REPUBLIC OF TURKEY
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF ELECTRICAL - ELECTRONICS ENGINEERING

PRESSURE PROBE WITH BUILT-IN TEMPERATURE SENSOR AND CONDUCTIVITY CELL DESIGN AND REALIZATION OF THE PROTOTYPE

İBRAHİM TÜFEKCİ
MASTER OF SCIENCE

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I hereby declare that all information in this thesis has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all information that is not original to this work.

[Signature]

İbrahim TÜFEKCİ

ABSTRACT

PRESSURE PROBE WITH BUILT-IN TEMPERATURE SENSOR AND CONDUCTIVITY CELL DESIGN AND REALIZATION OF THE PROTOTYPE

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Department of Electrical and Electronics Engineering

Supervisor: ASSOC. PROF. DR. MAHMUD YUSUF TANRIKULU

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In this thesis, a monolithic three-parameter sensor that can measure the pressure, Electrical Conductivity (EC), and temperature values of any liquid and send the measured values with universal data outputs has been designed and prototyped.

In this context, different pressure measurement methods have been investigated. It has been found appropriate to use piezoresistive pressure sensors using the gauge measurement method. Different temperature sensors have been tested for temperature measurement and PT-100 temperature sensor has been decided to be used.

Different materials and different cell models have been tried for electrical conductivity measurement. For these measurements, 2 active and 2 passive graphite electrodes have been used to obtain the cell with a wider EC measurement range. In addition, single-pole / double-throw (SPDT) switches have been used to send smooth square waves to active electrodes. An adjustable voltage is applied to active electrodes of EC cell with the help of microcontroller. Furthermore, the frequency of the voltage to be applied can be controlled by the microcontroller. These controls allow the sensor to be used in different liquids.

Two ADCs of the microcontroller are used to measure the temperature together with pressure and EC. This helps to reduce the influence of temperature on EC and pressure measurement.

The three parameter sensor is designed to have industrial norms in the framework of this thesis. In this context, the parts of the PCB and sensors that do not come into contact with water are coated with electronic gel for sealing. The outer cover of the sensor, which will remain in liquid continuously, is made of corrosion resistant 316 stainless steel.

Since the prototype sensor has a diameter of 22 mm, a 4-layer PCB is designed. Due to the low usable area of the PCB, the PCB is designed in such a way that materials can be placed on both surfaces.

The sensor can read the pressure, temperature and EC raw values with the microcontroller it contains, and record it in the desired range to the flash memory. When the request to read data is received, it can convert the raw values into readable format and send them over RS-485. The completed prototype sensor was kept in the trial pool for 20 days and the accuracy of the results has been observed. In addition, the sensor was sent to an independent accredited laboratory and tested, so the accuracy of the measurement values was proven. It has been seen that the designed sensor can operate more accurate than most of the sensors of same type.

Keywords: pressure measurement, electrical conductivity measurement, temperature measurement, MEMS ,4 pole EC cell design, water quality

ÖZET

SICAKLIK SENSÖRÜ VE İLETKENLIK HÜCRESI GÖMÜLÜ BASINÇ PROBU TASARIMI VE PROTOTIPIN GERÇEKLENMESI

İbrahim TÜFEKCİ

Elektrik ve Elektronik Mühendisliği Anabilim Dalı

Danışman: Doç. Dr. Mahmud Yusuf TANRIKULU

Ocak 2021, 61 sayfa

Bu tezde herhangi bir sıvının basınç, Elektriksel İletkenlik (EC), ve sıcaklık değerlerini ölçebilen ve ölçtüğü değerleri evrensel veri çıkışları ile gönderebilen yekpare bir üç parametreli sensör tasarlanmış ve prototipi gerçekleştirilmiştir.

Bu bağlamda farklı basınç ölçüm yöntemleri araştırılmış ve gauge ölçüm methodunu kullanan piezorezistif basınç sensörlerinin kullanılması uygun bulunmuştur. Sıcaklık ölçümü için yine farklı sıcaklık sensörleri denenmiş ve PT-100 sıcaklık sensörünin prototip sensörde kullanılmasına karar verilmiştir.

Elektriksel iletkenlik ölçümü için gerekli olan hücre tasarımında farklı materyaller ve farklı modellemeler denenmiştir. Elektriksel iletkenlik ölçümünü için 2 aktif 2 pasif grafit elektrotlar kullanılarak daha geniş EC ölçüm aralığına sahip hücre elde edilmiştir. Ayrıca aktif elektrotlara düzgün kare dalgalar gönderilebilmesi için single-pole / double-throw (SPDT) anahtarları kullanılmıştır. Mikroişlemci yardımı ile aktif uçlara uygulanan Eksitasyon kare dalga voltajı (±VEXC) yazılım vasıtası ile ayarlanabilir hale getirilmiştir. Ayrıca yine uygulanacak voltajın frekansı mikroişlemci vasıtasıyla kontrol edilebilmektedir. Bu kontroller sensörün farklı sıvılarda da kullanılabilmesine olanak sağlamıştır.

Mikroişlemcinin iki ADC'si, basınç ve EC ile birlikte sıcaklığı ölçmek için kullanılmıştır. İki farklı ADC kullanılması ile veri akışındaki zaman kaybı azalacağından sıcaklığın, EC ve basınç ölçümü üzerindeki etkisinin azaltılması planlanmıştır.

Tez konusu üç parametreli sensör endüstriyel normlarda tasarlanmıştır. Bu bağlamda sızdırmazlık için PCB ve sensörlerin suya temas etmeyen kısımları elektronik jel ile kaplanmıştır. Sürekli olarak sıvı içerisinde kalacak olan sensörün dış kılıfı korozyona dayanıklı 316 paslanmaz çelikten üretilmiştir.

Prototip sensörün 22 mm. çapta olması sebebiyle 4 katmanlı bir PCB tasarlanmıştır. PCB'nin kullanılabilir alanının az olmasından dolayı, tasarım her iki yüzeyede entegreler yerleştirilebilecek şekilde tasarlanmıştır.

Sensör basınç, sıcaklık ve EC ham değerlerini içerisinde barındırdığı mikroişlemci ile okuyarak flash memorye istenilen aralıkta kayıt yapabilmektedir. Veri okuma isteği geldiğinde ham değerleri okunabilir hale dönüştürerek RS-485 üzerinden gönderebilmektedir. Tamamlanmış olan prototip sensör deneme havuzunda 20 gün süre ile bekletilmiş ve sonuçların doğruluğu gözlemlenmiştir. Ayrıca sensör bağımsız bir akredite laborotuvara gönderilierek teste tabii tutulmuş ve ölçüm değerlerinin doğruluğu ispatlanmıştır. Tasarlanan sensörün aynı tipteki çoğu sensörden daha doğru çalışabildiği gözlemlenmiştir.

Anahtar Kelimeler: basınç ölçümü, elektriksel iletkenlik ölçümü, sıcaklık ölçümü, MEMS, 4 kutuplu EC hücre tasarımı, su kalitesi

I would like to dedicate this thesis to my beautiful wife Hande Aycan Tüfekci, my dearest father and mother Ali-Hatice Tüfekci.

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NOMENCLATURE

EC	: Electrical Conductivity
CNT	: Carbon Nanotube
SWNT	: Single Walled Nanotube
Pt	: Platinum
MEMS	: Microelectromechanical systems
RTD	: Resistance Temperature Detector
NTC	: Negative Temperature Coefficient

1. INTRODUCTION

Water level tracking is extremely important to countries with limited water reserves and agriculture dependent economies. Measuring water level is mainly performed by water level tracking stations based on pressure measurement principles. Considering the value of drinking and irrigation water; measuring simply the water level is not enough to perform efficient tracking, water temperature and electrical conductivity (EC) of water are also important since irrigation water with high EC may be detrimental to agriculture in terms of affecting the quality and quantity of products. Water temperature is linked to EC value of water since as water temperature increases, solubility of water also increases and hence EC value increases. Therefore precise measurements of EC value, water temperature, and water level in irrigation wells on agricultural fields are crucial to authorities and to farmers who plan irrigation accordingly.

All of those important parameters are measured via different types of sensors. From an economical point of view, purchasing different types of sensors is not very cost effective especially considering how few sensor companies produce stationary EC sensors and due to lack of producement how expensive they are. Instead measuring three different parameters with three different sensors, only one sensor can be used. Such sensor may be very practical since EC measurement is performed by frequent visitations of employees and requires a lot of labor and time.

Developing a sensor which requires less maintenance and calibration; that can operate by solar panel and battery, ergonomic, energy efficient and can be designed accordingly to fit even small irrigation wells is the main goal of this thesis. Similar products are made by European and American companies but considering the need of water level tracking in Turkey, it is important to produce a local, cost effective sensor with high sensitivity on level and EC measurements of water. Such sensor may also be marketed to foreign countries as a contribution to economy of Turkey. The designed sensor has been prototyped by a local company and may become a gain for the country. It is anticipated to be very profitable considering the number of sensors bought yearly.

Probes required for the parameters planned in sensor design have been provided from different companies. For pressure measurement, the products of three different companies have been compared with their price performance and measurements. The raw data obtained from the cells have been made more sensitive and able to exchange faster by software transmission. The water point was processed mathematically by software, the temperature was minimized in the pressure diaphragm and the water level information was obtained.

PT 100 and PT 1000 probes are used as temperature sensors. The third parameter, which is temperature measurement, has a direct effect on EC. Since the temperature change will alter the resolution value, the temperature information received from this sensor is used in EC value calculations. In addition, the water temperature information that the user will need is provided by this sensor.

As a result of the researches for EC measurement, it has been observed that generally three different materials are being used for electrodes. These materials are graphite, titanium palladium alloy and type 316 stainless steel. Electrode prototypes of different sizes, shapes and areas have been created and tested using graphite and type 316 stainless steel materials. Details of materials and sensors that have been used are elaborated in the following sections of this thesis.

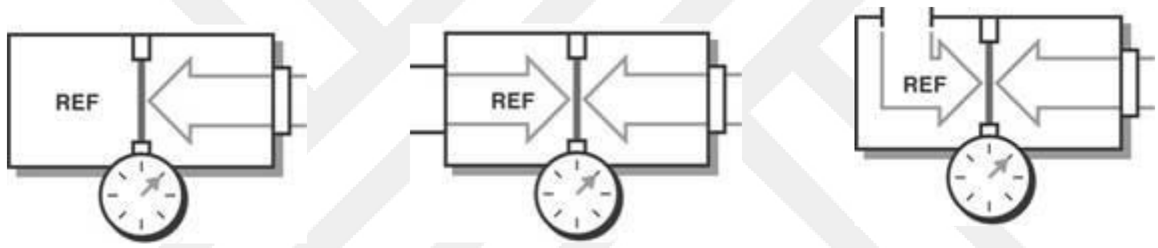
1.1. Pressure sensors review

Centuries after Galileo and Toricelli introduced the fact that pressure is a measurable phenomenon; C.S.Smith developed a new measurement when he had found silicon based piezo resistance in 1954 (Smith, 1954, s. 42-49). The discovery greatly contributed to the development of pressure measurement using micro electro mechanical systems (MEMS) technology. As an another contribution in 1970, Pfann and Thurstan discovered unique electronic and mechanical properties of nanotubes can be used in this field by developing MEMS based pressure sensor using two vertical and two longitudinal piezoresistives in Wheatston Bridge (Pfann W.G., 1961).

Liu (C. Liu, 1999) and Dai (Dai, 2001) developed the first piezoresistive pressure sensor using carbon nanotubes (CNT) in 1996. As a result of their work on membranes, they have seen that when pressure is applied to membranes, a change of resistance has occurred in single walled nanotubes (SWNT). As the applied pressure had lifted off, they have realized that membranes had returned to its original form and so the value of its resistance had returned to its original value too. This discovery has laid the foundation of pressure sensors which are used today.

Since pressure sensors are used widely in many different fields such as automotive, biomedical, aerospace, hydrology and meteorology; various pressure sensors with different MEMS technologies, outer body structures, measurement ranges and manufacturing materials are developed to fit in those various industry areas.

Figure 1.1 shows the different measurement methods that are used in pressure sensors ("Measurement Air Pressure", 2016).



Absolute pressure Differential pressure Gauge pressure

Figure 1.1. Different types of pressure measurement methods. ("Measurement Air Pressure", 2016)

Absolute pressure is defined as the pressure of having no matter inside a space, or a perfect vacuum. Measurements taken in absolute pressure use this absolute zero as their reference point (Difference Between Gauge and Absolute Pressure Measurement, 2013).

Differential pressure is simply the difference between two applied pressures. For example, if the pressure at point A equals 100psi and the pressure at point B equals 60psi, then the differential pressure is 40psi (100psi – 60psi) (Differential Pressure Gauges Measure).

Gauge pressure is measured in relation to ambient atmospheric pressure. The output of gauge pressure sensor is directly influenced by the changes of the atmospheric pressure which can be changed by whether conditions or altitude (Difference Between Gauge and Absolute Pressure Measurement, 2013).

Gauge pressure sensors usually have just one pressure port. The ambient air pressure is directed through a vent hole or a tube to the back of the sensing element. A vented gauge pressure transmitter allows outside air pressure to be exposed to the negative side of the pressure sensing diaphragm so it always measures according to ambient barometric pressure (Difference Between Absolute and Gauge Pressure).

Therefore, a vented gauge pressure sensor reads zero pressure when the process pressure connection is kept open to atmospheric air. Since the use of vented gauge pressure in sensors is affected by atmospheric changes, it is important to in eliminate the effects due to these changes, the sensor operating with the vented gauge method has been used in this study.

1.1.1. Pressure sensors sensing principles

As mentioned before, sensors with different designs have been developed and manufactured for the use of pressure sensors in different sectors and conditions. However, the main purpose of each sensing principle is to provide measurement by converting the external mechanical effect into an electrical signal. There are mainly five types of sensors as described below.

Resistive sensors: Resistive pressure sensors utilize the change in electrical resistance of a strain gauge bonded to the diaphragm that's exposed to the pressure medium (Pressure Sensors: The Design Engineer's Guide). The strain gauges often include a metal resistive element on a flexible backing connected to the diaphragm, or can be manufactured by using thin-film processes. The metal diaphragm yields on high over-pressure and also burst-pressure ability.

Capacitive sensors: Capacitive sensors can show capacitance change as a plate deviates under applied pressure and such sensors can measure below 10 mbar, can be highly sensitive and can stand against large overloads. However usage of capacitive sensors is limited since it requires special joining and sealing requirements.

Piezoelectric: Piezoelectric pressure sensors utilize the property of piezoelectric materials like quartz, to generate a charge on the surface when pressure is applied. The charge magnitude is proportional to the force applied, and the polarity shows the direction of change. The charge accumulates and is distributed quickly as pressure changes, and this leads to measurement of dynamic pressures which change fast.

Optical: Optical sensors, which utilize interferometry to measure pressure-induced changes in optical fiber, are undisturbed by electromagnetic interference, allowing use in noisy environments or near sources such as radiography equipment. Optical sensors are mainly developed using tiny components or MEMS technology, and they can be medically safe for implantation since they can measure the pressure at multiple points along fibers.

MEMS: Microelectromechanical systems (MEMS) devices combine small mechanical and electronic components on a silicon chip. MEMS can be used to manufacture different parts of an integrated circuit (IC) such as transistors, interconnection parts on IC and other mechanical components with electronical properties.

1.1.2. Types of MEMS pressure sensors

MEMS technology can be used to make various sensors including several types of pressure sensor. Two types of pressure sensors manufactured by MEMS technology are piezoresistive and capacitive. In both sensors, a flexible layer is developed which performs as a diaphragm that deflects under pressure but they differ in terms of measuring the displacement caused by this deflection (Pressure Sensors: The Design Engineer's Guide).

1.1.2.1. Capacitive pressure sensors

In order to create a capacitive sensor, conducting layers are deposited on the diaphragm and the bottom of a cavity. Usually a capacitance is a few picofarads.

Capacitance changes because of the changes of spacing between conductors due to deformation of diaphragm. This change can be measured by placing the sensor in a tuned circuit which changes its frequency when pressure changes.

Capacitive pressure sensors can be used with electronic components on a chip to make an oscillator that generates an output signal. Since fabricating large inductances on silicon is difficult, sensors will usually be based on a RC circuit. This method is very suitable for wireless readout since it can generate a high frequency signal which can be detected with a suitable external antenna.

Also a capacitance may also be measured directly by calculating the time taken to charge the capacitor from a current source. This can be compared with a reference capacitor to account for manufacturing tolerance and to reduce thermal effects.

In both cases, the proximity of the electronics and the sensor element decreases possible errors caused by noise and stray capacitance.

1.1.2.2. Piezoresistive pressure sensors

Piezoresistive strain gauges are among the most common types of pressure sensors. They use the change in electrical resistance of a material when they stretch to measure the pressure. Piezoresistive sensors are convenient for many applications because of their simplicity and sturdiness. They can be used to perform many measurements such as absolute, gauge, relative and differential pressure measurement, whether its high or low-pressure applications.

1.1.2.2.1. Working Principle

The basic principle of the piezoresistive pressure sensor is to use a strain gauge made from a conductive material that changes its electrical resistance when it is stretched. The strain gauge can be attached to a diaphragm that recognizes a change in resistance when the sensor element is deformed (Piezoresistive pressure sensors). Then the change in resistance is transformed to an output signal.

Three different effects contribute to the change in resistance of a conductor. These are summarized below.

• Since the resistance of a conductor is proportional to its length, any stretching to increase the length, also increases its resistance.

• When a conductor is stretched its cross-sectional area is reduced hence the resistance increases.

• When some materials stretch, its connatural resistivity increases.

Piezoresistive effect differs between materials. The sensitivity is shown by the gauge factor that is formulated as the relative resistance change divided by the strain where strain (ε) is defined as the relative change in length which can be calculated as can be seen in formula below:

$$GF = (\Delta R / R) / \varepsilon \quad (1)$$

$$\varepsilon = \Delta L / L \quad (2)$$

Figure 1.2. shows the wheatstone bridge circuit which is usually used to measure the change in resistance in the piezoresistive strain gauge sensor. By using this method, small changes in the resistance of the sensor can be transformed to an output voltage (Piezoresistive pressure sensors).

