5 Hardware Development

5.1 Introduction

Hardware development includes all the necessary steps to build the testbench. This means designing and building the measurement cell, and connecting it properly to the reading devices. The general schematic of the bench is the following:

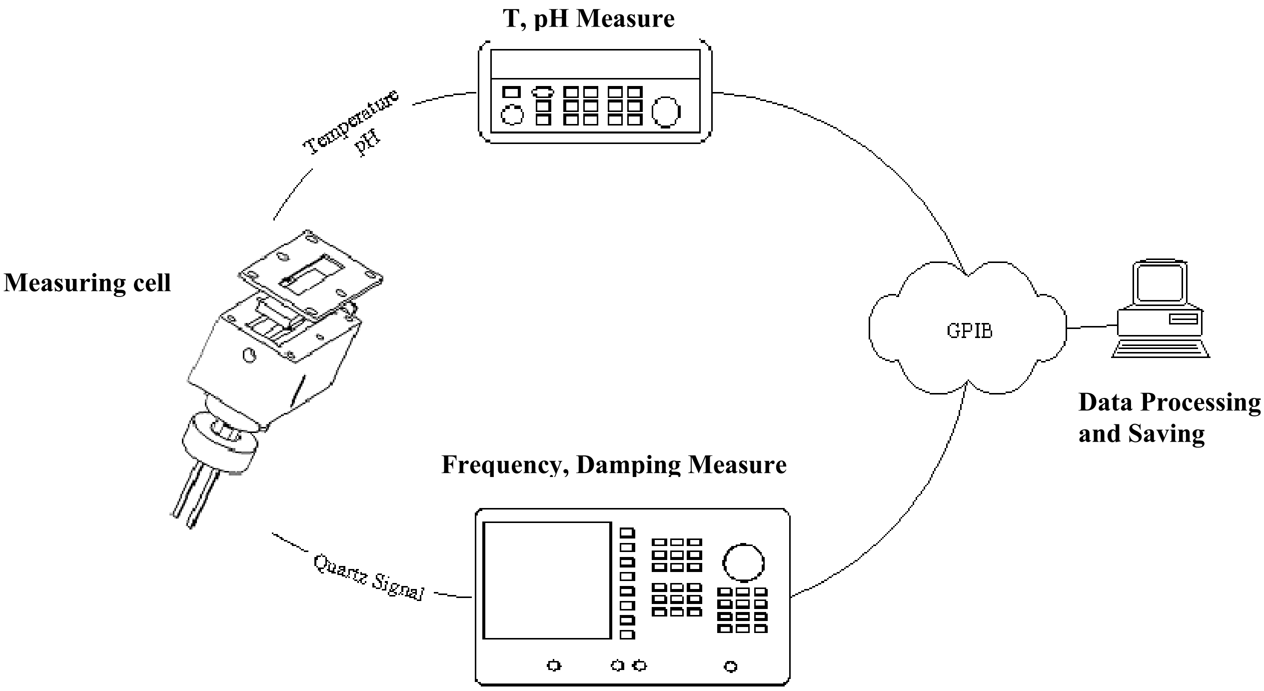


Figure 3: Testbench Hardware Schematic

As we see, the test bench is composed basically by the measurement cell, a datalogger, which will read the sensors added to the measurement cell, and a Network Analyzer that we will use to read the oscillation signal of the quartz. Both devices will be connected to a PC through the GPIB bus. This PC is going to control and supervise all the testbench.

The first step is to design the measurement cell, and this theme will be developed in the first section of this chapter. The next section will explain the physical connection of the cell to the test bench, and the developed hardware necessary to do it.

5.2 Measurement cell Design

5.2.1 Requirements of the Cell

The first step to design the measurement cell is to define the requirements that it had to accomplish (Fig. 4). Once that we define the basic requirements we can design the cell to fit them and maybe to fit more additional non-essential requirements.

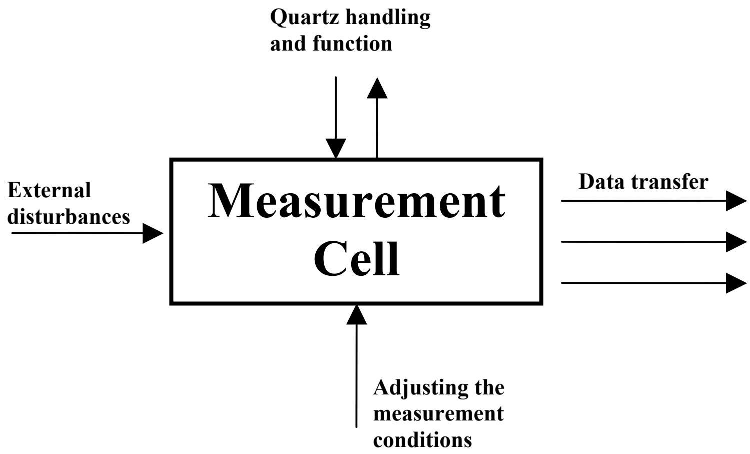


Figure 4: Measurement cell Schema

The first and most important requirement is the placement and correct isolation of the quartz. The aim of this measurement cell is the characterization of a single QCMB (Quartz Crystal Micro Balance), and so, due to its testing character, this quartz has to be easy to place and remove.

The second requirement is the stability. As we want to measure both the frequency and the damping of the quartz oscillation, we need to avoid the possible mechanical noise. Mechanical noise is all the oscillations and vibrations due to the environment. For example, the coolers of the Network Analyzer, or the occasional movement of the operator.

The third requirement is the insertion of a pH sensor. It is the aim of this measurement cell to study the effects of the pH variations on the hydrogel, so a correct pH measurement is essential. Normally pH electrodes need to be deeply immersed in the fluid to characterize it, so it has to be contemplated during the design process.

As the hydrogel is also sensible to variations on the temperature, this is a very important parameter to measure and control, even when the aim of this testbench is not to study the behavior of the polymer against temperature changes.
Another important requirement is the size of the chamber. As we want to measure properties of a special fluid we need that these properties keep as constant as possible. With liquids we can get

it taking a sample as small as possible, so even when the property that we want to measure - in this case pH and temperature – is not constant in the whole volume, we can consider it so.

The designed measurement cell has to accomplish all this requirements, and so every part of the design will cover the given solution to them.

5.2.2 Measurement cell Basic Structure

One of the basic requirements of the present cell is mechanical stability. The easiest way to get this stability is increasing its damping coefficient via increasing the mass. As a result, the fabrication material is brass, as it was already said, due to its heaviness and its resistance to chemical composites.

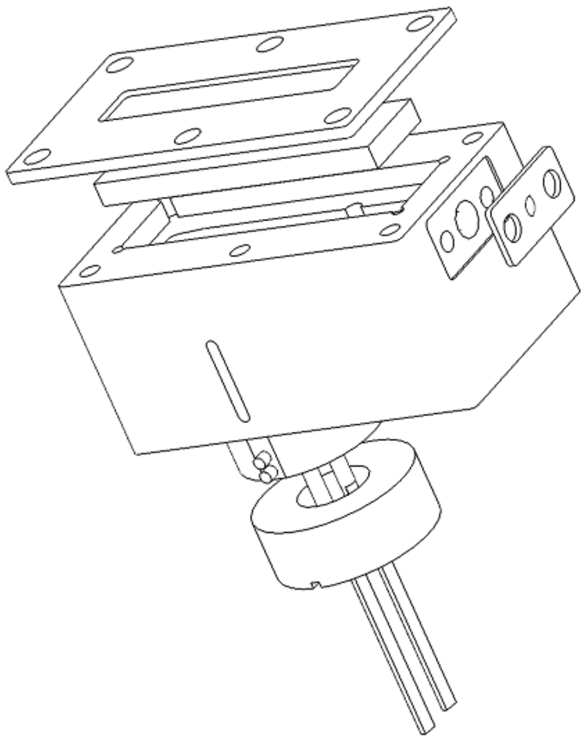


Figure 5: Measurement cell exploded view

The measurement cell, shown in Fig. 5, is designed as a parallelepiped, where the different chambers for measuring, temperature sensor and quartz placement are going to be mechanically punched.

