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Universidade do Algarve

**Analog 16-hydrophone vertical line array for
the Acoustic-Oceanographic buoy - AOB**

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Abstract

This report contains the user guide and the system reference for the analog 16-hydrophone AOB vertical line array. The array is a 67.5m long cable with 16 4m-spaced hydrophones and 17 digital thermistor sensors, distributed along its length. Each module has a dedicated preamplifier to increase signal strength at the hydrophone output and drive a balanced line to transmit the signal to the surface buoy's electronics. The thermistor sensors are digital devices that transmit the temperatures values through a 1-wire digital serial bus. This report presents the system user guide and the system reference guide. The user guide has instructions for system deployment, everyday usage and maintenance. The system reference guide is intended for specialized technicians for system repairing and/or upgrade.

Chapter 1

Introduction

Following the requirements of CINTAL projects for underwater acoustic research there was the need for an acoustically dense array with, however nearly the same acoustic aperture than the previous 8-hydrophone vertical array of the AOB1 system [2]. Therefore the most important improvement is the increase of the number of hydrophones and also the array geometry that is should be equispaced at 4 m so as to allow for easy beamforming for surface noise studies and time-reversal as required by UAB - Underwater Acoustic Barriers project.

The other requirement is that the new array system should be interconnected with the AOB2 surface buoy[1], therefore the same bandwidth and connector pinout. The array mechanical design should be improved so as to offer a better compact and streamered line of cables for easy handle during deploying and recovering operations. Another requirement is that each hydrophone module should also contain a temperature sensor for online reading. The handling of the temperature data stream should be as light as possible in terms of cabling.

The result is a new array that follows a very similar design to that of the older AOB1 model with, however several improvements: i) a more compact mechanical design including a polyester sleeve covering the cables along the array, ii) a new proprietary preamplifier design and 3) a new digital temperature sensor bus system with T-sensors colocated with the hydrophones.

The following sections will describe the array from a basic user perspective up to a more detailed description. The next section starts with an overall description. Following is the user-manual. The third section covers all the array design details.

Chapter 2

Overall Description

The analog array is a 67.5m long cable with 16, 4m-spaced hydrophones and 16+1 hydrophone colocated digital thermistor sensors, distributed along its length (figure 2.1). Each module has a dedicated preamplifier to enhance the signal and drive one balanced

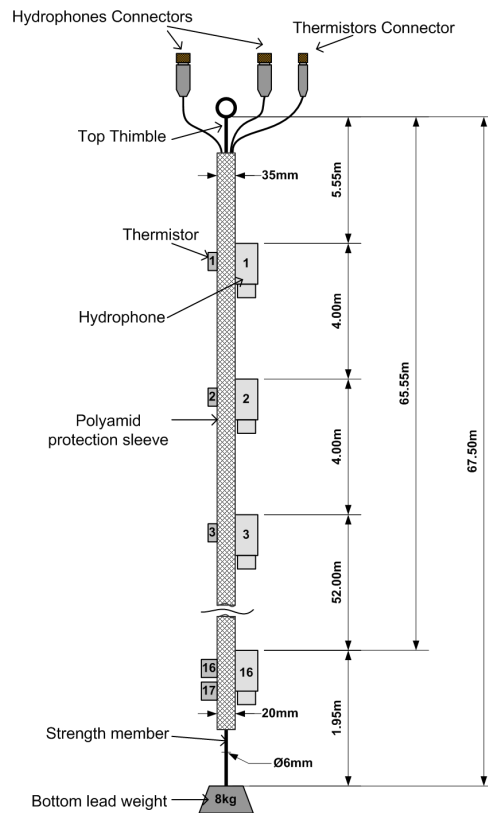


Figure 2.1: AOB2 analog array with dimensions.

line, to transmit the signal to the surface buoy's electronics. The thermistor sensors are digital devices that transmit the temperature values through a single wire serial digital network that requires only two wires. The signals received at the hydrophone modules are available at two connectors on the top of the array. A third connector is used for the thermistor bus. The cables are protected by a polyamide sleeve; one internal strength member cable is used to handle the vertical mechanical forces applied to the array, and one ballast weight is placed on the bottom to stretch the array and keep nearly vertical. The result is a thin and compact array with all the sensors at precise positions (figure

2.1).

In the AOB2 system (figure 2.2), the array is attached to the buoy's bottom cover support ring, and the signal connectors are attached to the buoy's top cover. The buoy is floating at the sea surface and, with the help of the ballast, the array is kept as much vertical as possible.

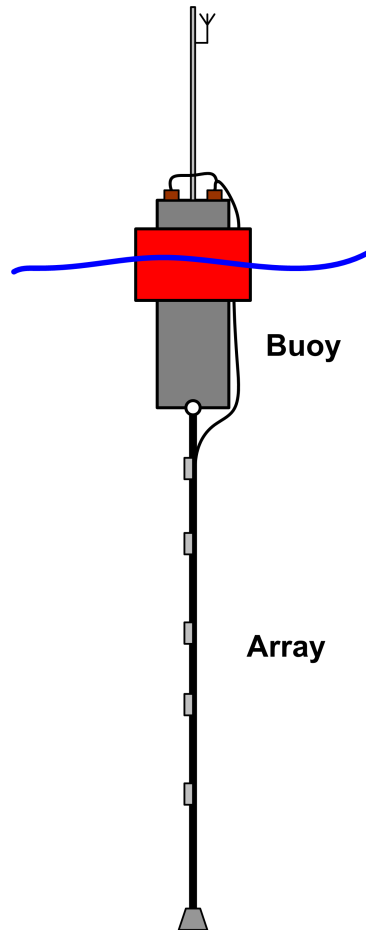


Figure 2.2: AOB2 system overview: analog array with dimensions (a) and complete system drawing (b).

Chapter 3

User Manual

3.1 Introduction

The first thing the user must notice is that the array is not a standalone element, it is part of the AOB2 system and, therefore, all the information shown in this manual should not be used alone but always as a complement to the AOB2 report/manual.

This chapter details the high-level operations regarding the correct use and maintenance of the array, plus some troubleshooting hints. The next chapter introduces the user to the hardware details about the array. The following two sections present the pre-deployment, the recover and post-deployment procedures. The fourth section enumerates some maintenance recommendations. The last section gives some hints to solve possible problems that may happen with this device while being used at sea or during maintenance/preparation for sea trial.

3.2 Hardware overview

This section describes the few hardware parts that compose the array:

- the main cable, composed by the electrical wires, sensors and one strength member all protected by a polyamid mesh sleeve;
- hydrophone cases, to protect the hydrophone and the pre-amplifier electronics inside a polyurethane mold;
- thermistor's, inside a polyurethane mold;
- a Dynema based strength member to maintain the vertical structure of the array and to attach the sensors so that they are held always at the constant distance;
- top thimble, fasten to the top of the strength member and used to securely attach the array to the buoy using a shackle. The shackle is made of plastic to avoid parasitic sounds when in contact with metal;
- bottom thimble, fasten to the bottom of the strength member and used to secure the ballast weights.
- ballast, made of lead weights, for keeping the array vertical when underwater.

The array technical specifications, including the electronic parts, are described in table A.1 of appendix A. Care must be taken with all the hardware parts specially bending of electrical cables, water, sand or other contaminant in the connectors, sensor cases or strength member.

3.3.1 Hardware

1. read the pre-deployment procedures for the AOB2 buoy;
2. check if the top and bottom thimbles are correctly tighten to the strength member;
3. check if the top and bottom thimbles have pvc electrical tape around to prevent acoustic noises;
4. attach the ballast weight to the bottom thimble using a shackle;
5. secure the shackle using plastic cable ties;
6. arrange the array in the deck in an 8-shape, assuring that the top end is the ballast (first in the water);
7. attach the array to the buoy connecting the top thimble with the array support in the buoy, using a shackle;
8. secure the shackle using plastic cable ties;
9. check the connectors' o-rings, if necessary apply silicone-based grease;
10. there are three electrical connectors to be attached to the surface buoy: two large 24-pin connectors one for each 8 hydrophone sub-array and one smaller 5-pin connector for the digital thermistor sensor array. The two large connectors are marked H1 and H2 for the upper half and lower half arrays, respectively. They should attached to the respectively marked H1 and H2 receptacles on the buoy's top cover. The 5-pin smaller connector should be attached to the respective receptacle on the buoys' cover. The user should ensure that the digital thermistor master card is correctly installed inside surface buoy (see 4.3 for details). Don't forget to pass the array cable inside the buoy's float.

Please refer to the AOB2 manual [1] for data acquisition software initialization and preparing/testing before deployment. This section will concentrate on the installation of the thermistor chain software, which is a new piece of hardware not previously described.

The installation of the thermistor chain software is done by placing the file `ThermistorChainDigital.py` in the `/AOB/programs` directory from where it will be activated as an additional service to be run on system startup (see section 4.3.12.2 for more details on this file format). Configuration of the software can be achieved by editing the `ThermistorChainDigital.py` in any text editor, variables to change if any are: the serial port (`/dev/ttyS1` for serial port 2) and additionally the line `coef = (0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0)` which is the compensation value to be applied to each individual sensor. Data is written to the file `/AOB/data/termchain-data.log` at the interval at which it is received from the thermistor chain. Each data line in the `termchain-data.log` file is of the following format:

09,11,2006,05:10:12,23.250000,23.062500,22.875000,22.937500,22.937500,
23.062500,22.937500,22.875000,22.875000,22.812500,22.812500,22.750000,
22.937500,22.750000,23.000000,23.000000,23.312500

The first fields are date and acquisition time, then followed by the temperature sensor readings in degrees C, separated by the comma delimiter.

3.4 Deployment, recover and post-deployment procedures

The steps for a safe recovery and storage of the array are as follows:

1. read the deployment procedure for the AOB2 system. The array is the first element to enter the water, starting with the ballast. Pay attention to the sea current to avoid entangling the array under the ships' propeller;
2. read the recovery procedure for the AOB2 Buoy.
3. after the buoy is on the deck, start pulling the array out of water. If possible arrange the array in an 8 shape immediately.
4. wash the array and the buoy with fresh water.
5. remove the electrical connectors. Pay attention not to loose the connector's o-rings.
6. place the dummies in the buoy and array connectors.
7. remove the top shackle.
8. leave the ballast weights attached, unless it cause problems to the transport or storage.
9. let the array dry.
10. store it in the AOB2 box, over the buoy.

