# FINAL PROJECT

## Developing and Testing an Amplifier system for Piezoelectric Sensors


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# ABSTRACT

Piezoelectric sensors are used in condition monitoring system to monitor forces, vibration, strain, acoustic emission and for other applications.

The sensors produce a small electric charge which needs to be amplified using a charge amplifier. Then a voltage amplifier will be used to increase the level of the voltage to a suitable level for data capturing using a digital acquisition system.

The task to be performed is to build and test a charge amplifier that could be used with piezoelectric sensors re-using an old PC for the power supply and recycle the casing of the computer for the device to be built.

Nowadays recycling is very important when you manufacture any product given the fact that we can get economic and environmental benefits without affecting the product quality. Specifically in this project an old computer which was going to be doomed, has been used to make the casing for our device and also to feed the charge amplifier through its power supply.

The amplifier has been manufactured by the welding of integrated circuits. It has taken three stages of amplification which highlights the operational amplifiers LF 356 and LF 351.

We should add that this is not a conventional project of design, but a project mainly based on electronics and recycling. The most important thing is the proper functioning of the device and it complies with the requirements of the market, given that it is mostly a product that it has been recycled and reused.

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This acknowledgement also extends to all the staff of the workshop for their help and dedication.

# GLOSARY

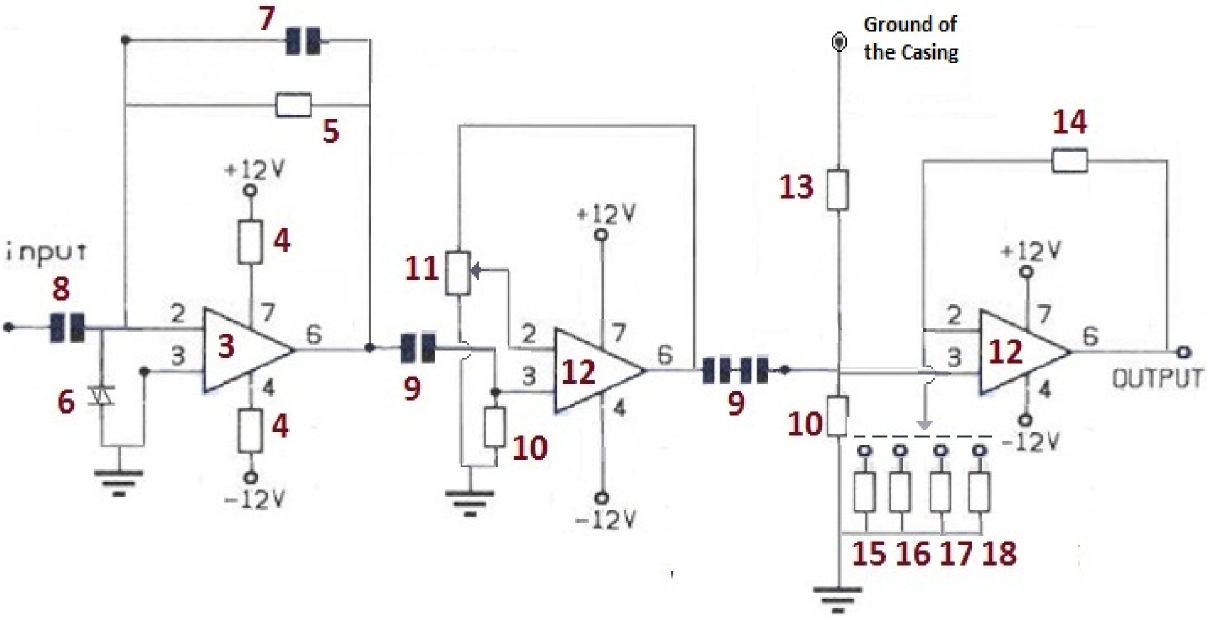



**Illustration 1: Charge Amplifier Circuit**

1. Piezoelectric sensor
2. Integrated circuit board
3. LF 356
4. 1KΩ Resistor
5. 200MΩ Resistor
6. Zs 151 Diodes
7. 1000 pF Capacitor
8. 1 mF Capacitor
9. 47mF Capacitor
10. 470KΩ Resistor
11. 0-10KΩ Potentiometer
12. LF 351
13. 180 Ω Resistor
14. 47KΩ Resistor
15. 1.54KΩ Resistor
16. 5.23KΩ Resistor
17. 22KΩ Resistor
18. 1.33KΩ Resistor
19. Charge Amplifier Casing

**1. Piezoelectric sensor:** This is the piezoelectric sensor which produces a small signal. The amplifier circuit is created exclusively for this sensor.

**Illustration 2: Piezoelectric sensor**

**2. Integrated circuit board:** The integrated circuit board is the board on which the circuit has been built and where the components have been soldered.

**3. LF 356:** These amplifiers are capable of amplifying 1000 times the input signal and are the first monolithic JFET input operational amplifiers to incorporate well matched, high voltage JFETs on the same chip with standard bipolar transistors.

**12. LF 351:** The LF351 is a JFET input operational amplifier with an internally compensated input offset voltage. The JFET input device provides wide bandwidth, low input bias currents and offset currents.

**19. Casing:** The charge amplifier casing where the power supply and the circuit are placed.

**Illustration 3: Charge Amplifier Casing**

# CHAPTER 1

# 1. Introduction to the Project

## 1.1. Introduction

This chapter gives a perspective of the project; it provides information about the history, it explains what a piezoelectric sensor is, what an amplifier is and its applications and features, and a basic introduction to the electronics used in this project. At the end, a Gantt chart and a table describe the planning of the project.

## 1.2. Aims and objectives of the Project

This report collects the final project of Electrical Engineering and it is an academic requirement to complete the degree.

The project objectives contain three main components as outlined below:

- Provide and prove the opportunity and responsibility of creating, finding or selecting, formulating, planning, carrying out and reporting on a challenging project.
- Develop personal skills of initiative, independence, enterprise, planning, research and communication.
- Use, develop and integrate knowledge and skills acquired earlier, during the degree.

OBJECTIVES OF THE PROJECT

- Build a charge amplifier circuit suitable for a piezoelectric sensor with adjustable gain, sensitivity and overload option using a power supply from an old PC as the device power supply.
- Recycle an old computer casing to create the casing for the device.
- The design should be compatible with existing sensors and commercial amplifiers.

The Project also has three distinct parts: Circuit/device building, report and final demonstration/oral presentation.

One of them is the Circuit/device building and testing which requires building the electronic circuit that can be connected to the piezoelectric sensor that will amplify the signal to a suitable level (e.g. +/- 10V). You can get adjustable gain and sensitivity with compatibility to commercial products in relation to wire connection (e.g. BNC cable, etc.).

## 1.3. Piezoelectricity and Piezoelectric sensors

Piezoelectricity is the charge which accumulates in certain solid materials (notably crystals, certain ceramics, and biological matter such as bone, DNA and various proteins) in response to applied mechanical strain. The word piezoelectricity means electricity resulting from pressure. It is derived from the Greek piezo or piezein (πιέζειν), which means to squeeze or press, and electric or electron (ήλεκτρον), which stands for amber, an ancient source of electric charge. Piezoelectricity is the direct result of the piezoelectric effect.

The piezoelectric effect is understood as the linear electromechanical interaction between the mechanical and the electrical state in crystalline materials with no inversion symmetry. The piezoelectric effect is a reversible process in that materials exhibiting the direct piezoelectric effect (the internal generation of electrical charge resulting from an applied mechanical force) also exhibit the reverse piezoelectric effect (the internal generation of a mechanical force resulting from an applied electrical field). For example, lead zirconate titanate crystals will generate measurable piezoelectricity when their static structure is deformed by about 0.1% of the original dimension. Conversely, those same crystals will change about 0.1% of their static dimension when an external electric field is applied to the material.

Piezoelectricity is found in useful applications such as the production and detection of sound, generation of high voltages, electronic frequency generation, microbalances, and ultrafine focusing of optical assemblies. It is also the basis of a number of scientific instrumental techniques with atomic resolution, the scanning probe microscopies such as STM, AFM, MTA, SNOM, etc., and everyday uses such as acting as the ignition source for cigarette lighters and push-start propane barbecues.