This design facilitates the construction of the measurement cell, which is designed using the software Solidworks® 2001 and produced in the workshop of the Electronics Faculty. In the design, we have to consider this construction process, in order to make a cell that is possible to be implemented. Also, the fact of building it as a punched parallelepiped helps to increment the solid volume, and the mass of the measurement cell.

On one of the biggest sides we find the measurement chamber, placed like a trench, which will be drilled from the top. This trench is covered by a 4-mm-dick glass and sealed using a 2-mm-dick windowed foil. This allows the measurement cell operator to check the correct functioning of the cell. The windowed foil is fixed with six screw and sealed using silicon rubber.

The pH sensor will be inserted through a hole, punched in the upper little side, and will be sealed using a perforated foil. The temperature sensor will be placed inside the measurement chamber nearby the quartz. Both temperature and pH sensors construction and placement will be detailed later.

The liquid flow is supplied through two one-millimeter-dick holes, called IN and OUT. These holes are continued, screwed and enlarged to allow the insertion of the connector. The connector follows the American standard 1 / 4 – 28, and is just a perforated screw slopped by a thin pipe. The pipe gets fixed and isolated when the connector is inserted (Fig. 6).

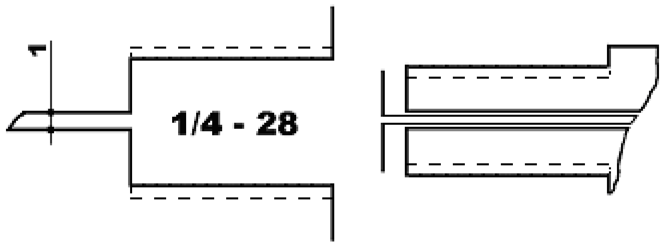


Figure 6: ¼ - 28 Flow connector

A general view of the measurement cell and its principal sections is shown in the next figure.

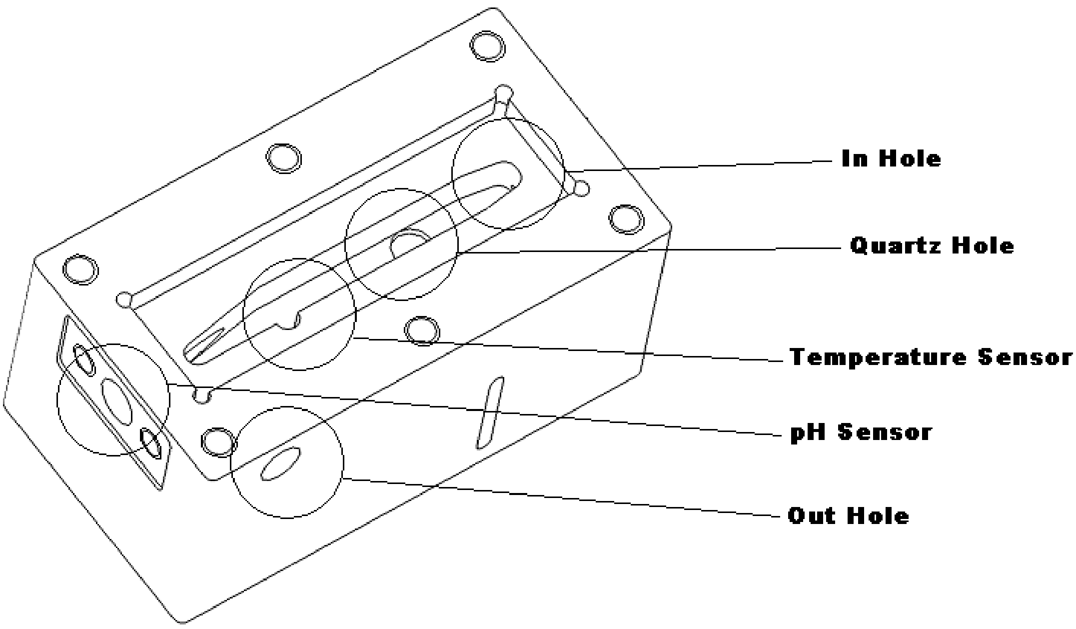


Figure 7: Measurement cell general view

5.2.3 Quartz Holder

The quartz holder (Fig. 8) is the most important part of the measurement cell design. Its function is to hold the quartz in contact to the fluid of the main chamber, and to connect the quartz electrically. Allowing a simple replacement of the quartz is also important.

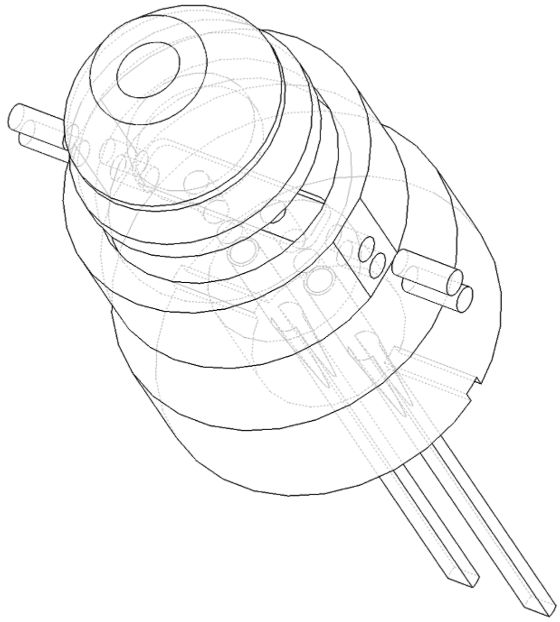


Figure 8: Holder explosion view

Its function presents two main difficulties. First of all, the quartz has to be hold strong enough to keep the isolation of the chamber, but on the other hand, the quartz is only 165 μm thick, what makes it extremely fragile, and easy to break, so this pressure cannot be too high.

The other difficulty is to contact the two electrodes of the quartz making them easy to be removed. The quartz is not going to be fixed but, as a testing measurement cell, it will be often replaced. The contact has to be constant and has to present the lowest possible damping; so it should minimize the bad noise effects.

Using the results and the basic measurement cell by the group of Dr. A. Bund, IPEC, which solved already these problems, the developed model is based on a two-ring fixing, using vertical pressure.

The complete structure is shown in the figures 8 and 9. The two rings and the quartz are hold by a holder, which supports the two contacts, and the whole complex is going to be fixed and pressed from down by a round screwed piece. The intention of this system is to allow the up-down movement of the quartz when it has to be inserted in its place. To avoid a rotation of the holder when it is pressed by the screw, it is designed with two little pieces or rails that will block any turning movement (Fig. 9).