3.5 Maintenance

Due to its characteristics, the array requires very few maintenance and a minimum checkup before any deployment is sufficient. Follow these steps:

- check if the o-rings are very dry or damaged before every experiment or deployment. If so replace them.
- check for any corrosion on every metallic parts(connectors, shackles), every 4 months and before every deployment.
- check the protection sleeve, for cuts, before each deployment.
- check the straps that hold the ballast before every deployment.
- check if the electrical cables are dry to cause breaches when bent, every 4 months. If so, replace them.

Always wash the array with fresh water after recovery to remove the salt water, and let it dry on air preferably protected from direct sun light.

3.6 Troubleshooting

This section describes possible problems that may occur with the array and their solutions. The only problems that can be found directly in the array are mechanical, since all electrical problems are only detected when the array is connected to the buoy, and for this ones both array and buoy must be checked.

- ☐ The buoy is very unstable at the sea:
 - Increase the ballast weight.
- ☐ The protection sleeve is damaged:
 - If it is not possible to replace at that moment, use some pvc tape, to cover the area.
- ☐ The shackle's bolts are too tight:
 - Remove the plastic tie.
 - Use some lubricant, like WD40, to remove the bolt.
 - If the shackle shows any oxidation, replace it.
- ☐ One connector has residues of water inside:
 - Remove the o-ring from the connector (using a thin plastic tie usually helps) and check if it is damaged. Replace if necessary.
 - If the o-ring is ok, the problem may be lack of silicone-based grease on the o-ring or the connector wasn't tight enough.
- ☐ The signals in one or more channels are not the expected:
 - Look at the troubleshooting section in the AOB2 manual.
 - Check the connectors to see if they are loose or if there is water inside, and make a test (stroke each hydrophone and check the result).
 - Apply some contact cleaner.
 - Check the buoy's electronics and software.
- ☐ A value of -28 or 0 degrees appear in the T-sensor reading:
 - a value of -28 denotes a reading error on the temperature sensor. It should be very unusual and may appear once in a while. If this reading becomes persistent in time, then a T-sensor may have a permanent problem and should be replaced. If this reading appears in a number of sensors say, a full section, it may mean that the bus is in open circuit between that section and the main master card. The solution is to replace the faulty portion of cable.
 - any other problem in the cable generates error messages and a T-sensor reading of 0 degrees - inside the buoy the error LED is on. In general these problems can not be simply solved (see section 4.3).

If the problem does not fit in any of the above, please contact Siplab/CINTAL for further assistance.

Chapter 4

System Reference

This chapter describes the array hardware in a higher technical detail. This information should be used by a qualified technician so as to ensure the minimum knowledge for testing or repairing electrical or mechanical components. This chapter is organized as follows: the first section addresses the array mechanical parts, the second section describes the hydrophone electronics and connections and the third and last section gives a tutorial description of the thermistor sensor electronics and respective master card.

4.1 Mechanical

The array mechanics includes all the elements used to keep the array structure intact and protect the electrical and electronic parts. All these elements are represented in figure 4.1.

4.1.1 Protection Sleeve

A polyamid sleeve is used to protect and to keep the wires and cables together. The sleeve is made of resistant and flexible polyamid mesh. The result is a compact, flexible and robust cable. The sleeve is manufactured by AUTECH (www.autec-vertrieb.de), and the used references are: GS-12, GS-15, GS-20 and GS-25 (AUFLEX).

4.1.2 Top Thimble

Top ring to connect the array to the buoy, using an inox shackle.

4.1.3 Bottom Thimble

Bottom ring to connect the array to the ballast, using an stainless-steel shackle.

4.1.4 Strength Member

The strength member is a 6mm Dyneema cable, with a very low stretching factor and breaking load of 1500 Kg. It goes from the top to the bottom of the array, inside the protection sleeve, and connects the top thimble with the bottom one. As it has a very low stretch factor, the sensors in the array are fasten to this cable, to be assured a fixed and stable position.

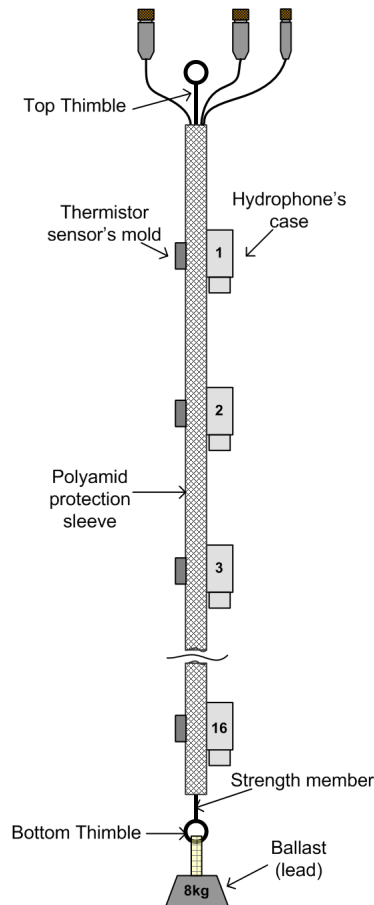


Figure 4.1: Mechanical Overview

4.1.5 Ballast

At the bottom of the array there is a 8kg ballast, made of lead weights, to keep the array under tension and as vertical as possible. The used weights are the same as scuba-divers, and are fastened to the bottom thimble using a strap (figure 4.2).

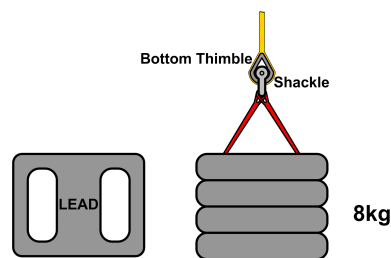


Figure 4.2: Ballast

4.1.6 Hydrophone Protection Case

A protection case was specially designed to keep the hydrophone and preamplifier electronics protected from the environment and to help fasten the hydrophone to the strength member at a known fixed depth position. Polyurethane resin UR5041 (RS code: 1608481)

is used to fill the case and isolate the electronics from the water. A spacer element is used to help tighten the case to the strength member. Figure 4.3 shows a self-explaining illustration. 3D drawings can be found in appendix G.

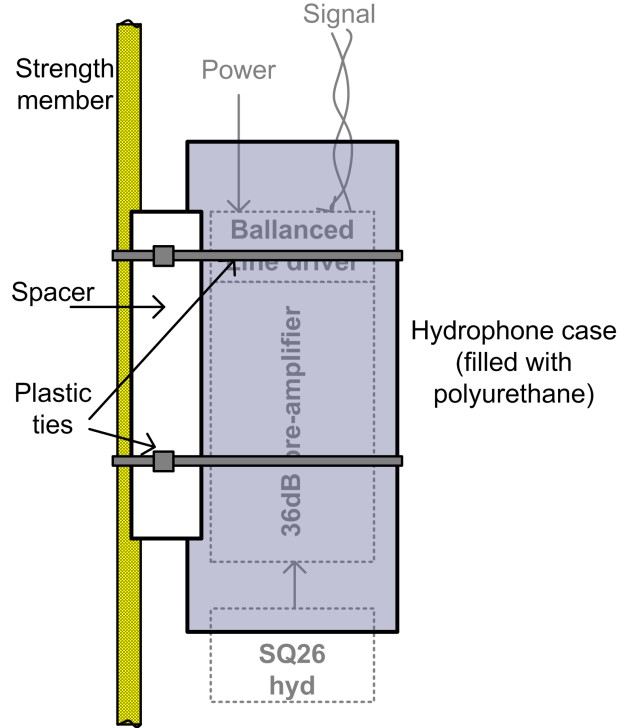


Figure 4.3: hydrophone pre-amplifier case mechanical overview.

4.2 Hydrophone electronics

4.2.1 Hydrophones

The hydrophones in use are the SQ26 (figure 4.4) manufactured by Sensor Technology Limited (<http://www.sensortech.ca/main.html>), whose main specifications are shown in table 4.1. Refer to figure 4.5 for a graph of the hydrophone sensitivity versus frequency. Hydrophone capacitance variations may be calculated as follows:

$$C_{SQ26} = 1.4\eta F \pm 10\% @ 20^\circ C \Rightarrow 1.26\eta F \leq C_{SQ26} \leq 1.54\eta F$$

$$C_{SQ26}(d) = C_{SQ26} \left(1 - 0.07 \frac{d}{1000}\right) = 1.4\eta F \left(1 - 0.07 \frac{d}{1000}\right)$$

where d is hydrophone depth in meter. These variations are shown in table 4.2. The relation between voltage and water pressure is

$$\frac{\Delta Q}{\Delta p} = 24 \eta C / \text{bar}$$

$$\Delta V = \frac{\Delta Q}{C} = \frac{24\eta C / \text{bar}}{1.4\eta F} = 17.1429 \text{ V/bar}$$



Figure 4.4: SQ26 foto

Voltage Sensitivity	$-193.5 \pm 1.0 \text{ dBV re } 1 \text{ Pa } 20^\circ\text{C}, 20 \text{ V/bar}$
Charge sensitivity	24 nC/bar ;
Capacitance	$1.4 \text{ nF} \pm 10\% 20^\circ\text{C}$
Sensitivity variation with temperature	$< 1 \text{ dB loss from } 0^\circ\text{C to } 35^\circ\text{C}$
Capacitance variation with temperature	$0.33\% \text{ increase per } ^\circ\text{C}$
Capacitance variation with depth	$7\% \text{ loss per } 1000\text{m}$
Operating depth	1000m
Frequency response	$\text{flat from } 1\text{Hz to } 28\text{kHz}$
Acceleration sensitivity	$< 0,2 \text{ mbar/g}$ when properly mounted
Storage and operating temperature	$-30^\circ\text{C to } 60^\circ\text{C}$
Diameter	25.4mm
Length	25.4mm
Mass	16 grams
Electrical leads	two red and black stranded, 28AWG 15cm long, Hytrel-insulated leads
Electrical insulation	$> 500 \text{ M}\Omega$
Water blocked leads	yes

Table 4.1: SQ26, Sensor Technology Ltd. hydrophone specifications

4.2.2 Pre-amplifiers

The pre-amplifiers were designed to adapt the small electrical signals obtained from the variation of the hydrophone's capacitance to the input voltage range of the acquisition electronics inputs (ADCs¹ inputs), taking into account the attenuation of the transmission line. As a starting point for the design of the circuit, the main goals are:

- approximate voltage gain of 36dB;

