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TREBALL FINAL DE GRAU

TÍTOL DEL TFG: Experimental setup building and test for a drop tower

TITULACIÓ: Grau en Enginyeria d'Aeronavegació

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Resum

En aquest document s’exposa un experiment que es realitzarà a la torre de caiguda lliure del ZARM. Ha estat desenvolupat al Laboratori de Microgravetat ubicat a l’Escola d’Enginyeria de Telecomunicacions i Aeroespacial de Castelldefels. Continuant amb la línea de recerca del laboratori, l’experiment pretén estudiar la viabilitat de l’ús d’ones acústiques per gestionar processos d’ebullició en condicions de microgravetat.

Les tasques que es presenten en aquest treball són les que he dut a terme durant el desenvolupament del projecte. La meva responsabilitat dins d’aquest experiment ha consistit en realitzar feines tan diverses com la definició dels requeriments, la selecció i distribució dels dispositius i elements que el conformen, el disseny i la fabricació de l’electrònica necessària per al seu correcte funcionament, una proposta del disseny estructural i finalment, en fer una sèrie de validacions.

Tot i que l’experiment encara no està acoblat, en aquesta memòria també estan incloses les diferents fites per finalitzar exitosament el seu muntatge i per garantir els resultats desitjats.

Per últim, s’inclouen una sèrie de discussions sobre els resultats obtinguts que permetran acabar de definir tots els elements que conformen l’experiment.

Title: Experimental setup building and test for a drop tower

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Overview

This document presents an experiment that will be carried out in the ZARM's drop tower. It has been developed at the Microgravity Laboratory located at the School of Telecommunications and Aerospace Engineering of Castelldefels. Following the research line of the laboratory, the experiment aims to study the feasibility of using acoustic waves to manage boiling processes under microgravity conditions.

The tasks shown in this work are the ones that I have carried out during the development of the project. My responsibility within this experiment has been to perform tasks as diverse as the definition of the requirements, the selection and distribution of the devices and elements that make it up, the design and manufacture of the electronics that were necessary for its correct performance, a proposal of the structural design and finally, make some validations.

Although all the parts of the experiment are not still joined, the steps to follow in order to successfully complete its assembly and to guarantee the desired results are included in this memory.

Finally, a series of discussions on the obtained results are included that will allow to define all the remaining elements that are also part of the experiment.

Acronyms

ISS International Space Station
LED Light-Emitting Diode
PCB Printed Circuit Board
IMU Inertial Measurement Unit
SD Secure Digital
fps frames per second
TBD To Be Defined
COG Centre of Gravity
PZT Piezoelectric Transducer
GND Ground
LSB Lowest Significant Bit
FS Full Scale
DC Direct Current
RX Receiver
TX Transmitter

CONTENTS

CHAPTER 1. INTRODUCTION

Cryogenic fuels are the best option in order to carry out long distance space missions. However, the main problem lies with their low storage temperature in microgravity conditions. Microgravity is the condition that appears when an object is accelerated freely as a result of a gravitational force. Under this condition, heat and mass transfer mechanisms vary and convection decreases as a consequence of solar radiation. Vapour bubbles under reduced g-forces cannot rise up the liquid phase as in normal gravity conditions and therefore, engine's efficiency is reduced and turbo pumps are endangered. This project aims to contribute to improve this engine's efficiency by designing and constructing an experiment which aims to control the boiling processes that take place inside the tanks. Our main goal is to demonstrate that bubbles can be managed by acoustic waves in microgravity conditions while there is a liquid motion. When a bubble in a liquid is subjected to an acoustic field, the resulting bubble oscillations can interact with the field, giving rise to the Bjerknes forces. The Bjerknes forces are powerful driving forces for bubble translation. Bubbles are moved to the pressure nodes or antinodes depending on their size [1]. The experiment will be designed as a flow boiling instead of a pool boiling [2].

Due to its requirements, the fact of performing our experiment in microgravity conditions is completely necessary. Satellites, the International Space Station, parabolic flights, sounding rockets and drop towers are feasible in order to do microgravity related experiments. Thus, the ZARM's drop tower has been chosen for our study because it achieves good enough microgravity conditions. Located in Bremen, Germany, the drop tower is the main facility of ZARM. With a height of 146 meters, it can reach a maximum time period spent in microgravity of 9.3 seconds (when it is used in a catapult mode) with a residual gravity level of 10^{-6} g [3].

This project has been developed in the Microgravity Laboratory located in the Castelldefels School of Telecommunications and Aerospace Engineering (EETAC) of the Universitat Politècnica de Catalunya-BarcelonaTech (UPC). This is not the first study focused on this field. The Laboratory started its activities on 2005 and similar experiments (Fig. 1.1) have been tested in some REXUS (Rocket Experiments for University Students) [4], SL (Space Loft) and also in the ZARM's drop tower. First studies were done by injecting bubbles but, the technique was changed and nowadays boiling is produced. Moreover, the liquid used now is also different; water has been replaced by HFE7100.

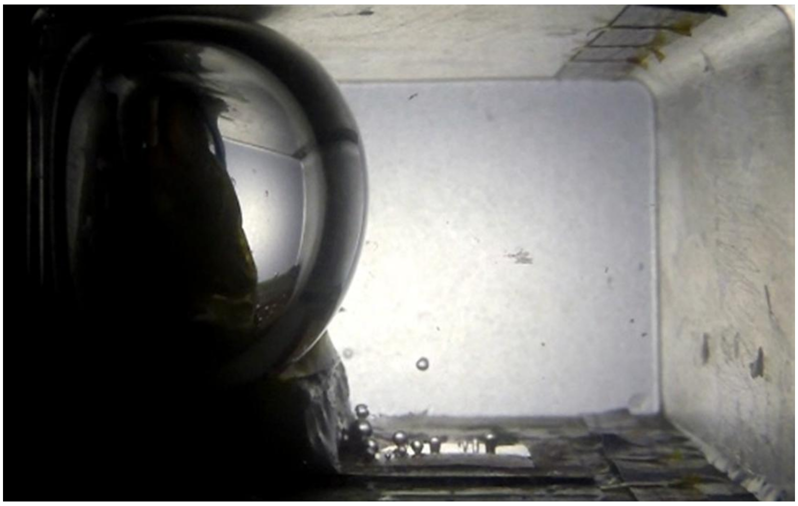


Fig. 1.1 Previous pool boiling experiment results obtained on a REXUS flight developed at the Microgravity Lab (UPC)

Nowadays, the Microgravity Laboratory participates in an international experiment, "Boiling", that will be launched in a few years into the ISS. The experiment which is presented in this project, is going to test and validate some technologies required for the “Boiling” experiment (the feasibility of introducing an acoustic wave generator system capable of manage the bubbles motions and heat transfer processes) so, it is a technological demonstrator.

1.1 Experimental setup

In general terms, the experiment will consist on four subsystems, the flow generation system, the boiling generation system, the acoustic wave generation system and the data acquisition system.

The flow generation system is composed by a circuit that joins, with the appropriate connections and cabling, a test cell and a pump in order to achieve the desired flow circulation. A flow meter and a pressure meter are integrated into the circuit to get information about the fluid.

Then, we have the test cell in which are allocated the boiling generation system and the acoustic wave generation system (but they are controlled from outer devices). Those systems are formed by a heater (powered by a 12V DC/DC regulator) to produce boiling and, a piezoelectric transducer which creates acoustic waves that enable us to manage the bubbles that are being generated. (Signals are generated with a function generator that is contained in a computer. After that, they are sent to a power amplifier and finally, to the PZT.) In addition, the test cell has three windows with the aim of locating two different cameras to record all the processes that occur inside and a LED panel. The first camera is a thermal one and the other one is a high-speed camera provided by ZARM. An additional camera, a GoPro, records an overview of the experiment which will allow us to check if everything is correct.

Finally, the data acquisition system is in charge of measuring the set of parameters from which the experimental data will be analyzed. Five thermocouples will be placed which are useful because they will report us the temperature of five different devices and, it enables us to ensure that the components are working safely. An accelerometer will be used to know the microgravity values that our experiment reaches during the free fall. The flow meter, the pressure meters and the cameras are also integrated on the data acquisition system but their outputs are directly connected into the experiment computer or the ZARM's module.

The necessary PCBs to achieve a correct performance of all the components have been designed by us. With these PCBs, two computers and two Arduinos, we can manage all the devices, get data and store it.

1.2 Equipment distribution

Experiments tested at ZARM's drop tower are introduced inside a capsule (Fig. 1.2) which is pressurized to atmospheric pressure as well as shockproof in order to resist the acceleration/deceleration forces. Its main components are: a base structure, four stringer racks for experiment accommodation, a pressurizable hull, and a lid plate with interfaces and release bolt.

Fig. 1.2 Standard drop capsule (pressurizable cover is removed), short version [5]

The experiments are assembled by parts on different platforms that are connected to the stringers of the rig in variable height (depending on the experiment requirements heights are modified by users). Finally, the stringer rig is set on the base structure and fixed. ZARM ships the required number of platforms to the experimenter when an experiment is foreseen for a drop tower campaign.

Three different versions of drop rigs of different height of the payload area are available (Fig. 1.3).

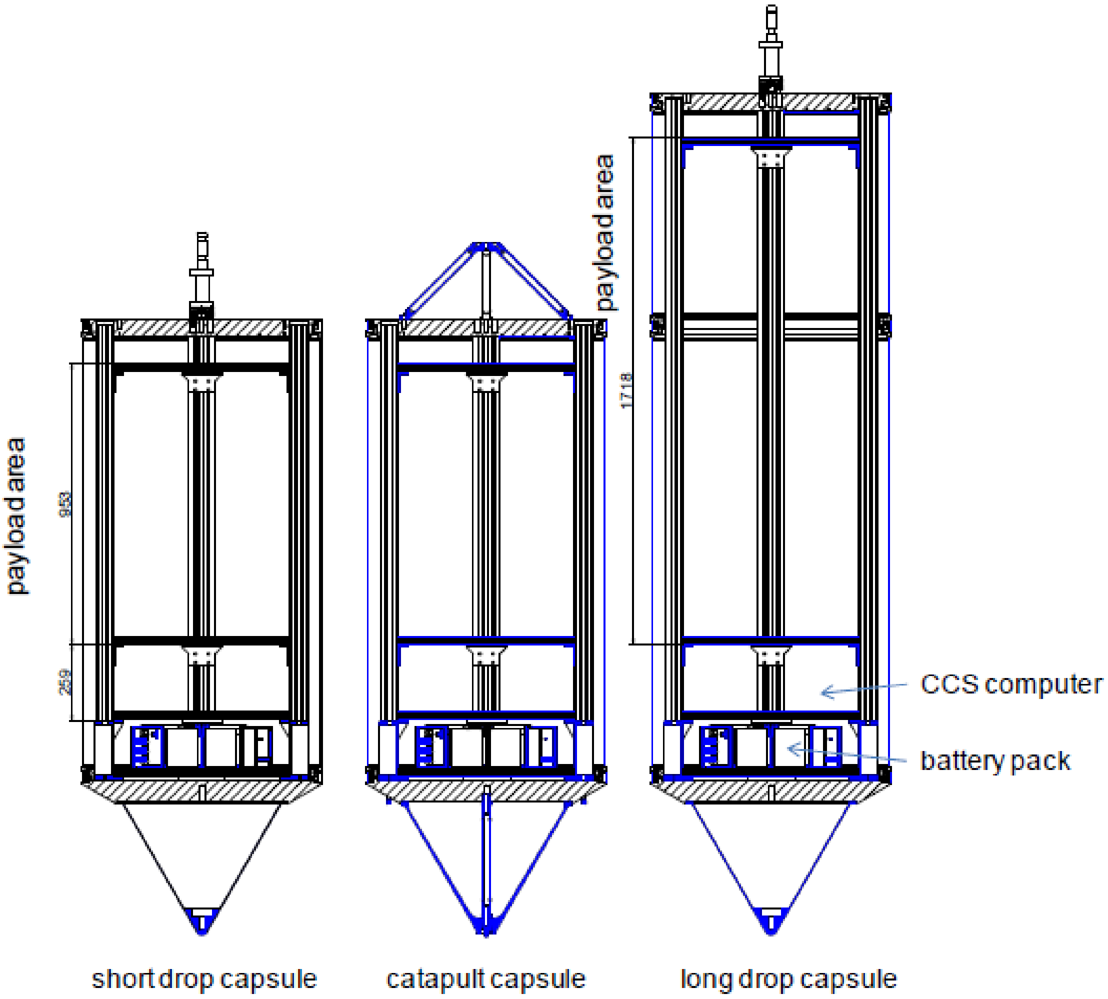


Fig. 1.3 The three versions of the drop tower capsule [5]

(For catapult mode experiments only the short capsule version is available.)

The capsule should not be larger than necessary. In order to accommodate our experiment, it is enough with the short capsule version (with only three platforms). In Fig. 1.4 and Fig. 1.5 we propose a distribution for the most important devices in our experiment.