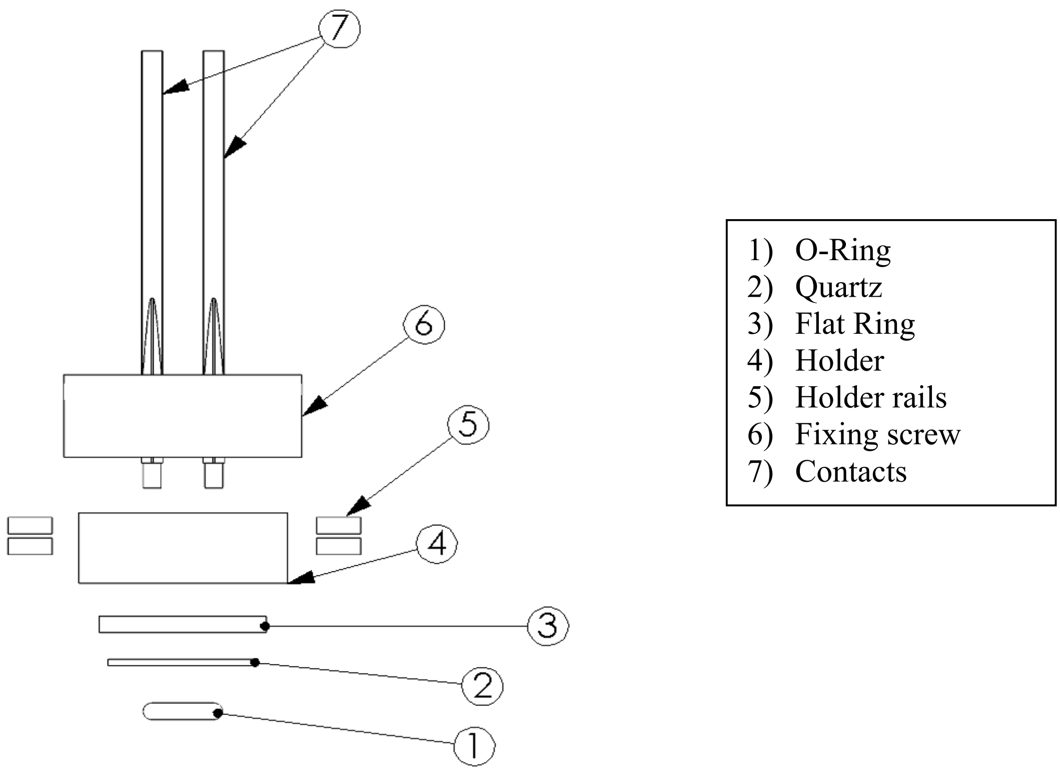


Figure 9: Quartz Holder Detailed view

The first ring is a simple flat ring, 19mm diameter and 3mm thick (Fig. 10). The quartz lay on this isolator, to present a smooth but solid surface. It is made from silicon, produced in the faculty's workshop. It presents a 6-mm-thick hole in the centre to allow the oscillations of the quartz.

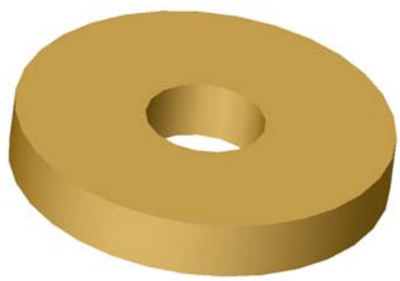


Figure 10: Flat Isolator

Remember that, due to the construction of the quartz's contacts, only the centre region covered by the gold contacts oscillates. These oscillations will cover a 5mm circle in the centre of the quartz. Therefore, both sides of this zone have to be free of direct contact to any surface.

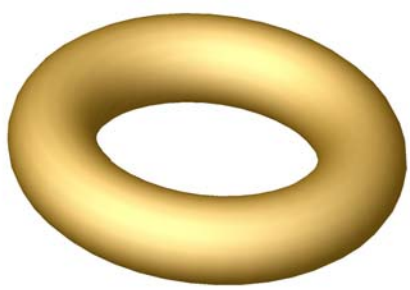


Figure 11: Ring Kalrez® Isolator

The top ring (Fig. 11) is an O-Ring made from Kalrez®, produced by DupontPow Elastomers. Kalrez® 4079 is a carbon black filled compound, which has excellent chemical resistance to acids and alkalis and also excellent mechanical properties [11]. It also exhibits low swell in organic and inorganic acids and aldehydes and has good response to temperature cycling effects. Of course, this is necessary, as this ring is going to be in permanent contact to the chamber fluid. Another kind of material could be seriously affected by the acids and alkalis used during the operation of the measurement cell. The dimensions of this ring are given by the provider; the ring that better suits the size requirements has a 7.2mm inner diameter and 2mm cross section diameter.

Trapped between both isolators, the quartz is fixed enough, while the 5mm centre can perfectly oscillate (Fig. 12). The section of the chamber has to be calculated in order to control the pressure that the quartz stands.

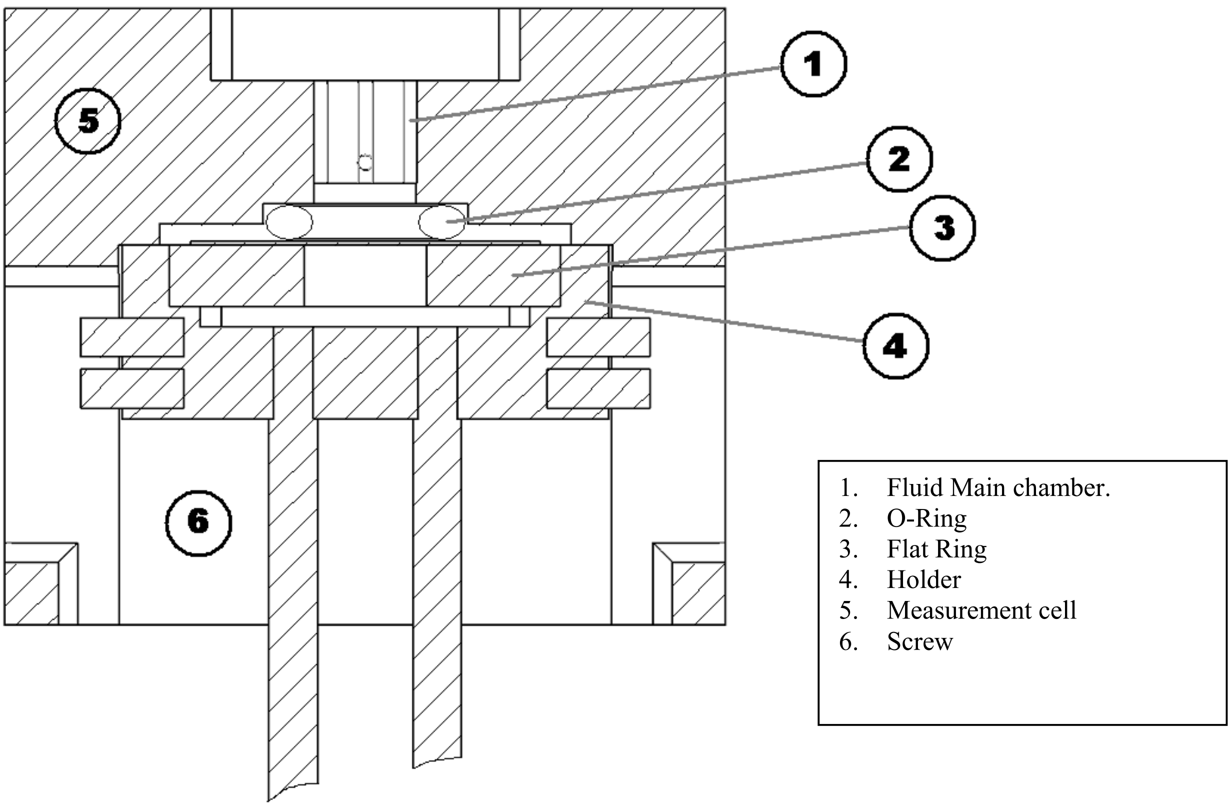


Figure 12: Quartz Holder Cut view

In principle, we calculate a compression of the Kalrez® ring between 5% and 10% when the system is mounted and closed. As this ring is 2 mm thick, this will mean that the place for it should be 1,9mm. The quartz itself is 165 µm thick, so the chamber for the ring is going to be 2 mm high. This will mean that, including the quartz side, the compression of the ring will be 8.25%, which is a good compromise. To avoid any longitudinal pressure the placement hole for the O-Ring will present a 10 m diameter; a bigger hole allows the ring to expand freely.