¹ADC - Analog to Digital Converter

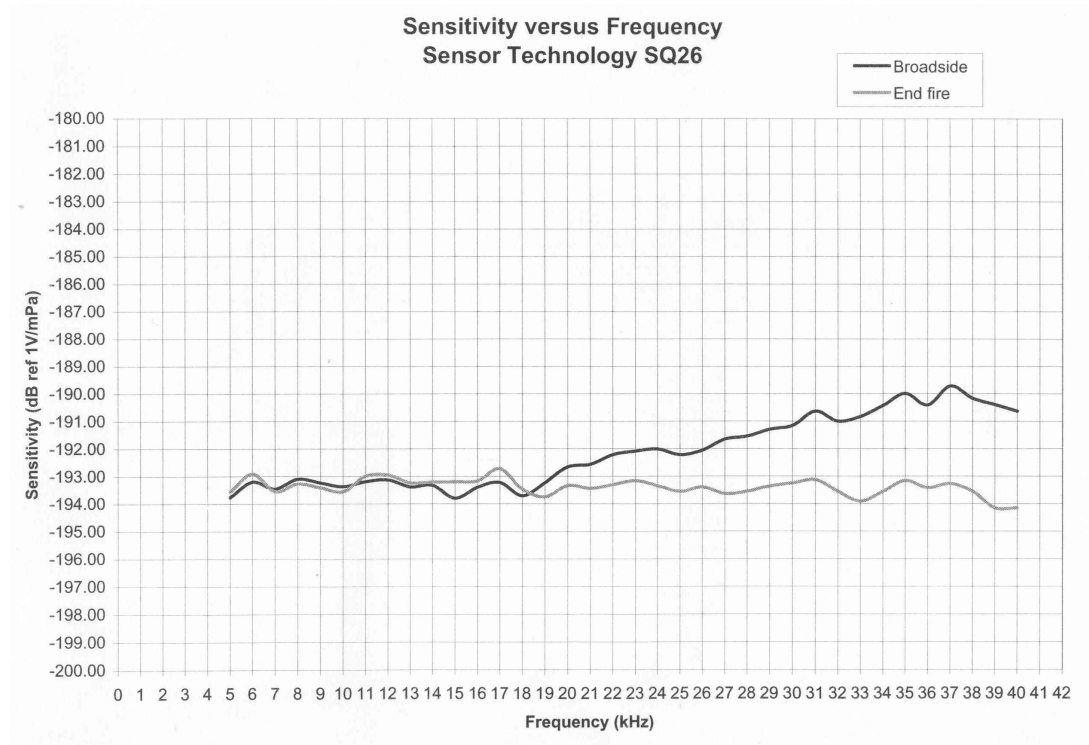


Figure 4.5: Sq26 - Sensitivity versus frequency

Depth [m]	Capacitance [ηF]
5.55	1.3994561
9.55	1.3990641
13.55	1.3986721
17.55	1.3982801
21.55	1.3978881
25.55	1.3974961
29.55	1.3971041
33.55	1.3967121
37.55	1.3963201
41.55	1.3959281
45.55	1.3955361
49.55	1.3951441
53.55	1.3947521
57.55	1.3943601
61.55	1.3939681
65.55	1.3935761

Table 4.2: hydrophone capacitance variations with depth

- -3dB bandwidth between 100Hz and above 17kHz;
- lowest noise as possible;
- differential output;
- output voltage range output between $-5V$ and $+5V$;

- low input bias currents (very important characteristic with capacitive transducers, like the hydrophones, to reduce offset voltages);
- smallest size as possible.

4.2.2.1 Circuit overview

The basic circuit is shown in figure 4.6. The design is based on a non-inverting op-amp-based scheme which circuit is proposed for an hydrophone transducer in the datasheets of two low-noise opamps, *LT1113* and *AD743*.

Amplifier *LT1113* is a low noise JFET opamp designed to amplify low level signals from high impedance capacitive transducers. Following the amplifier is a differential-output buffer amplifier, *SSM2142*, to convert the single ended signal to a balanced output signal. Capacitors C1 and C2 are used to eliminate DC signals and to set the amplifier's highpass cutoff frequency to 100Hz. Two diodes, D1 and D2, connected in anti-parallel are used to protect the opamp's input from high-voltages, that may occur due to very strong signals received by the hydrophone.

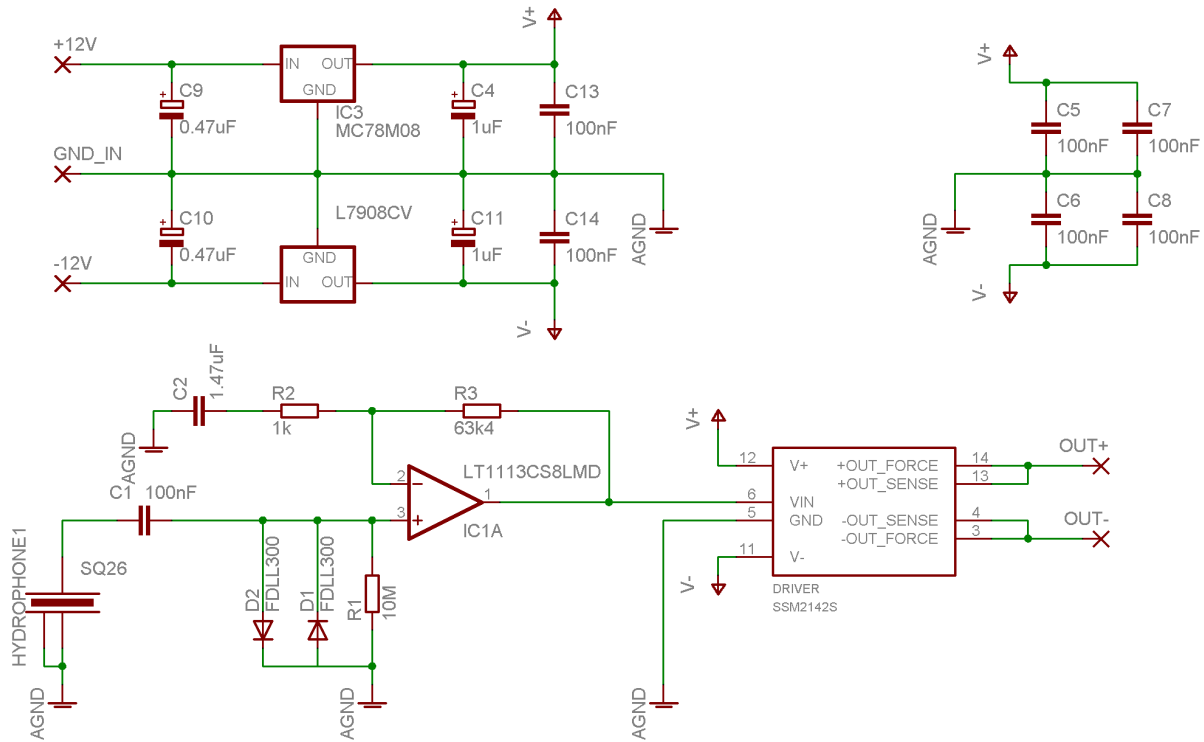


Figure 4.6: pre-amplifier circuit

4.2.2.2 Output Voltage Range

The output voltage range of the amplifier is limited by the power supply of the electronics. Using $\pm 8V$ voltage regulators, the output voltage range of the pre-amplifier is $-5V \leq V_{out} \leq +5V$, reference to ground, while the differential pre-amp output voltage range is $-10V \leq V_{out} \leq +10V$. See detailed calculus in appendix C.1.

4.2.2.3 Pre-amplifier gain

Detailed gain calculus can be found in appendix C.2 while a short table with a few important theoretical gain values are shown in table 4.3. Note the maximum gain in the frequency band of 36 dB and a highpass cutoff frequency of 108 Hz.

f (Hz)	A _{pre_amp}	A _{pre_amp} (dB)
0	0	$-\infty$
0.16	0.992	-69.5
108.27	45.6	33.17
108.3 $\rightarrow$ 52800	$1+R_3/R_2=64.4$	36.2
52800	45.6	33.17
∞	0	$-\infty$

Table 4.3: theoretical hydrophone pre-amplifier gain.

4.2.2.4 Pre-amplifier bandwidth

Pre-amplifier bandwidth varies with opamp characteristics and component temperature dependence. Detailed bandwidth calculus are shown in appendix C.3 and main results reported below.

$$\begin{aligned}
 \text{Preamp bandwidth:} & \quad 108.27Hz \leq B_{pre-amp} \leq 52796Hz \\
 \text{Temperature range:} & \quad 0^\circ C \leq T_{amb} \leq 70^\circ C \\
 \text{Top frequency variation:} & \quad 12423.4Hz \leq B_{pre-amp} \leq 52796Hz \\
 & \quad (\text{full temperature range})
 \end{aligned}$$

4.2.2.5 Noise

Ignoring the noise from the balanced line driver, which is not specified on the datasheet [8], the preamplifier noise main sources are the operational amplifier voltage and current noise (Table C.1) and the thermal noise on the resistors. All together give a final output noise of $E_{n-out} \approx 4.5019$ mV. Taking into account a pre-amplifier output range of $\pm 5V$ gives, for a sine wave at 1 kHz an output RMS voltage $V_{out-RMS} = \frac{5}{\sqrt{2}} = 3.5355V$ and therefore

$$\frac{3.5355}{4.5019 \times 10^{-3}} = 785.34$$

that in dB gives $20 \log(785) = 57.897dB$. The complete calculus to obtain these values is shown in appendix C.4. Attention must be payed to the fact that during the noise calculus, the noise bandwidth was assumed to be equal to the input signal bandwidth and not to the total noise bandwidth.

4.2.3 Cables and Connectors

The cabling system is designed to provide power to all the hydrophone pre-amplifiers and to bring the electrical signals from each hydrophone pre-amp to the surface buoy input connector.

4.2.3.1 Power supply cable

The power supply cable is a three wire cable, where each pre-amplifier is connected in a bus topology (figure 4.7). Table 4.4 shows the cable's properties.

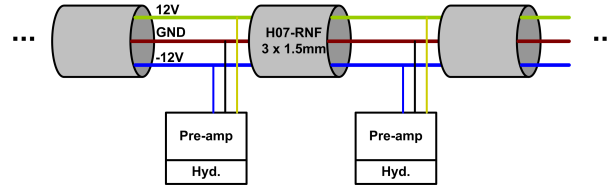


Figure 4.7: power supply cable

Number of cores	3
Cross-section	1.5 mm ²
Nominal Voltage	450/750 V rms
Nominal current	22 A
RS code	4099486

Table 4.4: power supply cable properties.