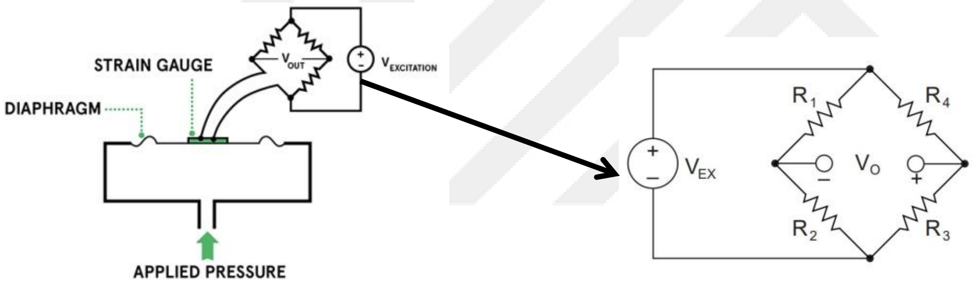


Figure 1.2. Wheatstone Bridge used in pressure sensor

The bridge is provided by an excitation on the voltage. If there is no strain and all the resistors in the bridge are balanced then the output will be zero volts. When there is a change in pressure, resistances on bridge will also change and this will lead to a corresponding output voltage or current. Formula below shows the equation of the calculation (Strain Gauge Measurement – A Tutorial, 1998).

$$V0 = [(R3 / (R3 + R4)) - R2 / (R1 + R2)] \, x \, Vex \quad (3)$$

To increase the output signal and to minimize the effects of temperature; using two or four sensing elements, where the each pair of elements being subject to equal and opposite strain, in bridge can improve performance.

1.1.2.2.2. Fabrication process

As explained above, piezoresistive strain gauge measurement is obtained by using a Wheatstone bridge circuit which is essentially a MEMS technology product. Figure 1.3. shows the fabrication which is made by six steps:

- Wafer is depositioned with silicon nitride.
- Photoresistive material is applied to the substrate surface.
- Photoresist is exposed using a light source, such as Deep UV (ultraviolet), Near UV or X-ray. It is important to place a suitable mask between photosensitive layer and the light source before application. UV light passes through the gaps on mask hits to the photosensitive layer.
- Bathed in tetra methyl ammonium hydroxide to dissolve areas where the photoresistive material contacts with UV light.
- Etching with reactive ion. On this stage the silicon without top photoresistive layer disrupts.
- Photoresist strip (piranha clean). On this step photoresistive layer decompose completely.

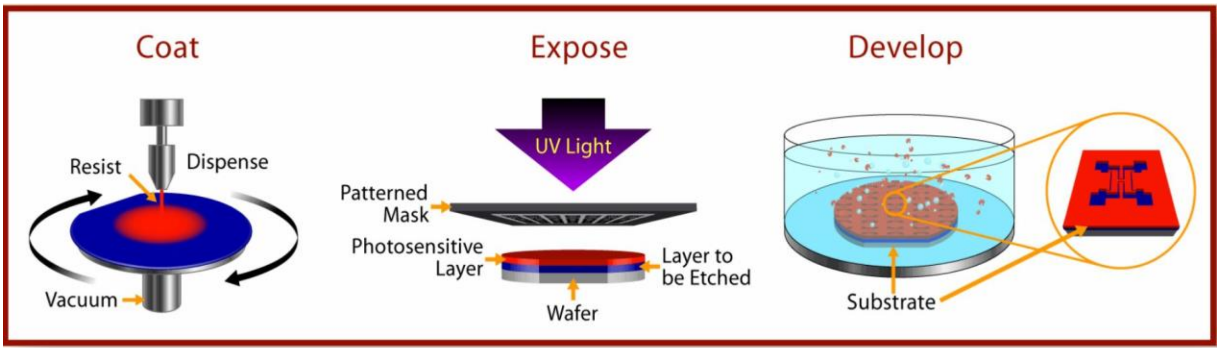


Figure 1.3. Fabrication process of piezoresistive strain gauge sensor (Modeling a Micro Pressure Sensor Activity, 2017)

Table 1.1. Advantage and disadvantages of the piezoresistive pressure sensor (Piezoresistive pressure sensors)

Piezoresistive strain gauge sensors advantages:	**Piezoresistive strain gauge sensors disadvantages:**
Most widely used type of pressure sensor.	Since the resistive elements are bonded to the diaphragm, adhesive problems may occur due to high temperature and pressure.

Construction is simple meaning low cost and durability.	Limitations on scaling, since scaling down the sensor decreases the sensitivity and increases the power consumption.
Good resistance to shock, vibration, and dynamic pressure changes.	Temperature dependent sensor output.
The readout circuits are basic and enable high-resolution measurement.	Sensor has to be powered – This considered as the main disadvantage since sensors are not suitable for low power or battery operated systems.
The output is linear with pressure and the response time is very fast.	
Can be used for a wide range of measurements (from 3 psi and up to 20000 psi) with a stable output.	
Can be very small and hence be fabricated as MEMS	

Table 1.2. Advantage and disadvantages of the capacitive pressure sensor (Pressure Sensors: The Design Engineer's Guide)

Capacitive sensors advantages:	**Capacitive sensors disadvantages:**
The capacitive element is mechanically basic and durable.	The output is inversely proportional to gap between parallel electrodes – means nonlinearity.
Can operate over a wide temperature range, also very tolerant to short term overpressure situations.	Sensitive to vibration.
Can measure a wide range of pressure (from 250 Pa up to 70 MPa) which makes them ideal for lower-pressure applications and severe environments.	Electronics as close as possible to the sensor for minimizing stray capacitance
Low power consumptions since there are no DC current flows through the capacitor.	

1.2. Temperature sensors

Temperature sensors are basically electronic devices to measure temperature of surrounding environment and convert the input into electronic data as output to observe or record measured changes.

The history of thermometer should not be considered as a single invention but considered as a development of ideas. The principle of certain substances such as air, expand and contract had been known by Hero of Alexandria (10–70 AD) and he have performed a demonstration with a closed tube which is partially filled with air and the end of the tube leading to a container filled with water (McGee, 1988).

Galileo Galilei have used the same mechanism in 16^{th} century to demonstrate the temperature of air by using a tube which the water level is controlled by the expansion and contraction of air (Doak, 2005, s. 36).

First thermoscope with a scale which can be considered as a thermometer has been developed by Santorio Santorio in 1625 (Bigotti, 2018, s. 73-103). His invention was simply a vertical tube with a bulb of air at the top and a container of water at below. The water level in this design has been controlled by expansion and contraction of the air, same as the air thermometer that we use today.

The word thermometer first used in 1624 in La Récréation Mathématique by J. Leurechon, who defined thermometer with a scale of 8 degrees (Benedict, 1984, s. 4). The word comes from the Greek words θερμός, thermos, meaning “hot” and μέτρον, metron, meaning “measure”.

Despite being used, there was no standard scale of thermometer in such years since each inventor had developed different and unique thermometers. Christiaan Huygens first suggested using the melting and boiling points of water as a standard in 1665 followed by Carlo Renaldini suggesting using fixed points on a universal scale. Isaac Newton proposed a scale of 12 degrees between the melting point of ice and body temperature in 1701 (Thermometer).

Sir William Siemens suggested using electrical conductors to increase electrical resistance with rising temperature in 1871. Construction methods are determined between the years 1885 and 1900 by Callendar, Griffiths, Holborn and Wein between 1885 and 1900 (Siemens, 1871).

1.2.1. Temperature sensor types

Four types of temperature sensors are widely used today (4 Most Common Types of Temperature Sensor):

- Negative Temperature Coefficient (NTC) Thermistor

A thermistor is a thermally sensitive resistor that displays a perpetual, small and incremental change in resistance related to changes in temperature. NTC thermistors maintain high resistances at low temperatures. According to thermistor’s R-T table, as temperature increases, the resistance decreases incrementally. A small change in temperature results in a large change in resistance and as a benefit of this property, NTC thermistor measurements are more accurate and sensitive. Because of its exponential nature NTC thermistor’s output is non linear but it can be made linear depending on its application. Operating range varies from -50°C to 250 °C for glass encapsulated thermistors but it is usually around 150°C for standard thermistors.

- Thermocouples

A thermocouple is basically two wires made from different metals that are electrically linked at two points. The changing voltage provided between these two distinct metals reflects changes in temperature, proportionally. Thermocouples require a lookup table when they are used to control temperature and compensation. They have the widest temperature range from -200 to 1750 °C. But their accuracy is low (from 0.5 °C to 5 °C).

- Semiconductor-based temperature sensors

Semiconductor-based temperature sensors are generally adjoined into integrated circuits (ICs). These sensors utilize two identical diodes with temperature-sensitive voltage vs current characteristics that are used to monitor changes in temperature (Temperature Sensors). Such sensors’ responses are linear but their accuracy is the lowest comparing to other basic sensor types. Their temperature ranges are also the narrowest that is from -70 °C to 150 °C, and have the slowest response times.

- Resistance Temperature Detector (RTD)

A resistance temperature detector changes the resistance of the RTD element in related to temperature. An RTD is made of a film or a wire, to provide more accuracy, wrapped around ceramic or glass. Another material can be used is platinum which provides most accurate RTDs but increases cost. Alternatively nickel and copper may be used to reduce cost but they are not stable or repeatable like platinum. Platinum RTDs also offer a highly accurate linear output which varies from -200 °C to 600 °C.

1.3. EC Measurement

Quality of any liquid whether its used in daily life or industrial areas is undeniably important and can be defined using their chemical and physical properties. Electrical conductivity is one of those properties and naturally needs to be measured.

Electrical conductivity of a liquid arises from the dissociation of soluble salts, acids and bases to form positively charged cations and negatively charged anions. These ions cause charge transportation in electrical field and current flow.

Friedrich Kohlrausch developed the first conduct meter to measure electrical conductivity in 1869 by using alternative current (Friedrich Kohlrausch). In that measurement, two electrodes are placed opposite from each other and when the excitation square wave voltage (±VEXC) is applied; electrodes generate a current in the medium, that causing the cations and anions move to negatively and positively charged electrodes. If there are more free charge carriers in liquid, current flow and the electrical conductivity of liquid increases. As an example to this situation 10% acid is a great conductor since it has many ions and pure water is considered as a bad conductor because it contains few ions. However too much ion concentration does not necessarily means better conduction. If the ion concentration in liquids becomes excessive, increased electrostatic force leads to a mutual repulsion of ions and results in a decreased current. This situation occurs in highly concentrated media and is called polarization (Stern & Geary, 1957, s. 59).

Conductance’s electric resistance is calculated by ohms law from the measured current. Electrical resistance reflects the distance of electrodes related to surface and is based on the geometry of electrode arrangement. It varies depending on electrode design and influences a suitability for different applications. Conductivity is also dependent on the medium temperature. Therefore the temperature also must be measured. Conductivity values are referred to a reference temperature of 25°C.

The inductive measuring principle uses inductive conductivity sensor containing an electromagnetic transmission and reception coil in protective coating. An alternating magnetic field induces the electrical voltage of liquid which is generated in transmission coil.This magnetic field causes positively and negatively charged ions to move and to form an alternating current. This current again induces an alternating magnetic field and thus a current to flow in the reception coil. The intensity of the current is evaluated by the transmitter and the conductivity is calculated.

1.3.1. Four electrodes EC measurement

For applications requiring a wide measurement range, precise measurement of connectivity is often challenging. Electrical conductivity of liquids can be determined using the two or four electrode conductor measuring principal or the inductive measuring principle.

The advantage of two electrode conductor principle is the high measuring sensitivity it has that makes it suitable for media with low conductivity as shown in Figure 1.4. such as ultra pure water to drinking water. On the other hand, inductive conductivity measurement is more suitable for media with a high conductivity such as acids and bases.

Applications such as fermentation or chromatography require wide measuring range so four electrode conductivity method is more effective to measure. In this measurement, two electrodes are placed oppositely and applied ±VEXC voltage generates a current in the medium.

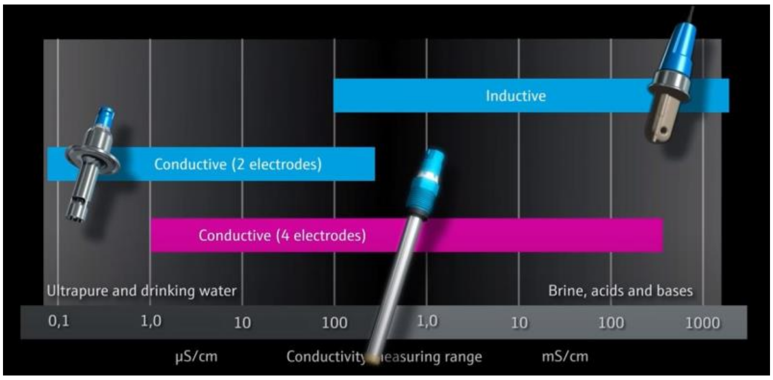


Figure 1.4. Comparison of the measuring range of 2-electrode conductive, 4-electrode conductive and inductive electrical conductivity measurement cells (Digital 4-electrode conductivity sensor).

Because of his generated current, cations start to move towards to negatively charged electrode and anions move towards to positively charged electrode. In this method, more free charge carriers means higher electrical conductivity in current flow.

However, if the ion concentration becomes too much, mutual repulsion of ions occurs and current becomes reduced. Figure 1.5. shows this phenomenon which is called polarization.

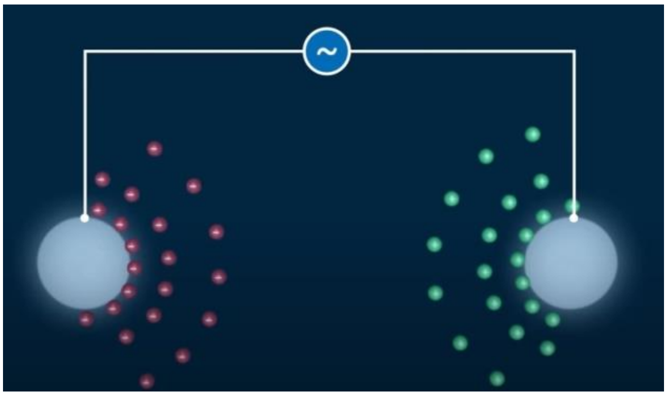


Figure 1.5. Polarization realized in conductive ec measurement with 2 electrodes (Digital 4-electrode conductivity sensor)

Figure 1.6. shows to compensate the polarization affect, two additional electrodes which act as passive observers are used in the four electrode measurement. Conductivity dependent potential difference in the medium is measured via these currentless electrodes. The connected transmitter uses the measured potential difference in the given current to calculate the conductance and finally the electrical conductivity.

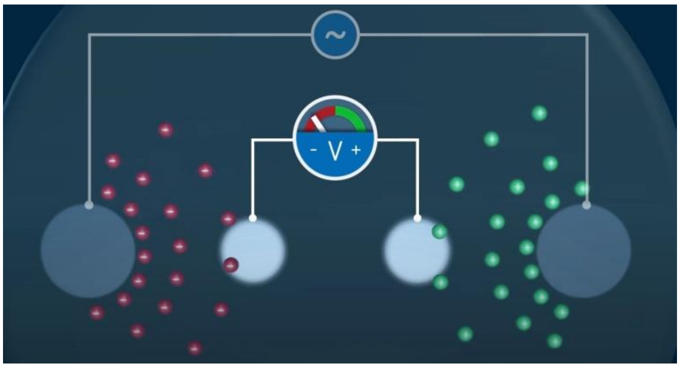


Figure 1.6. Four electrode conductivity measurement (Digital 4-electrode conductivity sensor)

For these reasons, it has been thought that the four-electrode sensor would be more suitable for this thesis and the design was carried out by researching four electrode conductivity measurement.

2. MATERIALS AND METHODS

This section presents the selection process of pressure sensor and temperature sensor together with the design of EC cell, all of which are the parts of the prototype studied throughout this thesis. Pressure and temperature sensors are used as purchased from the manufacturer while a new design is needed for EC sensor.

2.1. Pressure sensor selection

As explained in the previous sections, the type and measurement methods to be used for pressure sensor, temperature sensor, and EC cell for three parameter sensor prototype manufacturing have been determined. In this context, two piezoresistive pressure sensors with gauge pressure measurement method were determined and the datasheets of these sensors were examined. In this study, especially the pressure measurement range, material, sensitivity, linearity, size, operating temperature range, temperature compensation range and power consumption were investigated and compared.

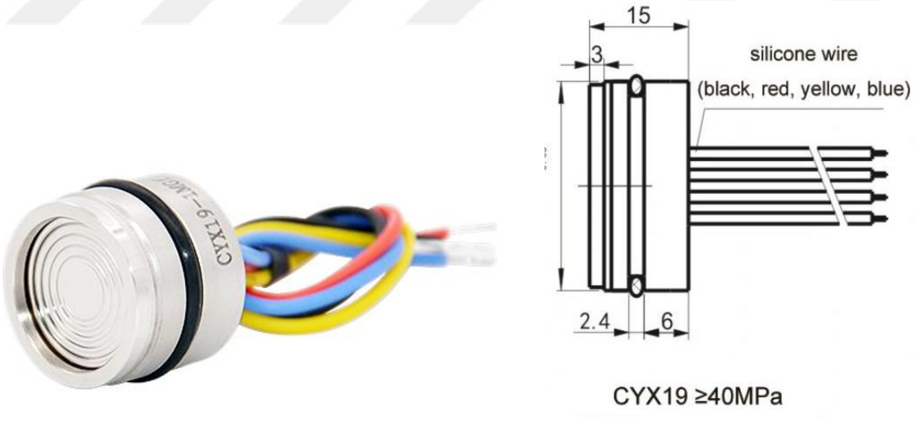


Figure 2.1. PS-01 and technical drawing (CYX19-32 series oil injection core pressure sensor)

Figure 2.1. shows the technical drawing and itself of the first sensor PS-01 planned to be purchased from Hua Tian company and the technical data of the sensor are shared in Table 2.1.