Another problem to solve is the contacting of the quartz. As it was explained, the quartz has two gold contacts, one on each side. The side that is not going to touch the fluid has also a prolongation of the contact from the other side, so both electrodes are accessible from the down side.

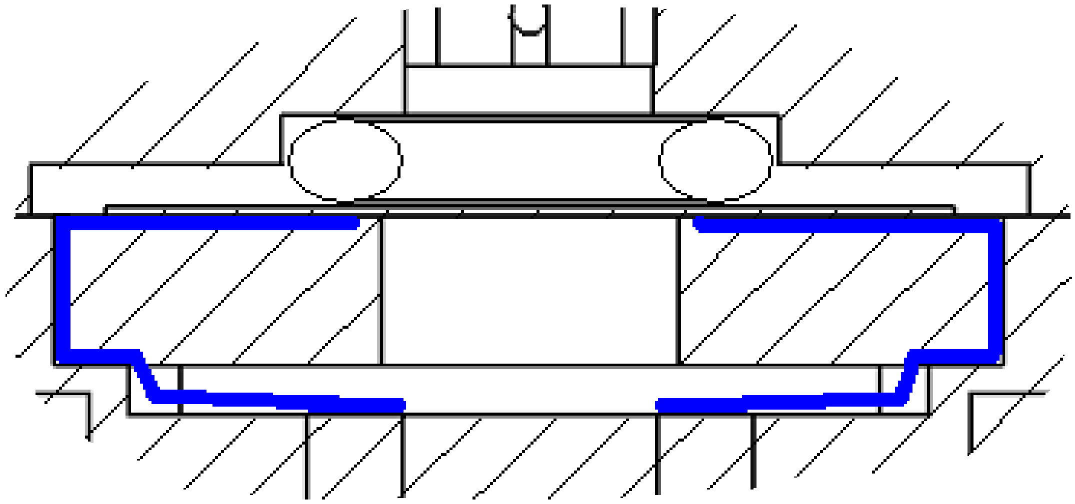


Figure 13: Quartz Holder Contacts Cut view

The contacts are made from brass, as this is a very good conductor, and they are fixed to the holder. Due to this, the holder cannot be made from brass too, but it will be made from Teflon. This allows a good press-passing fixation of the contacts and the rails, adding a good insulation. From the head of the contacts to the surface of the flat isolator, a metal prolongation is necessary. This will be made by using two thin copper foils, attached to the contacts that will pass under the flat isolator and reach the quartz contacts. In the figure, the thick lines represent the copper foils. The problem of the copper is that it oxidizes easily, and it's also doesn't make the best contact (the quartz of course is not soldered). The copper will be substituted by platinum in a further developement.

5.2.4 pH Measurement

As we need to measure the dependencies of the hydrogel towards changes on the acidity of the fluid, measurement of pH is necessary. And as it is already cleared, it should be measured, if it is possible, inside the chamber. Actually, it will be also possible to measure it outside the chamber, both before or after the fluid pass through the chamber. Anyway this will introduce inevitable delie in pH measurements, and several errors that of course we want to avoid.

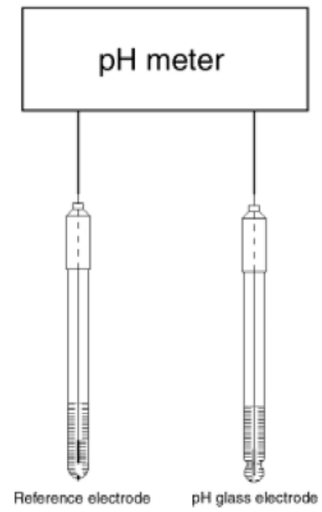


Figure 14: pH Sensor classical Set-up

Whether a substance is acidic or basic all depends on a single ion: H_3O^+, the hydronium ion. Basically, pH simply stands for the negative logarithm of the hydronium ion concentration. Thus a concentration of 10^{-7} mol/l H_3O^+ means a pH value of 7. Basically, the standard pH measurement is a matter of potentiometry, voltage measurement. A laboratory set should be composed by a pH electrode, a pH reference and a pH meter (Fig. 14). The pH electrode's potential changes with the H_3O^+ ion concentration in the solution. The pH meter measures the potential between a H electrode (sensitive to the hydronium ions) and a eference electrode (which gives a constant potential no matter what the concentration of our hydronium ion is). Later, through the Nernst equation (adapted to the used equipment) the measured voltage can be easily related to the pH, as it is a linear relation. Although normally is possible measuring pH using the "classical" set-up, it was soon realized that the two electrodes could be built into the same probe (even though they are still two totally separate electrodes). This is nowadays called the combined pH electrode, which is much more practical. A practical vision of the pH measuring can be found in [12].

pH Sensor

Due to the desired reduced volume of the measurement chamber, we choose a thin combined pH electrode, from Metrohm®, the 6.0224.100, a single-rod electrode whose immersed part is extremely narrow, having a diameter of 3 mm. This electrode is optimally suitable for pH measurements in very small sample volumes; the small diameter of the pH glass membrane (3 mm) allows measurements in sample volumes as low as 60 µL with the high accuracy and speed as using a standard-sized electrode. This combined micro pH electrode (Fig. 15) can be used in vessels with a diameter of only 4 mm.

Figure 15: Metrohm pH sensor

Besides its little size, its technical specifications suit the requirements of this measurement cell [13]:

Table 1: pH Electrode Specifications

pH Range	0 – 11
Temperature Range	0° – 60°
Minimum Immersion Depth	7 mm

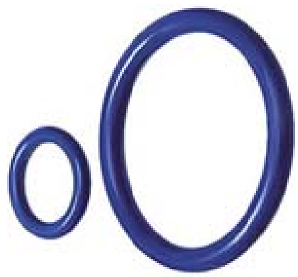
Te behavior of the hydrogel in acid or basic solutions is almost zero. The range interesting goes between approximately 1.5 to 9 pH, which is included in the range on this pH sensor. The temperature range is also wide enough, as it will work around 25°C.

To make a compromise between size of the main chamber and precision derived from the good functioning of the pH sensor, the mess chamber diameter has a 5mm diameter, and at least 2 cm long, to allow the pH electrode to be deeper inserted.

pH Sensor Sealing

The hole to insert the pH sensor has to be correctly isolated. To ensure the isolation of the pH sensor it is used an o-ring (Fig. 16) and the pH sensor will be sealed and fixed by radial pressure.

The dimensions of the ring and the chamber are calculated following the DIN 33771 norm, chapter 5, which is about O-Rings and their dimensions [14].



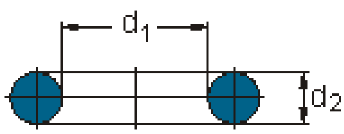


Figure 16: O-Ring. Dimensions Description

The starting point is the dimension of the pH channel, which is 3 mm thick, and we follow the rule to find the necessary ring.