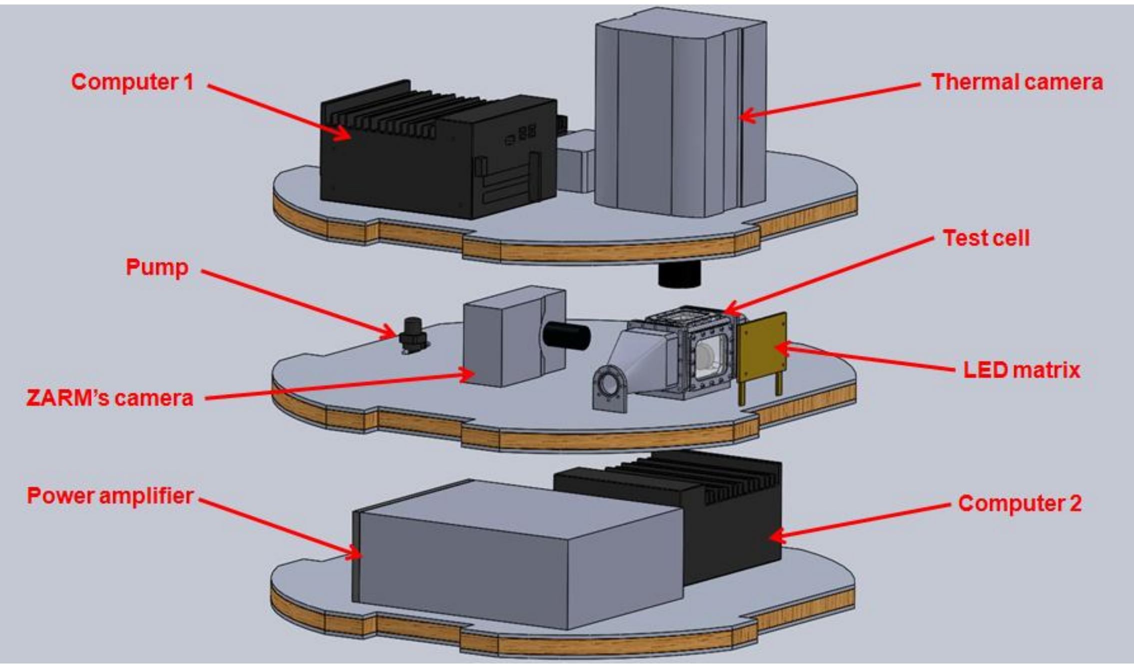


Fig. 1.4 Experiment devices distribution view 1

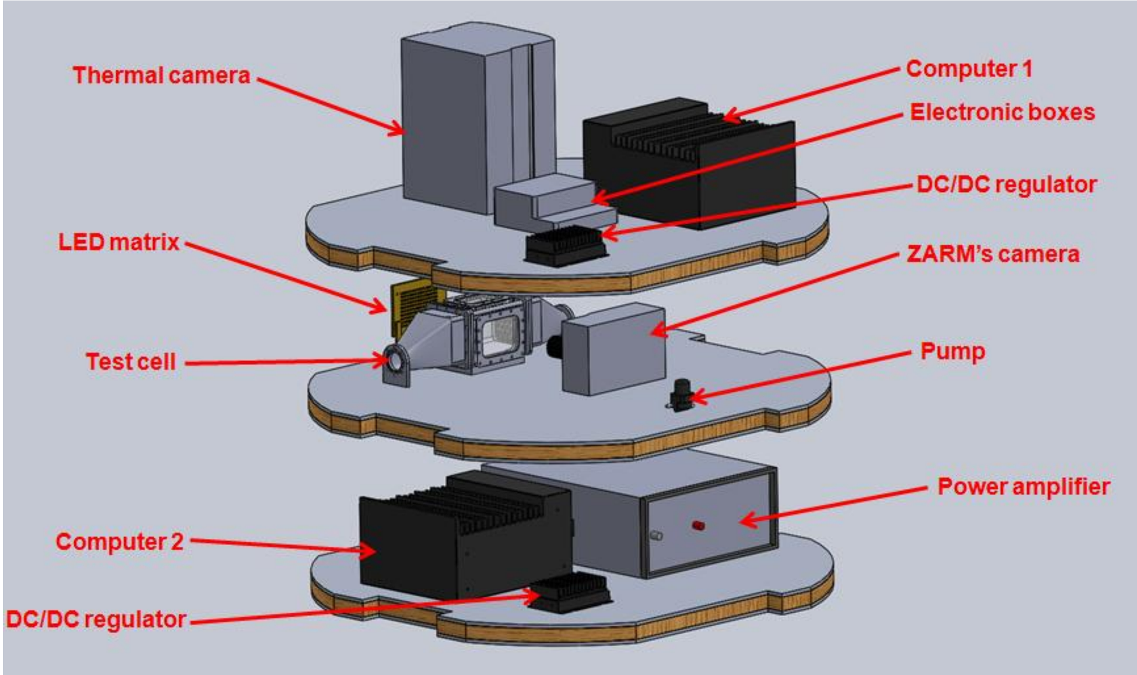


Fig. 1.5 Experiment devices distribution view 2

The distribution shown above has been thought in order to allocate on the upper platform all the PCBs and a computer for data acquisition. On the lower bulkhead it can be seen the computer which controls power stages (pump, heater, power amplifier and acoustic wave generation). The middle platform is where the experiment takes place.

Power distribution and communications block diagrams are shown in Fig. 1.6 and Fig. 1.7, they will help to have an overview of all the components that conform our experiment and how they are interfaced.

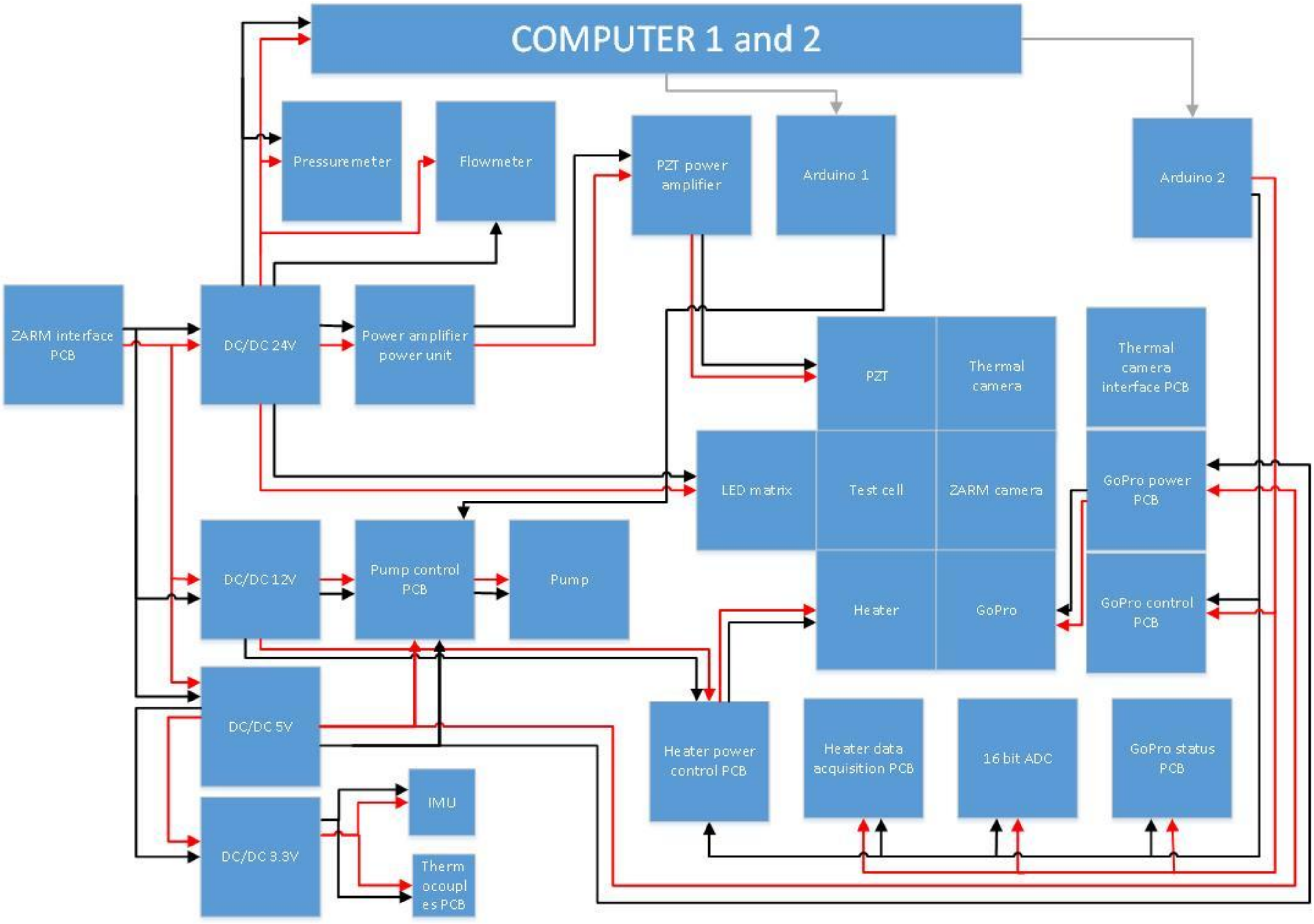


Fig. 1.6 Power distribution block diagram

In Fig. 1.6 we observe that the experiment contains devices that need different voltage inputs. For this reason, four DC/DC regulators are used: 3.3V, 5V, 12V and 24V (power is provided by ZARM from 24V DC batteries that do not regulate the output voltage).

On one hand, a 24V voltage supply is given to the computers, the pressure meter, the flow meter, the power amplifier unit and the LED matrix. For the pump control PCB and the heater power control PCB 12V are required. On the other hand, the DC/DC 5V regulator powers the 3.3V DC/DC regulator, the pump control PCB and the GoPro power PCB. Finally, for the IMU (or accelerometer PCB) and the thermocouples PCB the necessary voltage supply is 3.3V.

ZARM is responsible of managing its camera in terms of power supply and communications and the thermal camera has not been decided yet (this is why they are not connected in our diagrams).

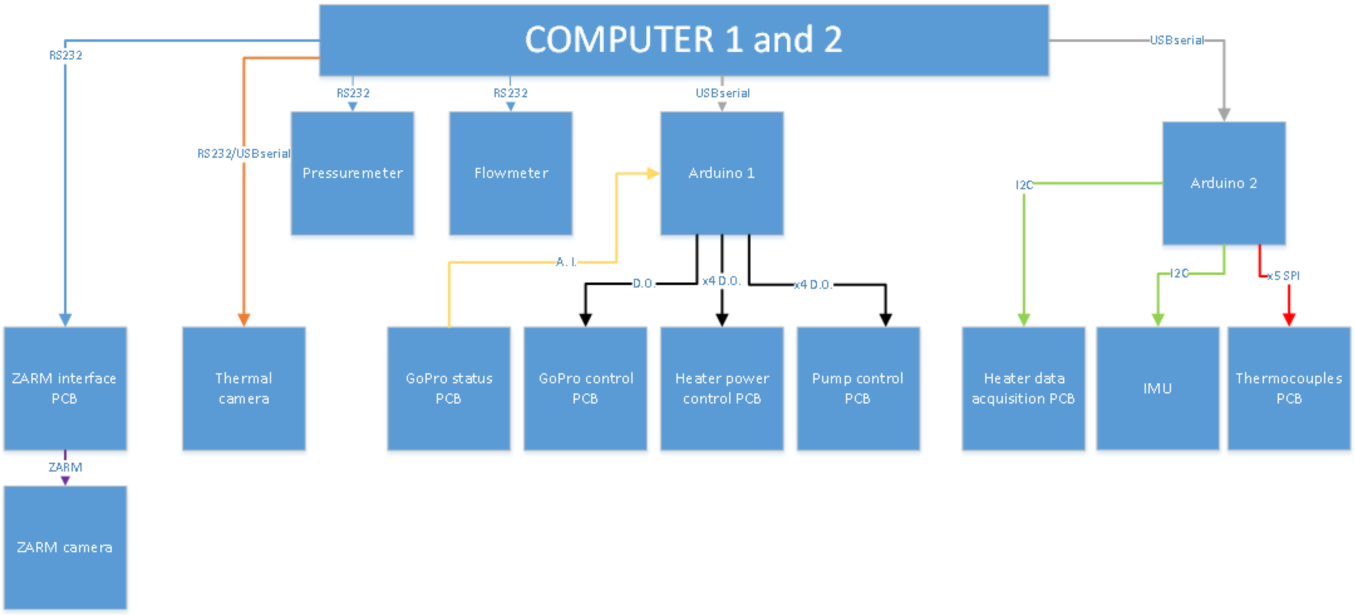


Fig. 1.7 Communications and signals block diagram

As it can be observed in Fig. 1.7, communications are basically USB serial, RS232, SPI and I2C.

Serial communication is the process of sending data one bit at a time, sequentially, over a communication channel or computer bus. RS232 is a standard for serial communication transmission of data. It has three lines: one for data transmission, another one for data reception and a third one in order to shortcut grounds. USB serial works similar to RS232 but they work with different voltage levels.

SPI is an interface bus commonly used to send data between microcontrollers and small peripherals such as shift registers, sensors, and SD cards. It uses separate clock and data lines, along with a select line to choose the device you wish to talk to.

I2C is a protocol intended to allow multiple “slave” digital integrated circuits (“chips”) to communicate with one or more “master” chips. It is only intended for short distance communications within a single device and it only requires two signal wires to exchange information.

Communications between the computers and the ZARM interface PCB, the flow meter and the pressure meter are RS232. Between the computers and the Arduinos, USB serial is used. These communication protocols are implemented because they are required by ZARM or by the device itself. Finally, in order to communicate the Arduinos with the IMU the chosen protocol is I2C while, for the thermocouples, we have decided to use SPI. I2C and SPI are used because they are faster than serial. It is not necessary to have the five thermocouples measuring at the same time (as far as the sampling frequency is high enough) because the temperature time response of the devices being controlled is quite low.

As explained before, the thermal camera has not been chosen yet but, it would be ideal that the selected camera allows us to use an USB serial or a RS232 interface to be able to communicate with the computer.

CHAPTER 2. EXPERIMENT REQUIREMENTS

In this chapter the requirements that our experiment must accomplish will be presented. It has to be mentioned that there are four different types of requirements: functional, performance, design and operational requirements.

2.1. Functional requirements

Functional requirements describe the tasks that the experiment has to fulfil to achieve our objectives.

INDEX	REQUIREMENTS
F.01	The experiment shall heat the liquid in the test-cell
F.02	The experiment shall apply different acoustic waves inside the test-cell
F.03	The experiment shall measure the heat flux of the heater
F.04	The experiment shall measure the temperature inside the test-cell
F.05	The experiment shall record a high-speed video of the phenomena inside the test-cell
F.06	The experiment shall measure accelerations suffered in different axis during the free fall
F.07	The experiment shall store all data on board
F.08	The experiment shall store the current status of the systems on board
F.09	The experiment shall be able to produce a liquid flow
F.10	The experiment shall record a video of the phenomena inside the test-cell in infrared spectrum
F.11	The experiment shall be able to be operated by telemetry and telecommand

Table 2.1 Functional requirements

2.2. Performance requirements

Performance requirements quantify the fulfilment level of functional requirements. Usually, performance requirements are calculations, technical details, and other specific functionalities that a system or component must accomplish.