4.2.3.2 Signal cable

The electrical signals from the hydrophones - pre-amplifier modules are connected to the surface buoy via a twisted-pair cooper cable, see figure 4.8. Table 4.5 show the cable's properties:

Number of cores	2
Inner conductor	10 × 0.254 mm (20 AWG)
Insulation	1.92 mm diameter PVC
Twists	Left hand lay, 17.24 twists/m
External diameter	5.12 ± 0.20 mm
Capacitance	77 pF/m
Resistance	34Ω /km
Maximum current	8 A
RS code	0360958

Table 4.5: signal cable properties

4.2.3.3 1-wire cable

The 1-wire bus uses a twisted-pair cable, equal to the signal cables. Figure 4.9 shows the connections between the 1-wire bus cable, the top connector and the temperature sensors.

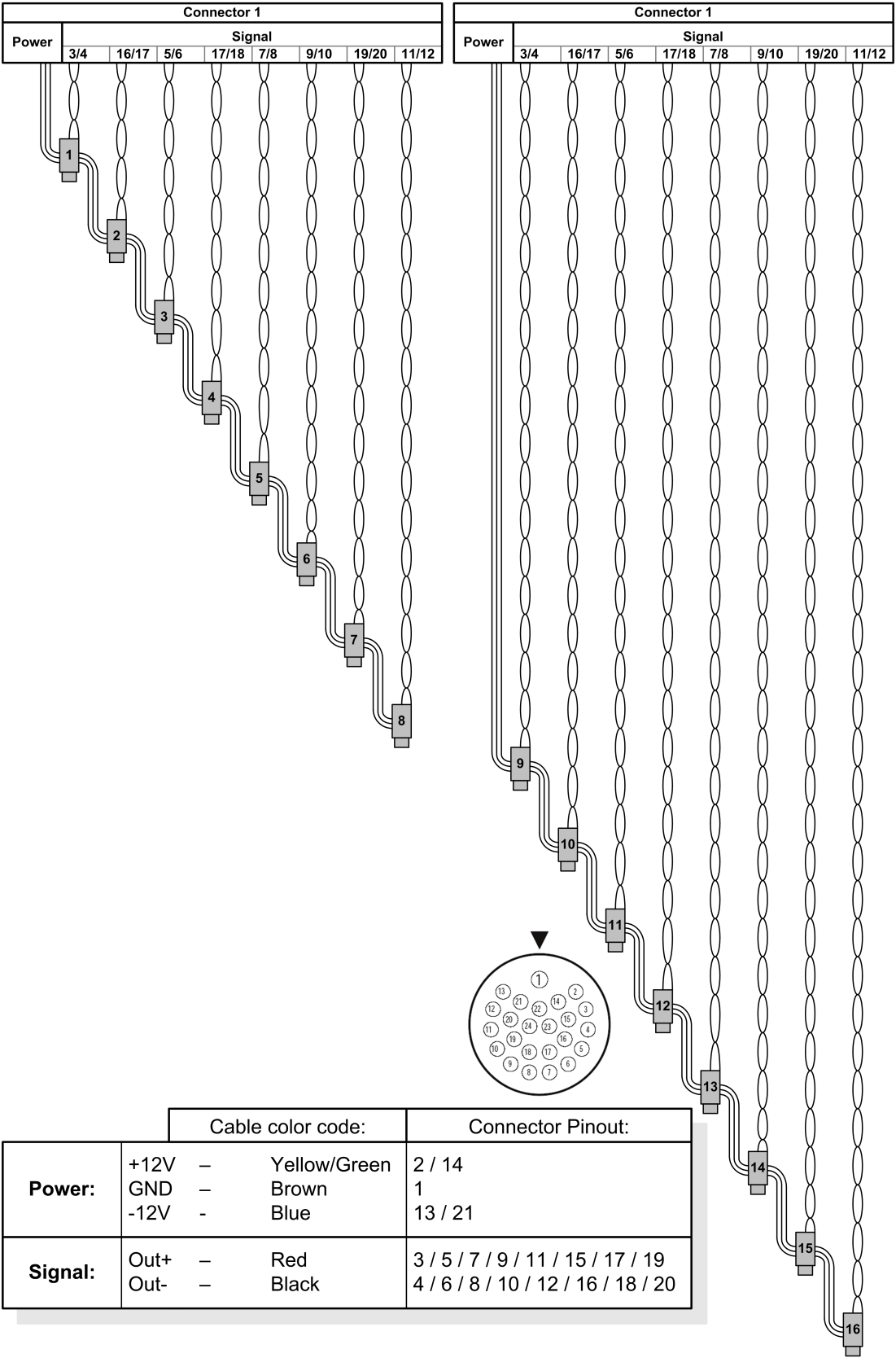


Figure 4.8: cables and connectors overview

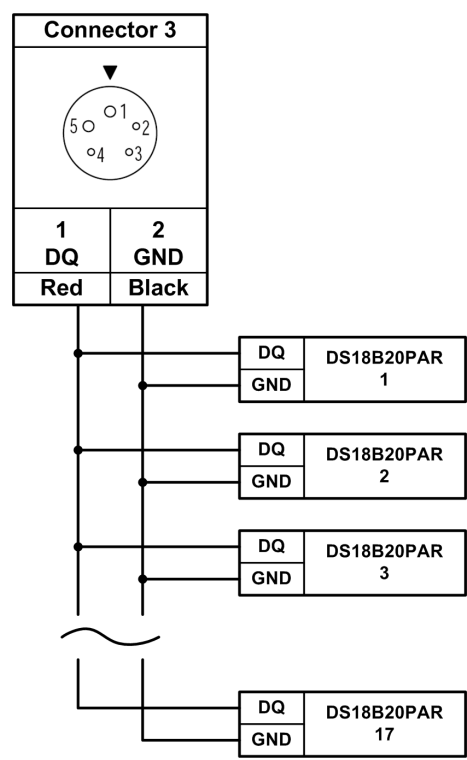


Figure 4.9: thermistors cable and connector overview

4.2.3.4 Connectors

▼ 5 1 2 4 3
MSSJ-CCP-5
1 - DQ (Data I/O) 2 - GND 3 - NC (Not connected) 4 - NC (Not connected) 5 - NC (Not connected)

Table 4.6: thermistors 1-wire bus connector.

All array connectors are made by Impulse(www.impulse-ent.com). A separate connector is used for the thermistors 1-wire bus. The connector reference is MSSJ-5. Figure 4.9 and table 4.6 show the connectors pinout. Hydrophone connections are made through two MHDL-CCP # 24. Figure 4.8 shows the array system cabling overview for the hydrophones and table 4.7 shows the hydrophone connectors' pinout.

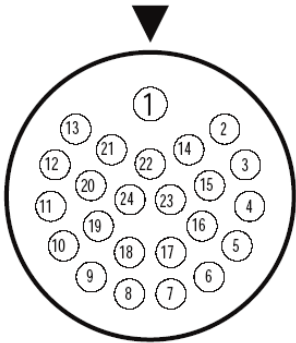
 MHDL-CCP-24	
Connector1	Connector2
1 - GND (Power) 2 - +12V (+Power) 3 - +Channel 1 4 - -Channel 1 5 - +Channel 3 6 - -Channel 3 7 - +Channel 5 8 - -Channel 5 9 - +Channel 6 10 - -Channel 6 11 - +Channel 8 12 - Channel 8 13 - -12V (-Power) 14 - +12V (+Power) 15 - +Channel 2 16 - -Channel 2 17 - +Channel 4 18 - -Channel 4 19 - +Channel 7 20 - -Channel 7 21 - -12V (-Power) 22 23 24	1 - GND (Power) 2 - +12V (+Power) 3 - +Channel 9 4 - -Channel 9 5 - +Channel 11 6 - -Channel 11 7 - +Channel 13 8 - -Channel 13 9 - +Channel 14 10 - -Channel 14 11 - +Channel 16 12 - Channel 16 13 - -12V (-Power) 14 - +12V (+Power) 15 - +Channel 10 16 - -Channel 10 17 - +Channel 12 18 - -Channel 12 19 - +Channel 15 20 - -Channel 15 21 - -12V (-Power) 22 23 24

Table 4.7: hydrophone connectors.

4.3 Thermistor chain electronics

The digital thermistor chain is a newly developed system that is composed of a thermistor sensor array and a master board. The sensor array is composed of a single cable with two wires that is connected to the master board. The master board communicates with a computer CPU via a standard RS-232 port. The digital thermistor array can be used integrated in the acoustic array or standalone (future version).

4.3.1 Overview and setup

The thermistor chain is formed of a 2 wire cable with 17 molded T-sensors and the electronic “Thermistor’s Chain Master” board. This card has an input for the 2 wires from the array, and a serial RS232 output as shown on figure 4.10. After the card is