## SENSORS

The principle of operation of a piezoelectric sensor is that a physical dimension, transformed into a force, acts on two opposing faces of the sensing element. Depending on the design of a sensor, different "modes" to load the piezoelectric element can be used: longitudinal, transversal and shear.

Detection of pressure variations in the form of sound is the most common sensor application, e.g. piezoelectric microphones (sound waves bend the piezoelectric material, creating a changing voltage) and piezoelectric pickups for Acoustic-electric guitars. A piezo sensor attached to the body of an instrument is known as a contact microphone.

Piezoelectric sensors especially are used with high frequency sound in ultrasonic transducers for medical imaging and also industrial nondestructive testing (NDT).

For many sensing techniques, the sensor can act as both a sensor and an actuator – often the term transducer is preferred when the device acts in this dual capacity, but most piezo devices have this property of reversibility whether it is used or not. Ultrasonic transducers, for example, can inject ultrasound waves into the body, receive the returned wave, and convert it to an electrical signal (a voltage). Most medical ultrasound transducers are piezoelectric.

In addition to those mentioned above, various sensor applications include:

- Piezoelectric elements are also used in the detection and generation of sonar waves.
- Power monitoring in high power applications (e.g. medical treatment, sonochemistry and industrial processing).
- Piezoelectric microbalances are used as very sensitive chemical and biological sensors.
- Piezos are sometimes used in strain gauges.
- Piezoelectric transducers are used in electronic drum pads to detect the impact of the drummer's sticks.
- Automotive engine management systems use piezoelectric transducers to detect detonation by sampling the vibrations of the engine block and also to detect the precise moment of fuel injection (needle lift sensors).
- Ultrasonic piezo sensors are used in the detection of acoustic emissions in acoustic emission testing.
- Crystal earpieces are sometimes used in old or low power radios

*Reduction of vibrations and noise*

Different teams of researchers have been investigating ways to reduce vibrations in materials by attaching piezo elements to the material. When the material is bent by a vibration in one direction, the vibration-reduction system responds to the bend and sends electric power to the piezo element to bend in the other direction. Future applications of this technology are expected in cars and houses to reduce noise.

## 1.4. Historical introduction of piezoelectric sensors

The pyroelectric effect, where a material generates an electric potential in response to a temperature change, was studied by Carl Linnaeus and Franz Aepinus in the mid-18th century. Drawing on this knowledge, both René Just Haüy and Antoine César Becquerel posited a relationship between mechanical stress and electric charge; however, experiments by both proved inconclusive.

The first demonstration of the direct piezoelectric effect was in 1880 by the brothers Pierre Curie and Jacques Curie. They combined their knowledge of pyroelectricity with their understanding of the underlying crystal structures that gave rise to pyroelectricity to predict crystal behavior, and demonstrated the effect using crystals of tourmaline, quartz, topaz, cane sugar, and Rochelle salt (sodium potassium tartrate tetrahydrate). Quartz and Rochelle salt exhibited the most piezoelectricity.

The Curies, however, did not predict the converse piezoelectric effect. The converse effect was mathematically deduced from fundamental thermodynamic principles by Gabriel Lippmann in 1881. The Curies immediately confirmed the existence of the converse effect, and went on to obtain quantitative proof of the complete reversibility of electro-elasto-mechanical deformations in piezoelectric crystals.

For the next few decades, piezoelectricity remained something of a laboratory curiosity. More work was done to explore and define the crystal structures that exhibited piezoelectricity. This culminated in 1910 with the publication of Woldemar Voigt's Lehrbuch der Kristallphysik (textbook on crystal physics), which described the 20 natural crystal classes capable of piezoelectricity, and rigorously defined the piezoelectric constants using tensor analysis.

*World War I and post-war*

The first practical application for piezoelectric devices was sonar, first developed during World War I. In France in 1917, Paul Langevin and his coworkers developed an ultrasonic submarine detector. The detector consisted of a transducer, made of thin quartz crystals carefully glued between two steel plates, and a hydrophone to detect the returned echo. By emitting a high-frequency chirp from the transducer, and measuring the amount of time it takes to hear an echo from the sound waves bouncing off an object, one can calculate the distance to that object.

The use of piezoelectricity in sonar and the success of that project created intense development interest in piezoelectric devices. Over the next few decades, new piezoelectric materials and new applications for those materials were explored and developed.

Piezoelectric devices found homes in many fields. Ceramic phonograph cartridges simplified player design, were cheap and accurate, and made record players cheaper to maintain and easier to build. The development of the ultrasonic transducer allowed for easy measurement of viscosity and elasticity in fluids and solids, resulting in huge advances in materials research. Ultrasonic time-domain reflectometers (which send an ultrasonic pulse through a material and measure reflections from discontinuities) could find flaws inside cast metal and stone objects, improving structural safety.

*World War II and post-war*

During World War II, independent research groups in the United States, Russia, and Japan discovered a new class of man-made materials, called ferroelectrics, which exhibited piezoelectric constants many times higher than natural materials. This led to intense research to develop barium titanate and later lead zirconate titanate materials with specific properties for particular applications.

One significant example of the use of piezoelectric crystals was developed by Bell Telephone Laboratories. Following World War I, Frederick R. Lack, working in radio telephony in the engineering department, developed the “AT cut” crystal, a crystal that operated through a wide range of temperatures. Lack's crystal didn't need the heavy accessories previous crystal used, facilitating its use on aircraft. This development allowed Allied air forces to engage in coordinated mass attacks through the use of aviation radio.

Development of piezoelectric devices and materials in the United States was kept within the companies doing the development, mostly due to the wartime beginnings of the field, and in the interests of securing profitable patents. New materials were the first to be developed — quartz crystals were the first commercially exploited piezoelectric material, but scientists searched for higher-performance materials. Despite the advances in materials and the maturation of manufacturing processes, the United States market had not grown as quickly. Without many new applications, the growth of the United States' piezoelectric industry suffered.

In contrast, Japanese manufacturers shared their information, quickly overcoming technical and manufacturing challenges and creating new markets. Japanese efforts in materials research created piezoceramic materials competitive to the U.S. materials, but free of expensive patent restrictions. Major Japanese piezoelectric developments include new designs of piezoceramic filters for radios and televisions, piezo buzzers and audio transducers that can connect directly to electronic circuits, and the piezoelectric igniter, which generates sparks for small engine ignition systems (and gas-grill lighters) by compressing a ceramic disc. Ultrasonic transducers that transmit sound waves through air had existed for quite some time, but first saw major commercial use in early television remote controls. These transducers now are mounted on several car models as an echolocation device, helping the driver determine the distance from the rear of the car to any objects that may be in its path.

## 1.5. Charge Amplifiers

A charge amplifier is a current integrator driven by an electrical source with capacitive nature such as a piezoelectric sensor. Contrary to what its name may suggest, a charge amplifier does not amplify the electric charge present at its input. The charge amplifier just transfers the input charge to another reference capacitor and produces an output voltage equal to the voltage across the reference capacitor. Thus the output voltage is proportional to the charge of the reference capacitor and, respectively, to the input charge; hence the circuit acts as a charge-to-voltage converter. The input impedance of the circuit is almost zero because of the Miller effect. Hence all the stray capacitances are virtually grounded and they have no influence on the output signal.

Common applications include piezoelectric sensors and photodiodes, in which the charge output from the transducer is converted into a voltage. Charge amplifiers are often found in instrumentation, and in the readout circuitry of CCD imagers and flat-panel X-ray detector arrays. In read-out circuits the objective is usually to measure the very small charge stored within an in-pixel capacitor, despite the capacitance of the circuit-track to the readout circuit being a couple of orders of magnitude greater than the in-pixel capacitor.

Advantages include:

- Enables quasi-static measurements in certain situations, such as constant pressures on a piezo lasting several minutes.
- Piezo element transducer can be used in much hotter environments than those with internal electronics.
- Gain is dependent only on the feedback capacitor, unlike voltage amplifiers, which are affected greatly by the input capacitance of the amplifier and the parallel capacitance of the cable.

## 1.6. Integrated circuit piezoelectric sensor

An Integrated circuit piezoelectric sensor is used to measure piezoelectricity in circuitry.

ICP is an acronym for "integrated circuit piezoelectric", and is a registered trademark of PCB Group, Inc. (1,603,466), parent company of PCB Piezotronics. ICP (IEPE-type) piezoelectric transducers measure dynamic pressure, force, strain, and acceleration. IEPE is the standard for piezoelectric transducers and is also an acronym for integrated electronics piezoelectric.