These are the specifications to accomplish:

Table 2: O-Ring Chamber Recommended Dimensions. Norm. DIN 33771 Ch. 5

d2 (W)	1.8 mm	Section diameter of the ring
d1	2.5 mm	Inner diameter of the ring
d10 (G)	3 mm (tolerance DIN H8)	Inner diameter of the hole
d5	3 mm (tolerance DIN f7)	Outer diameter of the sensor
d6	5.9 mm (tolerance DIN H9)	Outer chamber diameter
R	0.2 mm	Diameter of the squares
b1 (F)	2.4 mm	Side length of the chamber

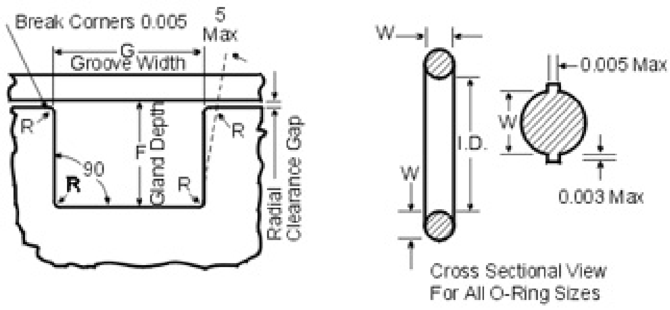


Figure 17: O-Ring Chamber Design. Norm. DIN 33771 Ch. 5

As it is used a crystal sensor, which is pretty delicate and can easily break, and the pressure in the chamber is not going to be high, it is selected a bigger ring. Among the different rings to order, these suits better the requirements:

Table 3: O-Ring Recommended size

A	d1 = 2.8	d2 = 1.6
B	d1 = 2.57	d2 = 1.78

The value of d6 is recalculated, following the Eq. (3), as the used ring dimensions doesn’t appears on the table (2).

$$d_{6\min} = \left(d_{1\max} + 2 \cdot d_{2\max}\right)\left(1 - \frac{K}{100}\right) \qquad \textbf{(3)}$$

Where Kmax is 13%

Table 4: O-Ring Dimensions

DIN (2.5/1.8)	d6 min = 5.22 mm
A	d6 min = 5,33 mm
B	d6 min =5.37 mm

The Norm values are so acceptable, and the dimension is 5.9 mm diameter.

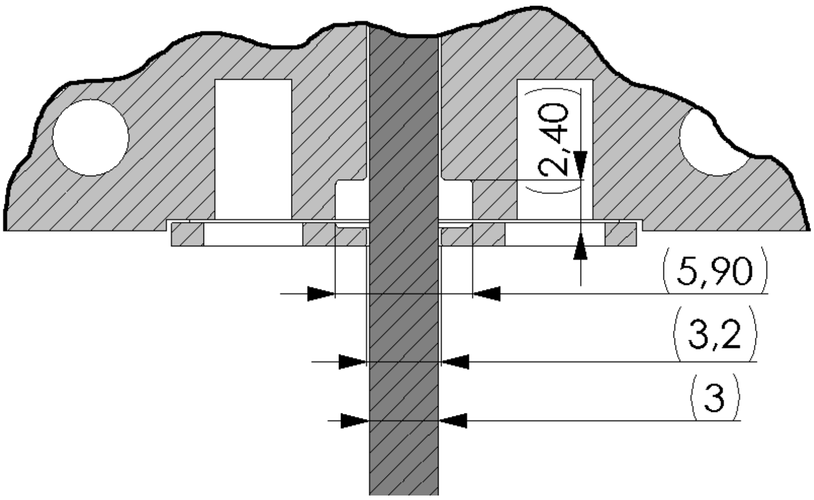
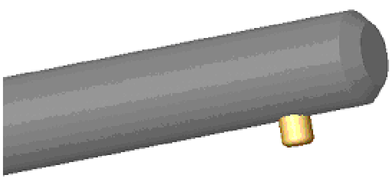


Figure 18: pH Insertion Cut View



Unfortunately, the pH sensor has a little notch (Fig. 19) at the side-end, corresponding to the electrode termination. This made impossible to use a 3,2mm hole, as was designed, so it was enlarged to 4mm. Due to the same reason, it was definitely better to use the first bigger gasket.

Figure 19: pH Sensor Notch

5.2.5 Temperature Measurement

As the hydrogel is also very sensible to variations of the temperature, this is a very important parameter to measure and control, even when the aim of this testbench is not to study the behavior of the polymer against temperature changes. Anyway, the movement, the use of the equipment, and many other external perturbances can vary the temperature some degrees, which can strongly influence the interpretation of the results if they are not contemplated.

The chamber is made from brass, which is a good temperature conductor. Due to this, the liquid temperature is the same as the temperature in the walls of the chamber. But this has also an important disadvantage; it is that the chamber itself is not to be good shielded against environmental changes on the temperature.

There are two possible solutions to this problem. The first one is isolating the complete chamber, and making its temperature constant and stable. This would be possible if it is surrounded by another chamber filled with water whose temperature can be controlled. The second possibility is to control the temperature of the incoming fluid itself. Of course the second possibility simplifies the design of the main chamber, and it is also possible to develop it in a further step, although the first possibility would give better performance. The placement of a isolating chamber, this means the first option, makes the design of the measurement cell more difficult, and it is not indispensable in a number of experiments. It could be added in a further version of the measurement cell, and so it will not be included in the design.

In the majority of industrial and laboratory processes, the measurement point is usually remote from the indicating or controlling instrument. This forces the use of devices to convert temperature into another form of signal, usually electrical and most commonly thermocouples, resistance thermometers and thermistors. Other alternatives indirect techniques for sensing and measuring temperature include optical pyrometry, other non-contact (infra-red), fiber-optic and quartz oscillation systems.

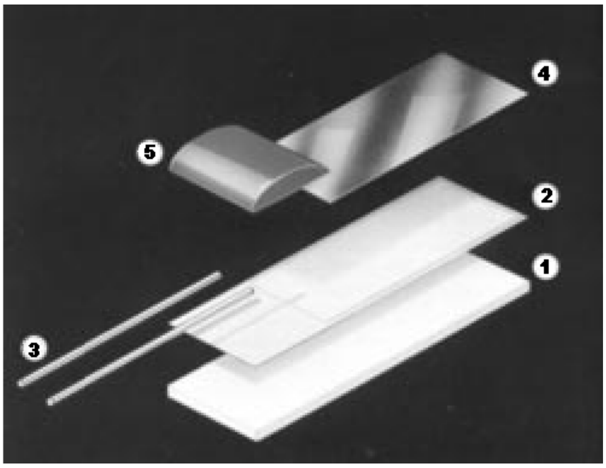
The used datalogger incorporated functions to measure temperatures using thermocouples, thermistors and RTDs (Resistance Temperature Detector). The use of these three forms of measuring requires some form of physical contact with the medium. Such contact can be the immersion or surface contact depending on the sensor construction and the application.

The fundamentals, and also the characteristics of the three possibilities are different. Thermocouples essentially comprise a thermoelement (a junction of two specified dissimilar metals) and an appropriate two wire extension lead. It operates on the basis of the junction located in the process producing a small voltage which increases with temperature. It does so on a reasonably stable and repeatable basis. Resistance Temperature Detectors utilize a precision resistor, whose value increases with temperatures (in the most common case of positive temperature coefficient). Such variations are very stable and precisely repeatable. Thermistors are an alternative group of temperatures sensors which display a large value of temperature coefficient of resistance. They provide high sensitivity over a limited temperature range. In practical terms, the alternative types of assembly utilize similar construction but must be used in different ways depending on the application [15,16].