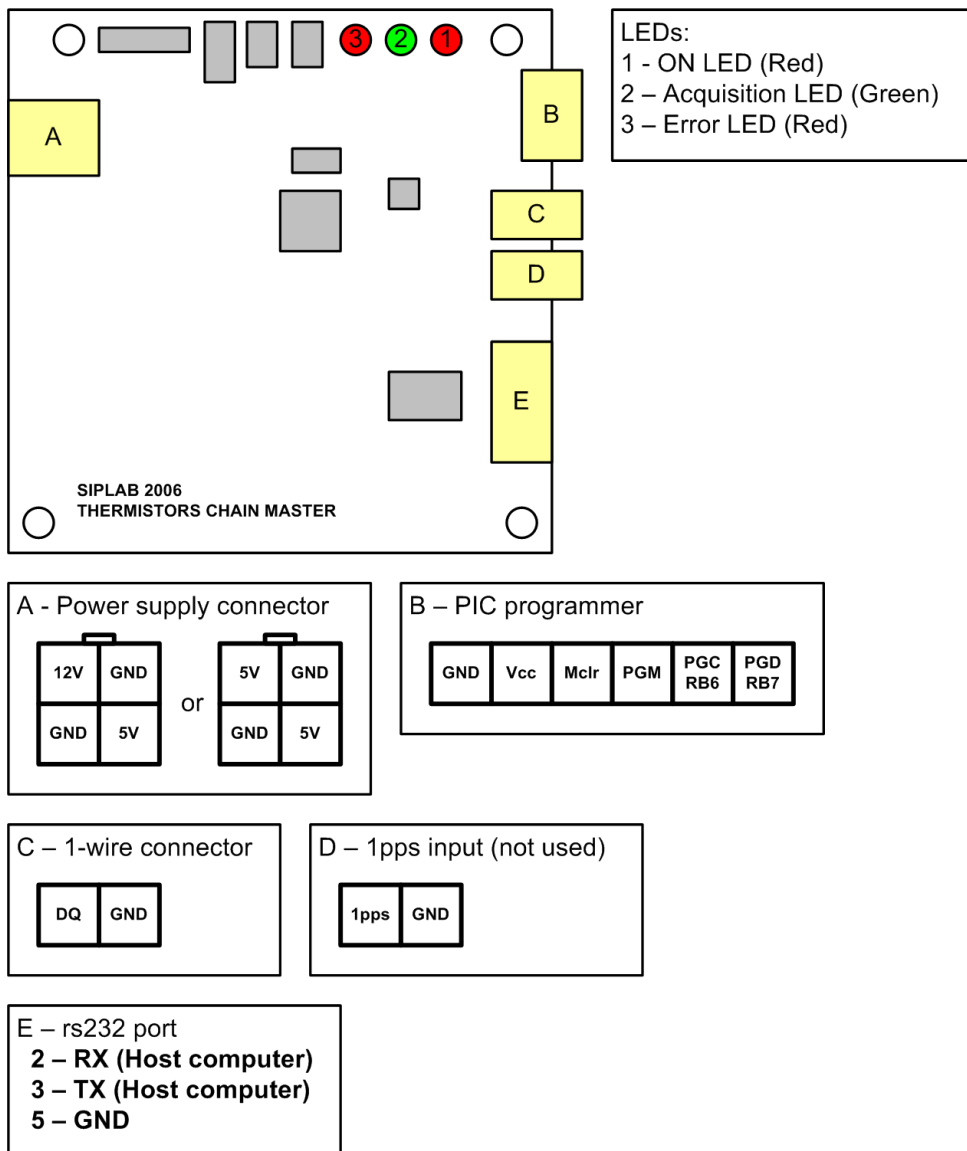


Figure 4.10: thermistors master card.

powered ON, it starts reading the temperatures from the array continuously. The card reads the 17 values approximately every 5 seconds, and sends the readings in ASCII

format to the serial port. The acquisition timing is obtained from the microcontroller's cristal oscillator taken as reference clock.

4.3.2 Power-up

Figure 4.11 shows the power-up flowchart.

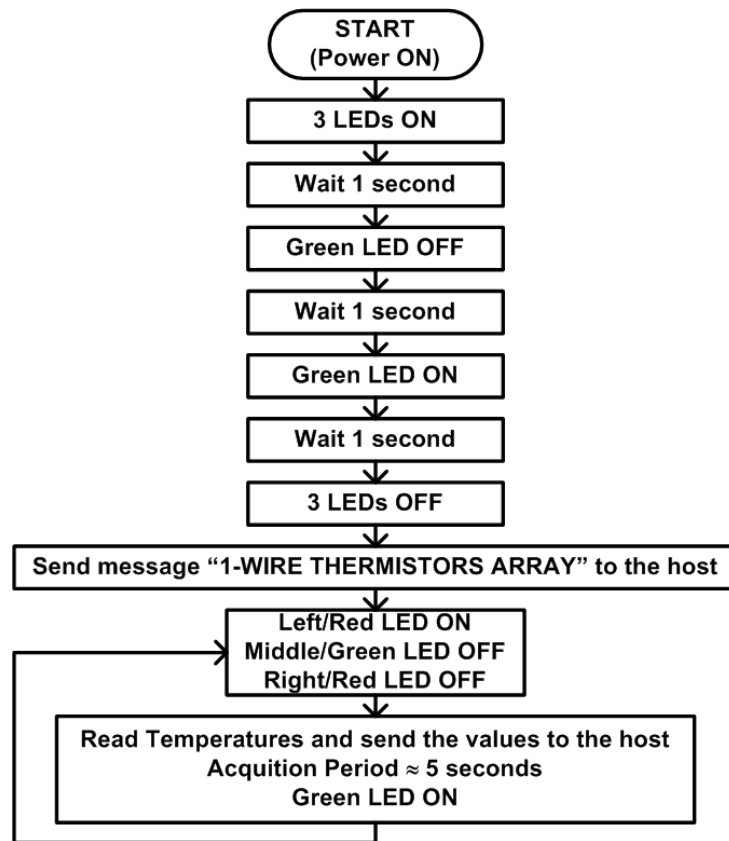


Figure 4.11: thermistors master card power-up flowchart

4.3.3 Status LEDs

The board's LED's show the status of the system, coded as follows:

- **ON LED** (Left/Red) - The microcontroller set this Led ON when the card is powered-ON.
- **ACQUISITION LED** (Middle/Green LED) - This Led is ON when the microcontroller is acquiring one set of 17 temperatures, and returns to OFF when the acquisition ends.
- **ERROR LED** (Right/Red) - This LED is turned ON every time one error occur. At the same time, one error message is sent through the serial port to the host computer.

4.3.4 Serial Interface Configuration

In order to receive the data from the card an RS-232 interface with the following configuration is necessary:

- Baud Rate: 19200 bauds
- Data: 8 bits
- Parity: None
- Stop Bits: 1
- Flow Control: None

4.3.5 Serial Interface Messages

The communication between the card and the computer host is performed through ASCII messages, in simplex mode, from the card to the host. The messages semantics allow the user to read them directly, using a serial port interface software (such as "Hyperterminal"). To make the development of the interface software easier for the host computer, the number of possible messages is finite and each message length is constant.

- Each message has a specific and constant number of characters, being either alphanumeric or hexadecimal values.
- The description of each message start and end with ". This characters are not sent by the card.
- In the description, spaces are shown as: □ .
- Some messages include linebreaks. Linebreaks are sent using **0x0A** (New Line) followed by **0x0D** (Carriage Return). To distinguish this, from the ASCII characters, lets assume a linebreak to be like: \\\

Message list:

- "\\1-WIRE□THERMISTORS□ARRAY\\" (26 characters)
 - This message is sent everytime the card's microcontroller is powered ON, or a software reset is performed in the microcontroller. This is always the first message sent by the card to the host.
- "\\TEMP\\" (6 characters)
 - This message is the header for a set of 17 temperature values. The 17 temperatures, from the array thermistors, are sent to the host after this message. The first temperature to be sent is from thermistor 1 and ends with the temperature from thermistor 17.
 - Each temperature value's size is constant and is composed with a signal character equal to '+' or '-', plus 7 characters with the value in degrees centigrades, plus one linebreak: "SXX,XXXX\\"
 - If the temperature returned is equal to "-28,000\\", this means an error occurred in the reading. CRC codes are used to validate every temperature values received from the sensors.
- "BUS□IN□SHORT-CIRCUIT\\" (21 characters)
 - This message is send if the 1-wire bus is in short-circuit.
- "NO□DEVICES□IN□THE□BUS\\" (22 characters)

- This message is send if there are no devices in the bus or, and most commonly, if the array is not connected to the card.
- "RESET-ACQ_ISR\\\" (14 characters)
 - This message is send after an error in the acquisition routine.
 - After the message is sent, the microcontroler performs a reset.
 - Contact to the card's manufacturer or refer to section 4.3.12
- "RESET-OWRESET\\\" (14 characters)
 - This message is send after an error in the 1-wire reset routine.
 - After the message is sent, the microcontroler performs a reset.
 - Contact to the card's manufacturer or refer to section 4.3.12

4.3.6 Thermistors

The temperature sensors used in the array are the "DS18B20-PAR", manufactured by Maxim (www.maxim-ic.com). Their specifications are

- 1-wire interface, requires only 2 pins connection to work;
- derives power from data line ("parasite power"), does not need a local power supply;
- multi-drop capability simplifies distributed temperature sensing applications;
- requires no external components;
- $\pm 0.5^{\circ}\text{C}$ accuracy from -10°C to $+85^{\circ}\text{C}$;
- measures temperatures from -55°C to $+100^{\circ}\text{C}$ (-67°F to $+212^{\circ}\text{F}$);
- thermometer resolution is user-selectable from 9 to 12 bits
- converts temperature to 12-bit digital word in 750 ms (max.);
- ideal for use in remote sensing applications (e.g., temperature probes) that do not have a local power source.

and the thermistor's pinout is shown in figure 4.12. Thermistor's typical error curve is given in figure 4.13 that mainly shows that these T-sensors have a bias of -0.2°C and a -3 standard deviation error less than 0.3°C . Refer to sensor datasheet [9] for further details.

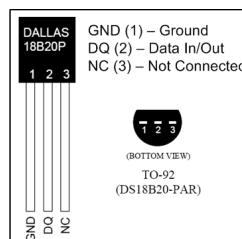


Figure 4.12: Thermistors pinout

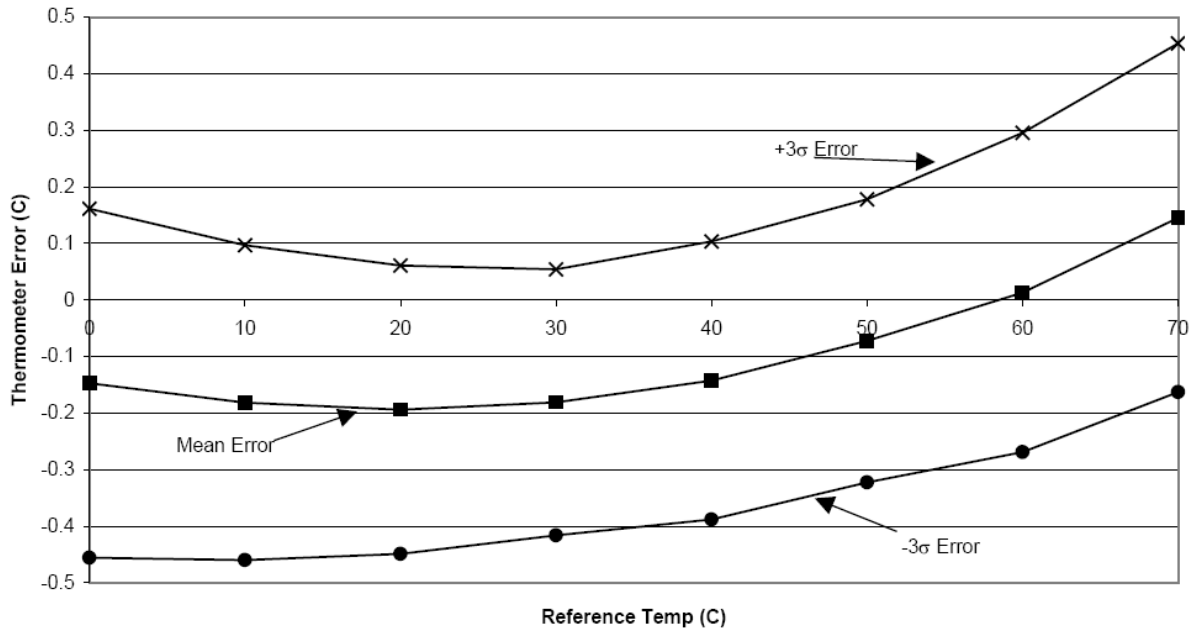


Figure 4.13: DS18B20-PAR typical error curve

4.3.7 1-Wire bus

The 1-wire bus is a digital serial data communication bus featuring: low-speed data, low signaling, low power, low cost, 1 wire data and 1 ground lines, and power over data line. More details info about 1-wire are available in reference [10].