ICP identifies PCB sensors that incorporate built-in, signal-conditioning electronics. The built-in electronics convert the high-impedance charge signal that is generated by the piezoelectric sensing element into a usable low-impedance voltage signal that can be readily transmitted, over ordinary two-wire or coaxial cables, to any voltage readout or recording device. The low-impedance signal can be transmitted over long cable distances and used in dirty field or factory environments with little degradation. In addition to providing crucial impedance conversion, ICP sensor circuitry can also include other signal conditioning features, such as gain, filtering, and self-test features. The simplicity of use, high accuracy, broad frequency range, and low cost of ICP accelerometers make them the recommended type for use in most vibration or shock applications. However, an exception to this assertion must be made for circumstances in which the temperature, at the installation point, exceeds the capability of the built-in circuitry. The routine temperature range of ICP accelerometers is +250 °F (+121 °C); specialty units are available that operate to +350 °F (+177 °C).

The electronics within ICP accelerometers require excitation power from a constant-current regulated, DC voltage source. This power source is sometimes built into vibration meters, FFT analyzers, and vibration data collectors. A separate signal conditioner is required when none is built into the readout. In addition to providing the required excitation, power supplies may also incorporate additional signal conditioning, such as gain, filtering, buffering, and overload indication.

## 1.7. Project Management process.

The process of Project Management is divided in four important parts:

### *1.7.1. Defining: Define the Project goals*

*1.7.2. Planning: It explains how the team needs to complete the goals with the tools, time, money and all the necessary things required to do it*

*1.7.3. Monitoring: This point means compare the finished work with the programmed works to know about the corrective things that were changed*

*1.7.4. Completing: Ensure that the finished design is realistic considering manufacture and materials and has a place on the market*

## 1.8. GANTT CHART

A Gantt chart is a type of bar chart that illustrates a project schedule. Gantt charts illustrate the start and finish dates of the terminal elements and summary elements of the project.

It is the best option to start one Project, starting to do the plan of the work. We need to think in the steps to follow and the time of each step. When we have the steps, the time for each steps and the position of each task, this is an important thing because we can't build the object if we didn't design it. We can take all information and put into a one easy graph that name is Gantt-Chart. With this graph is easy to know which task we need to do and the time that we have to do it. We can have an approximation of the duration of the project.

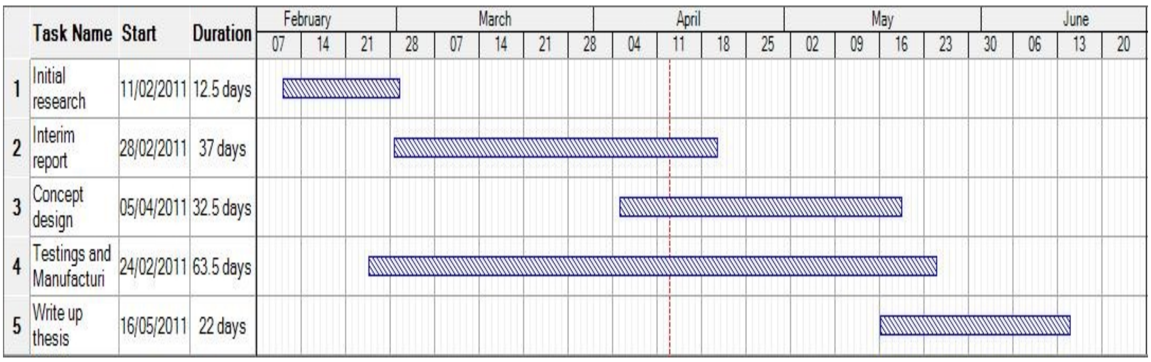



**Illustration 4: Gantt-Chart Graph.**

**Initial research:** Research information needed to begin the Project and consider all the possible ways to do it.

**Interim report:** Define progress and current situation.

**Concept design:** This point contends all necessary plans to build the object and all of relative information about the object.

**Electronic Testing and Manufacturing:** Build the product and check the product.

**Write up thesis:** Write all the things which were done in order to design and build the full product.

| Works | Start | Duration (days) | End |
|---|---|---|---|
| | | | |
| Initial Research | 11 February | 13 | 24 February |
| Interim Report | 28 February | 37 | 6 April |
| Concept Design | 05 April | 33 | 8 May |
| Electronic Testing and Manufacturing | 24 February | 64 | 2 May |
| Write up Thesis | 6 May | 20 | 26 May |

**Illustration 5: Gantt-Chart Table.**

## 1.9. Conclusion

In the first chapter the objectives of this report are stated. In order to start the report it is necessary to know the topic area well. The first pages talk about history, what a piezoelectric sensor is and how a charge amplifier works. The Gantt-Chart shows the estimated time that it will take to finish this project.

# CHAPTER 2

# 2. Methodological Design

## 2.1. Introduction

That chapter helps us to understand how the design has been carried out. It shows us the factors and strategies that were taken to make the project.

## 2.2. Methodological design process

The methodological design process tries to help us to find the best way to design our project. The correct methodology needs to be identified, so the methodology is the most important step to follow. If the methodology is wrong, then the design will most likely be wrong as well. The methodological design infers a goodness of fit between your final questions and your methodological design.

- strategy for collecting and analysing data
- selected investigation areas
- series of specifically designed tools
- work plan

## Getting your Methodological Design on Target

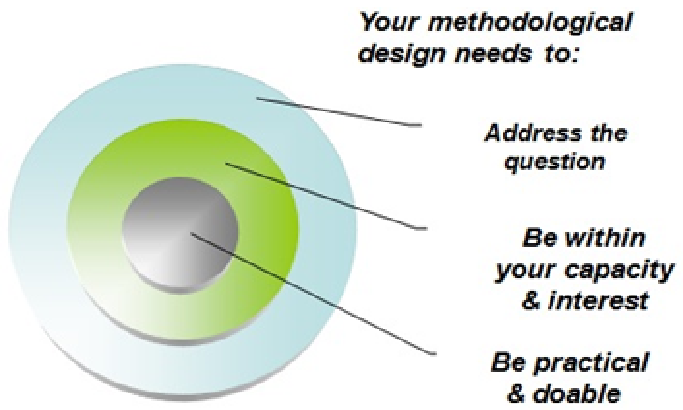



**Illustration 6: Methodological design requirements**

Whenever you start a project, you should have a good idea/understanding of what you will do. Things like research, strategy, checkups, changes, and everything else that come along when dealing with clients. Most designers have a certain path that they take for every single project.

The design process has seven steps that we should follow:

- *Project Initiation*
- *Orientation Research*
- *Strategy*
- *Exploration/Development*
- *Refinement*
- *Production*
- *Project Completion*

However, it is not the same to design a motor and to design a chair. For this the methodology is the most important step to follow, if the methodology is wrong probably so will the design.

- This diagram is for a product that was made previously but for this project is still valid, by removing the start word 'people' it is a easy methodology to follow. This methodology gives the principal ideas that need to be studied.

- Is a really easy diagram that only has five words, but these word have a lot of meaning because they suggest a lot of questions. For example:

  - ASK: What I need to do?   What are the constraints?

  - IMAGINE: Brainstorm ideas.  What are some solutions?

  - PLAN: Draw a diagram. Make a list of materials you need.

  - CREATE: Test it.

  - IMPROVE: Modify you design you design to make it better.

## 2.3. Mind map

This part has two important aspects that need to be presented to the model because it is better and comfortable to the operator. In the next points explains these aspects.

### *2.3.1. Ergonomics*

The term "ergonomics" is derived from two Greek words: "ergon," meaning work, and "nomoi," meaning natural laws. Ergonomists study human capabilities in relationship to work demands.

The Ergonomic work is defined for good postures to reduce unnecessary work on the body and the risk of injuring the users.

### *2.3.2. Anthropometrics*

Anthropometry is the study of the dimensions and abilities of the human body. Wheeled mobility devices are used by people with mobility impairments to support their mobility in buildings and in the community, e.g. manual wheelchairs, power wheelchairs and scooters. Static anthropometry is the measurement of body sizes at rest and functional anthropometry is the measurement of abilities related to completing tasks. In the case of wheeled mobility, static anthropometry includes measurement of people and their devices. Functional anthropometry includes measurement of reaching abilities, maneuvering and other aspects of space and equipment use from a

Anthropometrics have three big groups and inside of them we find the things that we need to think about.

