	1.542	1.541	1.541	1.541	1.541	1.54	1.54	1.54	1.54	1.539	1.539	1.539	1.539	1.5404
Calculated K (L/A)	67.04348	49.74194	110.1429	256.8333	128.4167	128.4167	81.10526	81.05263	81.05263	81.05263	77	118.3846	76.95	81	118.3846	102.4385
Calculated K2 (L/A)	4393.913	3260	7218.571	16843.33	8421.667	8421.667	5318.947	5318.947	5318.947	5318.947	5053	7773.846	5053	5318.947	7773.846	

table 41 Table of results

4 groups of tests have been done, solution of KCL liquid from 1N to 0.01N. Every group have 15 samples of measuring. The 15 data are collected by 2-5mins measuring: first put the electrodes into the liquid then start, wait and monitoring the measured data, the value of 1/R will goes higher then lower to the lowest point and finally keep goes high. During the monitoring period the lowest point is the actual results, so, 15 measurements' data should always extracted from that point.

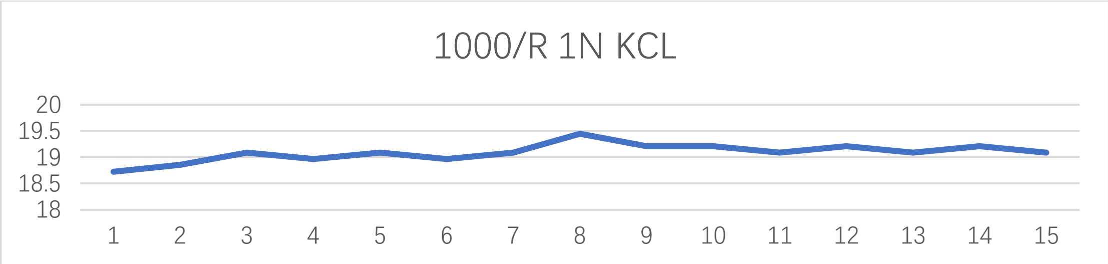


table 42 Line chart of test group1