4.3.7.1 Serial network

The 1-wire bus may work as a serial network, with one master device and one or more slaves. The master is a controller unit directly connected to the bus or through an interface chip. The slave devices include temperature sensors, memories, mixed signal, and secure authentication chips. The seventeen DS18B20-PAR are the slave devices in the array. Each 1-wire slave device have a unique 64-bits identification codes, stored in ROM and recorded from factory. The code includes a 8-bits CRC validation code, a 48-bits serial number and a 8-bits family number (28h = DS18B20-PAR's family devices), as shown in figure 4.14. This code is used as an address to access each device individually. At appendix E.1 is a list with address from all the sensors, in the array and the spares. The number



Figure 4.14: 64-bits lasered rom code

of lines needed for the 1-wire bus are only two, a single data line and a ground line. Three different network topologies are proposed by the manufacturer: Linear, Stubbed and Star. This array uses the Linear topology (figure 4.15), the 1-wire bus is a single pair, starting at the master and extending to the farthest slave device. Other slave devices are attached to the pair along its length without significant (>3m) branches or "stubs". The communication in the bus is always between one master and one or more slaves, and the slaves can't communicate between them. There is possible for the master to send



Figure 4.15: 1-wire bus linear topology

commands or data to one specific device or to several devices at the same time (point-to-point or point-multipoint). On the slaves side, they can only send data to the master one at the time (point-to-point) and after request from the master.

In the 1-wire network, two terms are used to describe measurements: radius and weight. The *radius* of a network is the wire run distance from the master end to the furthest slave device, in meters. The *weight* of a network is the total amount of connected wire in the network, in meters. To assure a reliable network, the radius must not be greater than 750m, due to protocol timings, and the weight is limited to 200m or 500m, due to signal attenuation: 200m when using a single pull-up resistor, and 500m when using active pullups to provide higher currents under logic control. The weight of a network is not only specified by the cable length but also by the slave devices and pcb boards:

- i-buttons slave devices : 1 meter per device;
- non i-buttons slave devices (DS18B20-PAR): 0.5 meters per device;
- pcb trace with 24pF: 1m.

In this array, the weight and radius of the network is:

$$weight_{slaves} = 17\text{devices} \times 0.5 = 8.5\text{meters}$$

$$weight_{cable} = \text{array length} + \text{cable length from the array to the master} \\ \approx 65.55m + 2.5m = 68.05m \approx 70\text{meters}$$

$$weight_{network} = weight_{slaves} + weight_{cable} = 8.5m + 70m = 78.5\text{meters}$$

$$radius_{network} = weight_{cable} = 70.5\text{meters}$$

Refer to Maxim application note AN148 [11] (guidelines for reliable 1-wire networks).

4.3.7.2 Parasite Power

Some slave devices, like DS18B20-PAR, don't need a local external power supply because they have an internal parasite power circuit, to "steal" power from the 1-wire bus data line (figure 4.16). When the data line is high, the device is directly powered and one capacitor is charged; when the data line is low, power is provided by the charged capacitor. Whenever the power from the bus and the capacitor aren't enough, the master circuit must provide a strong pullup on the 1-wire bus (figure 4.17). This situations always happens when the DS18B20-PAR is performing a temperature reading or is copying data to the EEPROM. No other activity can take place on the 1-Wire bus while the strong pullup is enabled. Refer to DS18B20-PAR datasheet for more details [9].

4.3.8 Data packet

The DS18B20-PAR's memory is organized as shown in figure 4.18. Each time a temperature is measured the value is stored in bytes 0 (LSB) and 1 (MSB), and then the

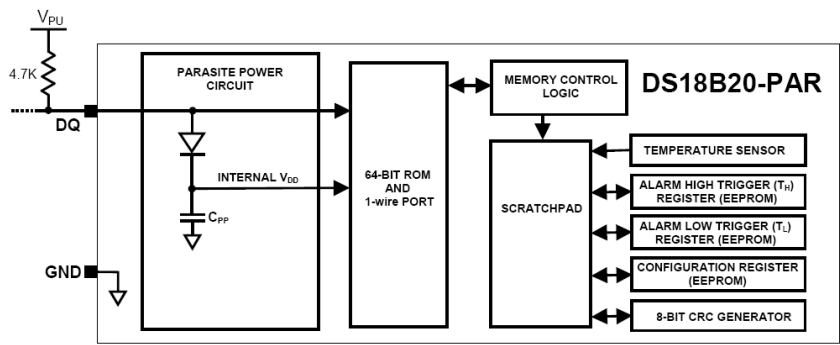


Figure 4.16: DS18B20-PAR’s parasite power circuit and internal block diagram

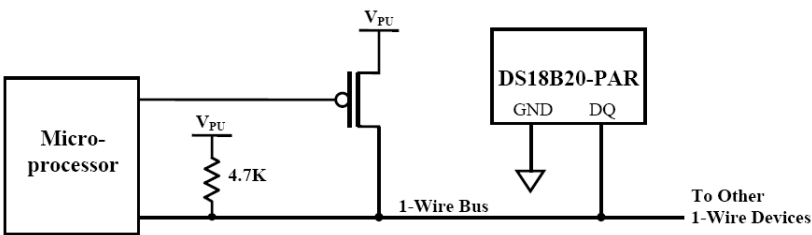


Figure 4.17: DS18B20

whole scratchpad packet (9 bytes) is sent to the master. The reason to send the whole scratchpad to the master is that a CRC code is included to validate the whole packet, and not only the temperature values. Temperature values have a resolution of 9, 10, 11 or

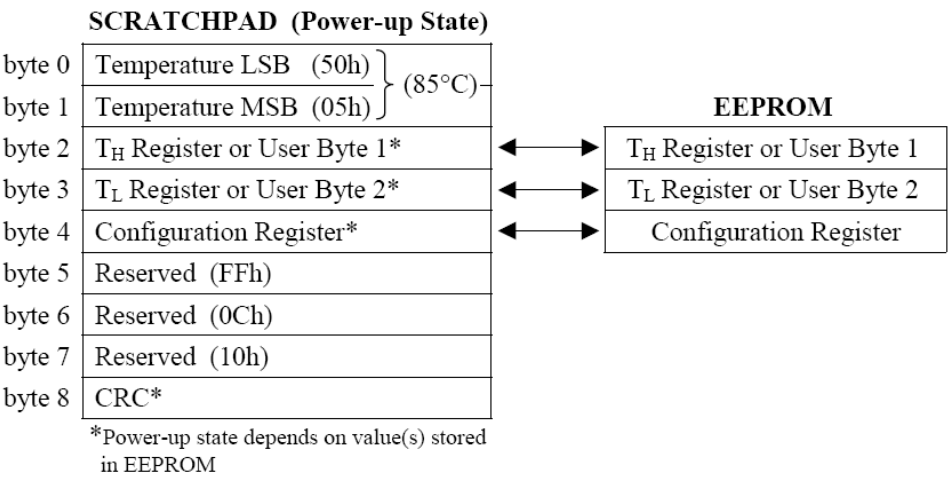


Figure 4.18: DS18B20-PAR memory chart

12-bits (0.5°C, 0.25°C, 0.125°C, 0.0625°C), user-configurable in the configuration register. The temperature data is stored as a 16-bit sign-extended two’s complement number in the temperature register (figure 4.19). The signal bit is bit11 and his values is extend from bit 12 to 15. For 11-bit resolution, bit 0 is undefined; for 10-bit resolution, bits 1 and 0 are undefined; and for 9-bit resolution bits 2, 1 and 0 are undefined. Table 4.8, shows some examples between temperature values and binary code. At power-up, the

	bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
LS Byte	2 ³	2 ²	2 ¹	2 ⁰	2 ⁻¹	2 ⁻²	2 ⁻³	2 ⁻⁴
	bit 15	bit 14	bit 13	bit 12	bit 11	bit 10	bit 9	bit 8
MS Byte	S	S	S	S	S	2 ⁶	2 ⁵	2 ⁴

Figure 4.19: DS18B20-PAR temperature registers format.

TEMPERATURE	DIGITAL OUTPUT (Binary)	DIGITAL OUTPUT (Hex)
+85°C ²	0000 0101 0101 0000	0550h
+25.0625°C	0000 0001 1001 0001	0191h
+10.125°C	0000 0000 1010 0010	00A2h
+0.5°C	0000 0000 0000 1000	0008h
0°C	0000 0000 0000 0000	0000h
-0.5°C	1111 1111 1111 1000	FFF8h
-10.125°C	1111 1111 0101 1110	FF5Eh
-25.0625°C	1111 1110 0110 1111	FE6Fh
-55°C	1111 1100 1001 0000	FC90h

Table 4.8: temperature conversion table.

default resolution is 12bits. Resolution also limits the acquisition time, the higher the resolution, more time is needed to perform an acquisition (table 4.9). Luckily, the 1-wire protocol allows the master to issue a temperature acquisition to the all the slaves at the same time. Nevertheless, after the acquisition ends, the master have to read each device temperature register (full scratchpad) one by one.