- Gender: height, size, weight, strength and body proportion.
- Age: height, size, weight, strength and body proportion.
- Ethnicity: height, size, weight, strength and body proportion.

## 2.4. Ethnography

The ethnography is a study that is used to know about traditions and customs of one region or culture, through several observations of different levels, perspectives and times, the investigator can arrive to know structures with the sense and meaning to understand the likes and the preferences of the customer. For this reason the ethnography maybe the most important part of the Project because it is important to know about a lot of factors like design, colour, utility, etc.

Ethnography is two things:

*2.4.1. The fundamental research method of cultural anthropology*

*2.4.2. The written text produced to report ethnographic research results.*

Ethnography as method seeks to answer central anthropological questions concerning the ways of life of living human beings. Ethnographic questions generally concern the link between culture and behavior and/or how cultural processes develop over time. The data base for ethnographies is usually extensive description of the details of social life or cultural phenomena in a small number of cases.

In order to answer their research questions and gather research material, ethnographers (sometimes called fieldworkers) often live among the people they are studying, or at least spend a considerable amount of time with them. While there, ethnographers engage in "participant observation", which means that they participate as much as possible in local daily life while also carefully observing everything they can about it. Through this, ethnographers seek to gain what is called an "emic" perspective, or the "native's point(s) of view" without imposing their own conceptual frameworks. The emic world view, which may be quite different from the "etic", or outsider's perspective on local life, is a unique and critical part of anthropology. Through the participant observation method, ethnographers record detailed fieldnotes, conduct interviews based on open-ended questions, and gather whatever site documents might be available in the setting as data.

As a qualitative research method and product, ethnography can be distinguished from three other ways of investigating and writing: quantitative research, public policy research, and journalism. The kinds of guiding questions which are addressed through these kinds of research are importantly different from those which can be addressed ethnographically. Because these differences can be confusing to students, causing them to spend valuable time in the field focused on something un-ethnographic, they are described briefly here.

Quantitative research usually arrives at percentages or otherwise counts instances of a phenomenon, and as such deals less descriptively with a larger number of cases than pure ethnography does. One of its main methods is widely distributed surveys or questionnaires.

Public policy research, which might be performed either qualitatively or quantitatively or both, is generally geared towards providing information that helps policy makers decide how a certain phenomenon might be understood in terms of better or worse social outcomes.

Journalism attempts to provide objective outsider news information in a quick, timely manner, often against a deadline. Journalists write for the kinds of audience that the newspaper, magazine, or other publication which hires them attempts to reach. General questions regarding culture are not usually considered crucial to the endeavor as they are in ethnography.

## 2.5. Brief

The main objective of this Project is build a charge amplifier circuit suitable for a piezoelectric sensor with adjustable gain, sensitivity and overload option using a power supply from an old PC as the device power supply.

Furthermore, we will have to recycle an old computer casing to create the casing for the device. The design should be compatible with existing sensors and commercial amplifiers.

## 2.6. Conclusion

This chapter has all the necessary aspects for the internal structure of the Project and three points that need to be clear to allow the project to be successful. Ergonomics and the anthropometry are closely linked topics and need to be taught to the workers. The ethnography is for the zone where the product needs to be taught.

# CHAPTER 3

# 3. The Design

## 3.1. Introduction

In this chapter

## 3.2. Product Design Specification (PDS)

Is a statement of what a not-yet-designed product intend do. Its aim is to ensure that the subsequent design and development of a product meets the needs of the user.

### 3.2.1. Functional

- *Overall geometry:* All the measures of the product.
- *Motion of parts:* The mobile parts in the product.
- *Forces involved:* The forces that the product will suffer.
- *Energy need:* The energy that the product needs to work.
- *Materials used:* The materials and components that we will use to build in the product.

### 3.2.2. Safety

- *Human:* The security that it needs to be present for the safety of for operators.

- *Operational: The security that it needs to be present when it is working.*

### 3.2.3. Quality

- *Quality in the control:* The product has to be easy and quick to control.
- *Reliability:* The confidence of the quality.

### 3.2.4. Manufacturing

- *Production of components:* The building process for each component.
- *Assemblage:* The assemblage of all components to build the product.
- *Transport:* The process of packaging the product.

#### 3.2.5. Timing

- *Design Schedule:* How much time need for design.
- *Development Schedule:* How much time need for development.
- *Production Schedule:* How much time need for building.

#### 3.2.6. Economic

- *Marketing analysis:* Analysis of the market around the product.
- *Design costs:* The cost of the design.
- *Manufacturing costs:* The costs of building the product.
- *Development costs:* The cost that the product needed to be developed.
- *Distribution costs:* The cost for the distribution.

#### 3.2.7. Ergonomic

- *User needs:* The ergonomics that it requires for the operators.
- *Ergonomic design:* The best ergonomic design possible.

#### 3.2.8. Ecological

- *Material selection:* The selection of the materials considering the environment and recycling an old computer.

#### 3.2.9. Aesthetic

- *Product appeal:* The appeal of the product says a lot about it.

#### 3.2.10. Life-Cycle

- *Distribution:* The packaging should protect the product against shock loading during storage and shipping, including onsite storage. The cost of shipping should be relative to the quantity and unit cost.
- *Operational:* The operative life that the product will have.

## 3.3. Designs

The operating mode of the electronic circuit and its features was taken into consideration more than the design of the casing's device because it had to be built by recycling a computer from the outset. It means that the design was going to be largely dependent on the computer casing's features.

However, it has been built trying to be as small and light as possible taking into account the concepts previously seen.

The below images show the initial designed circuits to built.

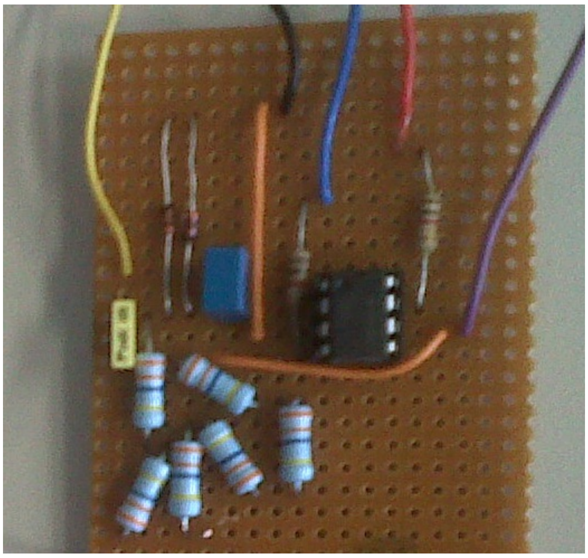


**Illustration 7: First circuit built**

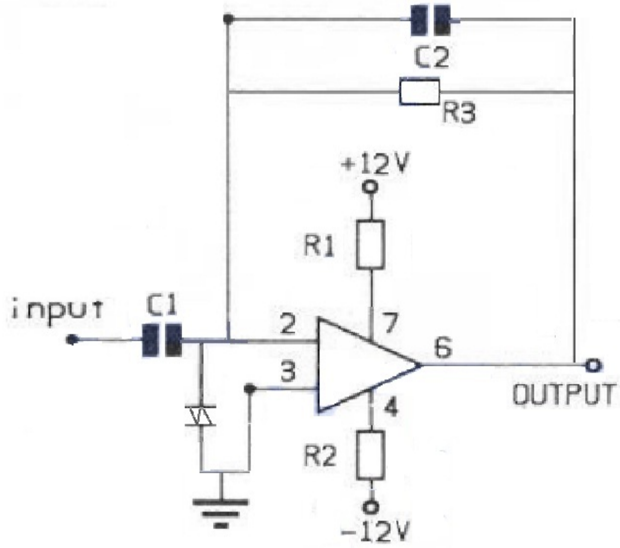



**Illustration 8: Electrical diagram**

MATERIAL REQUIRED to the first step building:

- Resistors
  - 1 x 200M
  - 2 x 1K
- Operational Amplifier
  - LF 356
- Diodes
  - 2 x Zs 151
- Capacitors
  - 1 x 1000 rF
  - 1 x 1 mF

The second and third step are easier to build, both of them occupy a smaller space than the first step. Furthermore, the second circuit was built in the same board as the third to reduce the space as much as possible.