Table 2.1. Technical details of the PS-01 (Hua Tians CYX19) (CYX19-32 series oil injection core pressure sensor)

PS-01 (Hua Tians CYX19)				
	Min.	Typ.	Max.	Units
Linearity		±0.15	±0.20	%FS,BFSL
Repeatability		±0.05	±0.075	%FS
Hysteresis		±0.05	±0.075	%FS
Zero output			±2	mV DC
FS output	70			mV DC
Zero thermal error		±0.75	±1.0	%FS,@35℃
Span thermal error		±0.75	±1.0	%FS,@35℃
Compensated temp. range	0~70(7kPa,20kPa,35kPa -10~80)			℃
Working temp. range	-40~125			℃
Storage temp. range	-40~125			℃
Stability error		±0.1	±0.2	%FS/year
Pressure range	0…0.2 bar to 0…1000Bar			
Diameter x height	ø 19 mm × 11.5 mm			
Housing and diaphragm	316 L stainless steel			
Temperature compensation	-10℃ ~80℃			
Long term stability	± 0.1%FS/year			
Power supply	≤2.0mA DC; ≤10V DC			
Pressure transducer oil filling	silicone			
Overpressure	1.5 times FS			
Net weight	16g			
Input impedance	2kΩ~6kΩ			
Output impedance	3.5kΩ~6kΩ			
Response(10% - 90%)	<1ms			
Insulation resistor	100MΩ, 100VDC			
Temperature resistant range	-20℃ ~250℃			

The measurement range of the Ps-01 pressure sensor is far above what is expected to be which is up to a maximum of 1000 bar. It was found to be extremely compact and useful in size. Temperature resistance range is quite satisfactory. ± 0.1% FS / year long term stability value is sufficient for the sensor to work correctly for a long time.

Figure 2.2. shows the technical drawing of the PS-02 sensor planned to be purchased from Keller company. The technical data of the sensor are given in Table 2.2.

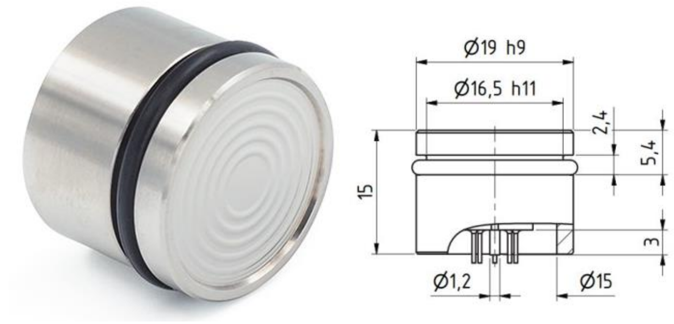


Figure 2.2. PS-02 Technical drawing (Series 10L)

Table 2.2. Technical details of the PS-02 (Keller Series 10L) (Series 10L)

PS-02 (Keller Series 10L)		
Accuracy @ RT (20…25 °C)	± 0,25 %FS typ.	Non-linearity (BFSL), pressure hysteresis, non-repeatability
	± 0,50 %FS max.	
Offset @ RT (20…25 °C)	< ± 25 mV/mA	Uncompensated
	< ± 2 mV/mA	Compensated with R3 or R4
Position dependency	≤ 2 mbar	Calibrated in vertical installation position with metal diaphragm facing downwards
Vacuum resistance		Pressure ranges 0,1/0,2/0,3/0,5 bar abs. are vacuum-optimized as standard.
Temperature coefficient zero Tczero pre-compensated with R1 or R2	≤ ± 0,015 %FS/K	For pressure ranges ≥ 2 bar
	≤ ± 0,3 mbar/K	For pressure ranges < 2 bar
Temperature coefficient sensitivity TCsens	≤ ± 0,06 %/K	For pressure ranges ≥ 3 bar
	≤ ± 0,12 %/K	For pressure ranges < 3 bar
Pressure range	0…0.1 bar to 0…200Bar	
Diameter x height	ø 19 mm × 15 mm	
Housing and diaphragm	316 L stainless steel	
Temperature compensation	-10℃ ~80℃	
Long term stability	± 0.15%FS/year	
Power supply	≤3.0mA DC; ≤10V DC	
Pressure transducer oil filling	silicone	
Overpressure	no data	
Net weight	25g	
Bridge resistance	3,5 kΩ ± 20 %	
Output impedance	160 Ω	
Response	no data	
Insulation resistor	> 100 MΩ @ 500 VD	
Temperature resistant range	-40…125 °C	

PS-02 sensor can measure up to a maximum of 200 bar. Even though this value is not as high as PS-01, it is sufficient to be used in the sensor to be prototyped. The PS-02 sensor, which is 3.5 mm higher in size, has a length difference that will affect the outer shell design. It falls behind PS-01 with ± 0.15% FS / year long term stability value. It can operate at lower temperatures than PS-01, but cannot work at high temperatures. Temperature compensation, essential for pressure measurement, is the same in both sensors. Also both sensors are made from the same material that is 316 stainless steel. In terms of power consumption, the PS-01 sensor is slightly better than a PS-02 sensor with a value of 2.0 mA.

As a result of examining all documents of the PS-01 sensor, no accuracy information was found. No information about linearity could be found in the PS-02 sensor. When the datasheets were examined, it was observed that the sensors were sufficient to be used in the prototype sensor. For this reason, it was decided to purchase, test and examine the sensors.

Apart from these sensors, Kistler brand 4260A and ES system brand ESCP-MIS1 pressure sensors were also examined. As a result of these examination, the sensors were eliminated before they were purchased due to the high energy consumption of the 4260A sensor and the low sensitivity and high energy consumption of the ESCP-MIS1 sensor.

2.2. Temperature sensor selection

For the selection of the temperature sensor, potential sensors that can be used are determined first, as it is done with the pressure sensor. After this determination, it has been predicted that PT-100, PT-1000 and NTC temperature sensors from different brands can be used.

The datasheets of these sensors are considered to be used. Also examinations and comparisons were made. Table 2.3. gives information on TS-01 Elimko brand A grade pt-100, TS-02 Gaimc brand B grade pt-1000, TS-03 jingpu brand NTC sensors.

Table 2.3. Technical details of temperature sensors (Thermistor Probes and Assemblies) (Rezistans Termometreler) (Platinum Resistance Temperature Sensor)

Sensing Element	**TS-01 (PT-1000)**
Accuracy	Grade B(±0.3°C)
Temp Range	Grade B: -70 ... +500°C
Shell Size	Diameter: ¢ 3 ... ¢ 9mm, length: 3mm … 1000mm

shell Material	stainless steel
Heat-shrinkable sleeve	Teflon tube
Wire	3 Wire
Sensing Element	**TS-02 (PT-100)**
Accuracy	Grade A (±0.15℃)
Temp Range	Grade B: -200 ... +650℃
Shell Size	Diameter: ¢ 3mm, length: 30mm
shell Material	stainless steel
Heat-shrinkable sleeve	Teflon tube
Wire	3 Wire
Sensing Element	**TS-03 (NTC 10k ±% 1 3950)**
Accuracy	: ±1 %
Temp Range	-30 ... +120℃
Shell Size	Diameter: ¢ 5, length: 25mm
shell Material	stainless steel
Heat-shrinkable sleeve	Teflon tube
Wire	2 Wire XH (2,54) -2Y

The TS-02 sensor is the best in terms of sensitivity, but studies have shown that the PT-1000 sensor operates more precisely than the PT-100 sensor. TS-03 sensor is the worst in terms of temperature measurement range and sensitivity among three.

While the diameters of TS-01 and TS-02 sensors are equal to each other, the length of the PT-1000 sensor is selectable. The TS-02 sensor is again the best option with a temperature measurement range of -200 ℃ to + 650 ℃ It has been observed that the three sensors whose datasheets have been examined have the potential to be used in the sensor to be prototyped. These three sensors were purchased to be tested in temperature cabinet on the designed electronic card. Results related to these tests are given in the Results & Discussion section.

2.3. EC cell design and manufacture

As explained in introduction, conductive EC measurement can be performed in two ways. The first one is two electrodes measurement while other is four electrode measurement. Since the desired measuring range cannot be reached with a two-electrode cell, researches have been made for the production of four-electrode cells.

EC measurement is basically performed by measuring the resistance of liquid. The resistivity of a material (ρ) is described as resistance of a cube of the material with conductive contacts on opposite surfaces. The resistance (R) is calculated for other shapes by:

$$R = \rho L/A \tag{4}$$

where:

L is the distance between the contacts

A is the area of the contacts.

In electrode manufacturing, usually 316 degree type stainless steel, titanium palladium alloy or graphite are used. Such materials’ sizes are adjusted to obtain a known cell constant. Theoretically, a cell constant of 1.0/cm defines two electrodes, each 1 cm2 area size and 1 cm apart. The constants for a known working range must be in accordance with the measuring system. For instance, when a sensor with a cell constant of 1.0/cm is considered, conductivity of pure water should be 1 μS/cm and the cell resistance should be 1 MΩ. If such cell was in sea water, the resistance would be 30 Ω. Since the resistance ratio is very broad, ordinary instruments are inefficient to measure excesses with just one cell constant.

A solution of 1 μS/cm is used in measurements with the cell constructed with large-field electrodes with a small gap between them. For example, a cell with 0.01/cm cell constant results in a approximately 10,000 Ω cell resistance instead of 1 MΩ. Since 10.000 Ω is easier to measure precisely than 1 MΩ; the meter can function in the same cell resistance range for ultrapure water and high conductivity seawater (Resistivity and Conductivity).

Below is the equations where K is defined as the cell constant which is calculated as the ratio of the distance between the electrodes (L) to the area of the electrodes (A) (Resistivity and Conductivity) :

$$K = L / A \tag{5}$$

The instrumentation then measures the cell conductance, Y:

$$Y = I / V \tag{6}$$

Then the conductivitiy of the liquid (Yx) is calculated as:

$$Yx = K \times Y \tag{7}$$

It has been predicted that the K coefficient should be between 2 / cm and 3 / cm in order to achieve the desired measurement range during the production phase. In this prediction, the EC values of the fluids which the sensor will be used in, are taken into account. By using a four-electrode sensor, it allows a wider range of EC measurement with lower cell constant as well as reducing polarization. The reason for this is that the current is measured with two passive observers.

2.3.1. EC cells designs

In its simplest form EC cell consists of two active and two passive electrodes. ±VEXC voltage is applied in square waves to the active electrodes of the cell, while voltage and current are measured from the passive electrodes.

Cell constant is important for a large scale EC measurement. Also the size and location of the electrodes are important. In this context, different EC cells have been designed at different times. The EC cells, which were produced as prototypes, were tested comparatively with the calibrated WTW Universal multi-parameter portable meter pH/Cond 3320 device.

2.3.1.1. First phase EC cell designs

In these designs, 316 stainless steel was used for the cells and polyoxymethylene material was used for the cell outer shell. 3D images of the products were drawn with the autocad program for sizing and cell constant determination before production. Figure 2.3. shows these drawings.

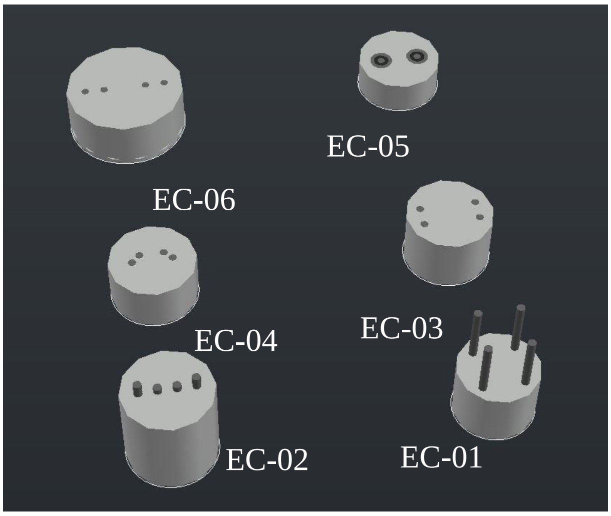


Figure 2.3. Autocad drawings of EC cells to be produced

Since there is no soldering on stainless steels, the cables are packed in the spaces created in the cells as shown in Figure 2.4. After the cable connection, the conductivity was tested between the cable ends and the electrodes.

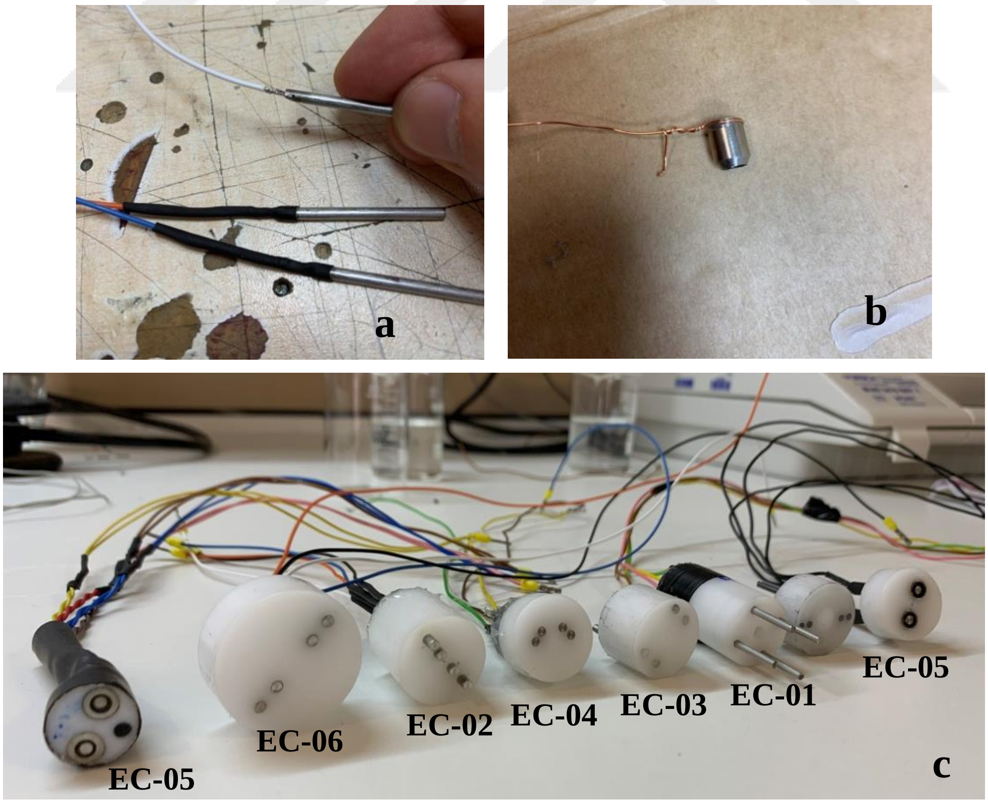


Figure 2.4. Produced versions of EC cells with different cross-section, size, cell constant and spacing.

The EC cells shown in Figure 2.4. were individually inserted into the development board and tested.

Table 2.4. The produced EC cells were tested using a WTW EC measurement device.

WTW	15 µS/cm	50 µS/cm	100 µS/cm	500 µS/cm	1000 µS/cm	3000 µS/cm	10000 µS/cm	20000 µS/cm	50000 µS/cm
EC-01	75	562	**Read values are not stable. Constantly high changes were observed.**						
EC-02	68	128	165	418	2400	3890	5670	18270	28000
EC-03	1.2	15	132	889	1520	4210	12850	17530	39850
EC-04	45	86	211	621	2050	3750	1540	22000	32900
EC-05	38	62	125	558	1290	3390	1190	18740	45720
EC-06	127	95	169	633	5850	**High changes were observed.**			

As shown in Table 2.4, when EC-01 exceeded 100 µS / cm and EC-05 exceeded 3 mS / cm, they started not to give stable values. Although different voltage and frequency trials were carried out, they continued to fail. The measurement values of the other four sensors remained well below the desired measurement accuracy. It has been observed that any of these sensors, since they all have very high error rates, are not suitable for the final prototype. Among these six sensors, EC-05 was the sensor that could follow the desired values closest. This sensor, which is shaped like a ring and rod in design, formed the basis for the next sensor design.

2.3.1.2. Second phase EC cell design

Based on the design of the EC-05 cell tested in step one, a new design of EC-07 shown in figure 2.5 has been designed with the autocad program.

Figure 2.5. Autocad drawing of EC-07. The first design in which active and passive electrodes face each other.

Figure 2.6. shows the EC-07 design which has two circular passive electrodes that are placed inside the ring-shaped active electrodes, just like in the EC-05 cell design. In the trials, a 5 mm diameter hole was drilled into a 7 mm diameter 316 stainless steel bar. A rod with a diameter of 3 mm was placed inside this ring and a deep material with a diameter of 5 mm and a hole of 3 mm inside was placed between the two electrodes. As shown in figure 2.7., a ring groove is opened to provide cable connection to the side wall of the ring active electrode of 7 mm diameter. Since soldering cannot be done to the passive electrode with a diameter of 3 mm, the cable connection was provided by welding.

Figure 2.6. active passive electrode before assembly.

Figure 2.7. Active passive electrodes assembled.

A 5 mm wide and 25 mm high slit was cut into the cylinder made of polyoxymethylene material with a length of 90 mm and a diameter of 40 mm. Holes with a diameter of 7 mm were drilled on both sides of the cylinder to accommodate the EC cells. Then, 3 mm wide and 12 mm long slots were opened to pass the EC cells cables.

The EC cells, which were created using 316 stainless steel and polyoxymethylene, were then placed in the places opened on the polyoxymethylene cylinder as in figure 2.8. Than hot silicone was applied to prevent contact with the liquid from the side opening of the polyoxymethylene cylinder.

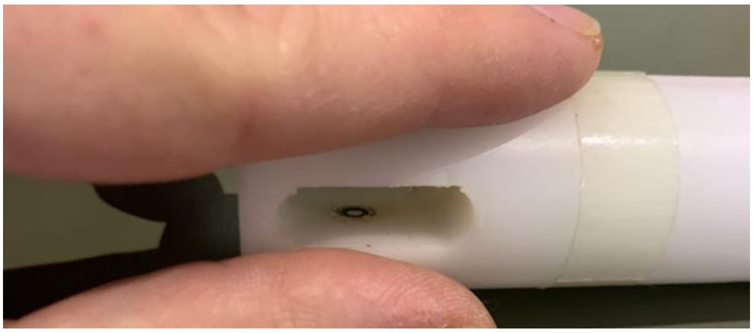


Figure 2.8. EC-07 cell, the first design in which the electrodes face each other.