Resolution	Max Conversion Time
9-bit	93.75 ms
10-bit	187.5 ms
11-bit	375 ms
12-bit	750 ms

Table 4.9: Temperature acquisition time

This system resolution is 12 bits. Refer to DS18B20-PAR datasheet for more details [9]

4.3.9 CRC

Both DS18B20-PAR 64-bit identification code and scratchpad includes a CRC(Cyclic Redudancy Check) code for errors detection. The identification ROM code's CRC is calculated from the first 56 bits of the code and is contained in the most significant byte. The scratchpad CRC is calculated from the data stored in the scratchpad, and therefore it changes when the data in the scratchpad changes. The CRCs provide the bus master with a method of data validation when data is read from the DS18B20-PAR. The Dallas Semiconductor 1-Wire CRC (DOW CRC) magnitude is 8 bits, and is capable of detect the following types of errors:

- Any odd number of errors.
- All double-bit errors.

- Any cluster of errors that can be contained within an 8-bit "window" (1-8 bits incorrect).
- Most larger clusters of errors.

The equivalent polynomial function of the DOW CRC is: $CRC = X^8 + X^5 + X^4 + 1$. The bus master can re-calculate the CRC and compare it to the CRC values from the DS18B20-PAR using the polynomial generator shown in figure 4.20. This circuit consists of a shift register and XOR gates, and the shift register bits are initialized to 0. Starting with the least significant bit of the ROM code or the least significant bit of byte 0 in the scratchpad, one bit at a time should be shifted into the shift register. After shifting in the 56th bit from the ROM or the most significant bit of byte 7 from the scratchpad, the polynomial generator will contain the re-calculated CRC. Next, the 8-bit ROM code or scratchpad CRC from the DS18B20-PAR must be shifted into the circuit. At this point, if the re-calculated CRC was correct, the shift register will contain all 0s. If memory is

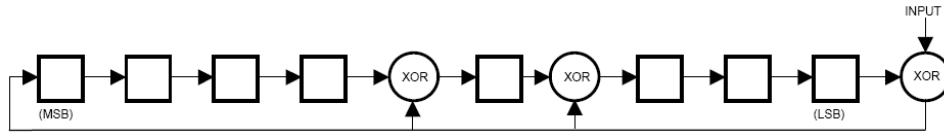


Figure 4.20: DOW CRC generator.

available in the master, one better and faster way to check the DOW CRC is to use a look-up table that is accessed directly for any 8-bit value currently stored in the CRC register and any 8-bit pattern of new data. For the simple case where the current value of the CRC register is 00 Hex, the 256 different bit combinations for the input byte can be evaluated and stored in a matrix, where the index to the matrix is equal to the value of the input byte (i.e., the index will be $I = 0-255$). It can be shown that if the current value of the CRC register is not 00 Hex, then for any current CRC value and any input byte, the lookup table values would be the same as for the simplified case, but the computation of the index into the table would take the form of:

$\begin{aligned} \text{New CRC} &= \text{Table}[I] \text{ for } I = 0 \text{ to } 255; \\ \text{where } I &= (\text{Current CRC}) \text{ EXOR } (\text{Input byte}) \end{aligned}$
--

Table 4.10 shows the lookup table values for the DOW CRC and table 4.11 shows an example about how to use it. The look-up table method is the one used in our system. Refer to Maxim application note AN27 [12] (Understanding and Using Cyclic Redundancy Checks).

4.3.10 1-Wire Bus Master

The system master is composed by a microcontroller PIC18F6620 [13] and a serial-to-1-wire interface chip DS2480B [14]. The microcontroller is responsible for:

- set the temperature acquisition rate to approximately 5seconds.
- communicate with the 1-wire slave devices, DS18B20-PAR, through the DS2480B;
- communicate with the host computer through an rs232 serial port interface.

```

table[0..255]= (
0, 94, 188, 226, 97, 63, 221, 131, 194, 156, 126, 32, 163, 253, 31, 65,
157, 195, 33, 127, 252, 162, 64, 30, 95, 1, 227, 189, 62, 96, 130, 220,
35, 125, 159, 193, 66, 28, 254, 160, 225, 191, 93, 3, 128, 222, 60, 98,
190, 224, 2, 92, 223, 129, 99, 61, 124, 34, 192, 158, 29, 67, 161, 255,
70, 24, 250, 164, 39, 121, 155, 197, 132, 218, 56, 102, 229, 187, 89, 7,
219, 133, 103, 57, 186, 228, 6, 88, 25, 71, 165, 251, 120, 38, 196, 154,
101, 59, 217, 135, 4, 90, 184, 230, 167, 249, 27, 69, 198, 152, 122, 36,
248, 166, 68, 26, 153, 199, 37, 123, 58, 100, 134, 216, 91, 5, 231, 185,
140, 210, 48, 110, 237, 179, 81, 15, 78, 16, 242, 172, 47, 113, 147, 205,
17, 79, 173, 243, 112, 46, 204, 146, 211, 141, 111, 49, 178, 236, 14, 80,
175, 241, 19, 77, 206, 144, 114, 44, 109, 51, 209, 143, 12, 82, 176, 238,
50, 108, 142, 208, 83, 13, 239, 177, 240, 174, 76, 18, 145, 207, 45, 115,
202, 148, 118, 40, 171, 245, 23, 73, 8, 86, 180, 234, 105, 55, 213, 139,
87, 9, 235, 181, 54, 104, 138, 212, 149, 203, 41, 119, 244, 170, 72, 22,
233, 183, 85, 11, 136, 214, 52, 106, 43, 117, 151, 201, 74, 20, 246, 168,
116, 42, 200, 150, 21, 75, 169, 247, 182, 232, 10, 84, 215, 137, 107, 53);

```

Table 4.10: DOW CRC lookup table.

Current CRC Value (= Current Table Index)	Input Data	New Index (= Current CRC xor Input Data)	Table (New Index) (=New CRC Value)
0000 0000 = 00h	0000 0010 = 02h	(00h xor 02h) = 02h = 2	Table[2]= 188 = 1011 1100 = BCh
1011 1100 = BCh	0001 1100 = 1Ch	(BCh xor 1Ch) = A0h = 160	Table[160]= 175 = 1010 1111 = AFh
1010 1111 = AFh	1011 1000 = B8h	(AFh xor B8h) = 17h = 23	Table[23]= 30 = 0001 1110 = 1Eh
0001 1110 = 1Eh	0000 0001 = 01h	(1Eh xor 01h) = 1 Fh = 31	Table[31]= 220 = 1101 1100 = DCh
1101 1100 = DCh	0000 0000 = 00h	(DCh xor 00h) = DCh = 220	Table[220]= 244 = 1111 0100 = F4h
1111 0100 = F4h	0000 0000 = 00h	(F4h xor 00h) = F4h = 244	Table[244]= 21 = 0001 0101 = 15h
0001 0101 = 15h	0000 0000 = 00h	(15h xor 00h) = 15h = 21	Table[21]= 162 = 1010 0010 = A2h
1010 0010 = A2h	1010 0010 = A2h	(A2h xor A2h) = 0h = 0	Table[0]= 0 = 0000 0000 = 00h

Table 4.11: table lookup method for computing DOW CRC.

After power up, the temperatures acquisition is continuous, and every 5 seconds one set of 17 temperatures is read, decoded to ASCII characters and sent to the host computer. It is important to refer that the sensors don't have any synchronization clock for continuous acquisition, and one acquisition is performed everytime the master send the order. In this way, the synchronising clock used is the microcontroller's crystal oscillator, which is not very precise when compared, for example, to a dedicated temperature compensated oscillator.

The DS2480B is an interface chip designed to connect masters, with UARTs or 5V RS232 interfaces, to the 1-wire bus (figure 4.21). This bridge allows any host with a very simple serial communication UART to generate properly timed and slew controlled 1-Wire waveforms. The DS2480B receives escaped commands and data, performs 1-Wire operations, and returns the result back to the host. To establish communication with the

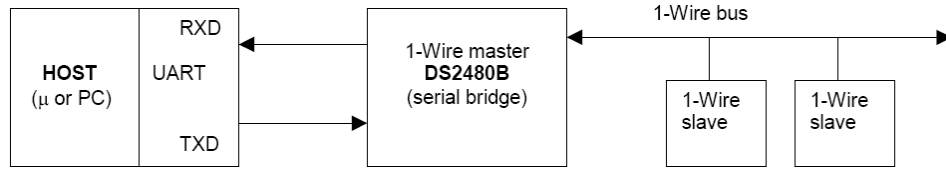


Figure 4.21: DS2480B usage (simplified).

bridge, the UART must be configured to:

- Baud Rate: 9600 bauds
- Data: 8 bits
- Parity: None
- Stop Bits: 1
- Flow Control: None

This is the startup default configuration to access the bridge, and is the configuration used by this system. If necessary, after the communication is established, it is possible to negotiate faster rates: 115.2kbps, 57.6kbps and 19.2kbps. An example of the physical connection of the DS1480B with the microcontroller is displayed in figure 4.22. Differences between this circuit and one used in the system is only the absence of the two diodes. Pin Vpp may be connected to 5V, if the master don't need to program any slave's EEPROM; otherwise this pin must be connected to 12V. In our system the DS18B20-PAR EEPROM is not used. According to the manufacturer [14] [11], an R-C filter must be used on

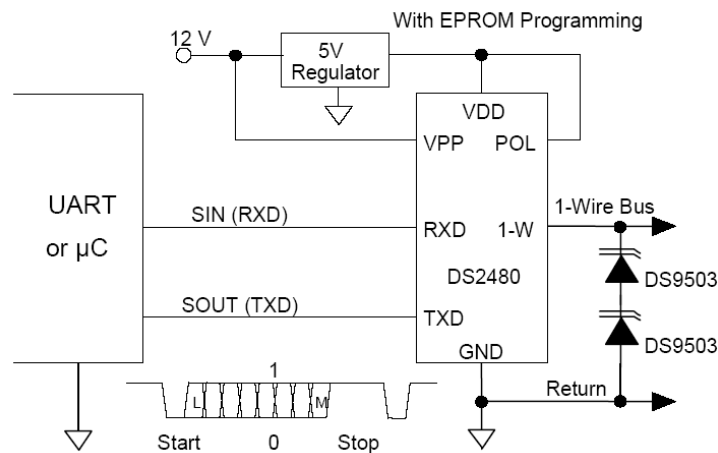


Figure 4.22: DS2480B circuit example.

networks longer than 1m and under 100m (figure 4.23). In our application this filter is

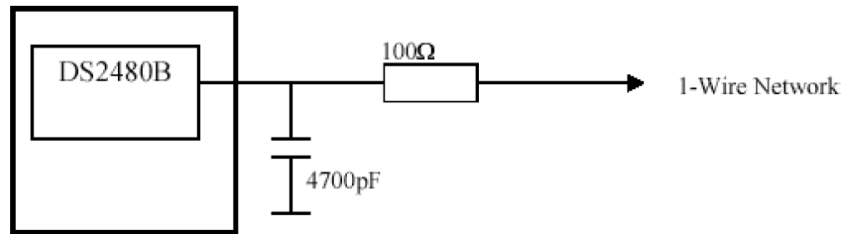


Figure 4.23: R-C filter helps DS2480B interfaces on short-to-medium networks.

bypassed and the network is still functioning ok. To improve the 1-wire network reliability and performance [11], the DS2480B 1-wire timings and slew-rates may be tuned to better match the network physical medium. Manufacturer tests with long and short bus lines has shown that the optimum timings for all networks areas follows:

- Pulldown Slew Rate: $1.37V/\mu s$
- Write-One Low Time: $11\mu s$
- Data Sample Offset/Recovery: $10\mu s$

These timings apply only to networks where the pullup voltage is between 4.5V and 5.5V.