INDEX	REQUIREMENTS
P.01	The heater shall be able to use a power of 6W to generate boiling
P.02	The liquid flow shall be between 0 and 10 cm/sec in the test cell
P.03[1]	The flow measurements shall be made at a rate of 10Hz
P.04	The liquid flow measurements shall be made with a range of 0-2 m/sec after the pump
P.05	The liquid flow measurements shall be made with a resolution of 5 cm/sec on the pump
P.06	The liquid flow measurements shall be made with an accuracy of 5 cm/sec on the pump
P.07	The pressure should be between 250 mbar to 1.5 bar inside the test cell
P.08[1]	The pressure measurements shall be made at a rate of 10Hz
P.09	The pressure measurements shall be made with a range of 0.2-2 bar
P.10	The pressure measurements shall be made with a resolution of 100 mbar
P.11	The pressure measurements shall be made with an accuracy of 200 mbar
P.12	The acoustic waves shall be generated during the microgravity phase
P.13	The acoustic system shall generate progressive waves of frequencies 5,10,15,20,25,30 and 35 kHz (may be modified in dependence of the experimental protocol)
P.14	The piezoelectric transducer shall be powered with at least 10W
P.15	The acoustic waves shall vary their amplitude using a power supply of providing a range of voltatges between 0–200V_{pp}
P.16[1]	The heat flux measurement shall be made at a rate of 10 measurements every second
P.17	The heat flux measurements shall be possible between 0 and 40W/cm2
P.18	The heat flux measurements shall be made with a resolution of +/- 0.5W/cm^2
P.19	The heat flux measurements shall be made with an accuracy of +/- 2W/cm^2 in the test cell
P.20[1]	The house keeping temperature measurement shall be made at a rate of 25 measurements every second
P.21	The temperature range shall be possible between -20 and 90ºC
P.22	The temperature measurements shall be made with a resolution of +/- 0.1ºC

P.23	The temperature measurements shall be made with an accuracy of +/- 0.1ºC
P.24[1]	The acceleration measurements shall be made at a rate of 800 measurements every second
P.25	The acceleration measurements shall be made with a resolution of +/- 0.005 g
P.26	The acceleration measurements shall be possible between 0 and 6 g
P.27	The acceleration measurements shall be made with an accuracy of +/- 0.01 g
P.28[1,2]	The ZARM camera should record in 512x512 1000 fps for catapult mode and 2000 fps for normal mode
P.29	The IR camera should record in TBDxTBD TBD fps for catapult mode and TBDfps for normal mode
P.30[1]	The GoPro camera should record in 720 p120 mode
P.31	The total power consumption shall be lower than 70Wh
P.32	The system peak power consumption shall be lower than 200W

Table 2.2 Performance requirements

[1] The frame rates have been chosen depending on the expected time response of the physical phenomena being observed.

[2] For the catapult mode, the microgravity phase takes longer in time than the drop mode. If the fps are mantained the camera buffer will be saturated and only one part of the experiment will be recorded.

2.3. Design requirements

Design requirements are the ones that we must take into account when creating our experiment. They are limitations due to dimensions, weight, temperature, pressure, etc. Functional and performance requirements are imposed by the experiment creators but, design requirements can come from other sources: ZARM’s drop tower limitations [5], the capsule used, safety restrictions, legal limitations...

INDEX	REQUIREMENTS
D.01	The overall weight of a platform (including the platform itself) shall not exceed 100 kg
D.02	The experiment should fit in a catapult capsule or in a short drop capsule
D.03	The module's internal thermal dissipation must not heat up the outer structure more than 10ºC above the ambient temperature
D.04	The module's internal thermal dissipation must not heat up the parts close to or in contact with the feed-through cable to more than +70ºC
D.05	An absorbent material shall be used at the top and bottom of the platform so that the possibility of fluid being transferred to other platforms is eliminated
D.06	Point load of a platform (to the centre) shall not exceed 50 kg
D.07	The distribution of mass should be evenly. The mass eccentricity should be as low as possible. If mass eccentricity is too high, additional counterbalance masses (accumulated to the payload) will be mounted to the rig at ZARM
D.08	The COG has to be within a circle of 1 mm in diameter around the vertical geometrical Catapult Capsule centre line (vgCCcl)
D.09	The experiment systems shall be able of withstand longitudinal shock forces of 50 g
D.10	The overall height of the experiment may not exceed 953 mm (short capsule)
D.11	The maximum overall mass of the drop capsule is 500 kg (400 kg catapult mode)
D.12	The test-cell shall contain a honeycomb wall in order to uniform the flow distribution
D.13	The capsule moment of inertia should vary less than 0.1 $kg \cdot m^2$
D.14	The downlink data rate shall not be greater than 500 kbps
D.15	The signal power in the PZT shall be amplified with a power amplifier
D.16	The camera shall look directly into the test-cell
D.17	The LED matrix shall face the camera form the opposite side of the test-cell

D.18	The test-cell shall have attached to the window closer to the LED matrix a diffuser sheet
D.19	The heater and the PZT shall be in contact with the test-cell from the inside and they should be in perpendicular faces between them
D.20	The test-cell shall have a valve to control overpressures inside it
D.21	The test-cell shall connect to a waste tank to collect fluid coming out from the overpressure valve
D.22[3]	The experiment shall retrieve data from all experiment sensors and status
D.23[3,4]	The ground segment shall store the received data from the sensors
D.24[3]	The ground segment shall decode the received data into readable data sets
D.25[3]	The ground segment shall display the free fall and experiment status
D.26	The overpressure valve shall be activated once 1 bar of pressure is achieved inside the test cell

Table 2.3 Design requirements

[3] The telemetry will download all the data from the sensors to let the user of the ground station check rather if the devices are properly behaving or not.

[4] The ground station will store the data as a redundant system just in case the onboard computer has a malfunction during the free fall.

2.4. Operational requirements

Operational requirements are the ones which ensure that the experiment is handled and operated safely and reliably.

INDEX	REQUIREMENTS
O.01	The experiment shall be capable of being turned on and off repeatedly while on the tower platform
O.02	The experiment shall operate the heater and acoustic wave generator autonomously or by telecommands
O.03	The experiment shall take measurements autonomously
O.04	The module shall be turned off after the free fall

O.05	Access to the test-cell from the outside should be provided to fill the test-cell with HFE7100 [6]
O.06	The experiment shall execute commands based on specific signals received from the control module
O.07	The experiment protocol shall start when switched on
O.08	The experiment segment shall activate the acoustic wave generator, the heater, the accelerometer and the thermocouples
O.09	The liquid shall be stored at a temperature between 0ºC and 30ºC

Table 2.4 Operational requirements

CHAPTER 3. ELECTRONICS

In the first chapter, the requirements that our experiment must fulfil were presented. Some of them were about electronics and, in order to accomplish them, we have designed and manufactured the necessary PCBs.

3.1. Power control PCBs

3.1.1. Pump PCB

The goal of this PCB is to provide power to a pump for control of the liquid flow produced. The maximum power allowed in the pump is 6W and with this PCB we are able to provide not only the maximum power but also 4.5 W, 3 W and 1.5W. For doing this function four Arduino signals are used to activate transistors (NPN working as a switch), but as far as the pump needs some special connections, the output of this transistors is powering a set of relays that are connected to the power lines of the pump.

In a previous version of this PCB, pump connections were designed only with transistors but, the pump needs to be connected to the circuit's ground reference. This is the reason why the maximum voltage fall that we could observe was of 5V. On the other hand, another version was produced using only relays but, the required current was too high and, when the relays were activated, the sensors powered from the Arduino suffered a modification on its output (and sometimes the Arduino was not able to activate them depending on the amount of devices connected to it). For this reason, the relays are activated using an external source that can be switched on using some transistors controlled with the Arduino (Fig. 3.1). In this way, the power requirements on the Arduino are minimized while being able to control the power line given to the pump.

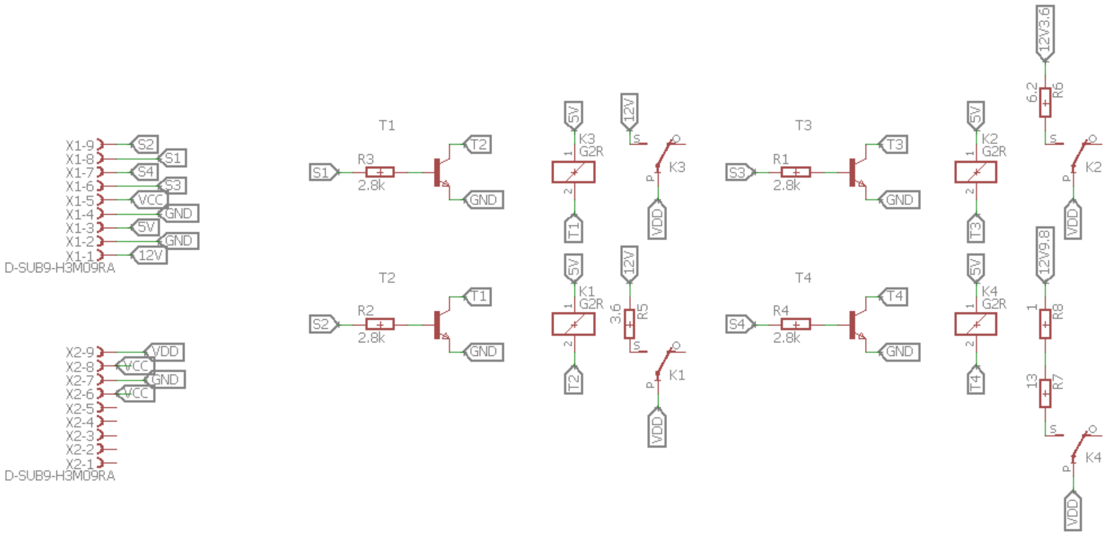


Fig. 3.1 Pump PCB schematic

The PCB also has two different d-sub 9 connectors, one used for the inputs of this PCB and the second one used as a direct connection for the pump.

PINS	D-SUB 9 INPUTS	D-SUB 9 PUMP CONNECTIONS
1	12 V	-
2	GND	-
3	5 V	-
4	GND	-
5	VCC	-
6	Arduino trigger 1	VCC
7	Arduino trigger 2	GND
8	Arduino trigger 3	VCC
9	Arduino trigger 4	VDD

Table 3.1 Interface of the pump PCB trough d-sub 9 connectors

Depending on the VCC’s value, the pump will work on one direction or another. In the d-sub9 pump connections, we have shortcut VCC because the pump is only wanted to operate in a given direction.

Finally, on the PCB board four different holes were implemented for allowing this PCB to be attached with screws into in aluminium box that is grounded for reducing capacitive interferences (Fig. 3.2 and Fig. 3.3).

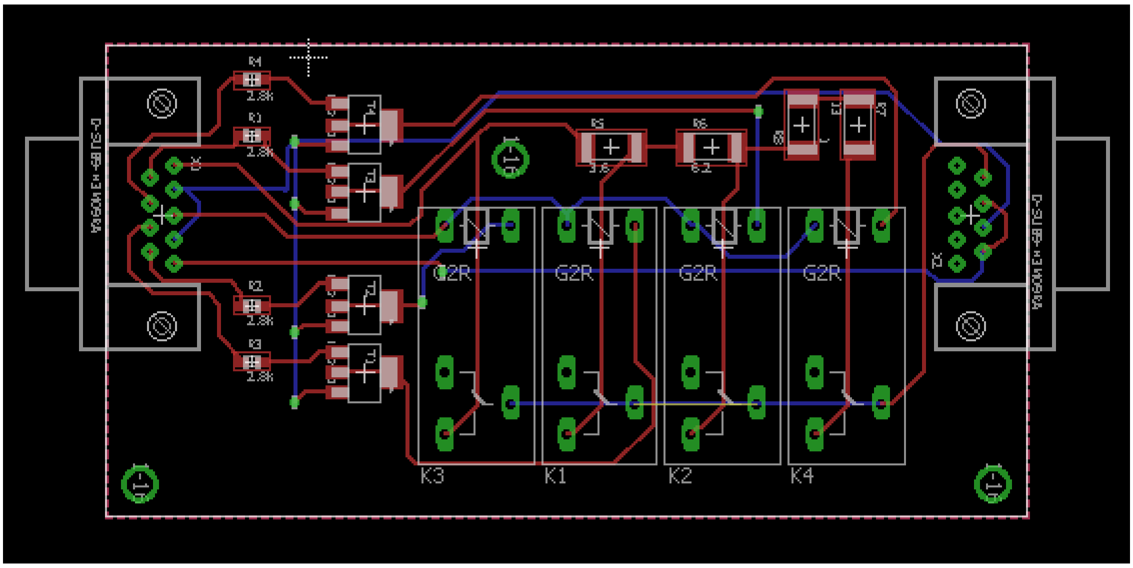


Fig. 3.2 Pump PCB board

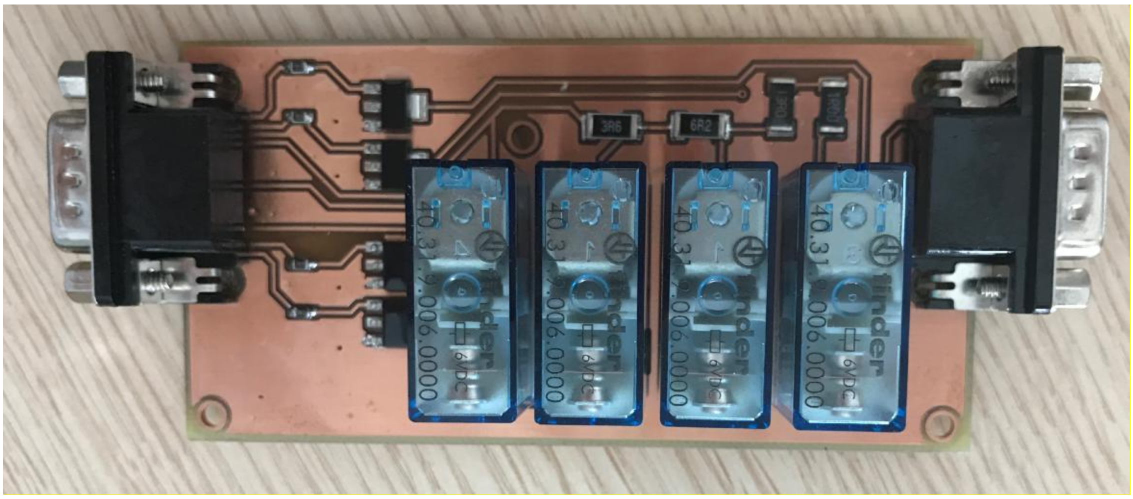


Fig. 3.3 Pump PCB

3.2. Data acquisition PCBs

3.2.1. Thermocouples PCB

This PCB is designed with five K thermocouples that measure the temperature of five different devices in the experiment. The data that they give us is useful because it enables us to know that everything is working properly in the experiment and prevent overheating any system on the experiment (Fig. 3.4).

The thermocouples are for housekeeping measures but the devices that they will analyse have not been decided yet. The most possible is that we record the temperature on the computers, the DC/DC regulators and the test cell liquid but it might change.