Due to the characteristics of this application, the possibilities that suit better are both the thermistors and RTDs. This is because both of them present high stability, and this is essential in this application, as the sensor is going to be fixed inside the measurement cell. A RTD will be preferred, due to the linearity, and over all to the fact that the datalogger can read it automatically, not needing complicated configuration. It only presents the problems of high sensitive to shock and vibration, and relative slow response time. The sensitivity to vibrations is not so important as the measurement cell is going to be really fixed (vibrations is even a bigger problem measuring the oscillations of the quartz), and the response time shouldn't affect so much, as the cell is not designed to measure fast changes on temperature. Anyway, the sensor should be as fast as possible.

The best situation is when the temperature is measured directly on the quartz, what means inside the main chamber, and in direct contact to the flowing liquid. This means leading with the problem that, due to the reduced size of the chamber, there is little room to place a temperature sensor there. The sensor has to fit inside the chamber; in this way, the effects of external temperature variations are minimized.

The minimum required accuracy is 0.1 K, approximately, in a range from -10°C to 100°C, also approximately. There are two types of RTDs: wirewound and thin film. Wirewound RTDs consist of wire wound on a bobbin, which is enclosed in glass. For thin-film RTDs, a film is deposited onto a ceramic substrate, and sealed (Fig. 20). To fit all these requirements it is better to use a thin film sensor, which is faster and cheaper than the Wirewound. It is selected a thin Film Platinum sensor, PTFC 101 A (Thought a cheaper PTFC 101 B will be used for testing and probing). These sensors offer high reliability, tight tolerance, excellent long-term stability, accuracy and resistance to vibration and thermal shock.



1=ceramic substrate
2=platinum film
3=lead wire (platinum-coated nickel)
4=glass protection for platinum film
5=glass protection for lead wires

Figure 20: Thin Film Platinum RTD Explosion view

Its characteristics follow the norm DIN IEC 751. Presents a nominal resistance of 100±0,06 Ω, und the accuracy is 0.15 K + 0.002 * T (°C), in a range from -40°C to 500°C. The temperature coefficient is 3850 ppm / K. The reaction speed is 0.3s in water, which is fast enough.

The size is detailed in the following schema.

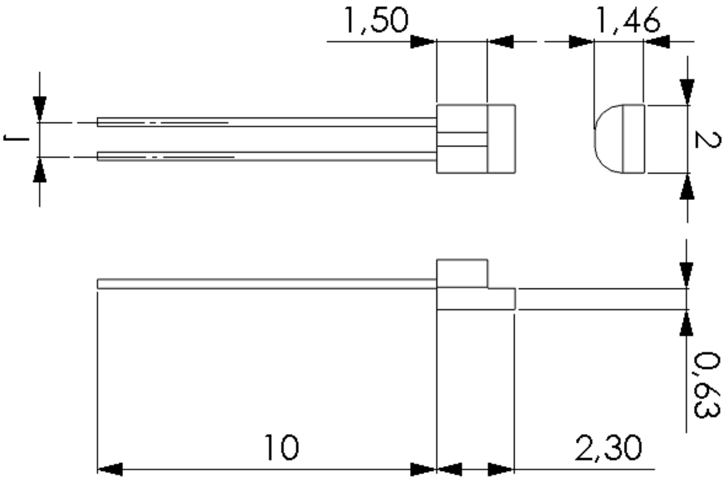


Figure 21: RTD Dimensions

The temperature sensor will be located inside the chamber, but not directly on the quartz, as it has to avoid the quartz holder. The place for the RTD is a hole, 3mm thick, accessed by another hole, 18mm thick.

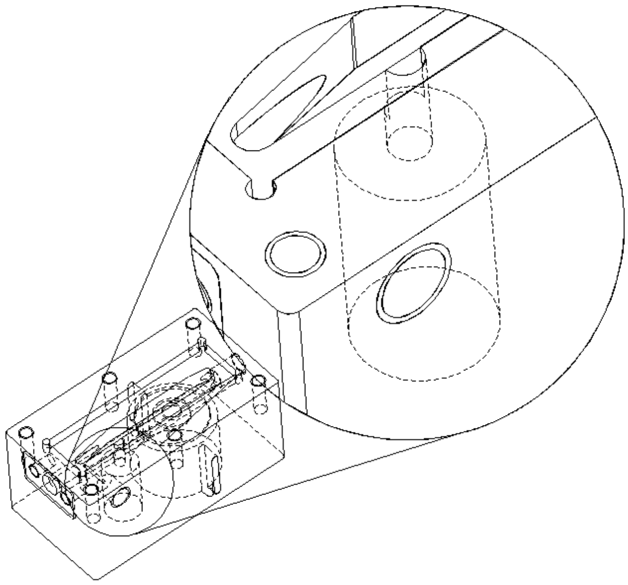


Figure 22: RTD Chamber Detailed View

Once the sensor is placed and connected to a 2-wires connector, it will be correctly fixed and sealed using two-component steel-filled epoxy glue.

5.3 Test Bench Design

5.3.1 Introduction

The present testbench will be composed by the computer, datalogger and Network analyzer, connected through GPIB. To the datalogger will be connected to the pH sensor and the temperature sensor. This section deepens in the physical characteristics of these devices and the way they are inserted in the bench. It will be also design any necessary extra interface, as an amplification step between the pH electrode and the datalogger.

5.3.2 GPIB - Interface

Figure 23: GPIB Connector

The IEEE-488 bus (GPIB) was developed to connect and control programmable instruments, and to provide a standard interface for communication between instruments from different sources. Hewlett-Packard originally developed the interfacing technique, and called it HP-IB. The interface quickly gained popularity in the computer industry. Because the interface was so versatile, in 1973 the IEEE committee renamed it GPIB (General Purpose Interface Bus).

The IEEE-488.1 standard greatly simplifies the interconnection of programmable instruments by clearly defining mechanical, hardware, and electrical protocol specifications. Instruments from different manufactures can be connected by a standard fully defined cable. In addition, the IEEE-488.2 standard enhances and strengthens the IEEE-488.1 standard by specifying data formats, status reporting, error handling, controller functionality, and common instruments commands. It focuses mainly on the software protocol issues and thus maintains compatibility with the hardware- oriented IEEE-488.1 standard. Other interesting characteristics are the possibility to connect up to 15 instruments - called devices - to one computer; the specified transfer rate, which gets to 1 MByte per second; and the cable length, till 20m between controller and one device or 2m between each device [17,18].

Summarizing, almost any instrument can be used with the IEEE-488 (GPIB) specification, because it says nothing about the function of the instrument itself. These characteristics make the GPIB an excellent option to plug to the computer the instruments that we need, and it also helps to make this testbench compatible with the other equipment in the laboratory.

Other possibility would be the using of the serial port, so called RS-232. This presents both advantages and disadvantages. The advantage is that the communication with datalogger and network analyzer will be independent, avoiding any kind of collision or interference, as is it always a point to point connection. The disadvantages are both a lower speed and the blocking of the two existing serial ports of any normal computer. Actually, this second reason was determinant as some equipment in the lab needs this port, so at least one of them has to be free.

On the other hand, we will see in the next chapter that the automatic operation of the GPIB bus through the VISA protocol will avoid any collision problem, what makes serial connection unnecessary.

Through GPIB, the PC reads the values provided by the datalogger and the Network Analyzer, and then it processes them and generates the data files. The computer will use a standard IEEE-488 PCI Controller card, produced by ICP-DAS. Both the Network Analyzer and the datalogger have integrated GPIB connector.