Cell constant value of cell EC-07:

$$K = L / A \quad (7)$$

K = 0.5 cm / (0.35cm x 0.35cm x π) – (0.25cm x 0.25cm x π)
K= 0.5cm / 0.1885 cm2
K = 2.6525 /cm

The EC-07 was connected to the development board and tested by putting it in the same liquids as the WTW device. In order to compensate the temperature affecting the EC measurement during the test phase, the pt-100 temperature sensor was also connected to the development board. The test results of the EC-07 cell are shown in Figures 2.9 and 2.10.

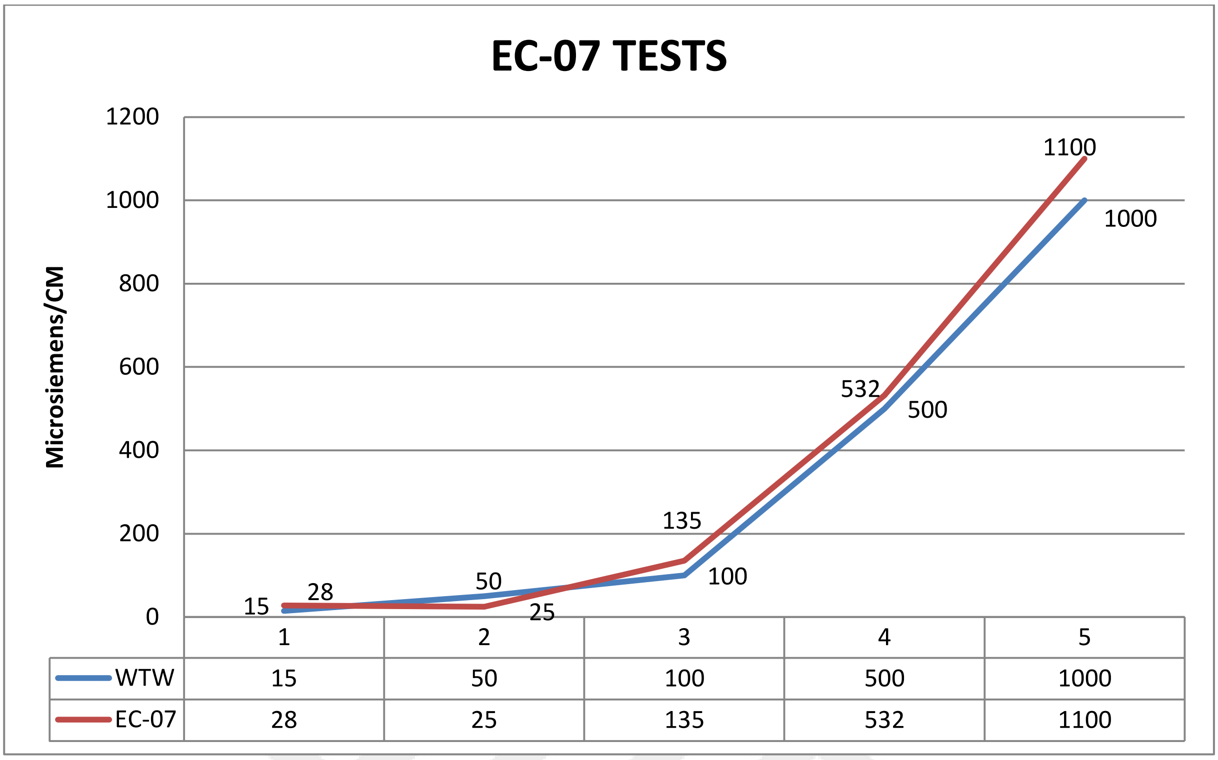


Figure 2.9. Comparison of EC-07 cell with WTW EC measuring device at low S/cm values.

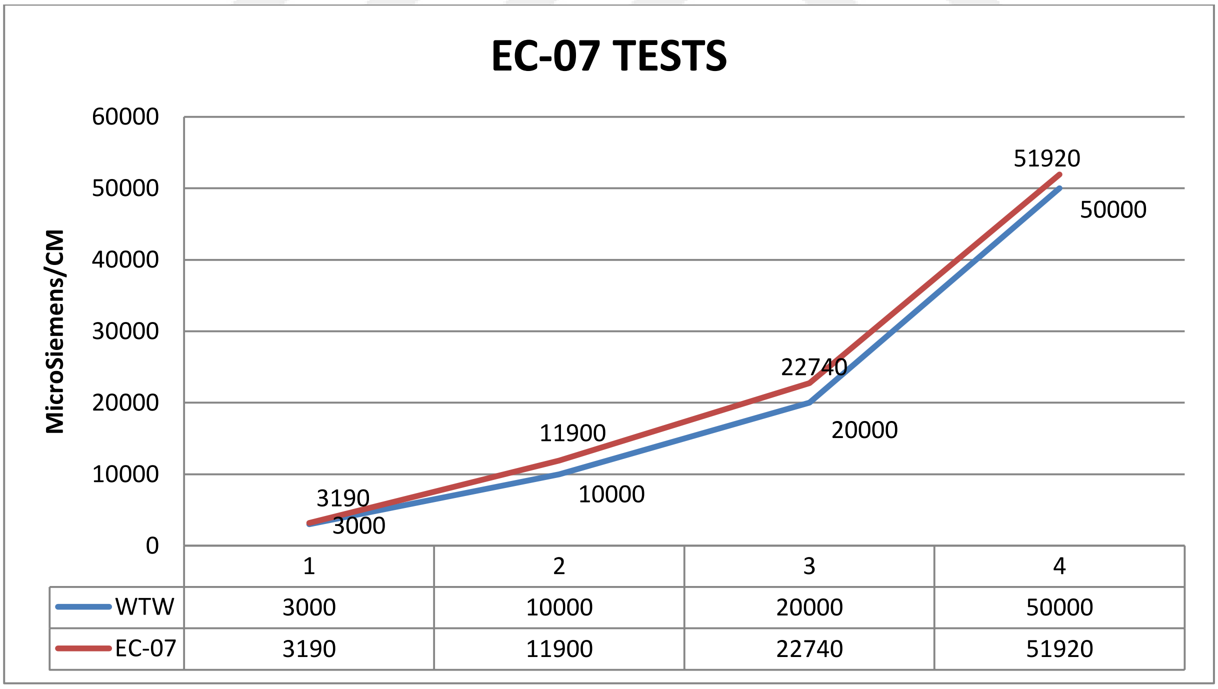


Figure 2.10. Comparison of EC-07 cell with WTW-3320 at high S/cm values.

The EC-07 cell has been the most successful cell among the cells that have been tried so far. For this reason, the EC-07 cell was decided to be used in design. However, due to the fact that the design has not achieved the desired precision, trials have been continued with different materials and different cell constants.

2.3.1.3. Third phase EC cell design

In line with the results obtained from EC-07, the EC-08 cell design was carried out using graphite material instead of 316 stainless steel. In addition, it was observed that the material of Polyoxymethylene placed between active and passive electrodes in cell EC-07 could not provide sufficient liquid insulation. For this reason, the space between active and passive electrodes was filled with polyethylene which is suitable for use in electronic materials during the experiments with graphite.

Graphite is basically the transformation of carbon atoms into crystal form. Carbon atoms are arranged to form a hexagonal ring, and carbon atoms are linked to each other with covalent chemical bonds to form plate-like planes.

Graphite cylinders with 7mm and 3mm diameters are used for the design of the EC-08 cell. The inside of the 7 mm diameter graphite cylinder was drilled 5 mm in diameter and a ring-shaped active electrode was formed as shown in Figure 2.11.

Figure 2.11. Active and passive electrodes made of graphite material for use in EC-08 cell.

In order to make cable connections to the walls of both active and passive electrodes, ring grooves were opened and cable connections were made. Figure 2.12. shows active and passive electrodes with completed wiring to these ring groove and their conductivity was tested.

Figure 2.12. Active and passive electrodes with completed wiring.

Figure 2.13. shows the passive electrodes centered with respect to active electrodes. Centering performed with the help of silicone. After this centering, the space between the two electrodes is filled with polyethylene.

Figure 2.13. Passive electrodes are centered with respect to active electrodes.

After the polyethylene is cured, the electrodes are removed and the surfaces that will touch liquid are smoothed by sanding. As shown in figure 2.14. the centered electrodes are then placed in the EC cell outer shell.

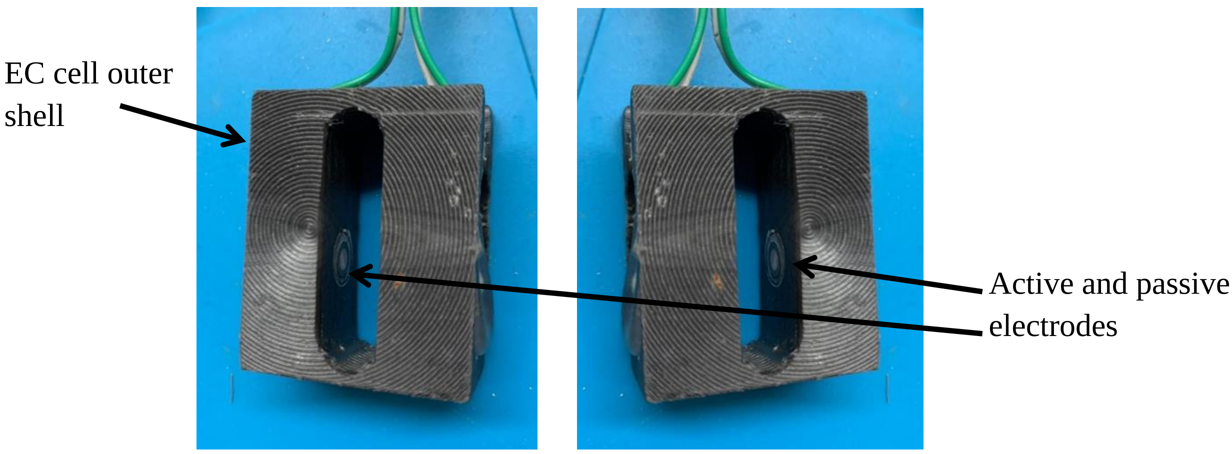


Figure 2.14. Wired and centered electrodes placed in the polyoxymethylene material.

The electrodes whose conductivity test has been performed for the last time were placed in their outer shell similar to the outer shell produced in the EC-07 cell.

The slot in the outer shell used here has a width of 4 mm. Therefore, the Cell Constant value of EC-08 cell is:

$K = L/A$

$K = 0.4 \text{ cm} / (0.35 \text{ cm} \times 0.35 \text{ cm} \times \pi) - (0.25 \text{ cm} \times 0.25 \text{ cm} \times \pi)$

$K = 0.4 \text{ cm} / 0.1885 \text{ cm}^2$

$K = 2.1220 \text{ /cm}$

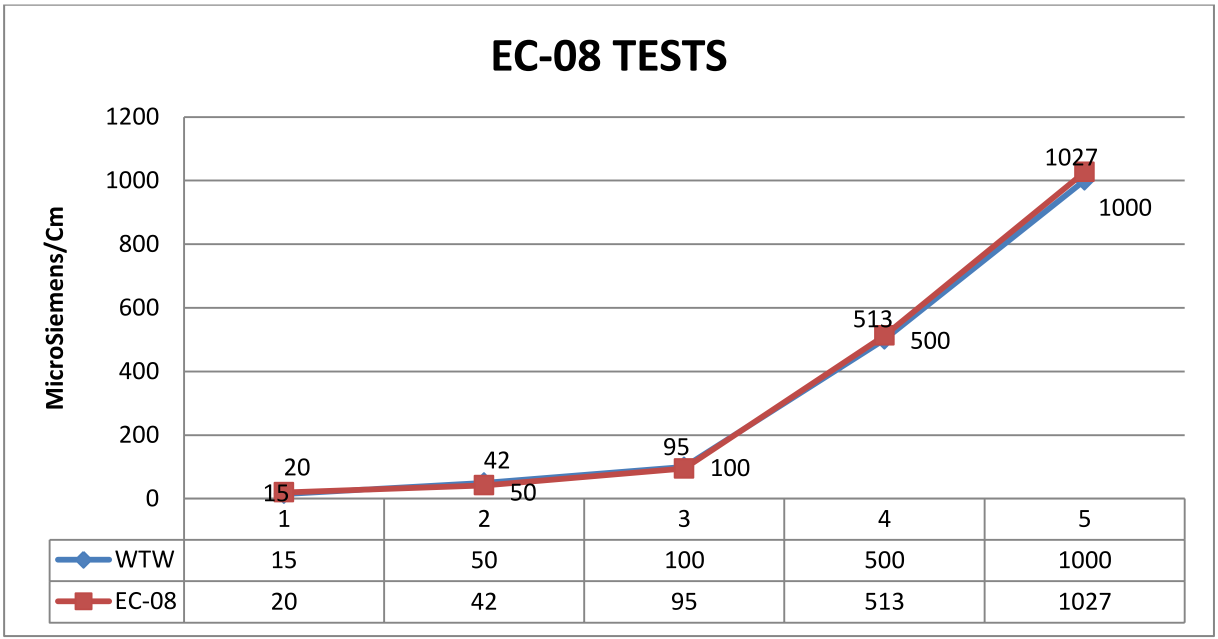


Figure 2.15. Comparison of EC-08 cell with WTW ec measuring device at low S/cm values.

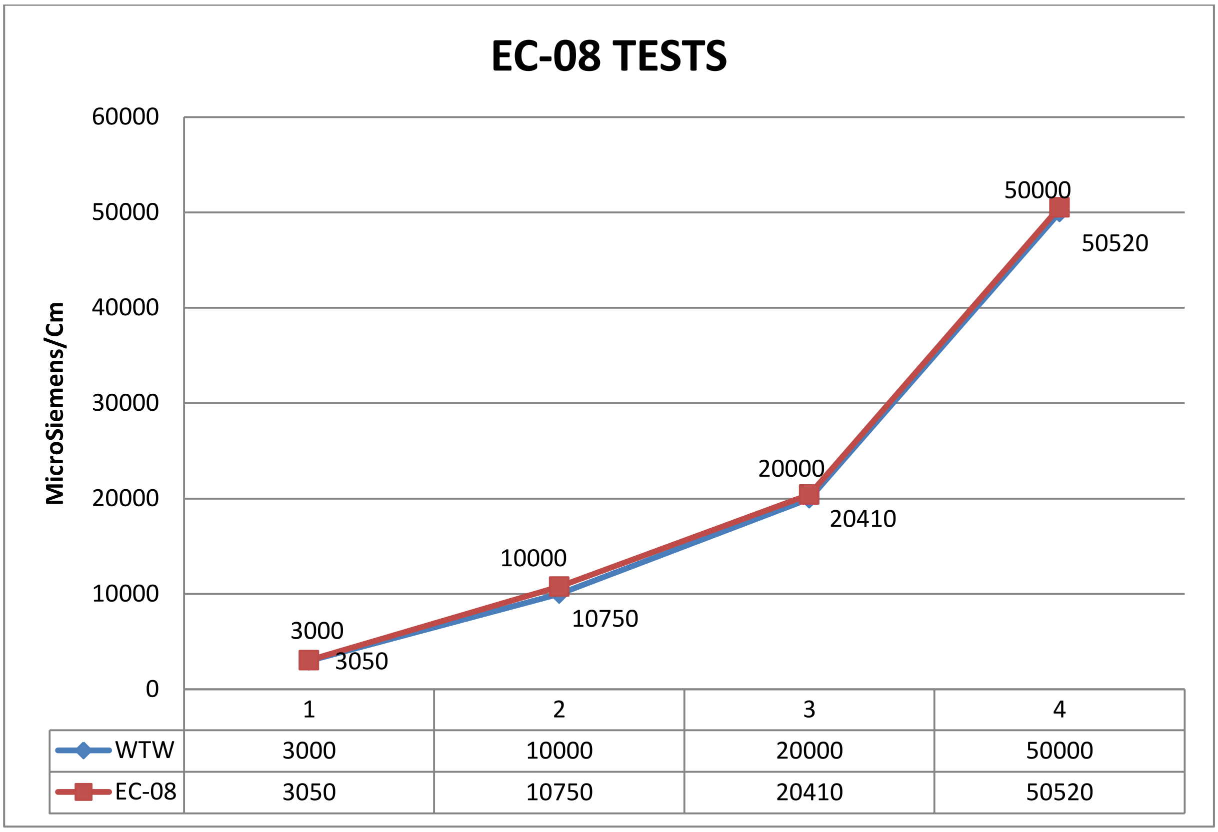


Figure 2.16. Comparison of EC-08 cell with WTW ec measuring device at high S/cm values.

Figure 2.15 and 2.16 show the comparison of EC-08 with WTW EC measuring device at low and high S/cm values respectively, it is observed that the EC-08 cell works more accurately than the previous designs. However, due to design deficiencies, the sensitivity was lower than expected. It is thought that the reason for this is that the diameter and height values of the produced electrodes do not match exactly. The liquid insulation between the electrodes is satisfactory but the cable places of the electrodes are covered with hot silicone. At this point, there is liquid contact to the back of the electrodes. This situation reduces the sensitivity of the EC-08 cell. This problem was prevented in the final design which is EC-09 cell. The test results of EC-09 cell are given in the Results & Discussions section.

2.4. Outer shell design

Figure 2.17. shows the autocad drawing of the scaled outer shell. In order to be resistant to water corrosion and impacts, 316 stainless steel material has been chosen. The part number 1 is made of Polyoxymethylene material.