All these thermocouples are conditioned using the MAX31855KASA+ amplifier. These amplifiers were selected because they have a digital output which avoids possible interference sources appearing on the PCB that could affect the observed measures (the only two possible interference sources are variations on the power supply level and conductive, capacitive or inductive interferences that can appear on the thermocouple). Thermocouples are soldered directly to the MAX31855KASA+ pads to obtain more accurate measures avoiding a cooper connection between the thermocouple and the amplifier (Fig. 3.5 and Fig. 3.6).

Communications with the Arduino are SPI. Consequently, it is not possible to measure the temperature of the five thermocouples at the same time but, with a very high sampling rate we can minimize this problem. Moreover, as far as this temperature is for housekeeping and the dynamics of those measurements will be quite slow (temperature does not vary too much with time) even if these measurements are not recorded at the same time, it won’t affect the experiment results.

In a previous version, this PCB had a DC/DC regulator incorporated. Finally, it was decided to design a common DC/DC regulator (which will be presented later) for all the sensors PCBs that need to be powered with 3.3V.

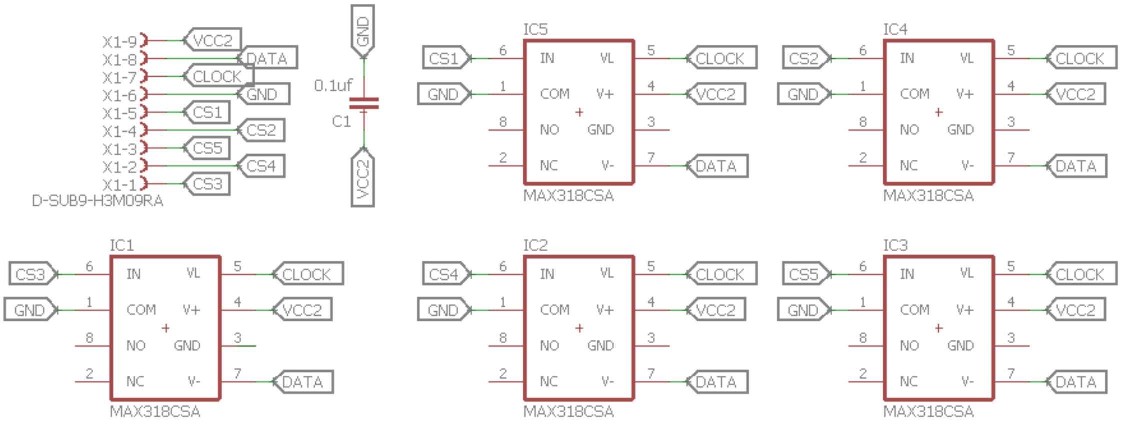


Fig. 3.4 Thermocouples PCB schematic

The interface of this PCB is a D-sub 9 connector. Its connections are shown in table 3.2.

PINS	THERMOCOUPLES D-SUB9 CONNECTIONS
1	CS1
2	CS2
3	CS3
4	CS4
5	CS5
6	GND
7	SCLK
8	MISO
9	VCC (3.3 V)

Table 3.2 Interface of the thermocouples PCB trough a d-sub9 connector

On this SPI communications protocol we do not have MOSI because the chips are only for reading data.

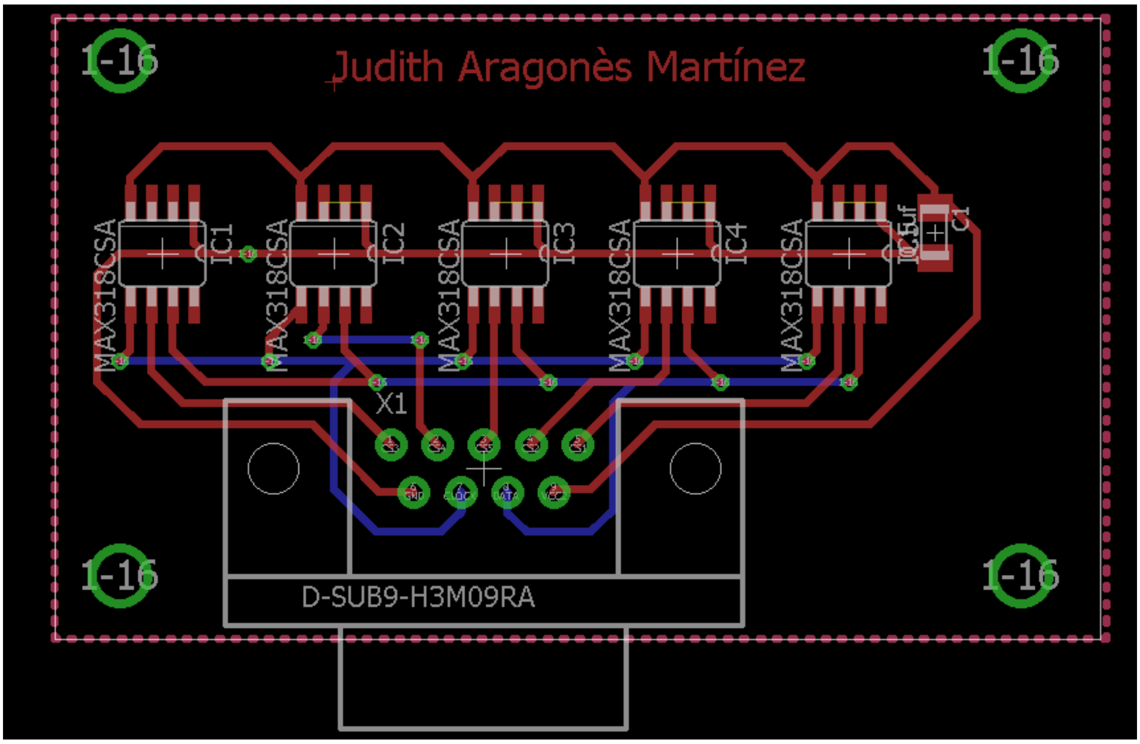


Fig. 3.5 Thermocouples PCB board

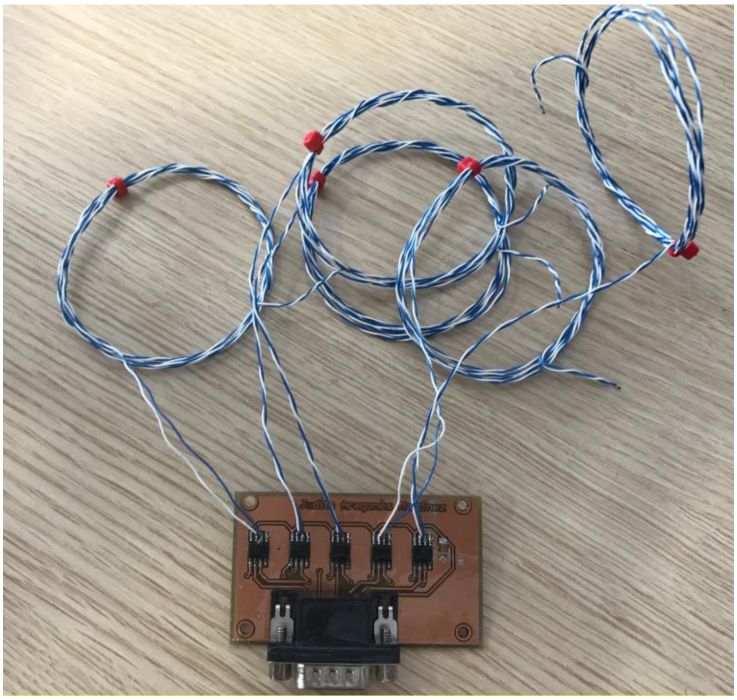


Fig. 3.6 Thermocouples PCB

3.2.2. Accelerometer PCB

The aim on this PCB is to acquire the acceleration data during the free fall. The accelerometer that we have chosen is the LSM9DS1which requires an analog supply voltage from 1.9V to 3.6V. It is a 3-axis device with a ±2/±4/±8/±16 g linear acceleration full scale which allows us to know the microgravity quality during the free fall. Its maximum sampling rate is 1 kHz and the resolution could vary depending on the selected scale between 0.061 and 0.732 mg/LSB. Finally, all these data will be sent through an I2C communications protocol (Fig. 3.7).

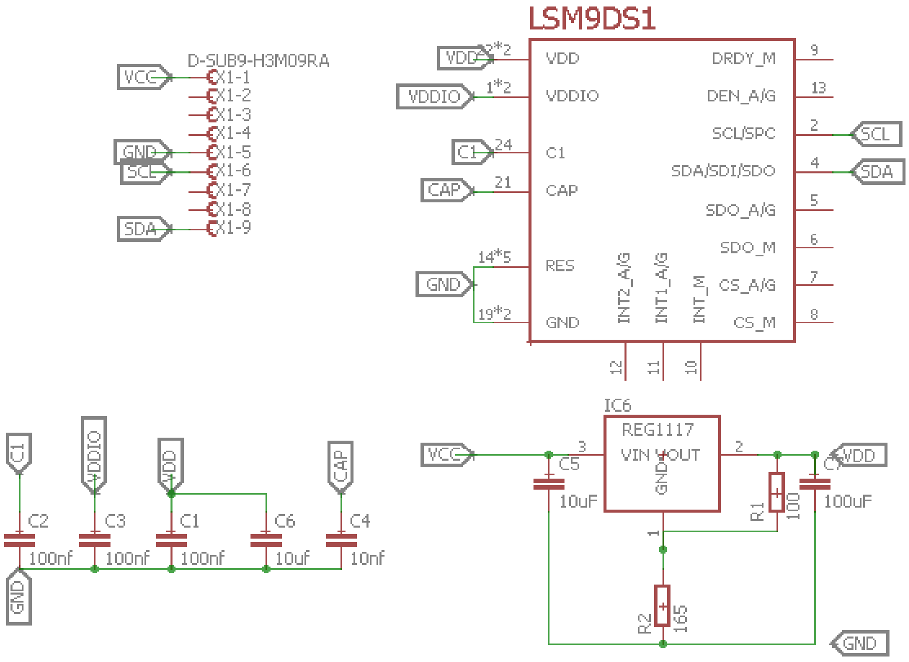


Fig. 3.7 Accelerometer PCB schematic

Once again, for this PCB, the connector chosen for the interface has been a d-sub9 because they are very robust and reliable (Fig. 3.8 and Fig. 3.9).

PINS	ACCELEROMETER D-SUB9 CONNECTIONS
1	VCC
2	-
3	-
4	-
5	GND
6	SCL
7	-
8	-
9	SDA

Table 3.3 Accelerometer PCB d-sub9 pin connections

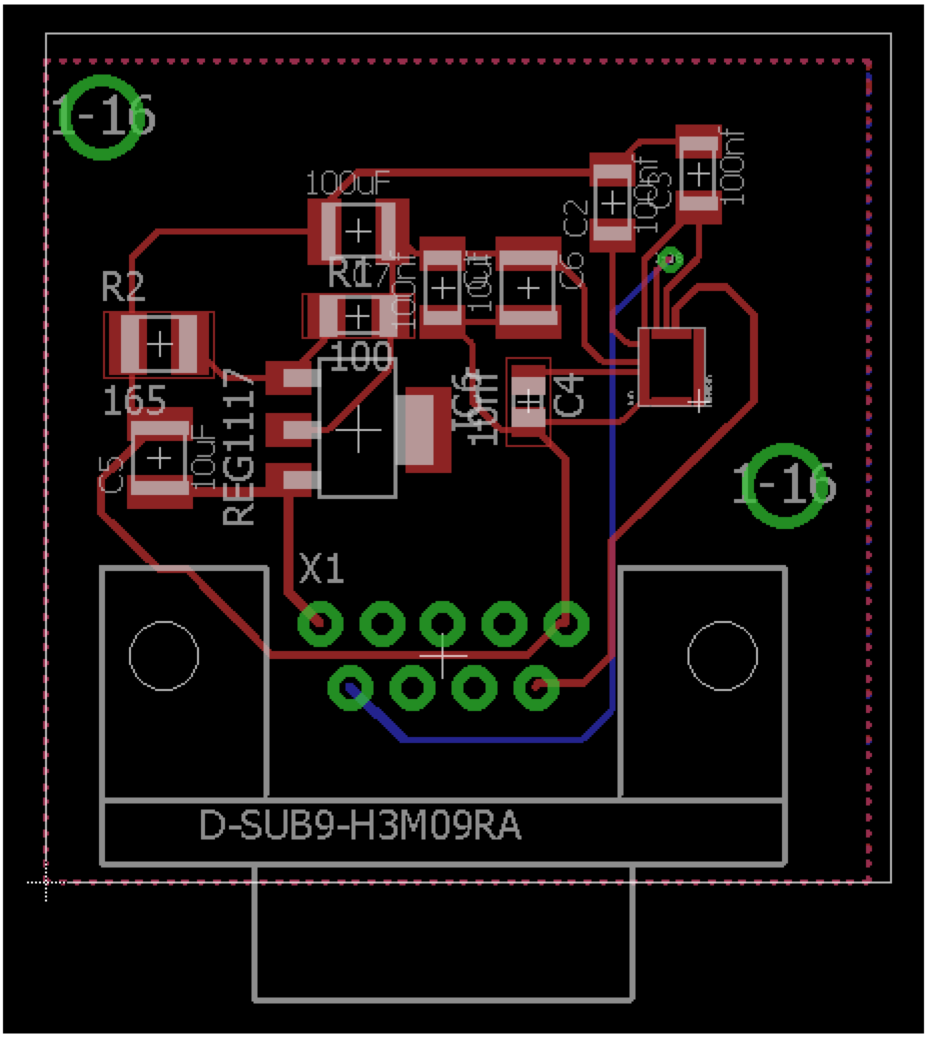


Fig. 3.8 Accelerometer PCB board

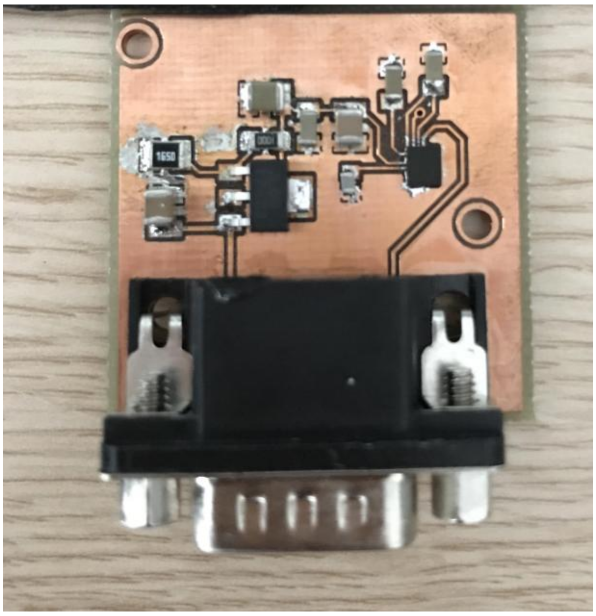


Fig. 3.9 Accelerometer PCB

3.3. DC/DC regulators PCBs

The devices and PCBs integrated in our experiment need different voltage supplies. Our first idea was to integrate a DC/DC regulator on each PCB but, finally, we decided that it was more efficient to design common DC/DC regulators. The experiment contains four DC/DC regulators: 3.3V, 5V, 12V and 24V.