Figure 24: IEEE-488 PCI Controller

5.3.3 Data Logger: Physical Interface

Data loggers are used to monitor multiple signals (temperature, voltage, etc.) over extended periods of time to characterize systems or to identify irregularities. Example applications include environmental chamber monitoring, component inspection, bench top testing, process troubleshooting, and temperature profiling [19].

Figure 25: datalogger Agilent 34970

It is used the datalogger Agilent® 34970 (Fig. 25), whose most important characteristic is its wide range of acquisition possibilities, and its configurability. It integrates an internal digital multimeter (DMM) which allows several kinds of different measurements, through converting a physical quantity being measured into an electrical signal which can be measured by the internal DMM. To make these measurements, the internal DMM incorporates the following functions:

- Temperature (thermocouple, RTD, and thermistors)
- Voltage (dc and ac up to 300V)
- Resistance (2-wire and 4-wire up to 100 MΩ)
- Current (dc and ac from 100nA to 1A)
- Frequency and Period (up to 300 kHz)

The internal DMM provides a universal input front-end for measuring a variety of transducer types without the need for additional external signal conditioning. The internal DMM includes signal conditioning, amplification (or attenuation), and a high resolution (up to 22 bits) analog-to-digital converter. A simplified diagram of the internal DMM is shown below (Fig. 26).

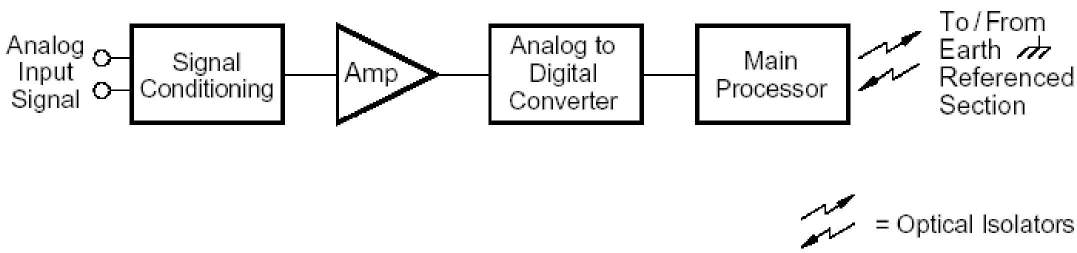


Figure 26: Internal DMM Schema

To extend the capabilities of the datalogger, it offers a complete selection of plug-in modules to add high-quality measurement, switching, and control capabilities. The plug-in modules communicate with the floating logic via the internal isolated digital bus, and the multiplexer modules also connect to the internal DMM via the internal analog bus. We have installed the multiplexer module in the datalogger.

34901A 20-Channel General-Purpose Multiplexer

The Agilent 34901A (Fig. 27) is a versatile multiplexer for general purpose scanning. It combines multifunction switching up to 60 channel/ second – at low resolution - scan rates to address a broad spectrum of data acquisition applications. It also allows two- and four-wire channels, achieved mixing channels of the same module. Each of the 20 channels switches mechanically both HI and LO inputs, thus providing fully isolated inputs to the internal multimeter. In simple terms, it allows the connection of the temperature sensor and the pH sensor, each to one channel, and both can be measured through the internal DMM.

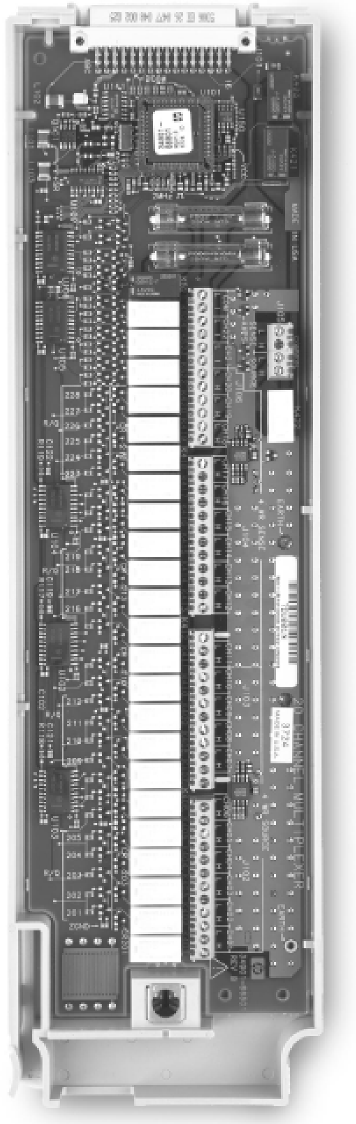


Figure 27: 34901A Module

Temperature Sensor Physical Interface

As was described, the temperature sensor is a 100 Ω RTD. The transducer varies its resistance depending on the temperature, following a standard linear relation. This relation is called TCR from Temperature Coefficient of Resistance, given by the equation Eq. (4). Stated another way, TCR is the average resistance increase per degree of a hypothetical RTD measuring 1 Ω at 0ºC. The RTD follows the standard from the IEC 751, which indicates a TRC of 0.00385 $\Omega/\Omega/$ºC [20].

$$TCR(\Omega/\Omega/C°) = \frac{R_{100°C} - R_{o°C}}{R_{o°C} \cdot 100°C} \quad (4)$$

The datalogger can measure RTD, after selecting the right TCR. This means that it can measure the resistance offered by the transducer and calculate the equivalent temperature value. In addition, it is possible to choose between 2-wires measurement and 4-wires measurement.

The 20 channels of the multiplexer module are divided in two different banks. Simply, when making four-wire resistance measurements, channels from bank A are automatically paired with channels from bank B, and so it has to be connected (Fig 26).

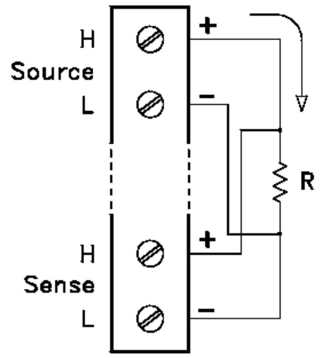


Figure 28: Figure: 4-Wires Schema

The 34901A module can automatically generate the constant current to feed the resistor during the resistance measurement, calculate the resistance of the wires and compensate it (when 4 wires measurement), and finally it calculates the equivalent temperature.

As it gives a more trustable result, it will be used 4-wires measurement, whenever it is possible. Anyway, we will try that the bench worked with both systems, and so will do the program.

pH Sensor Physical Interface

The pH sensor measurement presents more difficulties than the temperature transducer. pH electrodes are passive transducers, and this means that they don’t receive power to operate from any device but they take the energy from the environment, and normally from the same characteristic or property that they measure. This means that the transduced signal that they can supply is really weak. In this way, the physical characteristics of the pH sensor are critical.

Table 5: pH Electrode Physical Characteristics

Membrane resistance	300 ... 600 MΩ
Electrode neutral point	0 ± 15 mV (pH = 7)
Electrode slope	>0.97

The maximum membrane resistance is around 600 MΩ, and the input impedance of the datalogger can be selected to greater than 10GΩ. Normally, this difference could be enough to allow a correct measurement, but in this case it was not. The current supplied by the pH electrode is still too small.

Table 6: Datalogger Physical Characteristics

Input Resistance	10 MΩ or > 10,000 MΩ
Input Bias Current	< 30 pA at 25°C
Input Protection	300 V all ranges

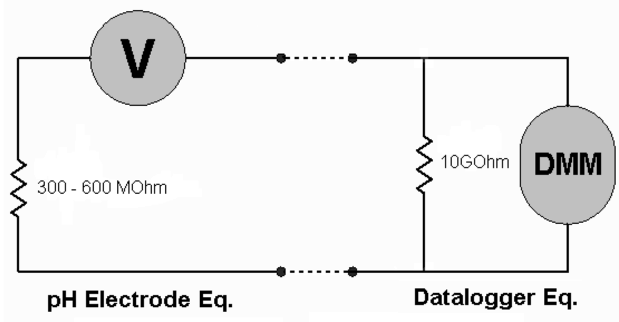


Figure 29: pH Sensor Equivalent.