To sum up, this is the circuit which was expected from the beginning of the project. Once achieved, it was time to start building the casing where the circuit would be placed. The casing construction will be explained in the following sections as well as the issue of power supply.

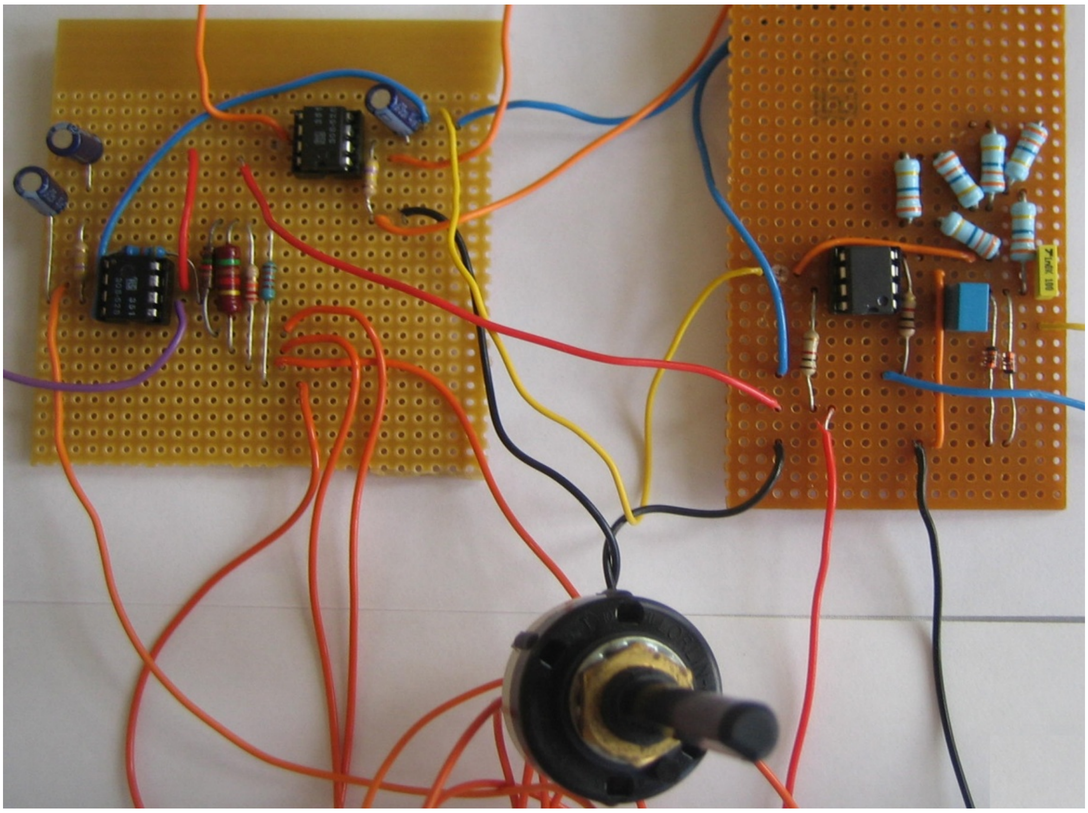


**Illustration 9: All circuits and the switch**

## 3.4. Power Supply

The power supply has been reused, so it was not necessary to perform a study of design. It was the power supply from an old computer and now it will become part of the new device. It is powering the device with ±12V, which is perfect for the charge amplifier. It converts general-purpose alternating current (AC) electric power from the mains (230V) to low-voltage direct current (DC) power for the internal components of the device.

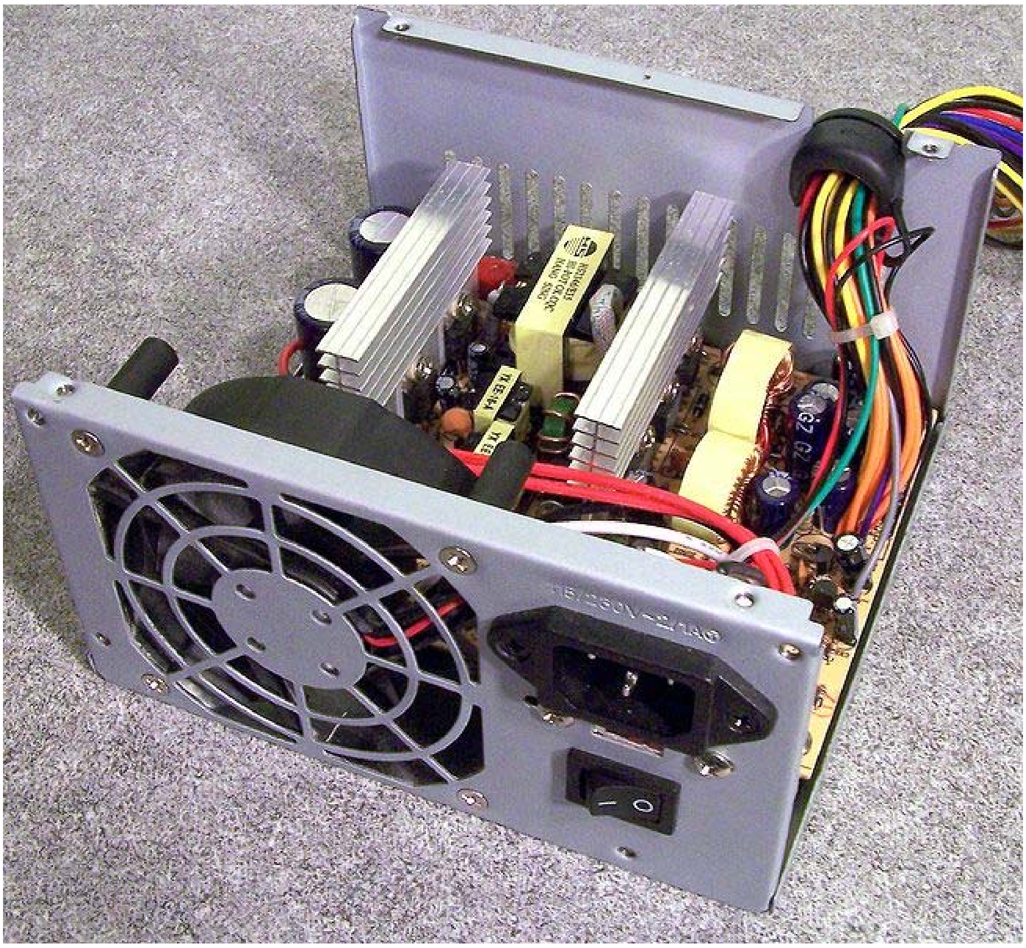


**Illustration 10: Reused power supply**

## 3.5. Final Detail Design and Building

The design could not be very flexible, being a recycled and reused device. The above factors in the PDS were taken into account to build both, the circuit and the casing.

This is the final detail design of the charge amplifier casing. It was studied and thought previously by following the steps seen before.