For the 3.3V and 5V regulators we have designed the PCBs using the Texas instruments PCB design software. It creates a PCB with the inputs and outputs required by users.

In order to simplify the design processes, the 12V and 24V DC/DC regulators have been purchased to the Traco power company due to the fact that they should present a high efficiency.

Linear regulators are a great choice for powering very low powered devices or applications where the difference between the input and output is small. Even though they are easy to use, simple and cheap, a linear regulator is normally inefficient but, as far as the output is really stable they are used to power sensitive sensors. Switching regulators on the other hand are highly efficient and available as modular chips which are compact and reliable so, they are used in power lines.

The 3.3V DC/DC regulator is the only one that is linear because all the PCBs that contain sensors are powered with 3.3V and they need a very stable and lineal power supply (in order to minimize the sensor’s error). The rest of the regulators are switching regulators.

All the switching regulators are connected to the ZARM’s 24V batteries because their efficiency is very high. Moreover, the lineal regulator is powered by de 5V DC/DC regulator because if we connect it to the batteries its efficiency would be really low.

3.3.1. 3.3V DC/DC regulator PCB

As it has been mentioned previously, this regulator is the only linear one and it has been designed with the Texas instruments PCB design software. It is used to power the IMU (or accelerometer PCB) and the thermocouples PCB. Fig. 3.10 presents the schematic of the board and, Fig. 3.11 and Fig. 3.12 show the PCB board design and the manufactured device.

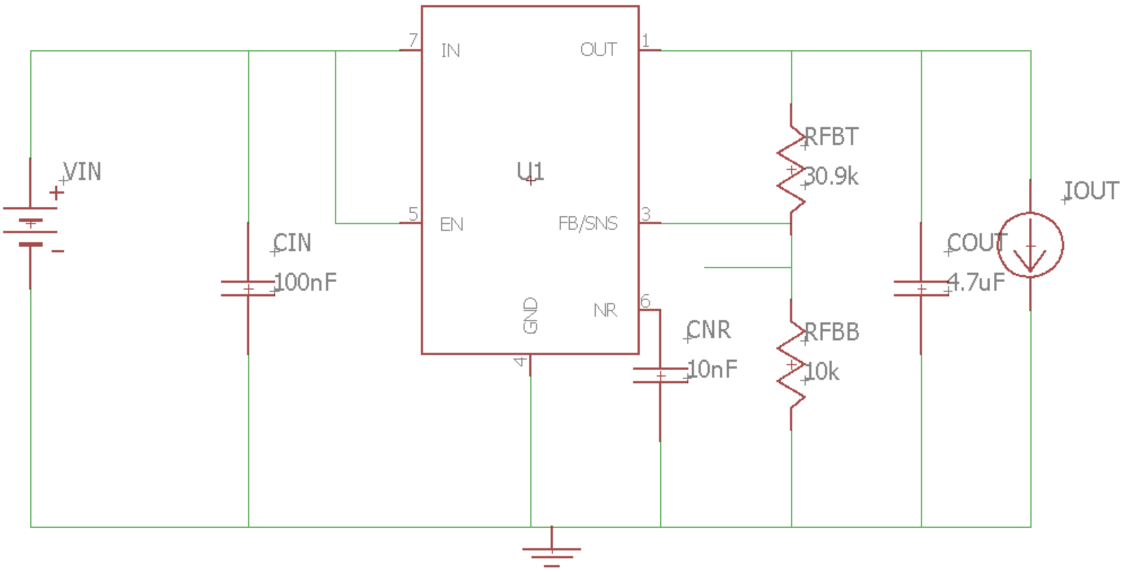


Fig. 3.10 3.3V DC/DC regulator PCB schematic

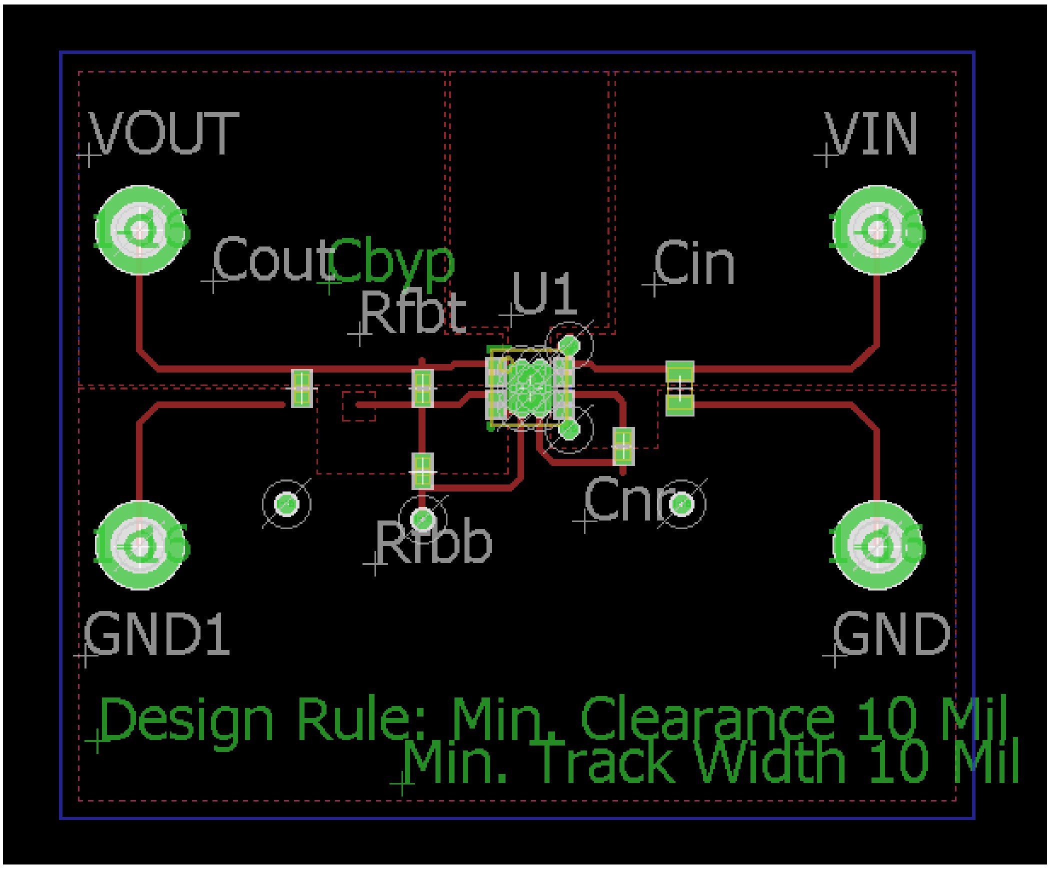


Fig. 3.11 3.3V DC/DC regulator PCB board

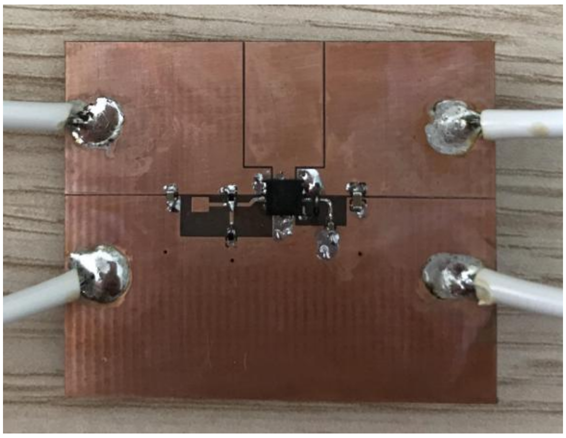


Fig. 3.12 3.3V DC/DC regulator PCB

3.3.2. 5V DC/DC regulator PCB

This is a switched regulator designed by the Texas instruments PCB design software which powers the 3.3V DC/DC regulator, the pump control PCB and the GoPro power control PCB. In Fig. 3.13, the schematic of the PCB is shown while Fig. 3.14 and Fig. 3.15 present the PCB design and its final appearance once manufactured.

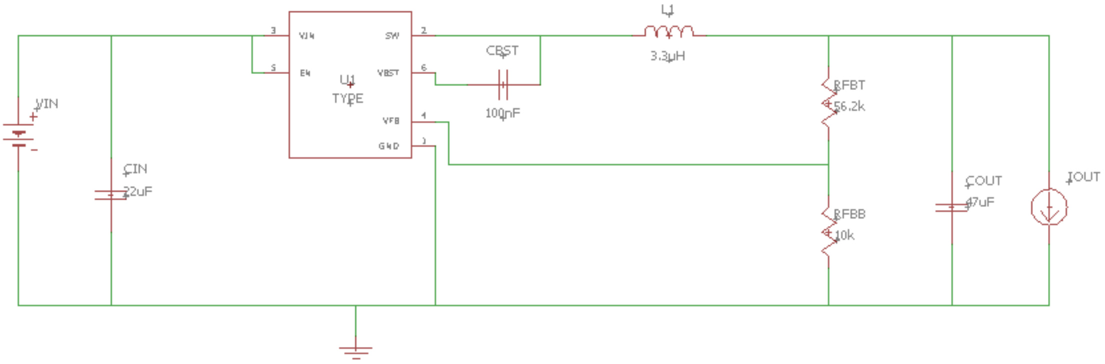


Fig. 3.13 5V DC/DC regulator PCB schematic

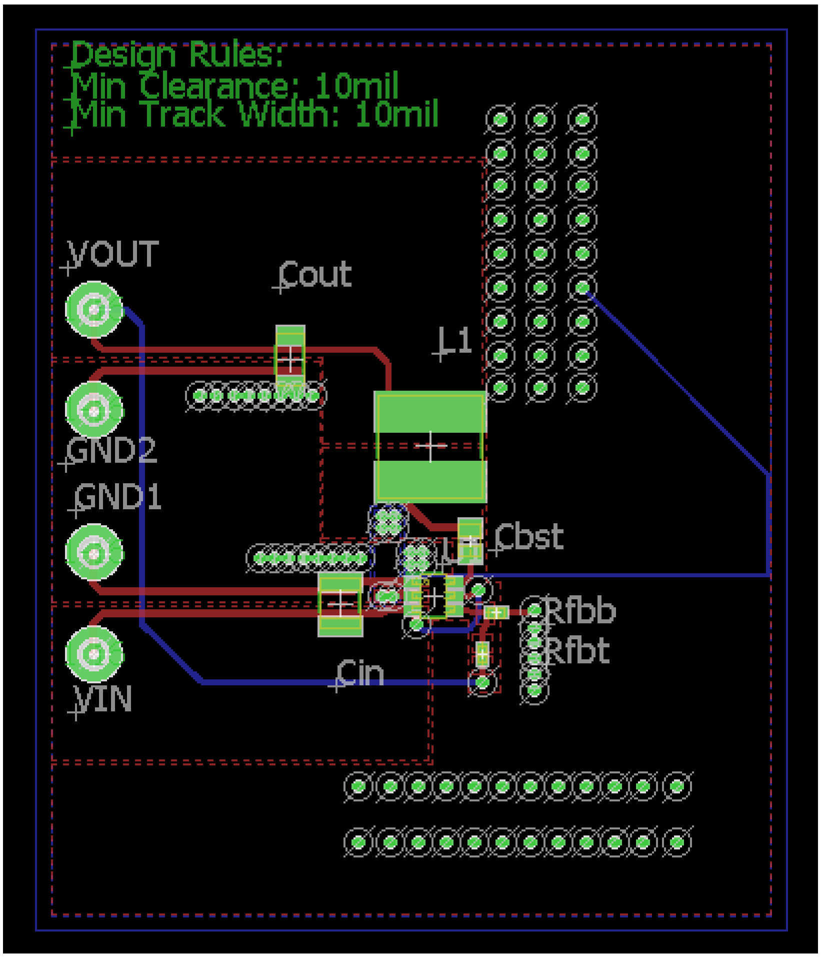


Fig. 3.14 5V DC/DC regulator PCB board

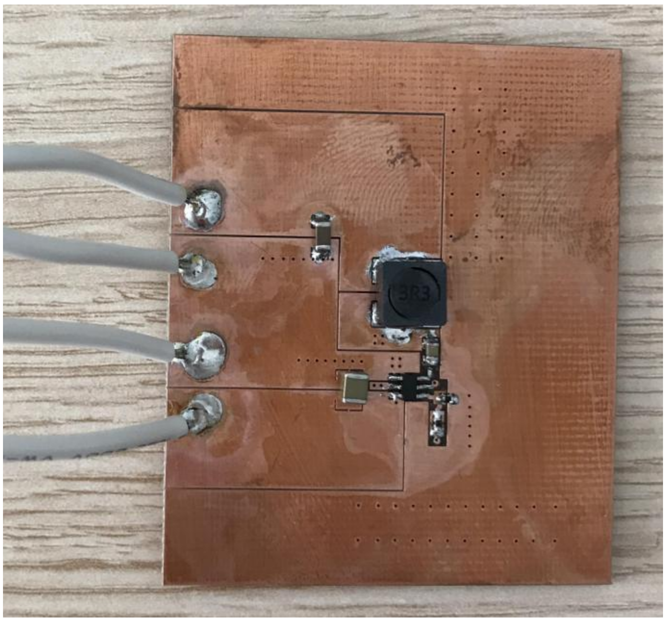


Fig. 3.15 5V DC/DC regulator PCB

3.3.3. 12V and 24V DC/DC regulators

These regulators are switching regulators that have been bought to the Traco power brand. The 12V DC/DC regulator powers the pump control PCB and the heater power control PCB. The 24V DC/DC regulator gives a voltage supply to the computers, the pressure meter, the flow meter, the power amplifier power unit and the LED matrix.

The 24V DC/DC regulator is shown in Fig. 3.16. The 12V DC/DC regulator is not shown because they look exactly the same.