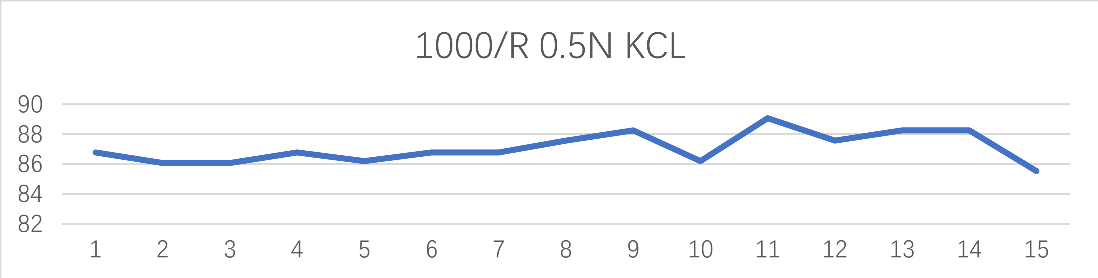


table 43 Line chart of test group2

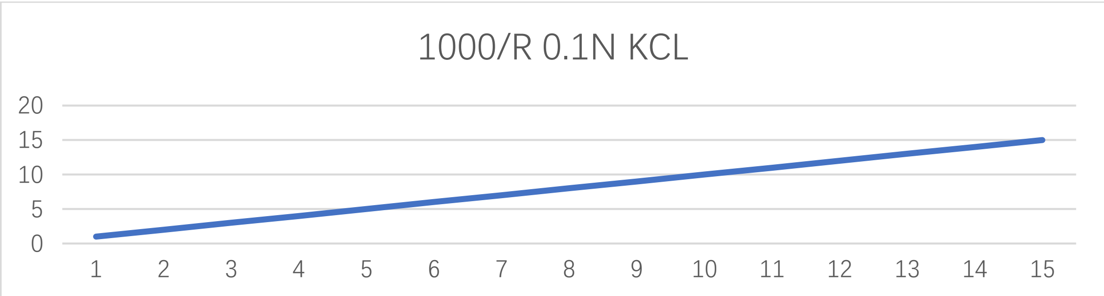


table 44 Line chart of test group3

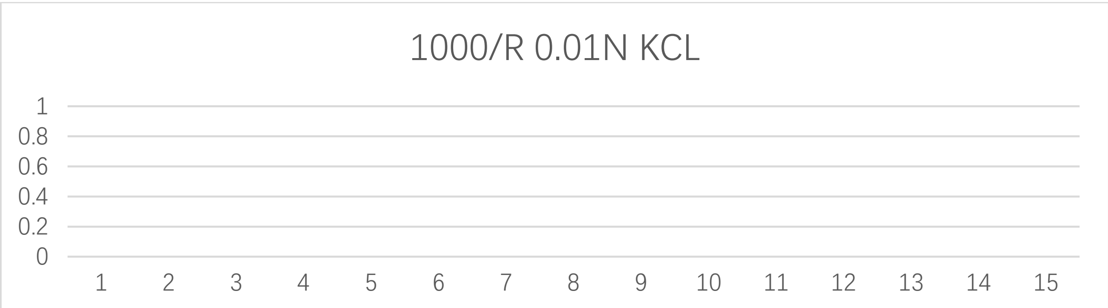


table 45 Line chart of test group4

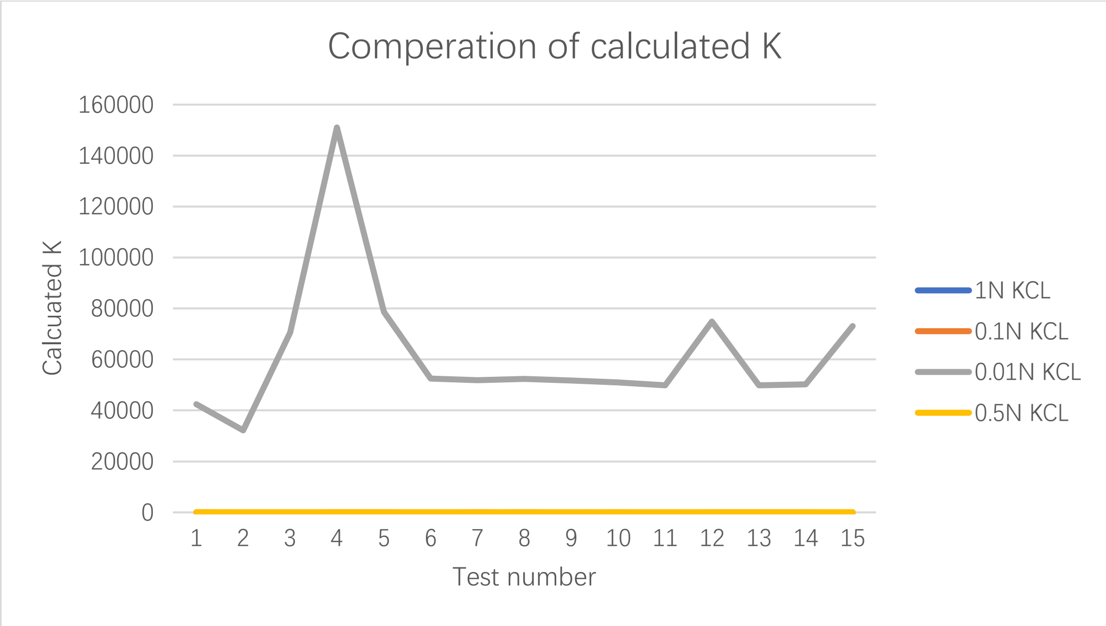


table 46 Comparison of 4 groups' K

The chart above shows the calculated K value's movement during the 15 times measurement. It is easy to find that the line of 0.01N is not stable and have critical errors. This means during the measuring of 0.01N KCL, the designed system is not reliable. So we delete the data from 0.01N group and get the chart below.

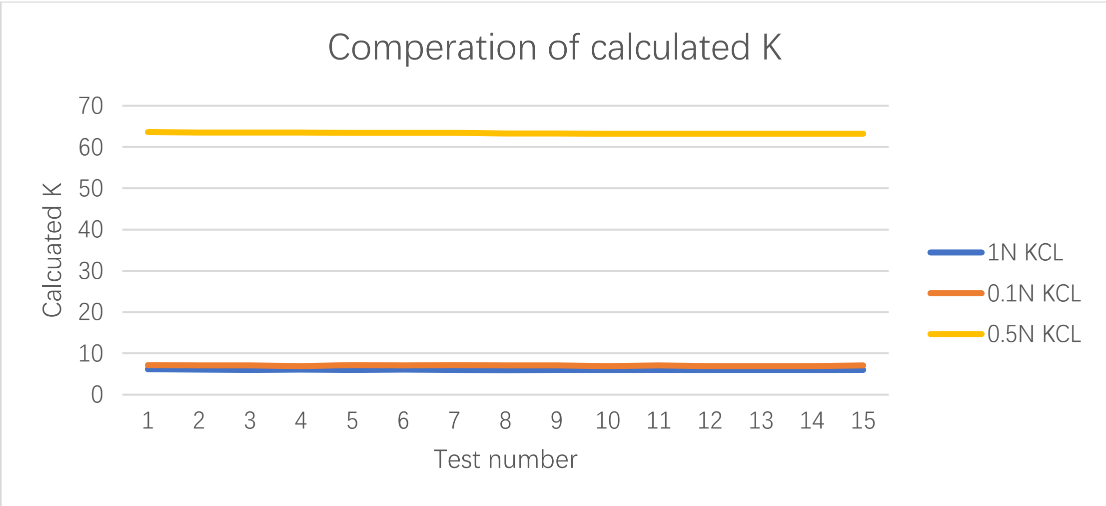


table 47 K value comparison of group 1-3

After we delete the group 4 0.01N, the line chart looks stable and reliable

2.2 Conclusion

The system can not working during the 0.01N situation but can work in good condition from 0.1N to 1N solution of EC. System can be defined as partly passed the test.