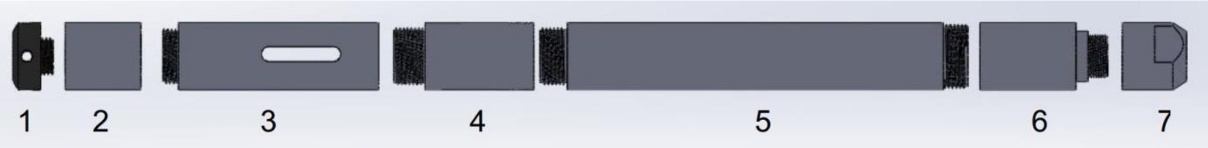


Figure 2.17. Autocad drawing of the outer shell.

The diameter of the outer shell, which consists of 7 parts in total, is 22 mm and its length is 320 mm. These measures were determined for 4 main reasons:

1- outer diameter of selected pressure sensor
2- length of the designed PCB
3- minimum inner diameter of the wells where the sensor will be used
4- length of EC cell to be used

O rings are placed on all 2, 3, 4, 5, 6 parts for waterproofing. Especially in the part where the EC cell will be placed, double o rings are used because this point is the most likely to contact with liquid. The reason for this is that the EC cell outer shell made of polyoxymethylene material fits directly into the stainless steel outer shell. These two materials have expansion differences against heat. For this reason, the contact point of both is the most vulnerable point of the sensor.

In addition to the o-rings to prevent liquid contact, the inside of the sensor outer shell is completely filled with electronic gel which is shown in figure 2.18. Thanks to this jelly-like gel, it is predicted that it will not touch the PCB or the pressure sensor, even if there are liquid leaks into the sensor.

Apart from these, after the cable connections are made, the space inside the 7th part is covered with polyethylene. Having a strong adhesive feature, polyethylene both prevented the cable from moving and reduced the possibility of liquid contact.

Figure 2.18. Electronic gel filling.

Figure 2.19. The gasket used at the main cable connection point. Thanks to this gasket, both sealing is provided and the load does not get on the cable connection point.

Figure 2.19. shows the gasket in the middle of the 6^{th} and 7^{th} parts. When these parts are thighten, this gasket is squeezed and expanded. It has been produced and used to prevent liquid contact and cable movement.

The 1^{st} part is made of Polyoxymethylene material which is used to avoid direct physical contact with the diaphragm of the pressure sensor. The liquid passed through the holes on the material and made contact with the diaphragm of the pressure sensor, thereby measuring the pressure.

Lock tide adhesive is applied on the gears before each piece is mounted together. The possibility of parts separation from each other is prevented since this adhesive has metal-metal adhesion. In addition, the possibility of liquid leakage between the parts has been reduced.

2.5. PCB design

In the preliminary research for this thesis, development board for PCB design was examined and the appropriate development board was sought. As a result of the researches made in this context, it has been observed that the NUCLEO-F091RC development board has the necessary infrastructures to be used in the thesis. In this context, it has been found appropriate to make the trials on this development board as a priority. The fact that most of the hardware elements required for EC and temperature measurement are available on the development board has formed the basis for PCB design. The schematics of the designed PCB have been drawn with the changes made on the schematics of this development board. The major changes have been made to the development board schematic are pressure sensor integration, 4… 20 mA, SPI-12 data outputs, hardware gain buffer integrations, and single-pole / double-throw (SPDT) additions.

Figure 2.20. shows the block diagram of the station type three parameter sensor with microcontroller control, compatible with different pressure, temperature sensors and EC cells, suitable for use in the field of hydrology. Two 32-bit Σ-Δ ADCs on the precision analog microcontroller is used. For accuracy and easy operation the peak to peak amplitude of excitation voltage and current were converted to a DC value.

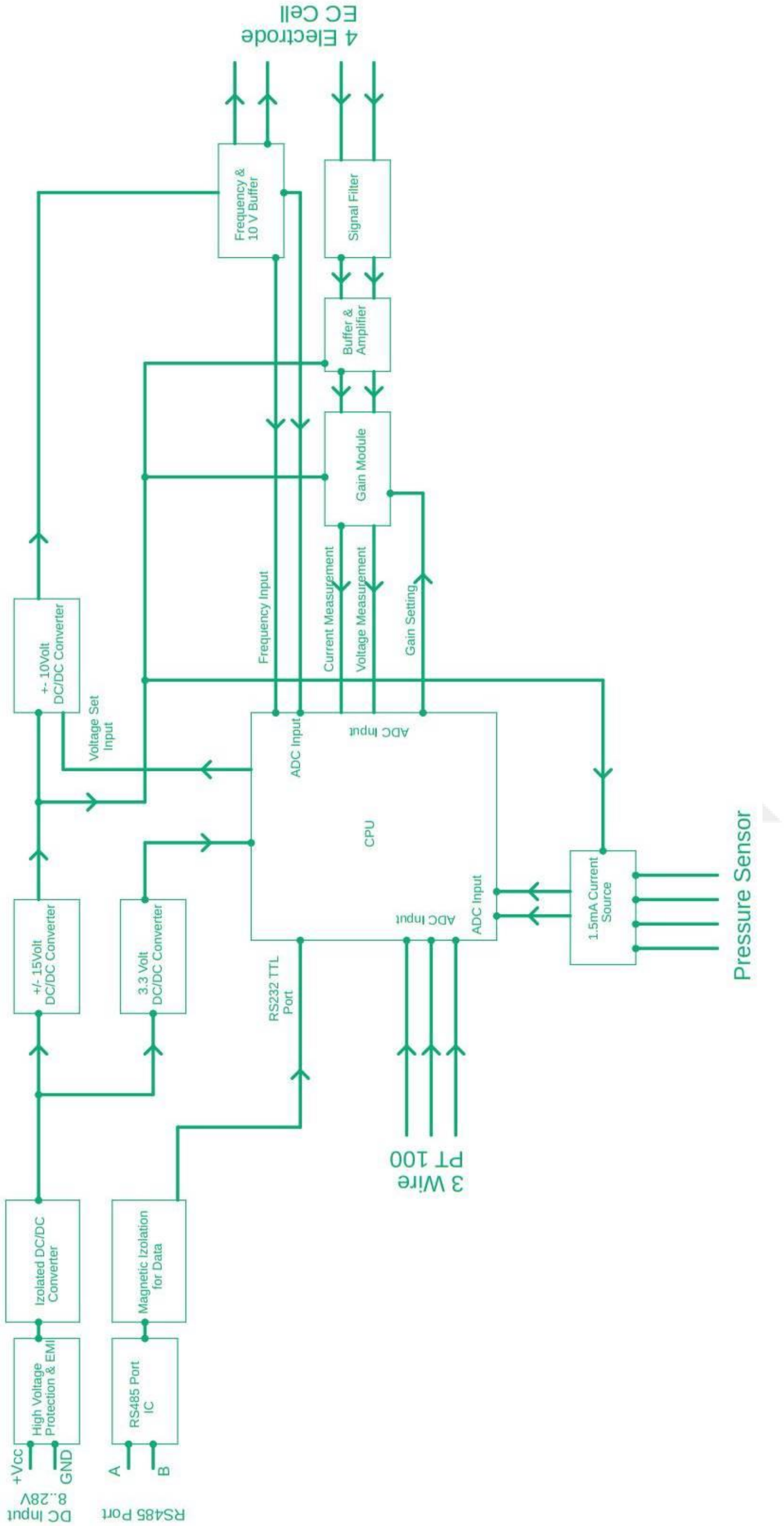


Figure 2.20. Block diagram of station type three parameter sensor

There are four cables in the main connection of the PCB. Two of them (VCC and GND) are used for power and the other two for data transfer (RS-485). A DC voltage in the range of 8… 24 volts is applied through the power input. The applied power reaches the isolated DC / DC converter by passing through high voltage protection (36 volt Varistor and TVS diode) and EMI. With the help of this DC / DC converter, the input voltage is reduced to 5 volts. This voltage is delivered to step up and step down DC / DC converters. 3.3 volt output is obtained with a step down DC / DC converter. It is delivered to microcontroller and zero drift op amp. With a step up DC / DC converter, ±15 volts are obtained with the help of diodes.

Figure 2.21 shows the schematic drawing of the integrators and microcontroller connections required for EC measurement. With ±15 volts, the necessary supply source for the active electrodes of the EC cell is provided. The voltage value to be applied to the active electrodes can be regulated by the microcontroller. Op amp amplifier circuit is used for this regulation.

An adjustable 0-10 volts is obtained by controlling the DAC output of the microcontroller. The excitation square wave voltage (+VEXC) in the set range 0 - 10 volts is inverted through the op amp and creates the voltage -VEXC. The microcontroller generates square wave switching signal for the SPDT switch. It also generates synchronization signals for synchronized sampling stages. As shown in figure 2.21. the resulting + VEXC and - VEXC are applied to the active electrodes of the EC cell. Here, a single-pole / double-throw (SPDT) switch is used to send symmetrical square waves to active electrodes.

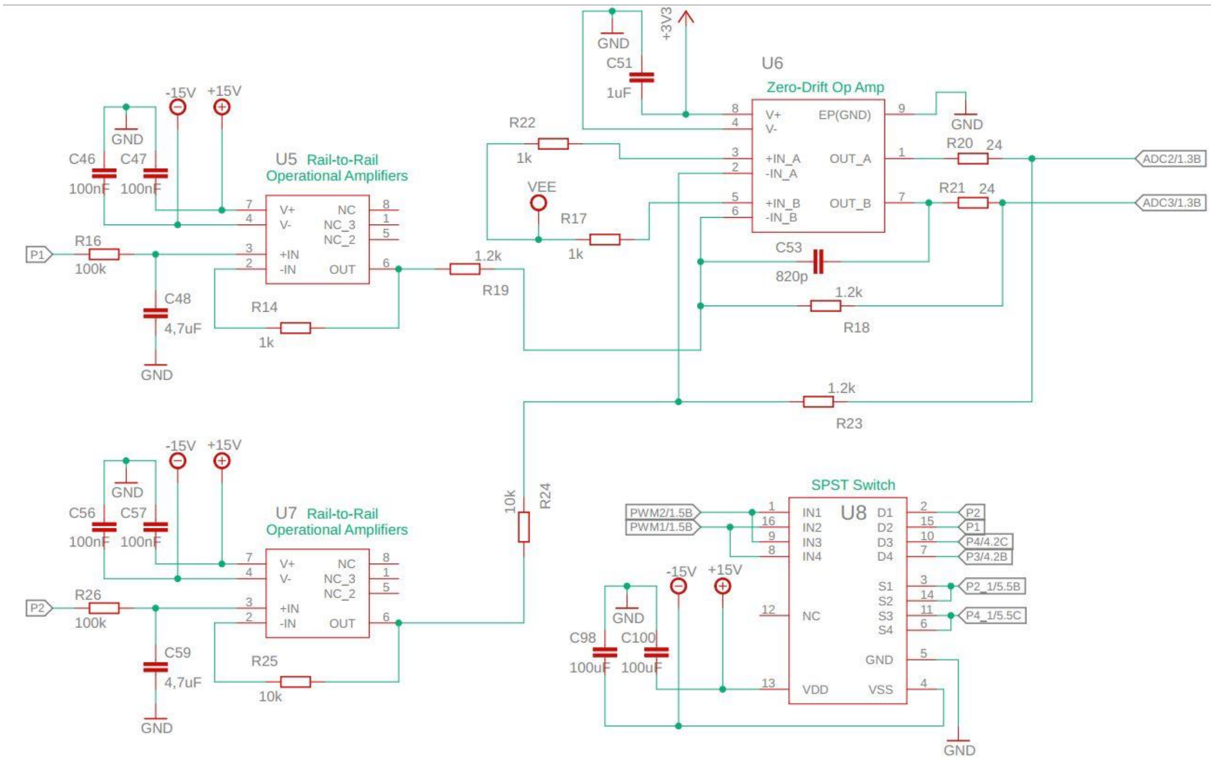


Figure 2.21. Schematic of EC module.

As shown in Figure 2.22. VOUT1 (differential output voltage channel) is applied to the AIN2 and AIN3 inputs of the microcontroller. VOUT2 (The differential output of the current channel) is applied to the AIN0 and AIN1 inputs. The impedance of the liquid in which the EC cell is located is calculated with the voltage and current values. The reading range of the EC is extended by using the low voltage hardware gain buffer integrations read from the passive electrodes of the EC cell. Pre-filter op amp buffers are used in passive electrodes to reduce the noise caused by environmental factors.

Figure 2.22. shows general pin connections of the microcontroller and the connection between the pt-100 temperature sensor and the microcontroller. The current source ADC input of the microcontroller and the pt-100 sensor are measured together with the reference voltage of the microcontroller. Since the impedance value changes due to the temperature change of the liquid, the EC value is rectified by using the temperature value from pt-100 while reading EC.

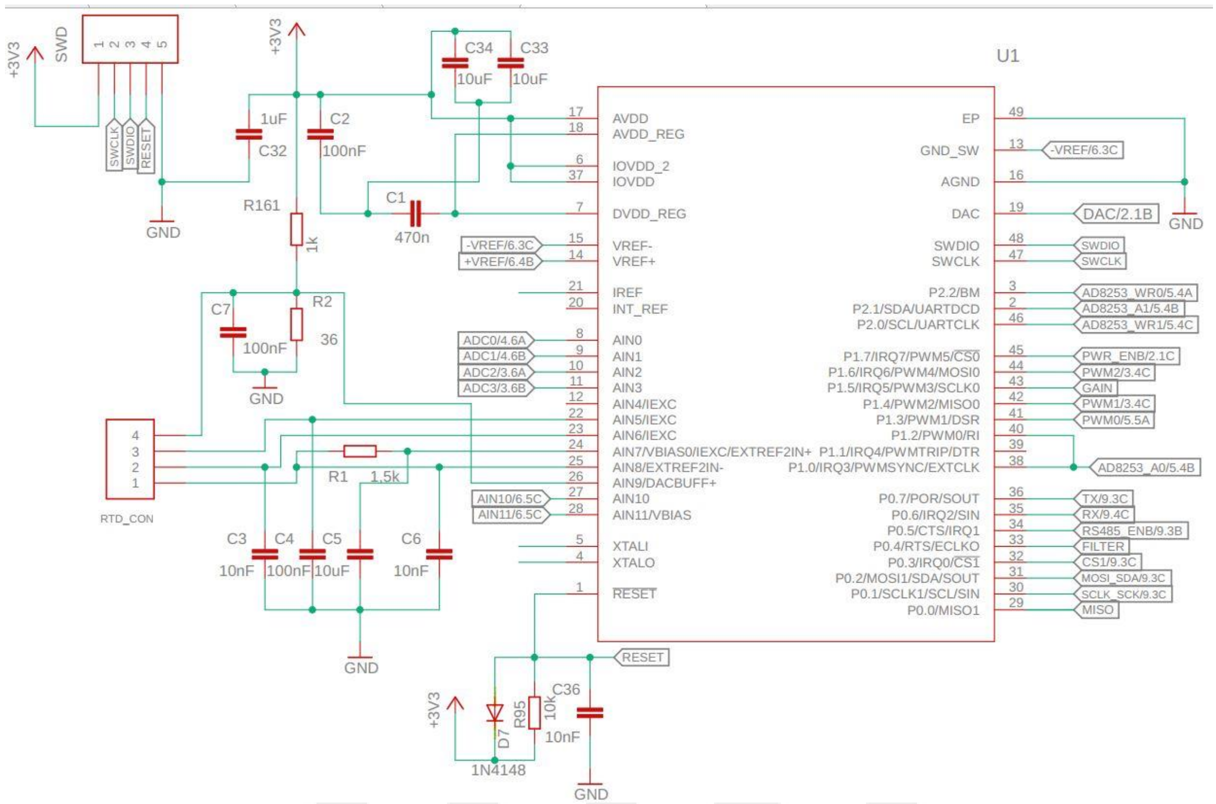


Figure 2.22. Schematic of the main connections of the microcontroller and the PT-100 temperature sensor.

The schematic drawings related to the pressure sensor are shown in Figure 2.23. For the pressure sensor operating with a current source, an external current source of 1.5 mA is obtained by passing +15 volts over a potentiometer. The reason for using a potentiometer is the minimal difference in the internal resistances of each sensor. With the help of potentiometer, a current source of 1.5 mA can be provided to each sensor even if the internal resistances are different. The resistance outputs of the wheatstone bridge, which vary depending on the pressure, are connected to the ADC of the microprocessor. Since the output of the sensor is in the order of mV, by using the hardware gain within the microcontroller itself, the range of the ADC is expanded and at the same time noise reduction is achieved.