Fig. 3.16 24V DC/DC regulator

3.4. Interface PCBs

3.4.1. Pressure meter/flow meter PCB

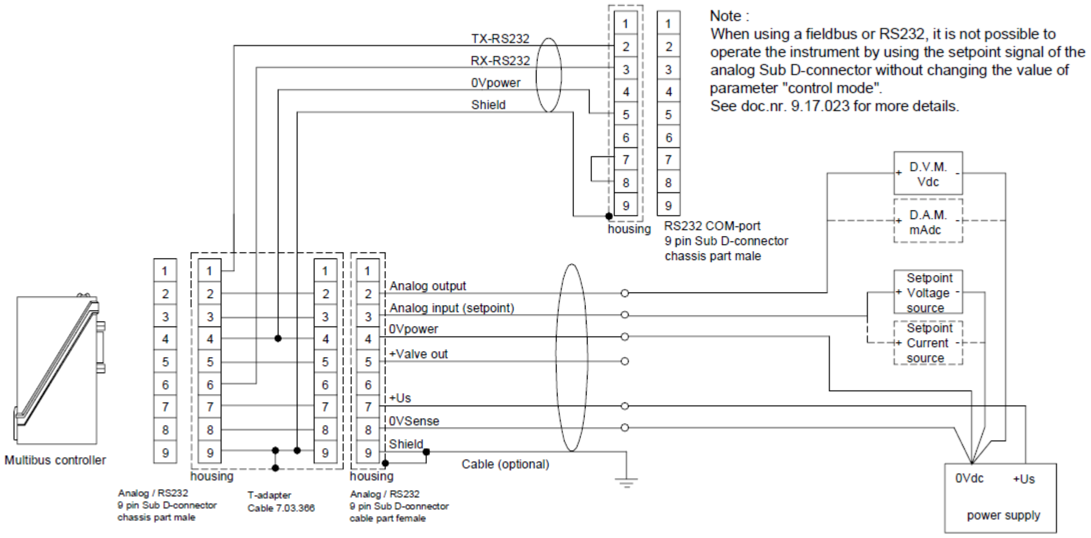
This PCB only contains three d-sub9 connectors (two males and one female) which have the aim of powering and communicating with the pressure meter and the flow meter through a RS232.

The flow meter (Fig. 3.17) and the pressure meter (Fig. 3.18) have been purchased to Bronkhorst. Both devices require a DC voltage supply between 15 and 24V. The flow meter has an accuracy of ± 0,5%Rd plus ± 0,1%FS (being Rd an error depending on the measurement) and a nominal range (based on air) of 16…2000 ml_n/min. The pressure meter has an accuracy that only depends on the full scale (± 0,5%FS) and a pressure range (min/max) of 0,022…1,1 / 0,12…6 barg (where barg indicates that it is the measurement on a gauge indicator).

Fig. 3.17 Flow meter

Fig. 3.18 Pressure meter

In order to assign all the d-sub9 pins connections, the instructions shown in the datasheet have been followed (Fig. 3.19).



Note :
When using a fieldbus or RS232, it is not possible to operate the instrument by using the setpoint signal of the analog Sub D-connector without changing the value of parameter "control mode".
See doc.nr. 9.17.023 for more details.

Fig. 3.19 Pressure meter/flow meter datasheet pin connections

X1 is the female d-sub9 which is connected to the sensor. X2 and X3 are male d-sub9 connectors. X2 is for the RS232 and X3 for power supply. In order be able to communicate with the device, it has to be taken into account that the transmission line of the sensor must be the reception line of the computer (RS232) and the transmission line of the computer (RS232) must be the reception line of the sensor (Fig. 3.20).

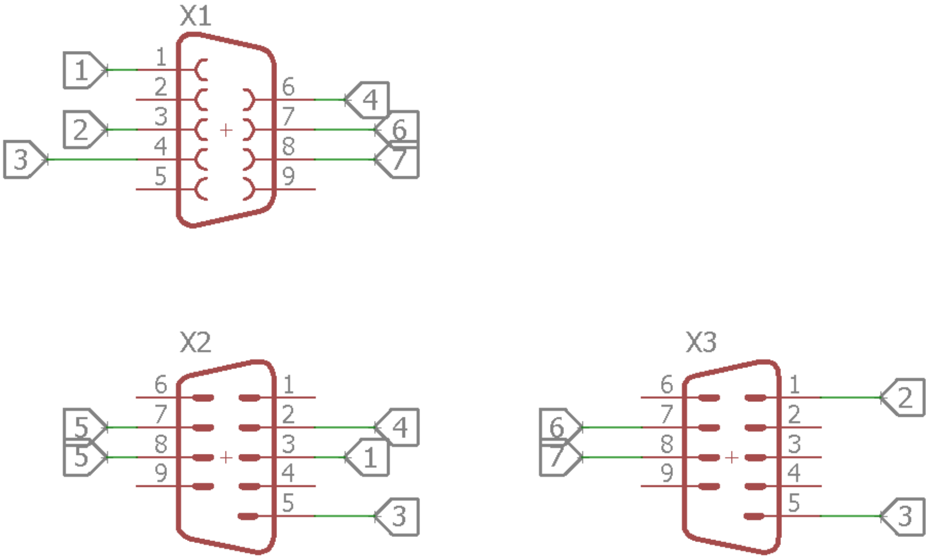


Fig. 3.20 Pressure meter/flow meter interface PCB schematic

PINS	D-SUB9 X1	D-SUB9 X2	D-SUB9 X3
1	TX-RS232	-	Analog input (setpoint)
2	-	RX-RS232	-
3	Analog input (setpoint)	TX-RS232	-
4	0V power	-	-
5	-	0V power	0V power
6	RX-RS232	-	-
7	+Us	Shortcut with d-sub9 X2 pin 8	0V sense
8	0V sense	Shortcut with d-sub9 X2 pin 7	+Us
9	-	-	-

Table 3.4 d-sub9 pin connections pressure meter/flow meter interface PCB

The final PCB design and the manufactured PCB can be observed in Fig. 3.21 and Fig. 3.22.

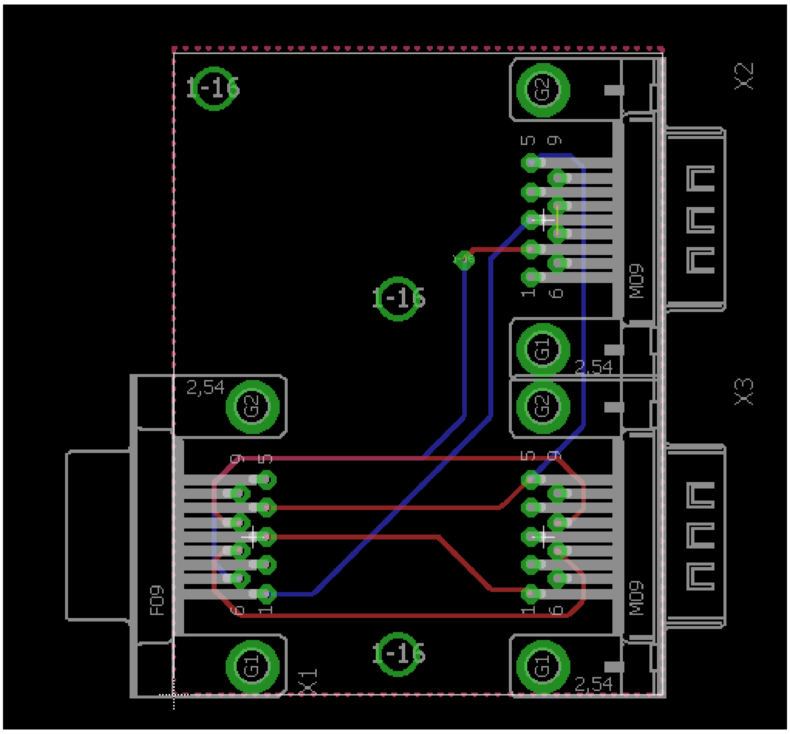


Fig. 3.21 Pressure meter/flow meter interface PCB board

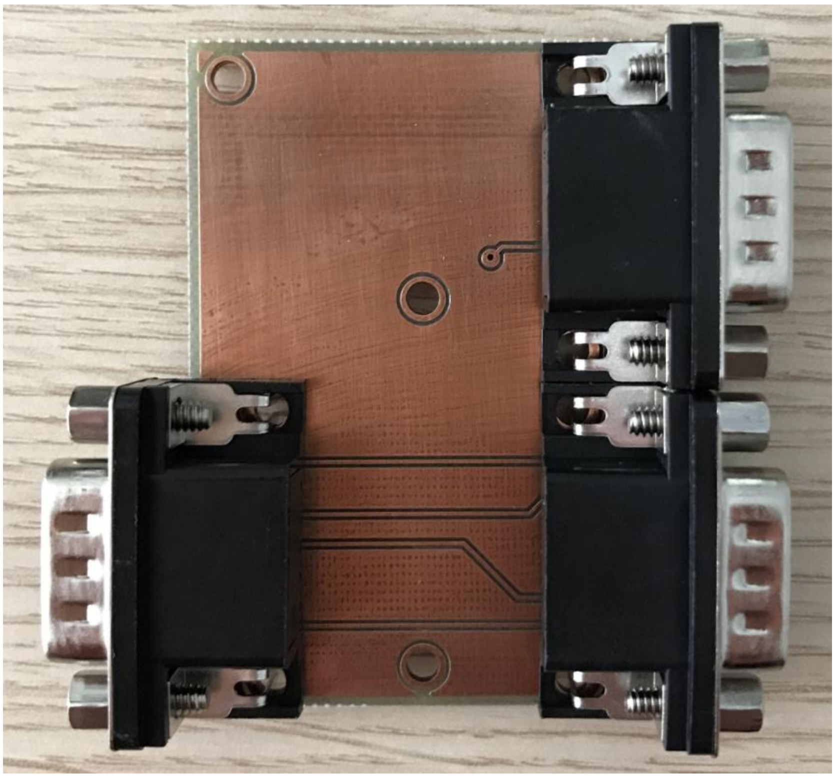


Fig. 3.22 Pressure meter/flow meter PCB

3.5. Electronics casing

For each PCB it has been designed an appropriate aluminium casing. All of these boxes are shortcut to ground in order to minimize all the possible capacitive interferences. Moreover, these casings are important because during the microgravity phase metallic particles will be in suspension and if one of those particles impacts on a PCB can cause malfunction. By introducing these boxes this risk is reduced.

These boxes are also used to attach the PCBs into the bulkheads. All the PCBs are directly screwed into the box using M3 bolts. In addition, all the casings have at least one overture where a d-sub9 comes through for stablishing all the necessary connections.

In Fig. 3.23 and Fig 3.24 an example of electronics box is shown (it is the pump PCB casing). All the boxes are designed in the same way and they are all similar but, the size of each one depends on the PCB that they correspond to.

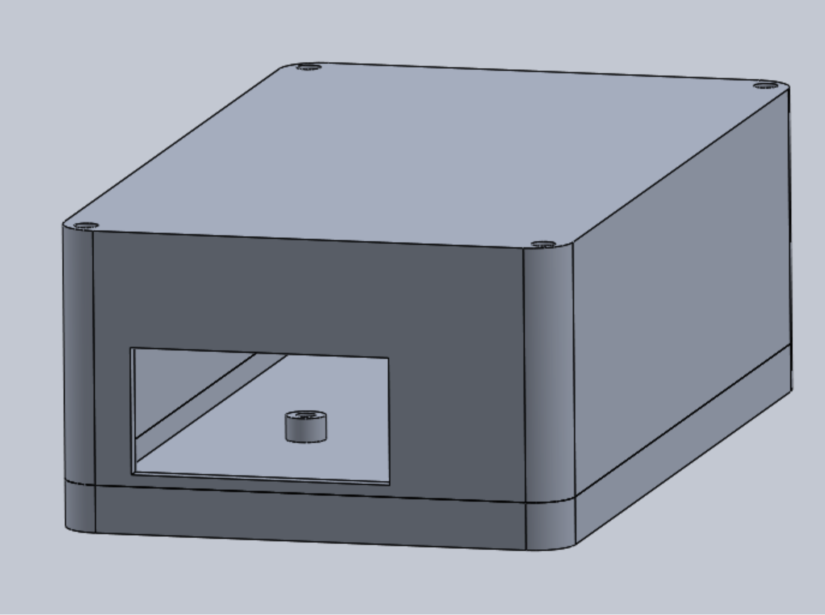


Fig. 3.23 Pump PCB aluminium box

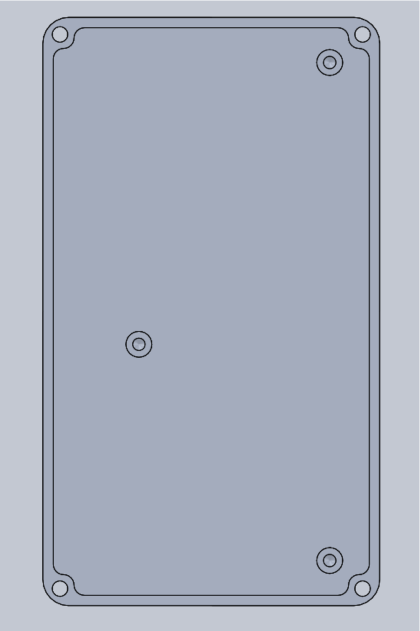


Fig. 3.24 Inside view of the pump PCB aluminium box

CHAPTER 4. EXPERIMENTAL RESULTS

In this chapter, the design parameters that are influencing the test cell will be discussed and some measurements obtained in the laboratory will be shown in order to justify the selection of the different devices, materials and shapes.

4.1. Test cell design

A first design proposal consists on an aluminium test cell with three methacrylate windows (one window is for the ZARM's camera, the opposite one to locate the LED matrix and the perpendicular to these two for the thermal camera). To prevent leakage on the windows, o rings will be implemented in all of them.

To obtain useful results, the dimensions of the test cell have to be as similar as possible to the ones that has the test cell contained on the ISS experiment ("Boiling").

The test cell has been divided into three pieces. The middle part is where the experimental phenomena are produced and the side parts have been designed to connect the test cell with the tubes that are going towards the pump. Those lateral elements have the shape of a diffuser to adapt the velocity of the liquid to the desired one.

Inside the test cell (Fig. 4.1), a honey comb [7] should be located in order to have a uniform flow distribution along the longitudinal axis. In front of the honey comb, on the other side of the cavity of the test cell, a PZT will be located. The heater will be allocated on the bottom surface of the test cell.