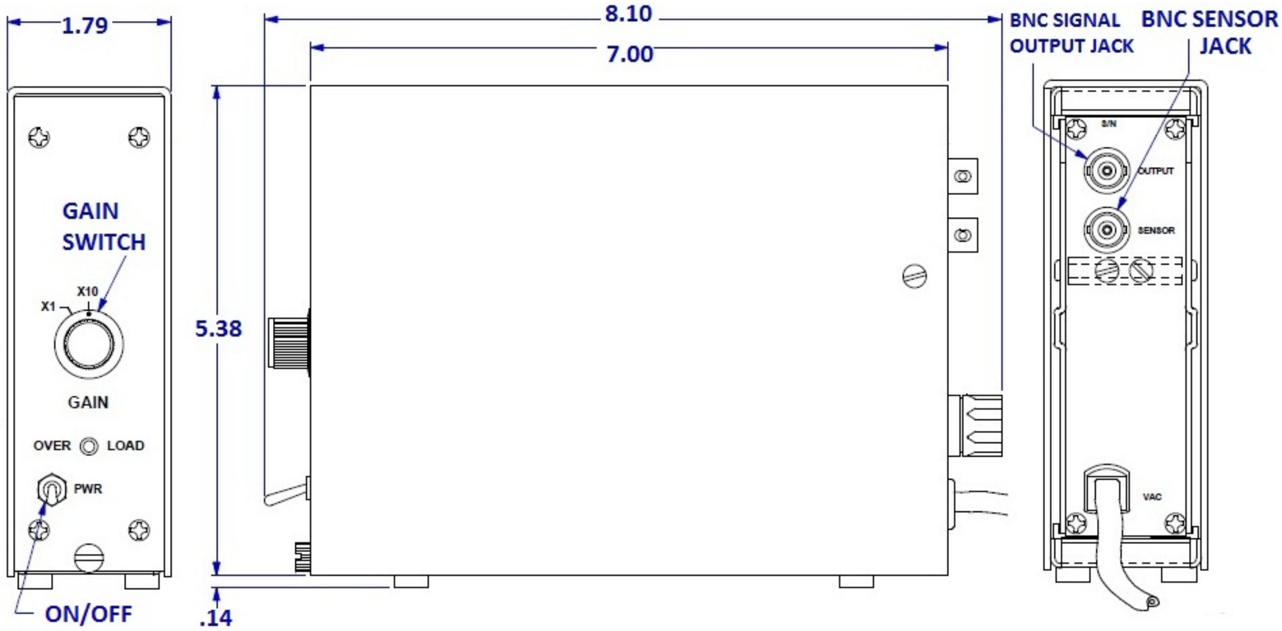



**Illustration 11: Final Detail Design**

# CHAPTER 4

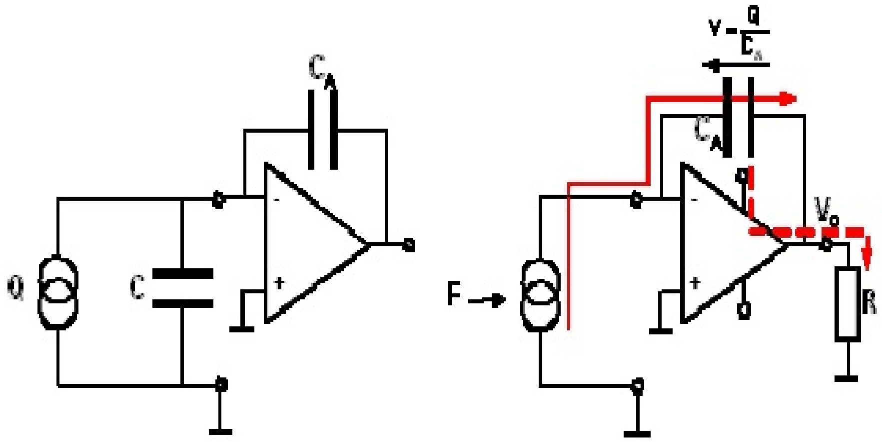
# 4. Manufacturing Process

## 4.1. Introduction

In this section the manufacturing process of the charge amplifier is explained, all the steps were followed and all results were recorded from the beginning. In addition, to carry out this project and to build the device, firstly the concepts and issues related to conditioning circuits to sensors must be studied. Materials, tools and laboratory equipment used during manufacturing are also cited below.

## 4.2. Basic Electronics used in this Project

Using a charge amplifier ensures that the electric charge Q, produced by a constant force F applied to the sensor, collects in capacitor CA turned into tension. This voltage appears directly on the amplifier output with the opposite sign, and is maintained even if the force applied to the sensor remains constant. The capacity of the sensor disappears because it is short-circuited to the ground through the amplifier.




$$V_o = -\frac{Q}{C_A} = \frac{kF}{C_A}$$

**Illustration 12: Representation of a Charge Amplifier**

The asymmetry voltages and amplifier bias currents cause the rapid decrease in the capacitor voltage due to integration of errors until the amplifier saturation. As a result, the amplifier circuit stops charging and the output signal loses the relationship with the input signal. To solve this problem we must ensure that the capacitor "CA" is discharged before starting the measurement. A switch is used to short out the capacitor permanently except during the measurement time.

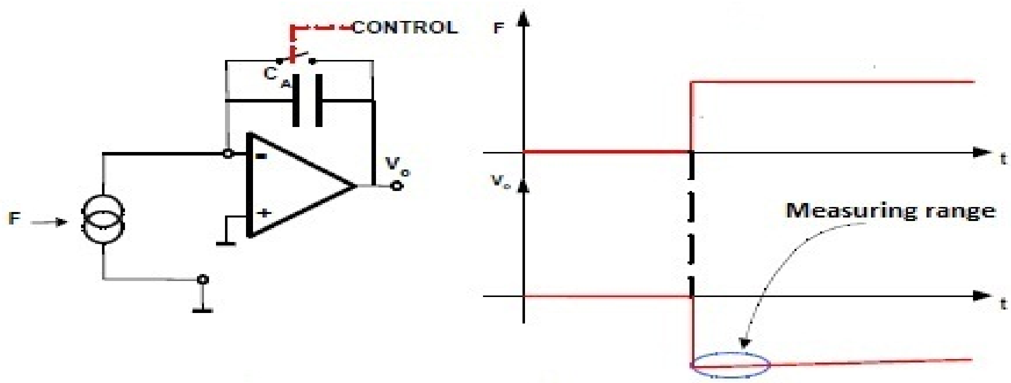



**Illustration 13: Shorting the capacitor**

A resistor is placed in series with the input in order to limit the negative peaks of the output voltage, although it introduces additional delays in the measurement. However, the circuit which has to be built in the first stage is a current-voltage converter. It makes a current-voltage conversion through a transimpedance amplifier.

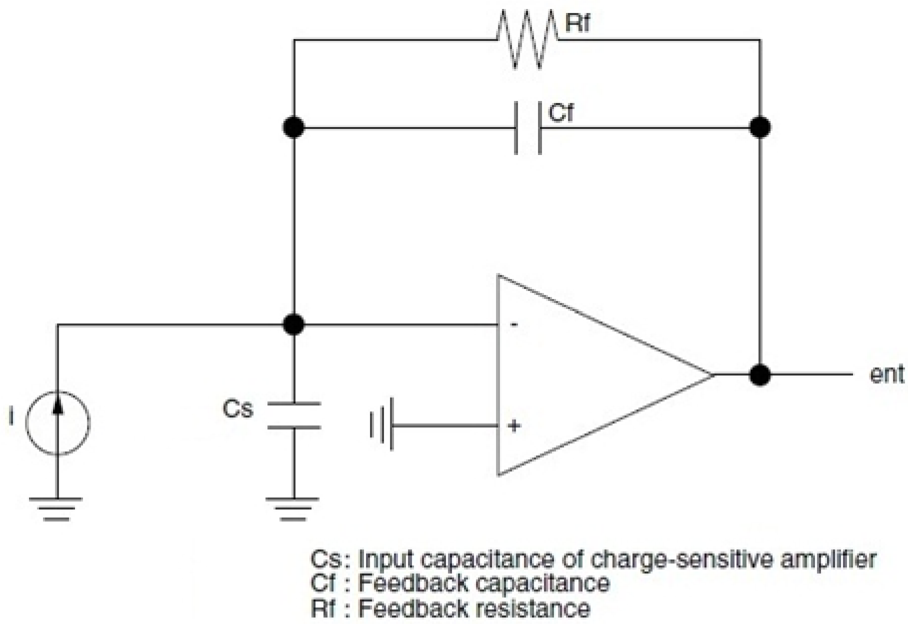



**Illustration 14: Transimpedance Amplifier**

Here, we can see an ideal charge amplifier for piezoelectric sensors which convert a small current signal into a big voltage signal. A capacitor is the input impedance of the circuit in order to get high impedance and low frequency. In the Output we get low impedance and a proportional voltage to the input current.

In order to calculate the magnitude of the impedances and capacitors the Theorem of Miller, Thévenin and Norton is implemented. Such calculations have not been included due to its complexity and length.

## 4.3. Materials

Materials which have been used throughout the project can be classified by:

- Workshop Materials and tools:
    - Power Supply
    - Digital oscilloscope
    - Analogical oscilloscope
    - Digital multimeter
    - Electric welder
    - Soldering tools

- Electronic material:
    - Resistors
    - Capacitors
    - Operational Amplifiers (LF351, LF356)
    - Potentiometers
    - Switchers
    - Diodes
    - Soldering board
    - electronic wires

- Reused and Recycled Materials:
    - An old computer casing
    - Power supply from an old computer
- Software:
    - Multisim 8

## 4.4. Manufacturing process

First of all a circuit was built with the intention of amplifying the sensor’s signal without taking into account the noise, gain and sensitivity.