Counting that the maximum measurable value of voltage (equivalent to 1 pH) rounds 300 mV, when the minimum impedance is 300 MΩ, this means, that the datalogger has to differentiate a currents of 300 mV / 300 MΩ = 1nA. The I_{bias} current of the datalogger rounds 25 pA (only 40 times more little), this explains that the direct connection of the pH electrode to the 34970 (Fig. 29) offers an inconstant result. The quality of the measurement in this case depends on the programmed PLC (integrating time), and, overall, on the values measured on other steps of the scan (like the temperature sensor). A constant measurement of the pH electrode value returned a constant voltage; a combination measuring another channel normally resulted in measuring only noise.

It becomes clear that some signal conditioning is necessary, between the pH electrode and the datalogger. To adapt the impedances, a simple signal follower will be used. The idea is to avoid a preamplification, which could add non-linearities to the signal. A follower adds only a little offset, that can be easily removed during the sensor calibration. The LMC6042, a CMOS Dual Micropower Operational Amplifier, is used for this kind of applications, due to its high input impedance (Tab. 7). The tension follower will be placed on a little board designed to it, whose schematic is shown in the Fig. 28.

Table 7: LMC6042 Physical Characteristics

Supply Voltage	4.5V <V+<15.5V
Input Bias Current	2 fA
Input Offset Current	1 fA
Input Resistance	10 TΩ
Typical Output Current	22mA

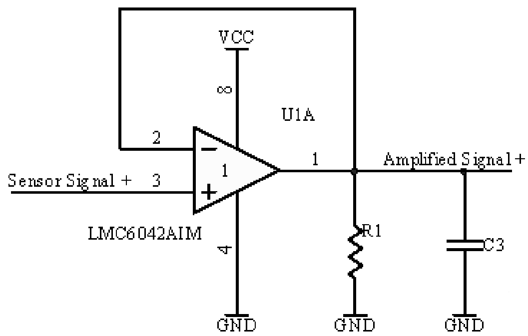


Figure 30: Voltage Follower Schematic

Now, the impedance presented to the pH electrode is higher than 10 TΩ, what is 16000 times bigger than the pH electrode's itself. The OPAMP supplies the datalogger with 22 mA current, and this already allows the measurements.

5.3.4 Network Analyzer

Network analyzers are a class of instruments that have been developed to characterize radio-frequency components accurately and efficiently as a function of frequency.

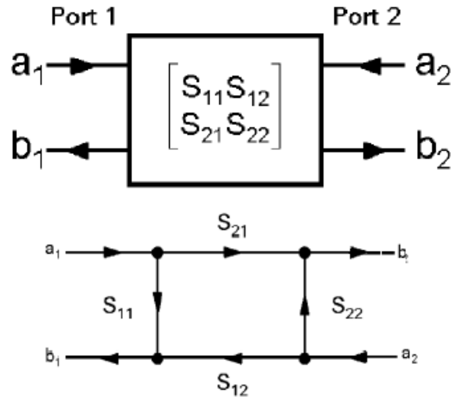


Figure 31: 2 port S-Parameters Definition

Network analysis is the process of creating a data model of the transfer and/or impedance characteristics of a linear network through stimulus-response testing over the frequency range of interest. Since linearity constrains networks stimulated by a sine wave to produce a sine-wave output, sine-wave testing is an ideal method for characterizing magnitude and phase response as a function of frequency. Incident energy on a device under test (DUT) (for example, an oscillator) is either reflected from or transmitted through the device. By measuring the amplitude ratios and phase differences between the two waves it is possible to characterize the reflection (impedance) and transmission (gain) characteristics of the device [21,22].

Network analyzers (NWA) are used normally to measure scattering parameters (S-parameters) of passive and active microwave devices. The S-parameters of a network provide a clear physical interpretation of the transmission and reflection performance of the device (Fig. 31). The S parameter terms related to other parameters with certain conditions. For instance, S11 is equivalent to a device input reflection coefficient Γ_{IN} under the condition the device has a perfect Z0 match on the output [23].

In this application, we are interested in measuring the central frequency and bandwidth (equivalent or proportional to damping) of the quartz's transmission admittance. In this situation, we are going to consider the quartz as a normal oscillator, and measure the S_{21} parameter, related with the transmitted energy in Eq. (5).

$$S_{21} = \frac{Transmitted \quad Wave}{Incident \quad Wave} \tag{5}$$

It is used the Network analyzer Advantest R3753BH. This is a two-input network analyzer: Normal signal input A and reference input R. The input range goes from 5 Hz to 500 Mhz. The range of the output signal goes from +21dBm to -63dBm.

Figure 32: Network Analyzer π-Network jig

As the impedance of the quartz is high, it is needed to use a PI-Network (Fig. 32), to adapt the impedances to the 50 Ω of the Network Analyzer. A connection that allows this impedance adaptation is shown in the Fig. 33. The NWA produces a signal through the output 2 (50 Ω) and it is read though the input A (50 Ω). R is used as the reference signal. The NWA calculates internally A/R, which is the transmission coefficient.

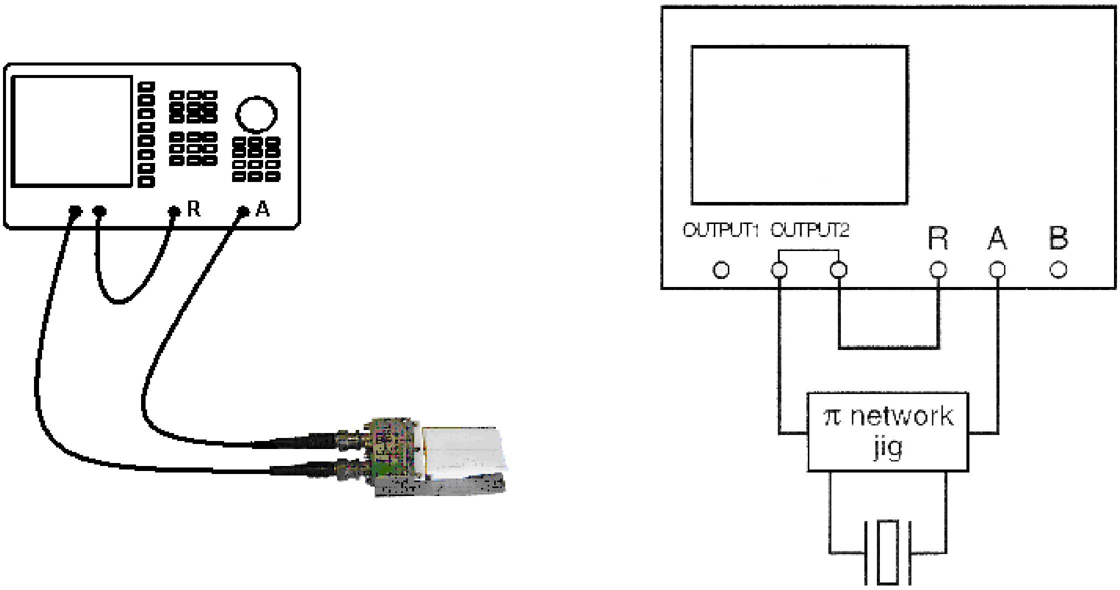


Figure 33: Network Analyzer Connection