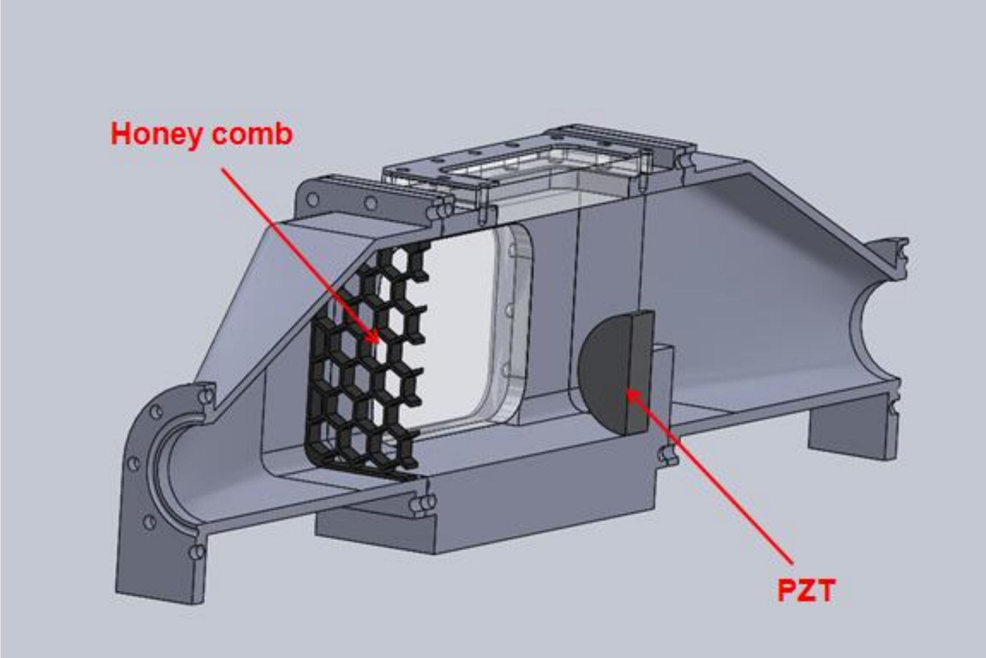


Fig. 4.1 Inside view of the test cell

On the test cell there are several holes (see Fig. 4.2). The hole B is used for sensors' cabling (like the heater, thermocouples or PZT). There is also a hole to fill the test cell with liquid (hole C) and, finally the hole A is used to let the gas get outside of the test cell during the filling procedure and during the boiling process to act as an overpressure valve for keeping pressure constant over the test cell.

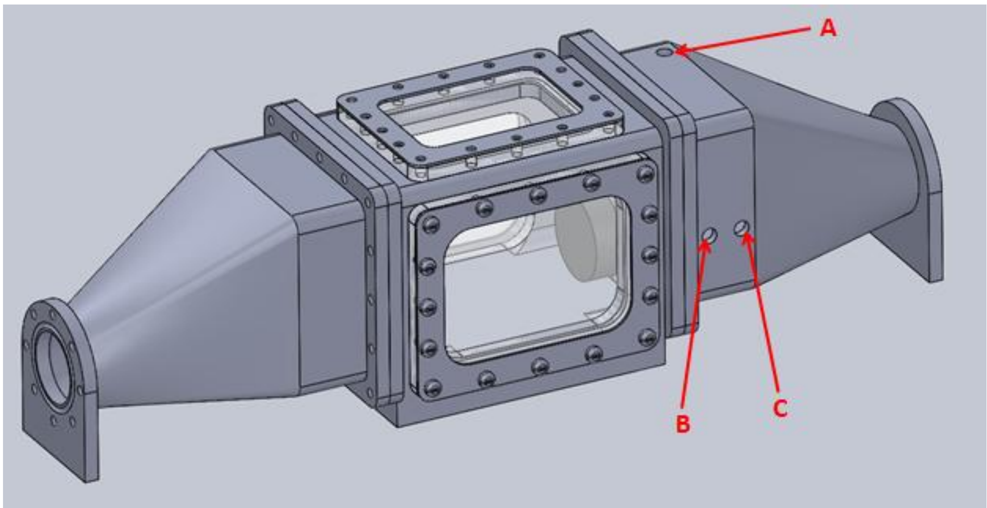


Fig. 4.2 Outside view of the test cell

4.1.1. PZT tests

A transducer is a device that is used to convert energy from one form to another (normally when converting input energy into output energy) for example, a conversion from mechanical to electrical energy (or vice versa). A common example is a microphone, which converts the input energy (the sound waves produced by a voice or instrument) to output energy (the electrical impulses in the form of amplified sound).

Piezoelectric transducers convert electrical pulses into mechanical vibrations. The word "piezoelectric" means electricity caused by pressure [8].

When an electric field is applied across the PZT, the polarized molecules that were initially disordered will align themselves with the electric field, resulting in small variations in the shape of the material (phenomena that can be used to produce small pressure variations that generate acoustic waves).

Electroacoustic transducers also include hydrophones (Fig. 4.3) which convert changes in water pressure to an electrical output. In the performed tests that are explained below, an hydrophone has been used to measure the pressure field produced by the PZTs in a liquid (HFE7100).

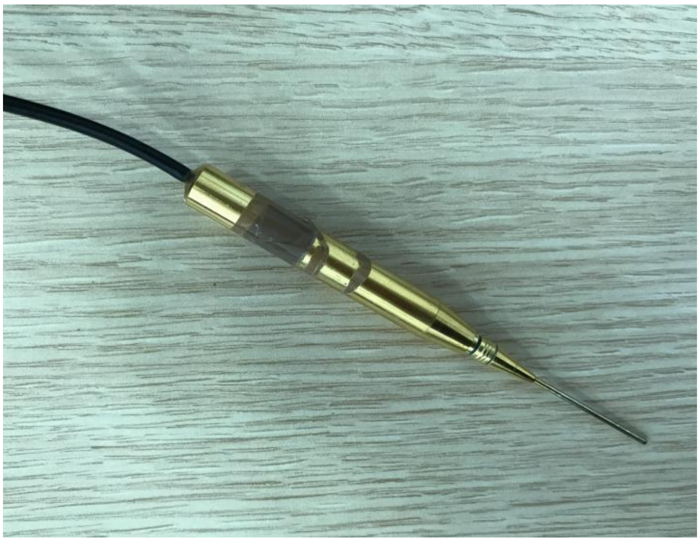


Fig. 4.3 Hydrophone

Our main goal with the PZT is to obtain a progressive wave inside the test cell, bubbles need to be detached from the heater and moved away from it. A wave is a method of energy propagation, the energy created in the turbulence is spread by the waves (the wave propagates through space and consequently, the energy it carries is also propagated). Furthermore, progressive waves are caused by any turbulence in a medium. This energy causes the particles on the way to oscillate. There are two types of waves: longitudinal waves and transverse waves. In a longitudinal wave, the oscillations of particles are parallel to the direction of propagation. In transverse waves, the oscillation of particles occurs perpendicular to the direction of propagation. The amplitude of each and every point of a propagating wave is the same, given that the wave is uniform. In our experiment, we work with acoustic waves that are longitudinal waves.

On the other hand, stationary waves, (also known as standing waves) occur due to the interception two identical waves travelling in opposite directions. A stationary wave does not carry a net energy through the path and its amplitude changes over distance but for a given point, the amplitude remains fixed.

Taking into account the previous results obtained at the Microgravity Lab, it has been seen that bubbles generated by boiling procedures are about 1 mm of diameter and have a resonance frequency (frequency at which the response amplitude is a relative maximum) of 5KHz. But, the PZTs used in those experiments have been discarded because their natural frequency was above 39KHz and so the wavelength was too small.

Two lines of different tests have been done with the aim of measuring the generated acoustic wave: the first were using a methacrylate test cell (Fig. 4.4) and the second ones an aluminium test cell (Fig. 4.5). Moreover, two different PZTs have been used for the tests. The first one with a resonance frequency of 232KHz (Fig. 4.6) which has been used in previous experiments and with a performance well known at the Microgravity Lab. The second one with a resonance frequency of 6.3KHz (Fig. 4.7) that is thought to have a better behaviour when working at a frequency of 5KHz which is the desired one.

Fig. 4.4 Methacrylate test cell

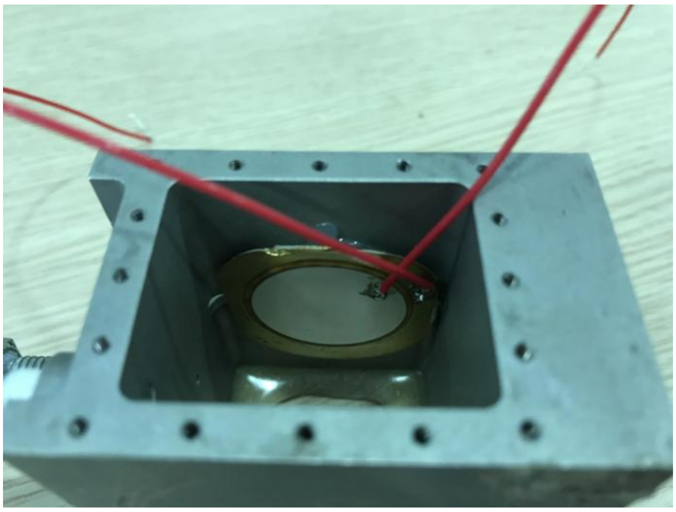


Fig. 4.5 Aluminium test cell

Fig. 4.6 232KHz PZT

Fig. 4.7 6.3KHz PZT

To measure the pressure field inside the methacrylate test cell we have considered four different scenarios: having the PZT inside or outside of the test cell and comparing two PZTs (one of 232KHz natural frequency and the other one of 6.3KHz).

It has been observed that when the PZTs were allocated inside the test cell, the measured amplitude was affected in such a way that depending on how the connections on the PZT were applied (polarity was changed), was decreasing (Fig. 4.8) or increasing (Fig. 4.9 and Fig. 4.10) its value when approaching the PZT. However, the frequency response of those measurements was as predicted by the theory. Having into account that the sound speed in HFE7100 is about **634,06 m/s** [9], the theoretical wavelength for a frequency of **230KHz** should be of **0,27 cm**. If Fig. 4.8, Fig. 4.9 and Fig. 4.11 are observed (which correspond to a 230KHz frequency), the experimental wavelengths obtained are quite similar to the theoretical one (approximately, a 0,30 cm wavelength is observed at the graphs). On the other hand, when a frequency of **5KHz** (Fig. 4.10) is applied, the theoretical wavelength corresponds to **12,68 cm**. Due to a lack of space (we only have a 3,5 cm test cell), the frequency response cannot be experimentally measured for a 5KHz frequency.

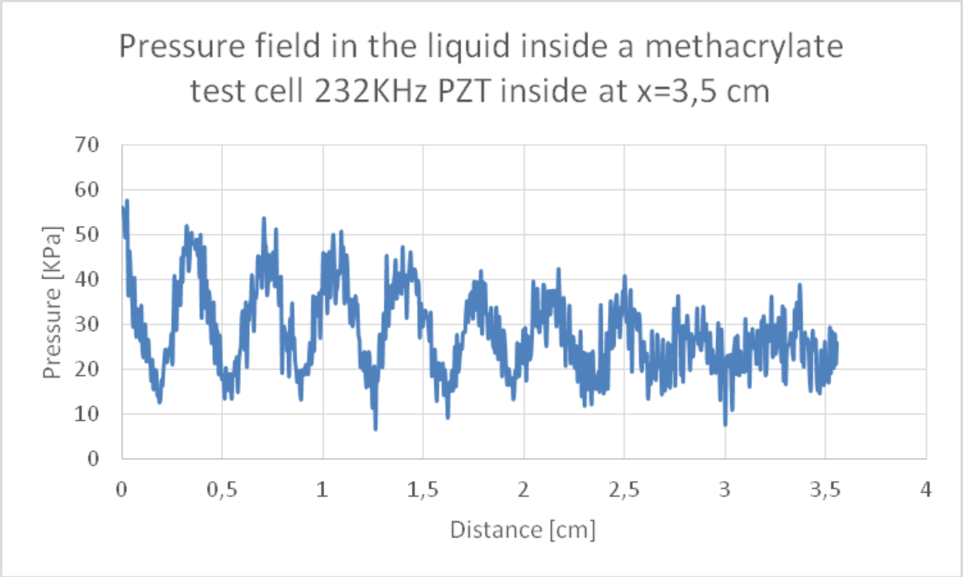


Fig. 4.8 Pressure field when applying 230KHz "inverse polarity"

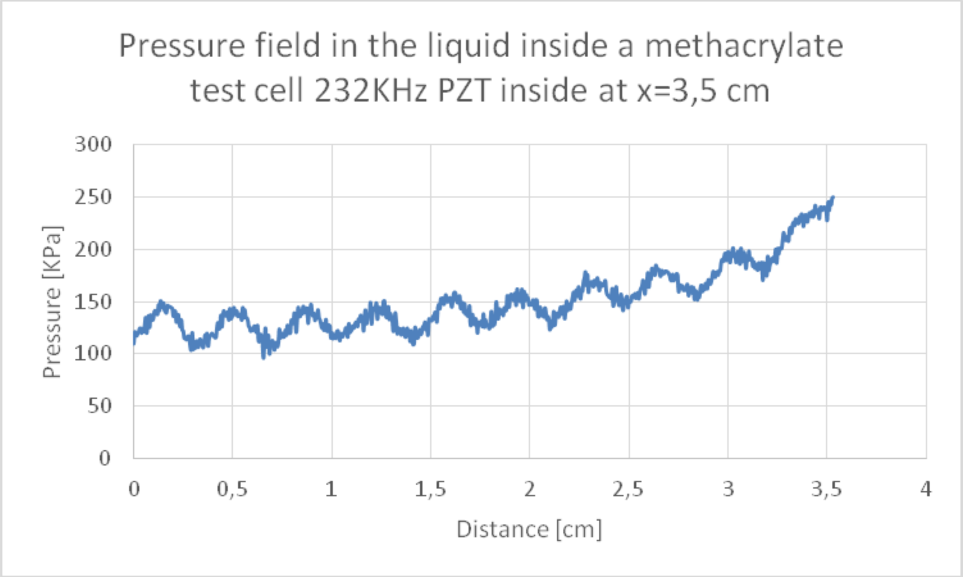


Fig. 4.9 Pressure field when applying 230KHz "normal polarity"

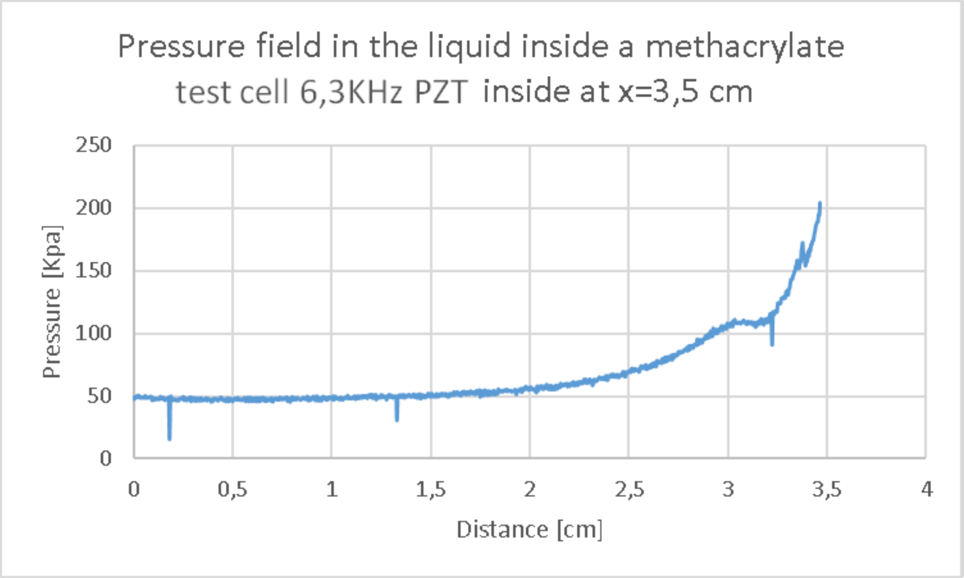


Fig. 4.10 Pressure field when applying 5KHz

It has also been seen that the 232KHz PZT located outside the test cell was producing a really high amplitude pressure field when working near its natural frequency (Fig. 4.11) but, when working below, its performance was highly reduced.