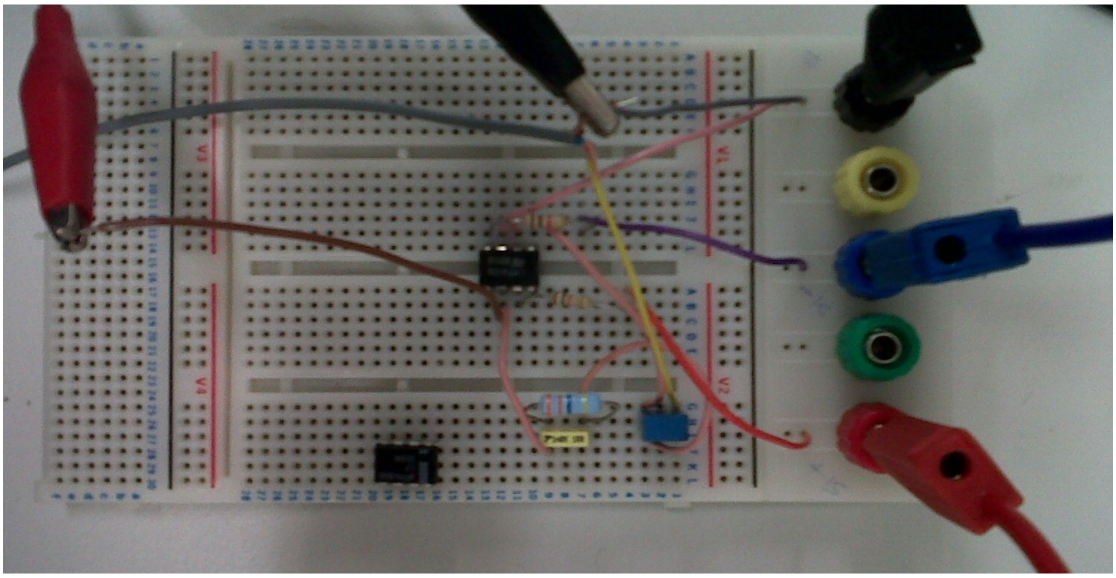


**Illustration 15: Provisional board**

It proceeded to solder the circuit after checking the correct operation on a provisional board in order to avoid errors.

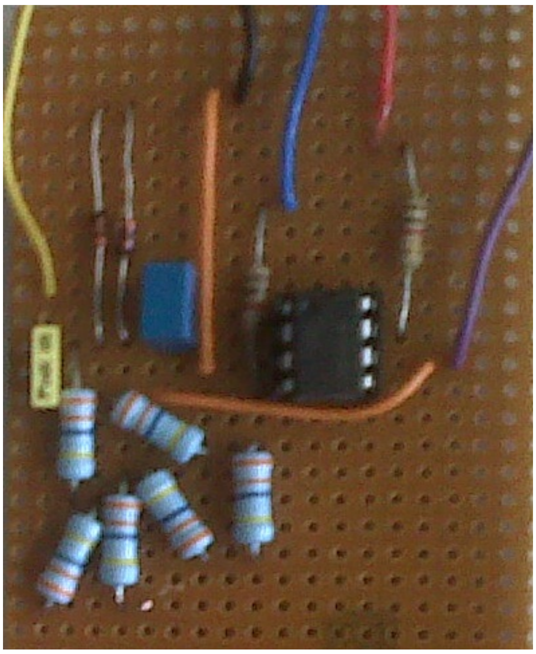


**Illustration 16: soldered circuit**

The result was better than expected and the voltage signal of the sensor was amplified 100 times (from approximately 10 mV to 1V), being shaken with the same intensity.

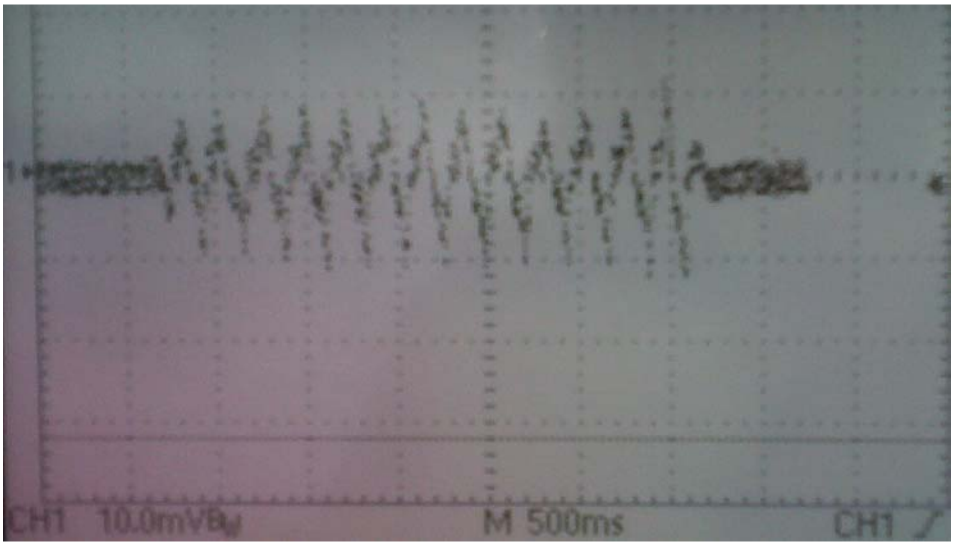



**Illustration 17: Signal of Piezoelectric sensor (10mV/Division).**

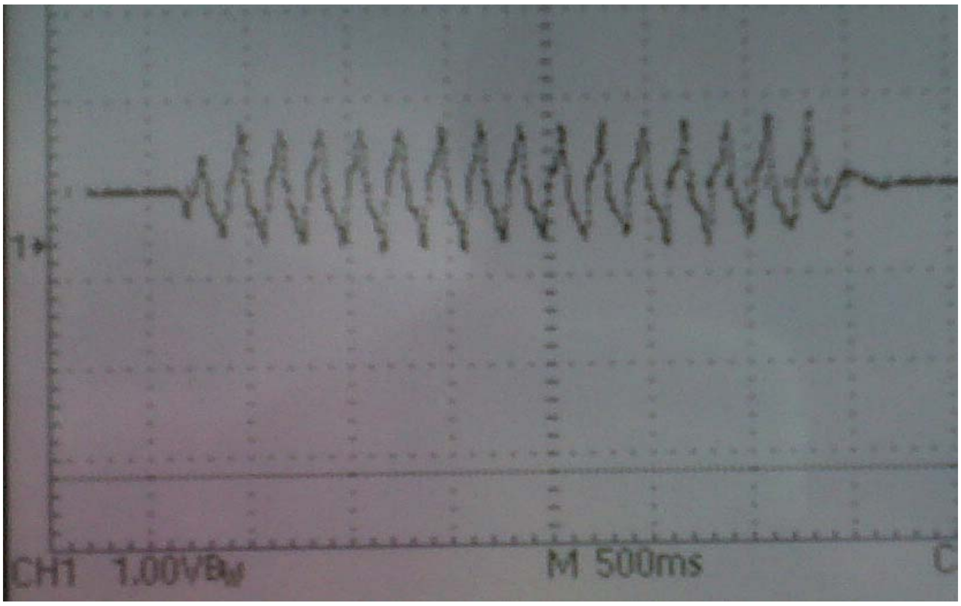



**Illustration 18: Amplified signal (1V/Division).**

At this point a charge amplifier circuit had been built. However, it did not include the building of a voltage amplifier circuit, a noise filter, thus affecting sensitivity and gain adjustment.

The next step was to build a voltage amplifier with capacitors to reduce noise and a potentiometer to adjust the Gain.