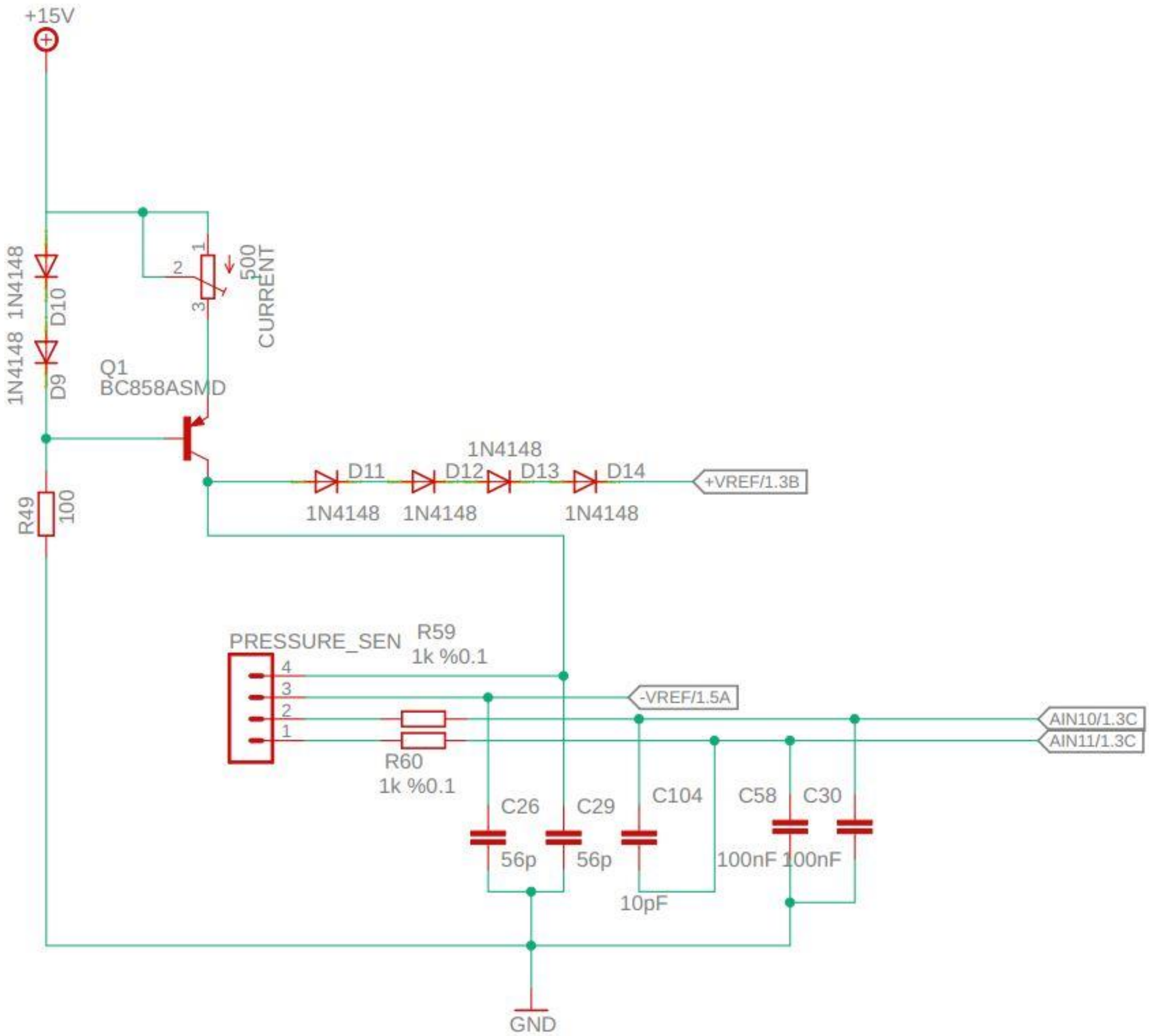


Figure 2.23. Schematic of the pressure sensor connection.

Figure 2.24. includes schematic drawings of RS-485 and SDI-12. The RS-232 port, which is the TTL output of the microcontroller, is used for the RS-485 port. The enable pin of RS-485 is controlled from the digital output port of the microcontroller. TTL ports are connected to the RS-485 IC by passing through the magnetic isolator IC.

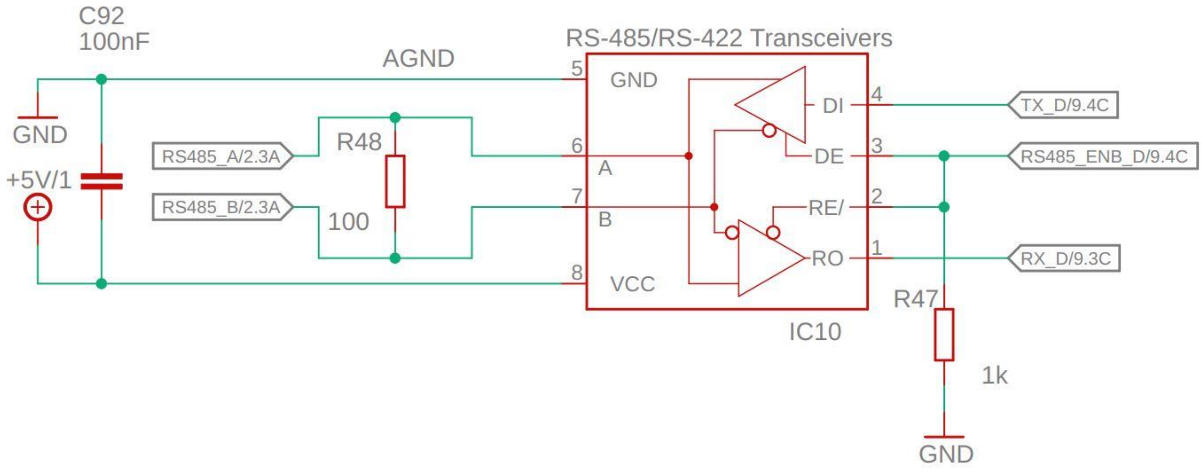


Figure 2.24. Schematic of the RS-485 and SDI-12.

In PCB design which is shown in figure 2.25., height is determined according to the inner diameter of the sensor, which is the final product. Since the inner diameter of the designed sensor is fixed, the height of the PCB is constant. For this reason, the width of the PCB has been increased. Again, due to the small size of the PCB, it is designed as four layers. In addition, the PCB drawing was made so that electronic elements can be placed on two surfaces.

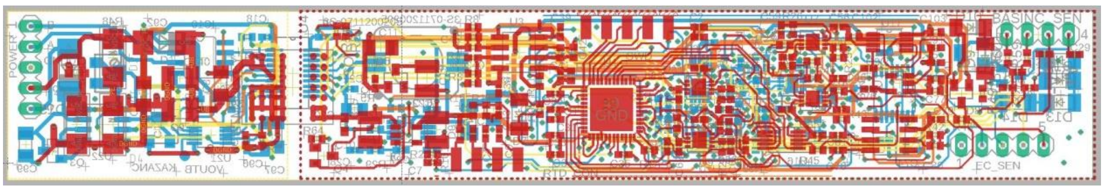


Figure 2.25. Final PCB design.

During the PCB design, a drawing was made especially with the input of one op-amp close to the output of the other op-amp. Thus, the path between op-amps was kept as short as possible. In addition, the connections were kept close to the microcontroller to reduce the error rate of temperature measurement with pt-100. The second layer is covered with GND to prevent possible noise.

2.6. Firmware

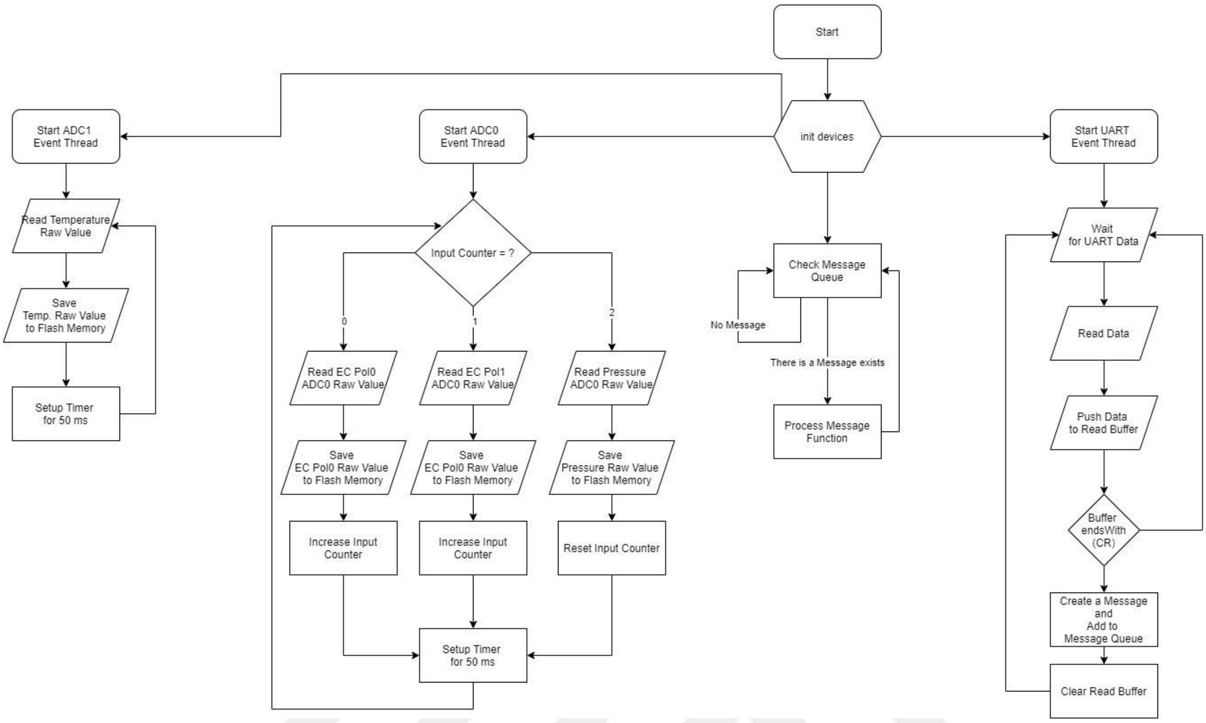


Figure 2.26. Firmware flowchart

As shown in Figure 2.26. the flowchart has been designed to provide the most stable and general structure possible.

It will be applicable regardless of the MCU used. It will be sufficient to make changes in coding according to the hardware design. C ++ language was used in firmware development. The same flowchart can be implemented in C or Assembly language.

2.6.1. General steps and description of units

The following adjustments are made respectively when the hardware is powered up;

1. Processor Clock Frequency

The CPU Clock Frequency can be selected in the most appropriate range for the MCU used. In this application, 16 MHz has been chosen.

2. Flash memory

Flash Memory is used to store required parameters and read raw values.

The MCU reads and sets the required operating parameters from Flash Memory at startup. Raw values are changed only by the ADC. All other units and functions access stored values read-only.

3. Communication

There are many standards for communication to the sensor. The three most widely used in the thesis protocol is preferred. These are RS-485 and SDI-12 as digital protocols, 4-20 mA as a analog protocol. The selected protocols can generally be used with any system. Rarely, a converter or additional hardware may be required. MCU basically uses UART protocol for digital communication. UART output has been converted to RS-485 and SDI-12 protocol with additional hardware. From now on, only UART name will be used for digital communication in firmware description.

4. DAC

The voltage to be applied to the EC unit is set with high precision amplifier. The DAC unit is connected to the + IN input of the amplifier and is used to adjust the voltage to be applied to the EC cell.

5. ADC

The MCU provides 2 24 Bit 12 Single (6 Differential) input ADCs. The first of these ADC units is used to read the EC and Pressure values and the second to read the Temperature values.

2.6.2. Algorithm

1. Set Clock Frequency
2. Prepare the message infrastructure
3.Set and Run Hardware Units
3.1. Set Flash Memory Volume
3.2. Read parameters from flash Memory
3.3. Set UART settings
3.4. Set up and run UART Interrupt settings
3.5. Configure DAC settings
3.6. Set it to the voltage setting specified in the parameters and run

3.7. Configure ADC0 and ADC1 settings

3.8. Configure SingleShot timer for ADC0 and setup for 50ms

3.9. Configure SingleShot timer for ADC1 and setup for 50ms

4. Create an infinite loop and check the message queue every loop. If there is a message in the queue, it comments the next message.

2.6.3. Operation of Units and System

A Message package is defined as follows;

```
struct app {
    int (*fun)(int argc, char *argv[]);
    int argc = 0;
    char **argv;
};
```

A package contains the following values in order;

1. A pointer to the function to be called by the package.
2. The number of parameters the function will take
3.A pointer to char ** type that holds the parameters that the function will take.

The functions that packages will run are defined in a general way similar to a C / C ++ main function in order to be suitable for every request. In this way, commands that will meet every need can be written and new commands can be added later if necessary. A function prototype is as follows;

```
int function_name(int argc, char **argv)
```

Each function has at least one parameter. This parameter is the name of the function itself. When needed, the desired function and parameters to be sent to the function are assigned to a message packet and added to the message queue. The infinite loop in the main function processes a packet every time it rotates. Thus, all consecutive command requests are processed sequentially. Message generation is usually done only by the UART unit. If different communication or similar units are added to the sensor, these new units can also be integrated into the message structure. A sample message package is created as follows;

```
app msg;

msg.fun = cmd_poll;
```

```
msg.argc = 1;
msg.argv = new char*[1];
msg.argv[0] = new char[9];
strcpy(msg.argv[0], "cmd_poll");

post_message(msg);    // post_message function adds the message to the queue.
```

2.6.4. ADC units

ADC units read SingleShot which means it will read once and stop unless a new reading order is received. Two timers are set up for ADC0 and ADC1. The timeout is set to 50ms for each timer. 50ms is considered long enough for the sensor to detect ambient changes, but also short enough for reading accuracy.

The ADC values read are kept in a structure named adc_file defined as follows.

```
struct adc_file {
    float p_curt;
    float p_volt;
    float n_curt;
    float n_volt;
    int pressure_raw;
    float temp;
};
```

When the timer set for ADC0 is timeout, it calls ADC0 read function. ADC0 reads the positive current value of EC unit at the first reading. Writes the read value to the adc_file structure where ADC read values are kept. Then it sets the timer again for 50ms. The next reading is the Positive Voltage value of the EC unit. After saving the value, it sets the timer again. EC Negative Current, EC Negative Voltage and Pressure Sensor raw values are read respectively and finally returns to the beginning. When the time set for ADC1 is timeout, PT100 reads the raw value and converts it to the real temperature value and saves the calculated value in the adc_file structure.

2.6.5. UART units

The UART unit runs Event Dirven. When data is written to the UART RX line, the interrupt function is triggered and a byte of data from the UART RX line is written to the buffer. If the written data is a line break (0x0a), then the data read from the beginning of the buffer is sent to the command interpreter function and the buffer is cleared. The command interpreter function breaks the data transmitted to it with a space (0x20) character. The first segment is considered to be the RS-485 address. The following parts are considered to be the command name and the parameters belonging to the command, respectively.

The command interpreter only checks if the command name is valid. It does not control the number and content of parameters. Parameter control is the task of the respective function. An example RS-485 command is as follows;

```
1 poll\r
```

3. RESULTS AND DISCUSSIONS

This section includes tests and comparative test results of pressure and temperature sensors whose datasheets have been examined. The compatibility and sensitivity of the appropriate sensors with the PCB and software that have been considered for integration are examined in this section. The results that effect the selection of the appropriate sensors for use in the prototype have been reached. The design and test results of the EC-09 cell, which is the last step of the EC cell design, are also given in this section.

In addition, the prototype sensor, the subject of this thesis, which has been fully completed and placed in its outer shell, has been placed in the trial pool. The sensor was connected to a data logger and the measured values were recorded and analyzed.

3.1. Pressure sensor tests

In this section, two pressure sensors with determined measurement methods for pressure measurement were supplied and connected to the Druck brand DPI-610 pressure calibrator. Figure 3.1. shows the pressure test setup. Different pressures were applied and the results were compared.

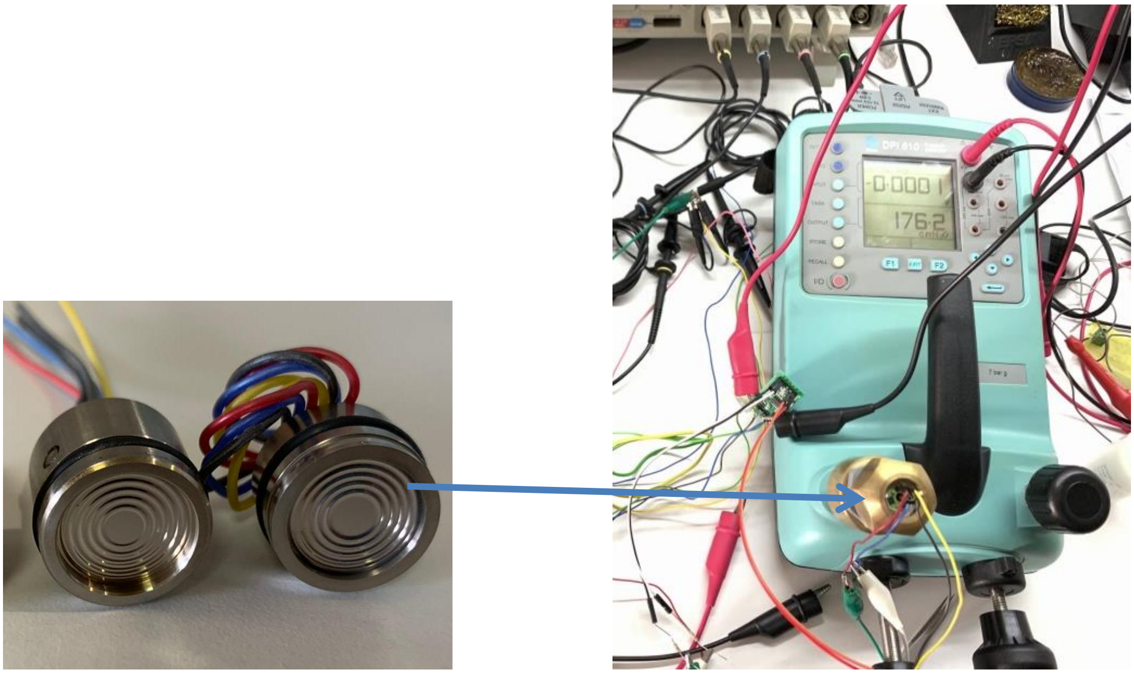


Figure 3.1. DPI 610 pressure calibrator and testing of purchased pressure sensors.

Table 3.1. Observed values as a result of different pressures applied to PS-01 and PS-02.