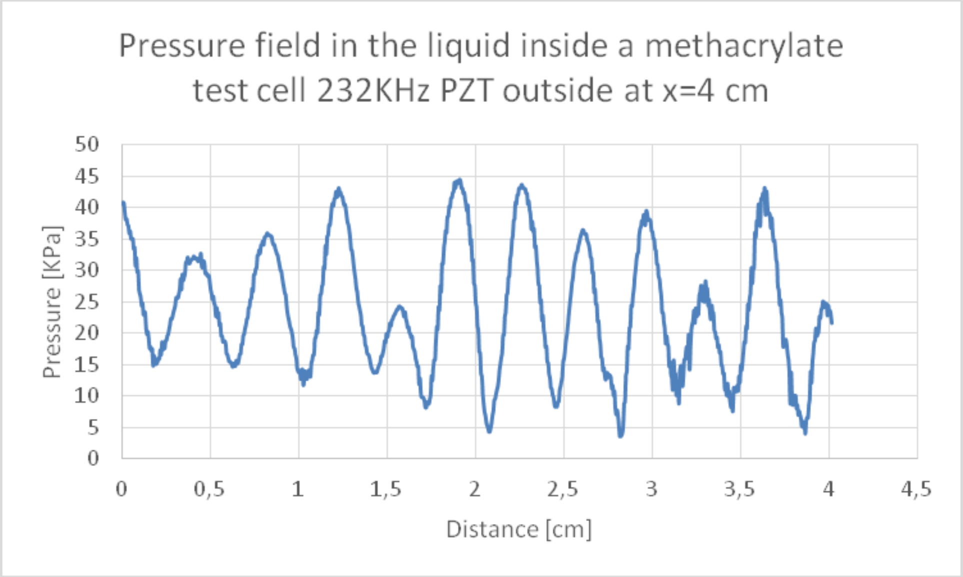


Fig. 4.11 Pressure field when applying 230KHz

On the other hand, the 6.3KHz PZT had a good behaviour in the amplitude but, the frequency response was hard to be observed when placed inside the test cell and when working at its natural frequency (Fig. 4.10).

The amplitude when the PZT is located inside the test cell (Fig. 4.8 and Fig. 4.9) cannot be properly evaluated (for any of the PZTs). Theoretically, it should be higher than the amplitude obtained when the PZT is located outside the test cell (Fig. 4.11) but, lower than the one measured with the hydrophone inside the test cell near the PZT (whenever the sensor is approached to the PZT, the amplitude is increased or decreased (depending on the polarity) in an exponential which may mean that it actually exists a capacitive interference).

The information obtained from the previous graphs has been taking into account when performing the analysis of the data obtained on the aluminium test cell. The results when the PZT was outside have been used to evaluate its frequency response while the amplitude response cannot be determined. However, in the aluminium test cell it has been harder to evaluate the frequency response because the dimensions were smaller and when working at low frequencies, it was not possible to observe half a wavelength.

Fig. 4.12 shows the pressure field produced by the PZT with a resonance frequency of 6,3KHz working at 30KHz when it is placed at the outside so, from this graph the frequency response of the PZT can be studied. The theoretical wavelength when applying **30KHz** is of **2,11** cm. However, the observed experimental wavelength (Fig. 4.12) is a bit smaller but still quite similar to the expected value (approximately 1,6 cm).

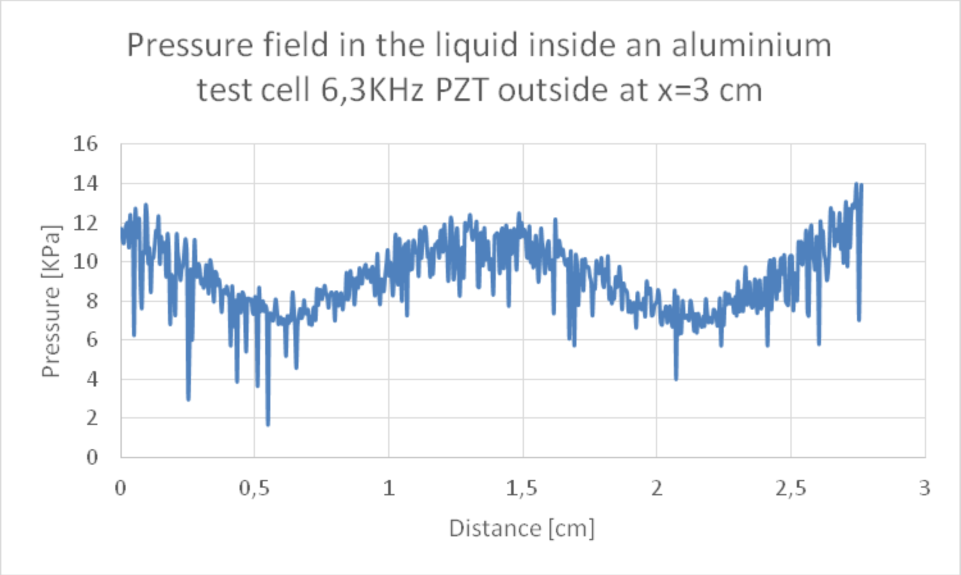


Fig. 4.12 Pressure field when applying 30KHz

In Fig. 4.13, the measured pressure field frequency response behaves as expected (theoretically, the wavelength should be around **0,79 cm;** experimentally it is around 0,9 cm). In addition, this figure allows us to estimate the amplitude of the pressure field when the PZT is inside the test cell but with a huge uncertainty.

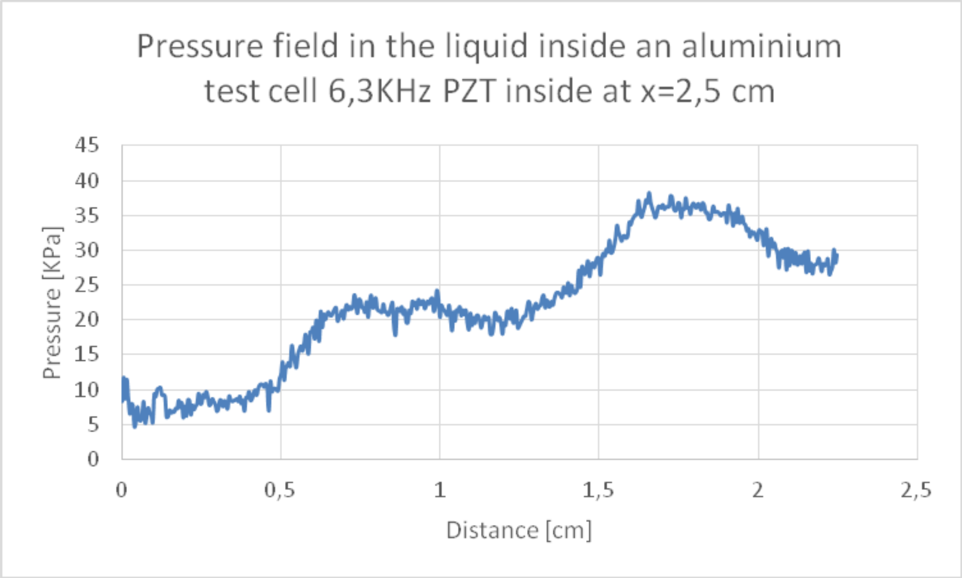


Fig. 4.13 Pressure field when applying 80KHz

After all, it has been proved that with the new 6.3KHz PZT we have higher amplitudes than with the older ones (the PZTs that were used at the laboratory for previous experiments which allowed us to obtain amplitudes around 6KPa at 39KHz [10]). However, for small frequencies the amplitude obtained with this PZT is not as high as the one obtained for the 232KHz PZT working at its natural frequency. It has been thought that this could be due to a relative difference between the natural frequency and the actual frequency imposed at those PZTs (it is not the same to work at 5KHz for a 6.3KHz PZT than working at 230KHz for a 232KHz PZT). Furthermore, the frequency response cannot be always obtained due to the low frequencies imposed and the small space available on the test cell to make measurements.

Although the main objective was to obtain a progressive wave, only standing waves have been measured. Further studies need to be performed in order to find a way to create a progressive wave.

CHAPTER 5. CONCLUSIONS AND NEXT STEPS

In this project the requirements for a drop tower experiment have been defined, the devices that compose the experiment have been chosen, an important part of the electronics have been designed and built and, finally, an initial approach of the mechanics has been presented.

First of all, the different requirements imposed by the platform selected for this experiment have been identified, in the same way that the requirements that the experiment must fulfil in order to be successful and generate useful experimental data. Moreover, the design and performance parameters of the different devices and systems that integrate the experiment have been thought with the aim of accomplishing the two previous set of requirements.

An initial mechanical design and the relation between the different systems and devices has been thought and presented. Some of the different devices and systems have been selected to accomplish specific requirements of the experiment. Moreover, some electronic systems have been designed from zero and manufactured.

The electronics worked as expected. However, some problems appeared while soldering the DC/DC regulators and the accelerometer PCBs because of the size of the components (they were too small). Different trials had be made to finally solder correctly these PCBs. In our opinion, this could have been solved using an oven to solder the PCBs instead of solder them ourselves.

During the PZT tests, it has been observed that having good results for the desired scenario was not trivial. A way to measure the frequency response was found but the amplitude can only be given in a certain margin. Moreover, when working at low frequencies, the frequency response cannot be clearly determined due to the lack of space on the test cells for observing a complete wavelength. Anyway, it has been possible to determine which PZT has a better performance at low frequencies and, from here a 6.3KHZ PZT has been chosen for the experiment.

There are still some steps left in order to finish the experiment and send it to ZARM so that it can be tested. First of all, ZARM should be contacted to obtain a drop date, to ask about their camera and to know about their interface requirements. Also, devices as the heater and the thermal camera have to be defined and purchased.

When all the experiment components are chosen, the remaining PCBs have to be designed and built, as well as its corresponding aluminum boxes (the LED matrix, the heater power control PCB, the heater data acquisition PCB, the 16 bit ADC, the GoPro status PCB, the GoPro control PCB, the GoPro power PCB, the thermal camera PCB and the ZARM interface PCB). Once the PZT final allocation respect to the heater is selected, the final size and shape of the test cell could be defined and it will have to be manufactured. In addition, the protocol, software and telemetry of the experiment have to be designed and programmed in an efficient way.

Platforms have to be requested to ZARM. They will send them and, once at the laboratory, all the devices of the experiment shall be safely attached to the platforms (making the corresponding holes, using the appropriate tools, etc). When a distribution of the experiment is implemented in the bulkheads, impact, deformation of structures and thermal simulations should be performed to have an idea of the behavior of the experiment inside the tower.

Finally, a check list has to be created in order to localize malfunctions, broken devices or other kind of failures after each drop. The last step will be to prepare the drop campaign and send the experiment to ZARM.

REFERENCES

[1] T. G. Leighton, A. Walton, M. J. Pickworth, Primary Bjerknes forces *European Journal of Physics*, vol. 11, no 1, p. 47, 1990.

[2] Misale, M., Guglielmini, G., & Priarone, A. (2009). HFE-7100 pool boiling heat transfer and critical heat flux in inclined narrow spaces. *International Journal of Refrigeration*, *32*(2), 235–245.

[3] Selig, H., Dittus, H., & Lämmerzahl, C. (2010). Drop tower microgravity improvement towards the nano-g level for the MICROSCOPE payload tests. *Microgravity Science and Technology*, *22*(4), 539–549.

[4] Garcia, A., Batlle, S., Sierra, V., López, G. & Quintana, G. (2016). *Student Experiment Documentation*, RX20_BOILUS_SED_v5_28June16.pdf.

[5] Operation, D. T., Company, S., & Fallturm, A. (2011). *ZARM Drop Tower Bremen User Manual*.

[6] Qi, H., Fang, D., Meng, X., & Wu, J. (2014). Liquid density of HFE-7000 and HFE-7100 from T = (283 to 363) K at pressures up to 100 MPa. *Journal of Chemical Thermodynamics*, *77*, 131–136.

[7] Zergoune, Z., Ichchou, M. N., Bareille, O., Harras, B., Benamar, R., & Troclet, B. (2017). Assessments of shear core effects on sound transmission loss through sandwich panels using a two-scale approach. *Computers and Structures*, *182*, 227–237.

[8] https://www.americanpiezo.com/piezo-theory/whats-a-transducer.html

[9] López, G. (2016). *Bubble dynamics in a boiling system under an acoustic field in a microgravity environment,* Bacherlor’s degree thesis.

[10] Artigas, V. (2017). *Effects of an acoustic field on vapour bubbles in microgravity,* Master thesis.