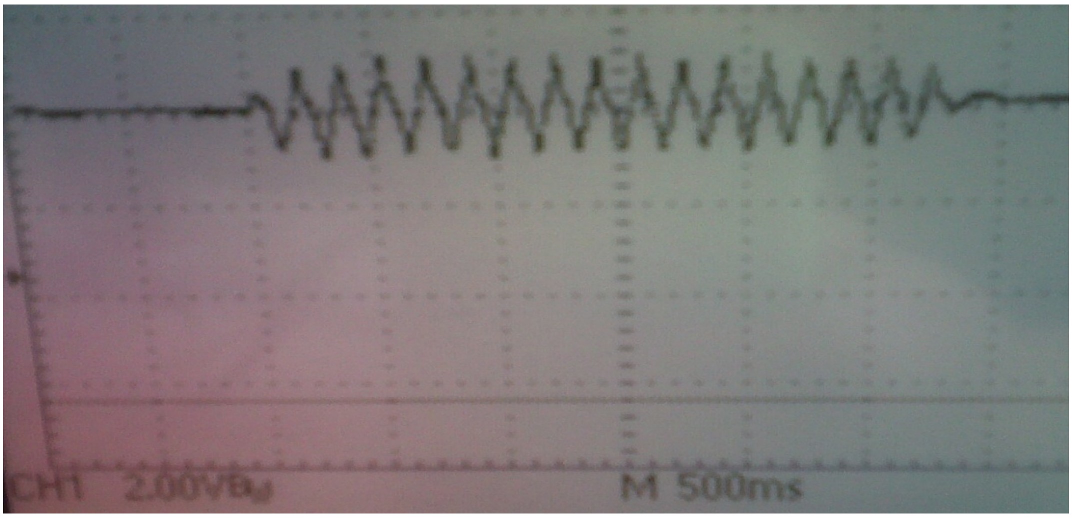



**Illustration 19: Second amplification stage (2V/Division).**

Finally, to finish the construction of the circuit, the last voltage amplifier stage with a switched resistor capable of controlling the signal sensitivity was made. Furthermore, a resistor was placed between the ground of the circuit and the device casing in order to absorb any external noise.

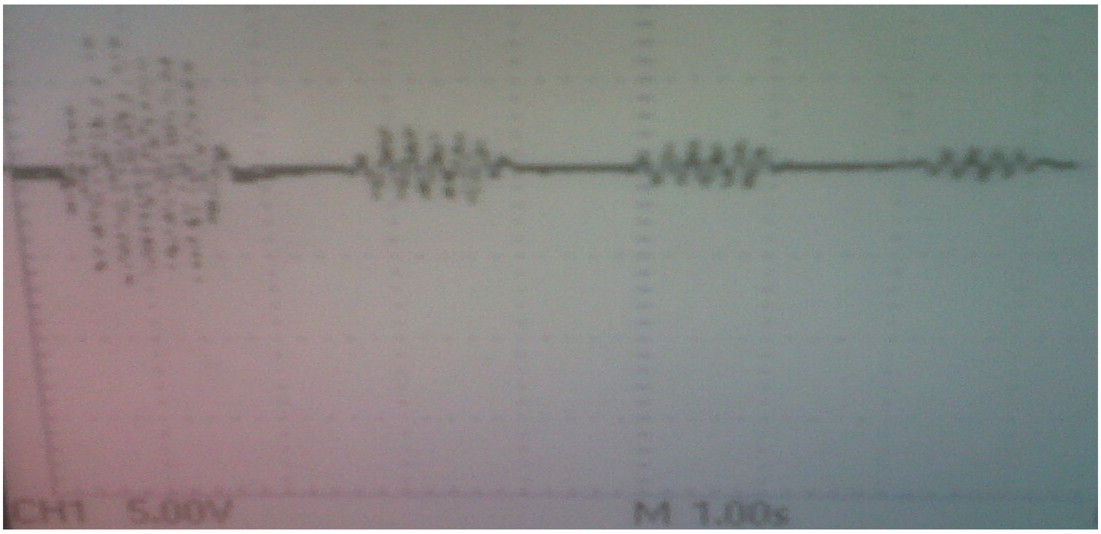



**Illustration 20: Adjust of gain and sensitivity (5V/Division).**

This image shows the variation of the sensitivity of reception of the signal produced by the sensor while the switching of resistors is changing.

The workshop staff were commissioned for the manufacture of the casing. They were informed that the casing had to comply with the requirements which were previously mentioned.

The building of the device was finished in the workshop by the staff through the following steps:

- Disassembly of the computer except the power supply
- Cutting of the casing to reduce the size shaping a tetrahedron
- Screw the circuits inside the casing
- Making the input and output connections
- Close the casing

# CHAPTER 5

# 5. Final Conclusion

## 5.1. The importance of recycling

Electronic devices are designed for a life span shorter and shorter. Given the volume of scrap that they generate, some vendors are betting on green technology. Electrical and electronic waste (computers and mobile phones) now account for 4% of the total waste in Europe, according to the Working Group for Waste Electrical and Electronic Equipment of the EU.

Most worrisome is that only 11% of this material is recycled. The European Environmental Bureau says that 90% of electronic waste is sent directly to landfills, burned or abandoned in any way. If a target of 70% of this waste was recycled, over 90,000 tonnes of metal, 30,000 tonnes of plastic and 13,000 tonnes of glass would be recovered.

Companies like IBM or HP, aware of the environmental problem and frightened by the so-called environmental tax announced by the U.S. government, they have developed their own recycling programs for obsolete computers in exchange for a fee ranging between 10 and 35 dollars.

Other companies have gone further and are about to bring out the organic computer. This is the case of the Japanese company NEC. The new PC will be called PowerMate ECO, and consists of a single piece that integrates the monitor, keyboard and CPU. It is made of special plastic material, a mixture of silica and polymer resin. In addition, the display has no boron, a metal widely used and is highly polluting. The price of an organic personal computer will be around 1,400£.

That is why it was decided to reuse an old computer to make the charge amplifier. Just by reusing the power supply would save between 20 and 50 pounds, in addition to environmental factors mentioned above. This is regardless of the cost of the casing construction, which has been minimized by reusing the computer case.

## 5.2. Final Conclusion

Given that I am a student of Industrial Technical Engineering and my specialty is Electricity, the knowledge and the skills learned have been vast. Despite the close relationship between electricity and electronics, most of what I have seen and used in this project was new for me.

On the one hand, it has been a very rewarding project for me and I have really enjoyed having been able to perform it. In addition, we have touched issues such as recycling and the effects of electronic devices in the environment, which are very trendy and are of vital importance in the field of engineering.

On the other hand, the adaptation to a new country, the differences between both universities, customs and especially the language were the hardest things for me. My period of transition was very long and it subtracted from the time I required for completion of my project. Also, my knowledge of electronics was too basic and I had to work very hard to improve it.

In conclusion, I think it was a good choice and I can say I'm proud to have studied at this university. Also, I have learned many things that will surely help me in the future.

## 5.3. Discussion of Conclusion

Despite the results obtained in this project, I would have liked to dispose of more time in order to improve it. I could have followed more closely the manufacturing process of the casing and I could have studied design improvements, as well as improvements to aesthetic and functional fields.

## 5.4. Further Development

As I said before, I would have liked to have more time to improve my project. I could have changed aesthetic and functional aspects. One of these aesthetic and functional aspects could have been to introduce a LED volt meter and a "Power ON" indicator. I also had thought about the possibility of introducing a fuse in a fuse holder to improve the device protection.

I also would have liked to think of a strategy to introduce this product in the market and compete with products from other companies with dignity.

## 5.5. Budget

Device Casing........................................................................................ 0£

Power Supply......................................................................................... 0£

Labour.................................................................................................. 0£

1mF Capacitor............................................................................... 0.15£

1nF Capacitor............................................................................... 0.60£

3 x 47mF Capacitor........................................................................ 0.45£

6 x 330KΩ Resistor........................................................................ 0.30£

2 x 1KΩ Resistor............................................................................ 0.20£

2 x 470KΩ Resistor........................................................................ 0.12£

180 Ω Resistor............................................................................... 0.10£

47 KΩ Resistor................................................................................ 0.06£

1.54 KΩ Resistor............................................................................ 0.75£

5.23 KΩ Resistor............................................................................ 0.05£

22 KΩ Resistor................................................................................ 0.40£

1.33 KΩ Resistor............................................................................ 0.11£

LF 351............................................................................................ 0.45£

LF 356............................................................................................ 1.02£

Board circuit.................................................................................... 0.5£

2 x Zs 151 Diode............................................................................ 1.66£

10K Potentiometer............................................................................. 1£

TOTAL.............................................................................. 7.92£

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