PS-01 (HUA TIAN CYX19) / Applied P.	**0**	**50**	**100**	**200**	**400**	**800**	**1000**
test-1	0	49.5	99.3	199.2	399	799.8	1000.1
test-2	0	48.7	99.1	199.8	397.8	799.8	999.8
test-3	0	49.9	98.8	198.7	397	800.2	999.2
test-4	0	47.9	99.8	198.7	398.8	800.42	998
test-5	0	48.8	99.7	200.2	400.2	797.5	999.54
test-6	0	50.1	98.2	200.4	400.85	798.6	1000.2
PS-01 AVG	**0**	**49.15**	**99.15**	**199.5**	**398.94**	**799.38**	**999.47**
PS-02 (KELLER SERIES 10L) / Applied P.	**0**	**50**	**100**	**200**	**400**	**800**	**1000**
test-1	0	49.9	101	199.5	398.2	799.12	995.4
test-2	0	49.2	100.8	199.54	397.5	797.54	997.5
test-3	0	49.2	100.1	198.78	399.6	797.25	997.56
test-4	0	48.65	98.8	200.1	397.85	796.8	996.9
test-5	0	48.56	99.75	200.15	399.21	796.52	998.8
test-6	0	50.4	98.32	200.1	397.45	796.89	997.12
PS-02 AVG	**0**	**49.31**	**99.79**	**199.7**	**398.3**	**797.35**	**997.21**

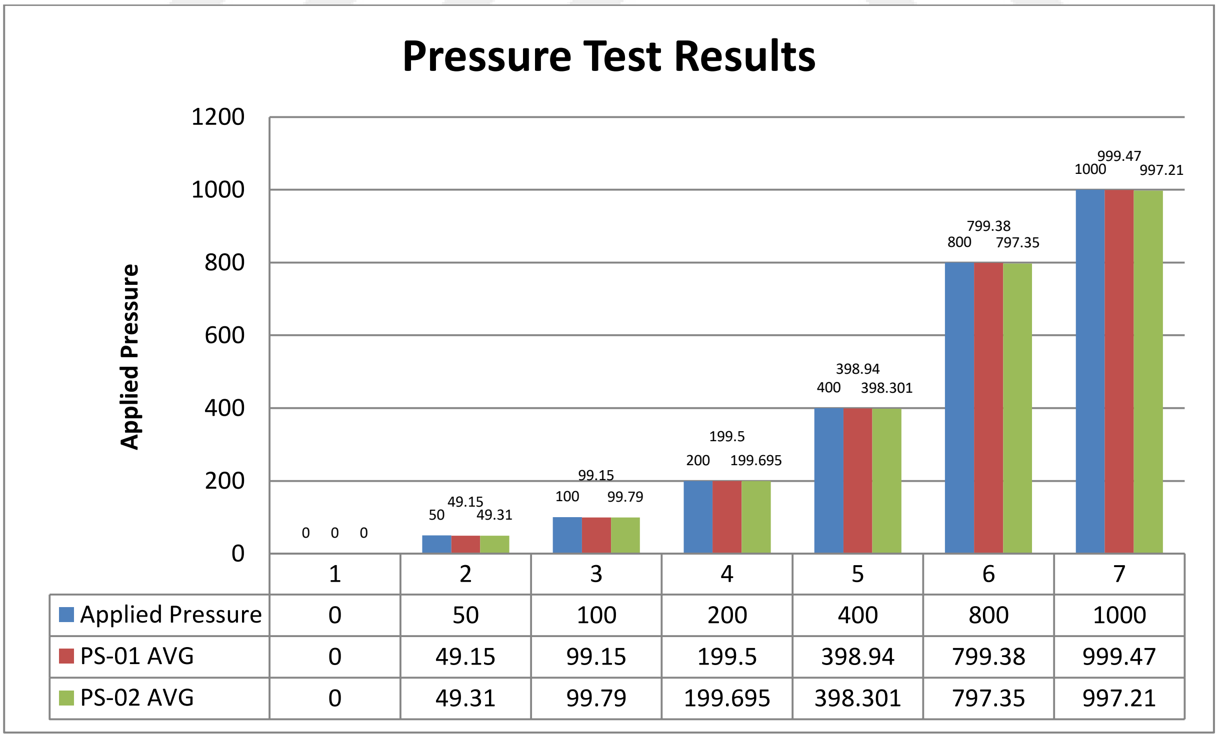


Figure 3.2. Comparison of the observed values as a result of different pressures applied to PS-01 and PS-02.

Table 3.1. shows the pressure sensors were tested six times in total at the same pressure values. Then the average values corresponding to each pressure value were recorded. Figure 3.2. shows these average values are plotted and compared. When the values of the pressure sensors of PS-02 (Keller series 10L) and PS-01(Hua Tian CYX19) have been examined, it is concluded that the PS-01 sensor gave better results at high pressures, while the PS-02 gave better results at low pressures. The PS-01 sensor has lower power consumption and is smaller in size, making the PS-01 sensor stand out. The response time of the PS-02 is faster than the PS-01. As a result of these observations, it was decided that the two sensors were suitable for prototype manufacturing in terms of performance.

Considering the price and procurement processes, it is more appropriate to choose the PS-01 sensor of the Hua Tian company, considering the mass production of this thesis subject prototype in the future. Offers received from companies, it was seen that the price of the Keller company was approximately six times the price of the Hua Tian company. Considering the sensor sensitivity and price difference, the PS-01 sensor of Hua Tian company was determined as the sensor to be used in prototype.

3.2. Temperature sensor tests

NTC and RTD sensors, which are suitable for price performance ratio that can be used in accordance with the prototype, have been tested on the development board. The products which are shown in Figure 3.3. used in this trial are waterproof 2 wire NTC, 3 wire PT-100 and PT-1000 from RTD group.

In the experiments, Hira Laboratory brand HR-C021T / SP model -40 °C to +80 °C heat cabinet was used and the results were recorded and evaluated comparatively.

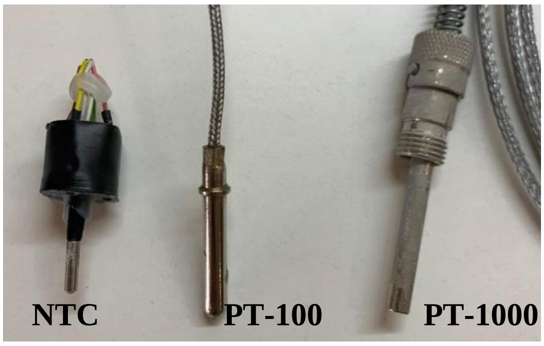
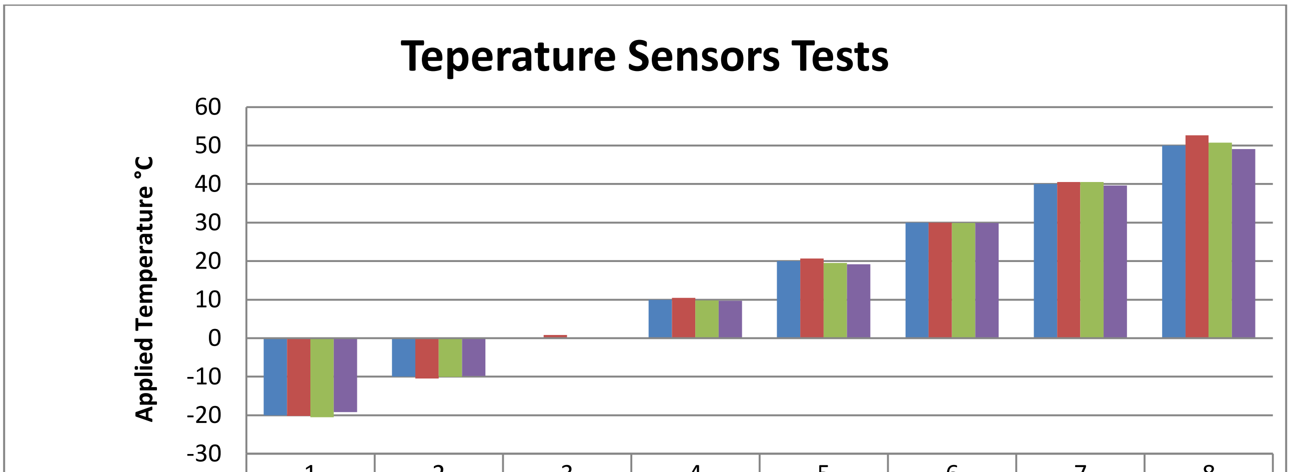


Figure 3.3. NTC, PT-100, PT-1000 temperature sensors.

Figure 3.4. shows the result obtained is that all sensors are suitable for use, considering the error rates. It is predicted that each sensor will work properly with the necessary firmware revisions. It was decided to use the PT-100 sensor, which was considered appropriate in design, size, and price, in the prototype to be produced.



	1	2	3	4	5	6	7	8
HIRA	-20	-10	0	10	20	30	40	50
TS-01 (PT-1000)	-20.2	-10.5	0.8	10.45	20.69	30.02	40.57	52.7
TS-02 (PT-100)	-20.5	-10.08	0.1	9.78	19.5	29.86	40.52	50.78
TS-03 (NTC)	-19.2	-9.8	-0.2	9.67	19.22	29.87	39.65	49.1

Figure 3.4. Comparison of data read from temperature sensors.

3.3. EC cell tests

In order to improve the measurement values of the EC-08 cell, the cell outer shell design and EC electrodes dimension details were given and produced by a professional manufacturer. According to these shared details EC-09 cell and EC electrodes has been manufactured with computer numerical control (CNC). Figure 3.5. shows assembled of the outer shell and EC electrodes. EC electrodes and outer shell have been combined and tested. Figures 3.6. and Figure 3.7 gives test results of EC-09 cell.

Figure 3.5. EC-09 Cell.

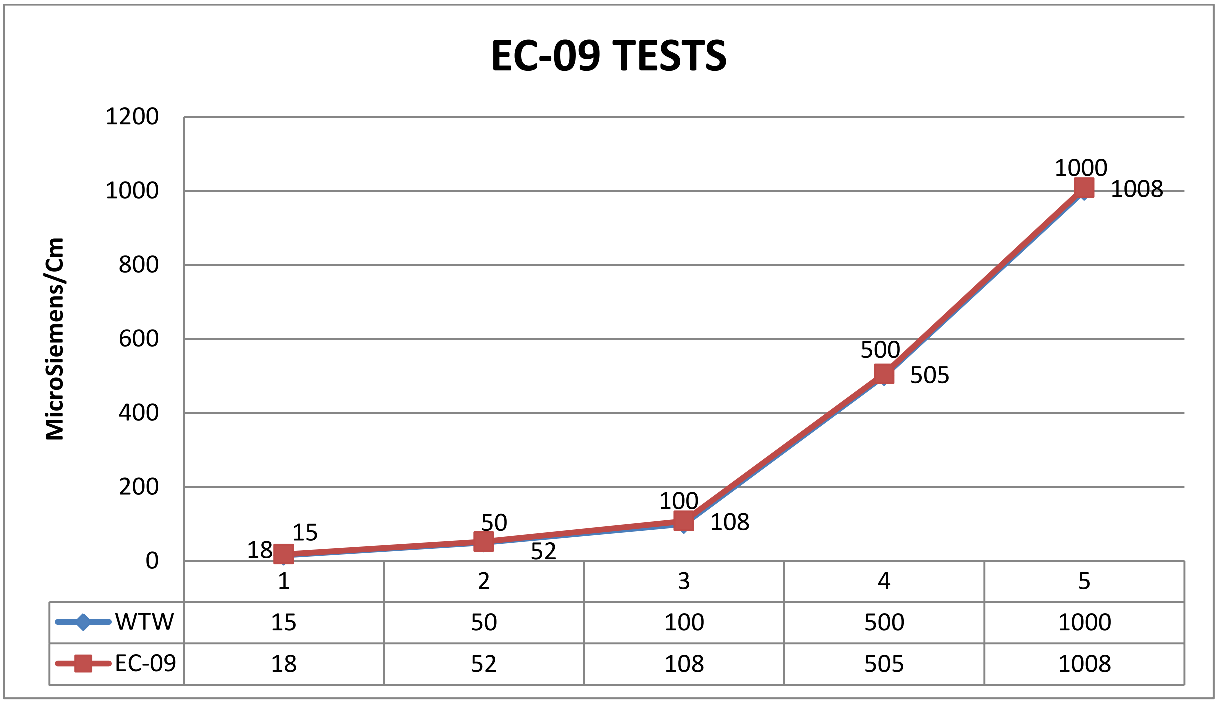


Figure 3.6. Comparison of EC-09 cell with WTW ec measuring device at low S/cm values.

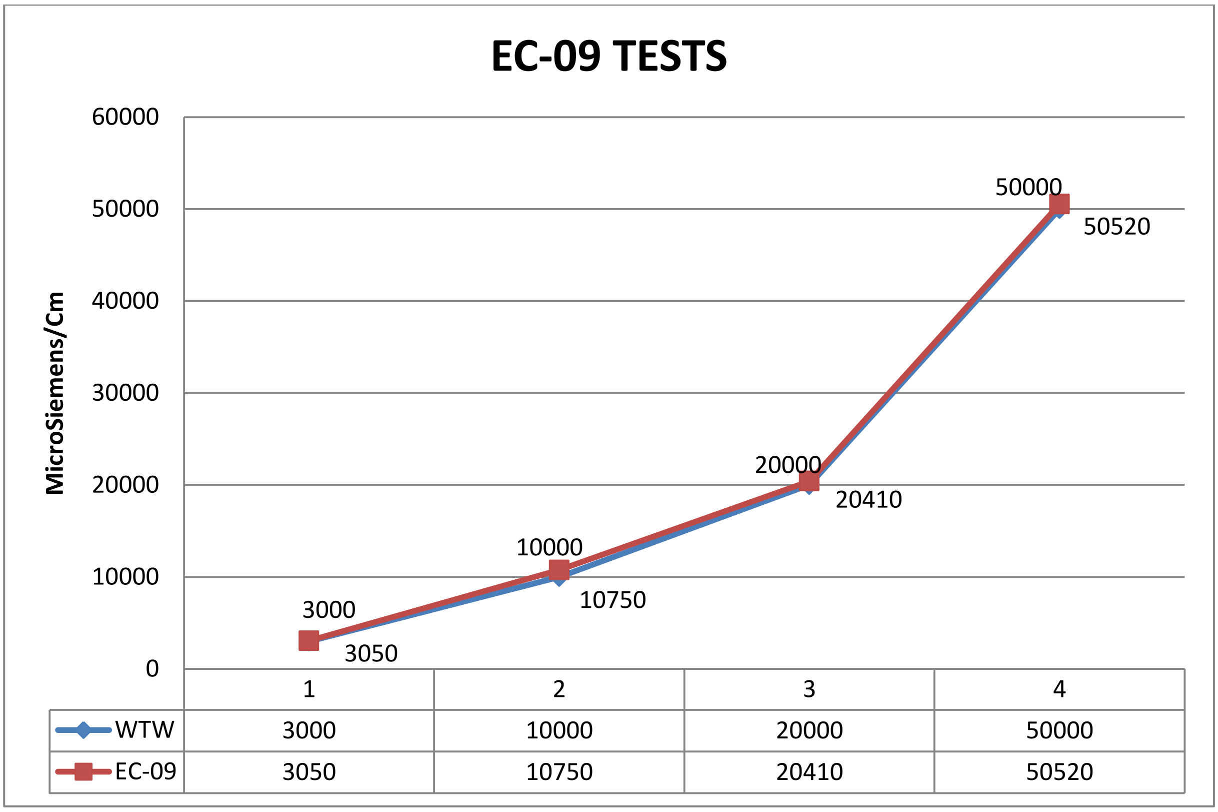


Figure 3.7. Comparison of EC-09 cell with WTW ec measuring device at high S/cm values.

EC-09 cell values have 1.23% error on full scale as shown in figure 3.8. The EC-09 cell continuously measures lower values than the WTW sensor. This error rate is acceptable for the prototype to be realized.

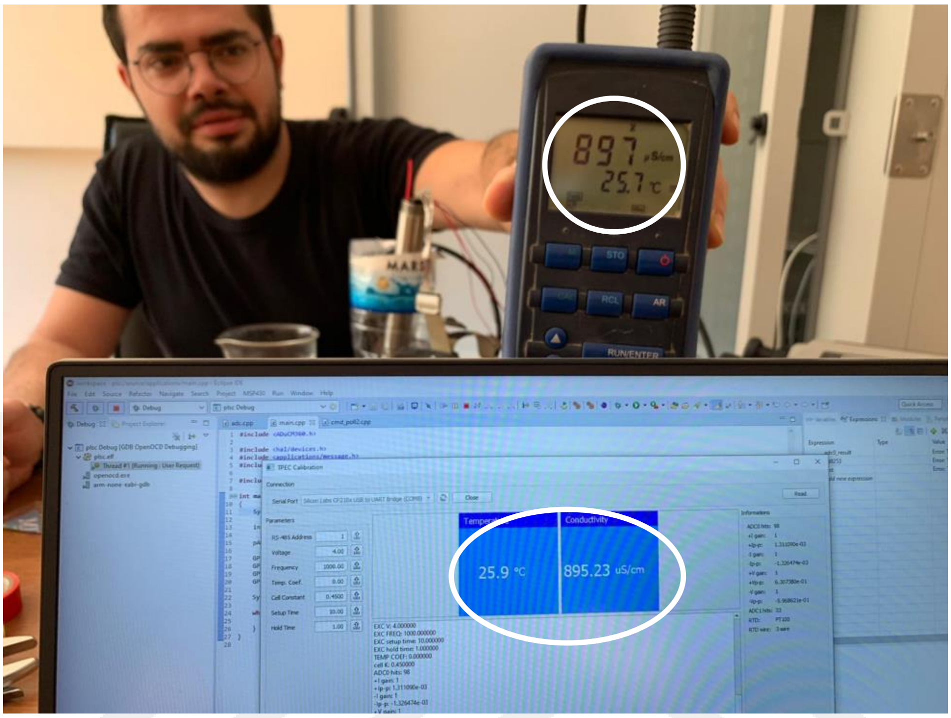
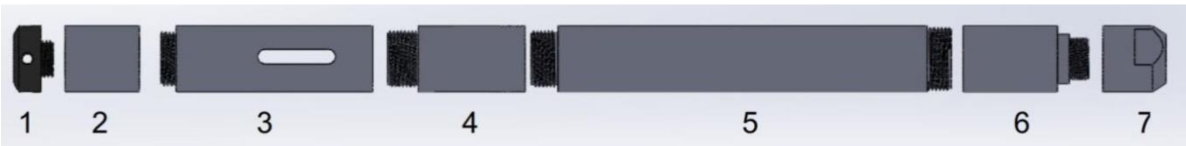


Figure 3.8. Comparison ec measurement of cell EC-09 with the WTW sensor.

3.4. Assembly and testing of prototype sensor

Figure 3.9. shows mounting steps of sensors, PCB and cable to the outer shell. In the three-parameter sensor, which is the subject of this thesis, piezoresistive atmospheric compensated (Gauge) pressure sensor is combined using a three-wire PT-100 temperature sensor and a four-electrode EC cell. The PCB is designed and produced in four layers that can fit into the outer shell. The design and production stages of the EC cell used were carried out in three phases in connection with each other. Since the tests performed in these phases effect the next design, the tests of this process are given in the materials & methods section.



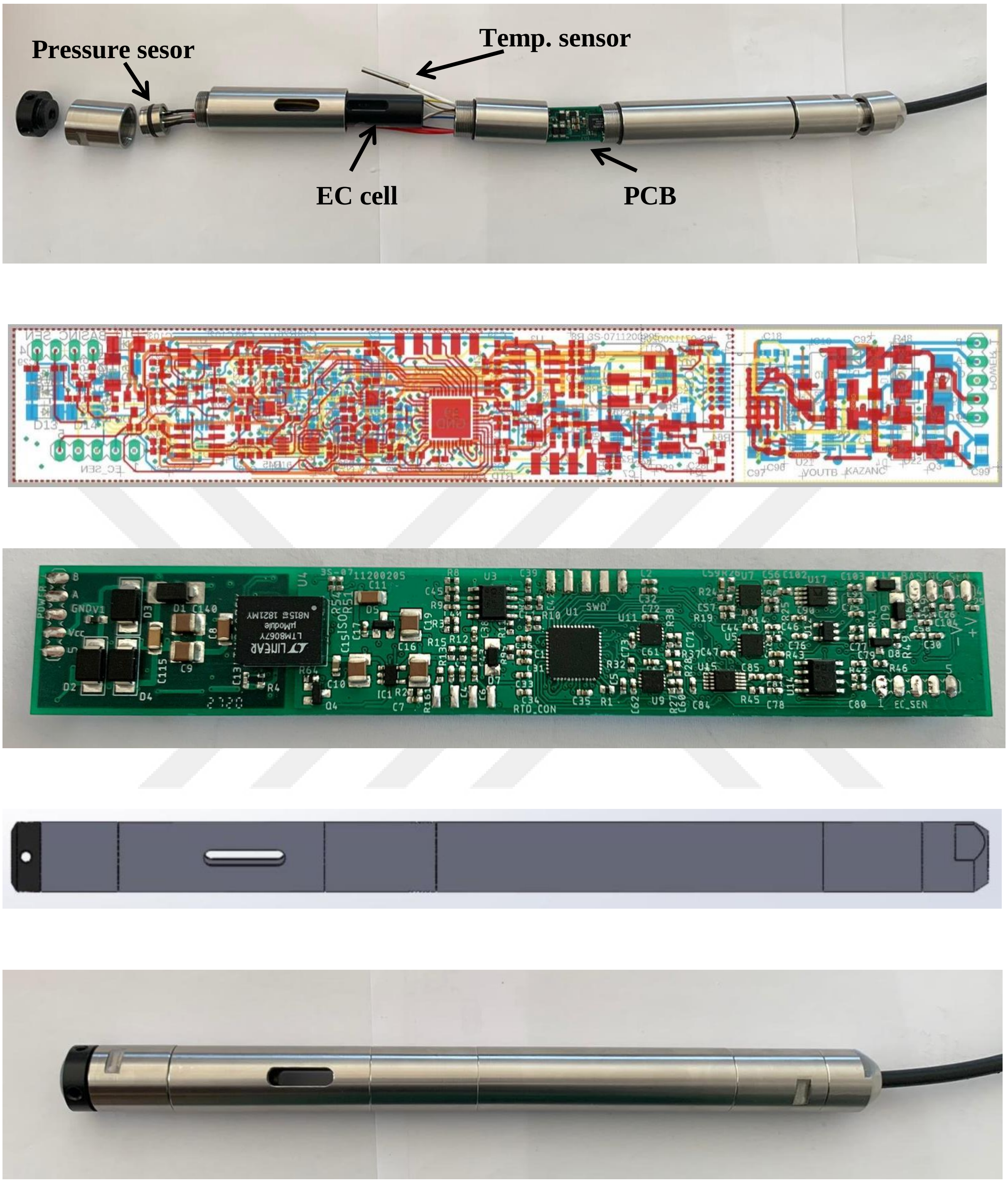


Figure 3.9. Prototype sensor overview.

Figure 3.10. shows the monolithic sensor was connected to a suitable data logger and put into the test pool. The data of the data logger, which was set to collect data at 5-minute intervals, was recorded for 20 days. Table 3.2. gives the daily average measurement values of the recorded data.

Table 3.2. Level, temperature and EC data of the prototyped sensor.

Date	Level	Temp	EC
	cm	°C	mS/cm
2020-11-07	83.1940	18.0727	2.3117
2020-11-08	82.8915	17.6970	2.3174
2020-11-09	82.4906	17.5727	2.3142
2020-11-10	82.0703	17.8037	2.3038
2020-11-11	81.8211	18.0004	2.2938
2020-11-12	81.6348	17.9942	2.2888
2020-11-13	81.4240	17.1444	2.2985
2020-11-14	81.1470	16.3321	2.3059
2020-11-15	80.9013	15.8113	2.3139
2020-11-16	80.7167	15.2839	2.3237
2020-11-17	80.6034	15.0780	2.3298
2020-11-18	80.3967	14.7232	2.3401
2020-11-19	80.5591	15.1929	2.3430
2020-11-20	80.0607	14.7815	2.3533
2020-11-21	79.8898	14.6858	2.3620
2020-11-22	79.6785	14.8434	2.3667
2020-11-23	79.4840	14.0351	2.3818
2020-11-24	79.3199	12.7427	2.4001
2020-11-25	79.1271	12.3902	2.4102
2020-11-26	78.9364	13.2833	2.4090
2020-11-27	78.4194	13.6238	2.4262

As can be observed in the table, the level of the pool decreases day by day in mm level depending on the evaporation. Due to evaporation, the percentage of salt dissolved in water increases and the EC value increases accordingly.

Since the pool is located in an open area and the test was carried out in November, the water temperature decreases day by day depending on the season. Comparing the daily measured water level temperature and EC values with the results in the table, it was decided that the sensor's measured values were satisfactory. For this reason, the sensor was sent to an accredited laboratory approved by Türkak in order to be tested independently. The results of these tests are shared in APPENDIX section.

Figure 3.10. The prototype sensor that was put into the test pool and the data logger it is connected to.

4. CONCLUSIONS AND FUTURE WORK

This thesis work presents the development a three parameter sensor for measuring the level, temperature, and electrical conductivity of the water. Circuits were built to detect these parameters and were tested through simulations as well as experimentally after full implementation on PCB and the outer body. Four electrodes are used to measure the electrical conductivity and a piezoresistive pressure sensor is used for measuring level of the water. Finally The pt-100 sensor was used both to measure the temperature of the water and to compensate for the effect of temperature on EC and pressure measurement.

The maintenance requirement of the sensor whose prototype is completed is very low. EC measurement, which is generally made by taking water sampling, is automated with this sensor. Sampling can be taken at desired time intervals via the data logger to which the sensor will be connected. The sensor with RS-485, SDI-12 and 4 ... 20 mA outputs will be able to work in harmony with different recording devices. When the measurement ranges and sensitivity of the companies that currently sell three-parameter sensors are examined, it is seen that the sensor we have prototyped is more successful.

4.1. Future work

This sensor, which has been designed and prototyped, can be reduced in size. Thus, measurements can be carried out even on very small diameter pipes. If a data logger is built into it, it may not need an external data logger. Wireless data transfer capabilities (Bluetooth, Wi-Fi or GSM / GPRS) can be added to the sensor. Thus, it can be equipped with the ability to record and send data by hiding it in the pipe it was thrown into, without needing any protection structure in the field. If the power consumption can be reduced, it can be made operable with a small solar panel and battery in order to maintain these capabilities. Thus, by adding only an antenna and a small solar panel outside the pipe, a self-sufficient measurement station may be created.

Electrode designs from different materials can be tried to avoid the cleaning and calibration required by EC measurement. In addition, the electrodes can be coated with a suitable material to prevent salt water corrosion and polarization.

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Sayfa 2/2
Page 2 Of 2

Gelecek Kalibrasyon Tarihi : *31.10.2021* **(Müşteri isteği doğrultusunda verilmiştir.)**
Next Calibration Date *(Next calibration date, provided according to customer request.)*

Makine/Cihaz : ***BASINÇ / SICAKLIK / İLETKENLİK SENSÖRÜ***
Instrument/Device
Ölçüm Sahası ***10000 mBar*** *Skala Bölüntüsü* ***0,01 mBar***
Measurement Range *Scale Division* ***0,1 °C***

Bulunduğu Yer : -
Place

Cihazın laboratuvara kabul tarihi : *31.10.2020*
Date of receipt of Device

Prosedür : *Test cihazı,EUROMET cg-17,Euramet CG-11,Euramet CG-08 Standartları, MEK-SİT-003,MEK-SİT-027 ve SIC-SİT-003 talimatlarına uygun olarak referanslar kullanılarak karşılaştırma metodu ile kalibrasyonu yapılmıştır.*
Procedures

Ölçüm Şartları : *Ölçüm sonuçları şartlandırılmış bir ortamda alınmıştır.*
Measurement Conditions

Çevre Şartları *Sıcaklık (başlangıç): 27,9 °C Bağıl nem(başlangıç): 44 %RH*
Environmental Conditions *Sıcaklık (bitiş): 28,3 °C Bağıl nem(bitiş): 45 %RH*

Fiziksel/Fonksiyonel Kontrol : *Fiziksel/Fonksiyonel hasar veya eksiklik görülmemiştir.*
Physical/Functional Control

BASINÇ ÖLÇÜMÜ

Tekrarlanabilirlik :
Repeatability

Set Değeri		*Basınç Göstergesi mBar*				*Tekrarlanabilirlik*
mBar		*Test 1*	*Test 2*	*Test 3*	*Ortalama*	
0%	0	0,00	0,00	0,00	0,00	0,00
50%	5000	4999,25	4999,25	4999,25	4999,25	0,00

Ölçüm Sonuçları :
Measurement Results

Set Değeri *Set Value*	*Basınç Göstergesi*			*Sapma*	*Histerisiz*	*(±)Belirsizlik* *Uncertainty*
	M1	*M2*	*Ort Değer (Mb)*	*Error*		
mBar	*Çıkış Up mBar*	*İniş Down mBar*	*Average Value*	*mBar*	*mBar*	*mBar*
0	0,00	0,00	0,000	0,000	0,000	0,10
2500	2500,56	2500,81	2500,685	0,685	0,250	0,49
5000	4999,33	5000,18	4999,755	-0,245	0,850	0,60
7500	7499,41	7500,86	7500,135	0,135	1,450	0,58
10000	9999,10	10001,11	10000,105	0,105	2,010	0,99

Kalibrasyonda kullanılan medium				Kalibrasyonun hangi pozisyonda		
Yağ	Su	Hava	Azot	Yatay	Dikey	Açık
		x		x		

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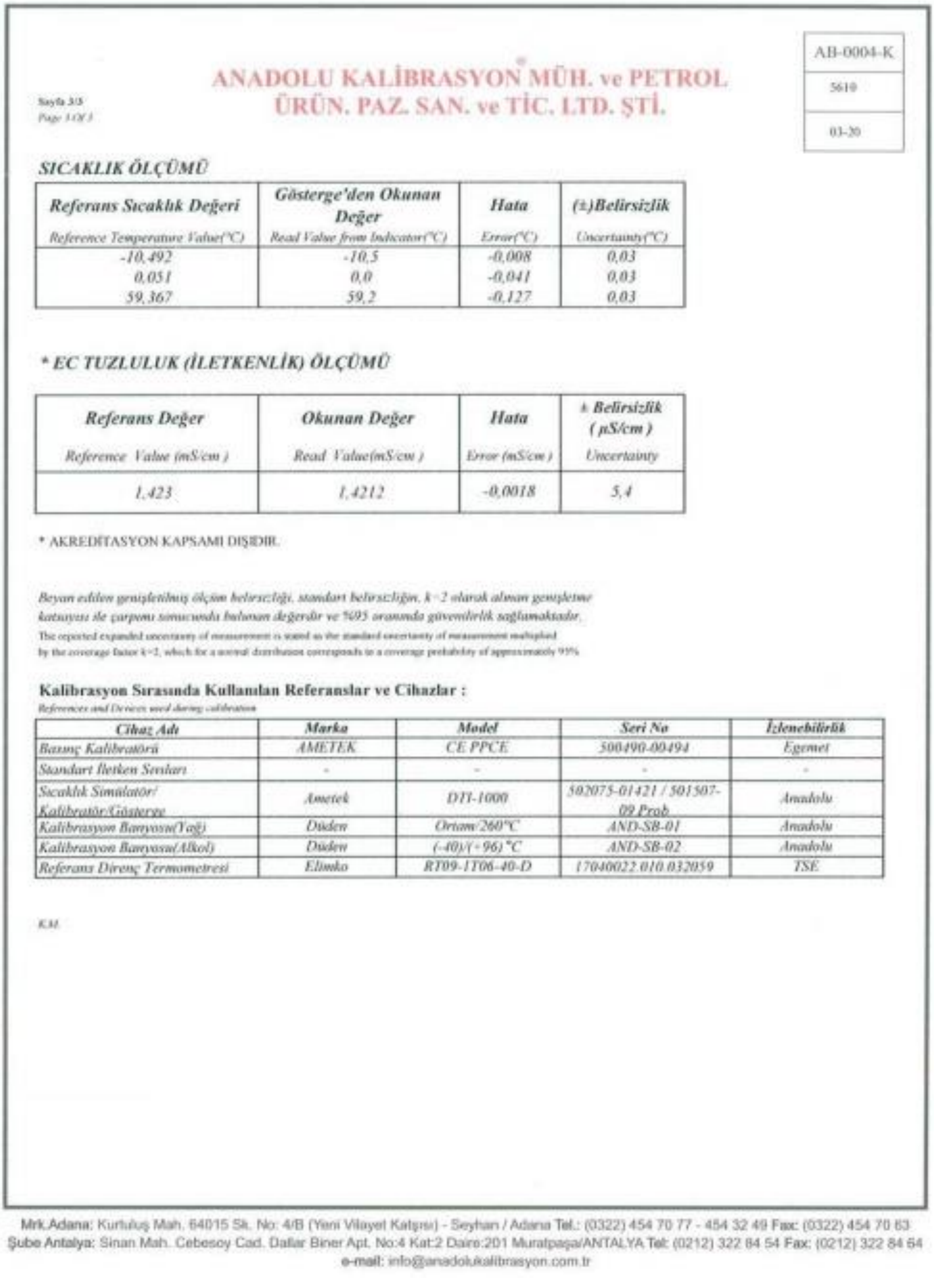
Antalya İrtibat Tel.: (0242) 322 84 54 **Fax**: (0242) 322 84 64 **e-mail**: info@anadolukalibrasyon.com.tr



Sayfa 3/3
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SICAKLIK ÖLÇÜMÜ

Referans Sıcaklık Değeri *Reference Temperature Value(°C)*	***Gösterge'den Okunan Değer*** *Read Value from Indicator(°C)*	***Hata*** *Error(°C)*	***(±)Belirsizlik*** *Uncertainty(°C)*
-10,492	-10,5	-0,008	0,03
0,051	0,0	-0,041	0,03
59,367	59,2	-0,127	0,03

**** EC TUZLULUK (İLETKENLİK) ÖLÇÜMÜ***

Referans Değer *Reference Value (mS/cm)*	***Okunan Değer*** *Read Value(mS/cm)*	***Hata*** *Error (mS/cm)*	***± Belirsizlik (µS/cm)*** *Uncertainty*
1,423	1,4212	-0,0018	5,4

* AKREDİTASYON KAPSAMI DIŞIDIR.

Beyan edilen genişletilmiş ölçüm belirsizliği, standart belirsizliğin, k=2 olarak alınan genişletme katsayısı ile çarpımı sonucunda bulunan değerdir ve %95 oranında güvenilirlik sağlamaktadır.
The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k=2, which for a normal distribution corresponds to a coverage probability of approximately 95%

Kalibrasyon Sırasında Kullanılan Referanslar ve Cihazlar :
References and Devices used during calibration

Cihaz Adı	*Marka*	*Model*	*Seri No*	*İzlenebilirlik*
Basınç Kalibratörü	*AMETEK*	*CE PPCE*	*500490-00494*	*Egemet*
Standart İletken Sıvıları	-	-	-	-
Sıcaklık Simülatör/ Kalibratör/Gösterge	*Ametek*	*DTI-1000*	*502075-01421 / 501507-09 Prob*	*Anadolu*
Kalibrasyon Banyosu(Yağ)	*Düden*	*Ortam/260°C*	*AND-SB-01*	*Anadolu*
Kalibrasyon Banyosu(Alkol)	*Düden*	*(-40)/(+96)°C*	*AND-SB-02*	*Anadolu*
Referans Direnç Termometresi	*Elimko*	*RT09-1T06-40-D*	*17040022.010.032059*	*TSE*

K.M.

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Figure 5.1. Sensor calibration documents taken from an accredited laboratory.

Comparing the test results obtained from the accredited laboratory with the parameters of competitors sensors are shown in table 5.1.

Table 5.1. Comparison of commercially available sensors with prototype sensor.

	Prototype	OTT PLSC (OTT PLS-C)	Keller 36XiWCTD (Series 36XiW-CTD)	Insitu AquaTroll-200 (Aqua TROLL® CTD Data Loggers)
Pressure measurement range	0…35 Bar	0…10 Bar	0…30 Bar	0…7.6 Bar
Pressure Accuracy	0.01%	0.05%	0.05%	0.1…0.3%
Pressure mambrane	SS316L	Ceramic	SS316L	Ceramic
Temp. measurement range	-50…100 C	-25…70 C	-10…80 C	-5…50 C
Temp. Accuracy	+/- 0.05	0.1	+/- 0.3	+/- 0.1
Temp Sensor	Pt-100	NTC	Silicon Based	Fixed
EC measurement Range	0…100 mS	0…100 mS	0…200 mS	0…100 mS
EC Accuracy	%0.1	%0.5	%2.5	%0.5
EC Cell	4 graphite	4 graphite	6 Titanium	Titanium

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