4.3.11 Electronic card

The electronic circuit for the thermistors chain master card is shown in figure 4.24. Assembled on a pcb board with PC-104 dimensions, the circuit includes the microcontroller PIC18F6620 unit plus the 1-wire bridge DS2480. One line driver/receiver for RS-232 chip (MAX203ECWP) connects the microcontroller's uart with the computer's RS-232 serial port. One 4 MHz cristal sets the microcontroller's working frequency. Input buttons are implemented on the circuit, but the current microcontroller software doesn't support them. All the connectors on the card and the LEDs functions are described in section 4.3.3 and in figure 4.10.

4.3.11.1 Microcontroller's frequency

The microcontroller frequency is set by the 4MHz crystal [13]:

$$\text{PIC mode} = \text{HS-PLL} \Rightarrow f_{osc} = f_{crystal} \times 4 = 16MHz \Rightarrow \frac{16MHz}{4} = 4MIPS$$

4.3.11.2 Microcontroller's programming

The circuit designed has an error in the programming connector (ICSP connector), and the programmer can't be directly connected to this port to program the PIC³. To make programming possible, all the PIC's Vcc pins must be disconnected from the circuit and routed only to the programmer. Figure 4.25 illustrates these changes.

³The actual circuit probably work if Microchip ICD2 programmer is used, but this was not tested.

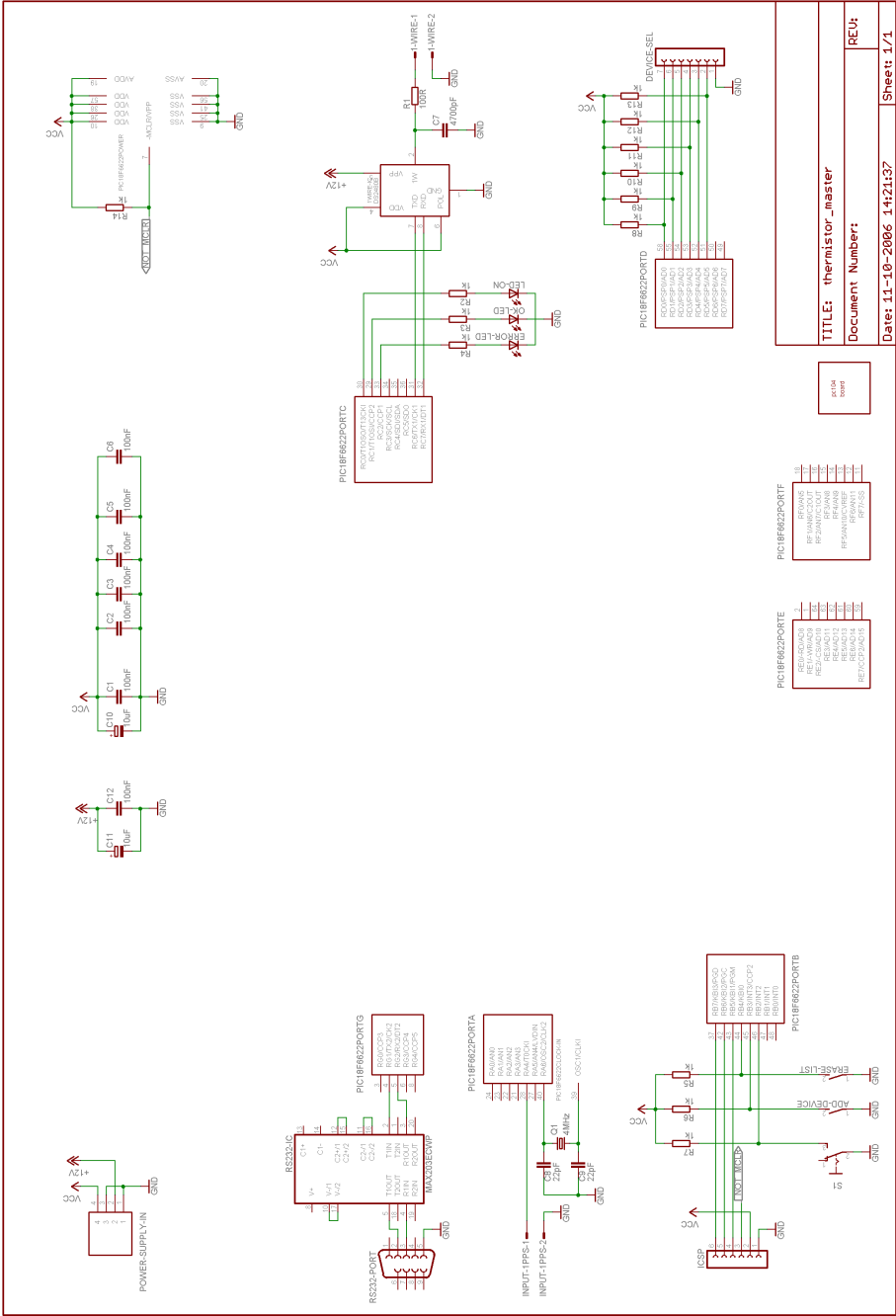


Figure 4.24: thermistor chain's electronic circuit.

4.3.11.3 Power supply

To work the circuit needs a voltage of 5V. The 12V voltage is only necessary if the microcontroller’s software needs to write any values in the 1-wire slave devices EEPROM; if not, the 12V input may be connected to 5V. In the current system the slave devices EEPROM is not used and in the 12V input receives 5V. Refer to DS2480B datasheet [14].

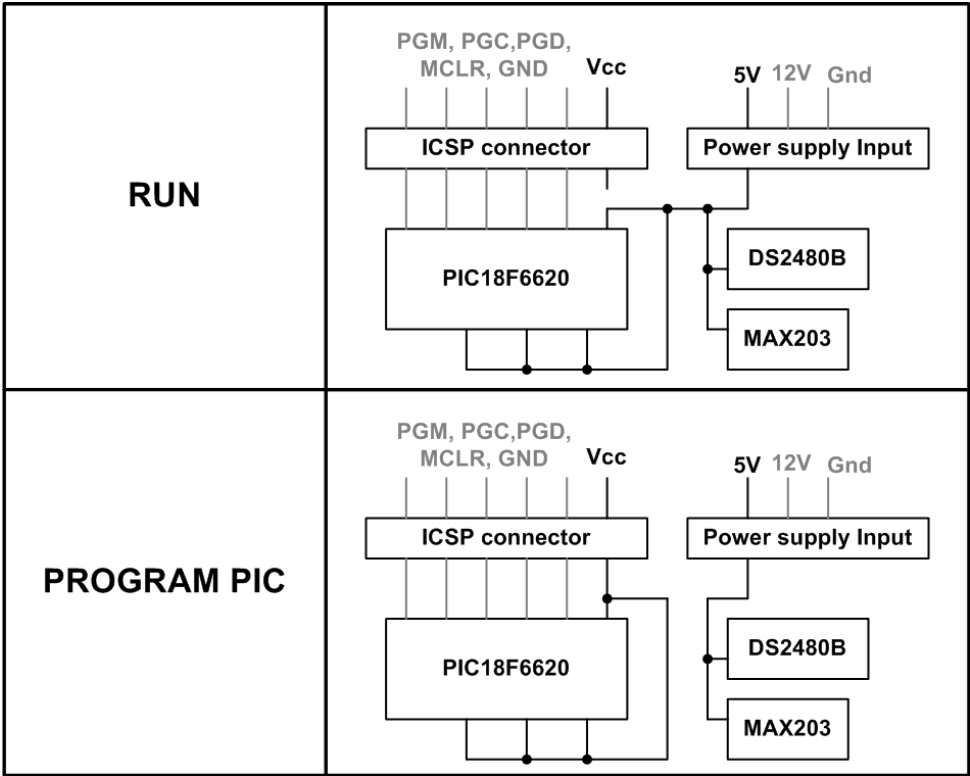


Figure 4.25: PIC programming schematic.

4.3.12 Thermistor reading software

The software for reading in the data provided by the digital thermistor chain is separated in two parts: one is the low level piece of software running in the PIC of the Master board card and the other is the RS-232 port reading from the AOB2 CPU.

4.3.12.1 PIC software

The acquisition program is explained in figure 4.26's flowchart. For detailed flowcharts refer to appendix E.2. For further details about 1-wire, besides DS18B20-PAR datasheet [9] and DS2480B datasheet [14], refer to Maxim application notes: AN148 [11], AN27 [12], AN155 [15] and app192 [16].

4.3.12.2 AOB2 thermistor reading software

Data is received from the Digital Thermistor Acquisition Board through the serial port. The software (in python) is a program which reads every line which comes in over the serial line and saves the respective data in an internal table. The table is filled when the Thermistor Chain signals at begin of transmission. For each acquired sensor there exists a compensation value which is added to the read value. Data is stored in `/AOB/data/termchain-data.log` where each line represents a complete acquisition cycle of all the channels. The source code shown in table 4.12 in python reads the data from the thermistor chain using the serial port.

4.4 Array system testing

The various system components were individually tested using computer simulators (pre-amplifier and thermistor chain board), lab tested either separately or connected together and mechanically tested both in pool and at sea and during a sea trial (RADAR'06). Several changes were introduced to the system, in particular to the pre-amplifiers design, during these various testing phases. The description made in this report reflects only the final design and is supposed to fulfill the requirements of the sponsor projects.

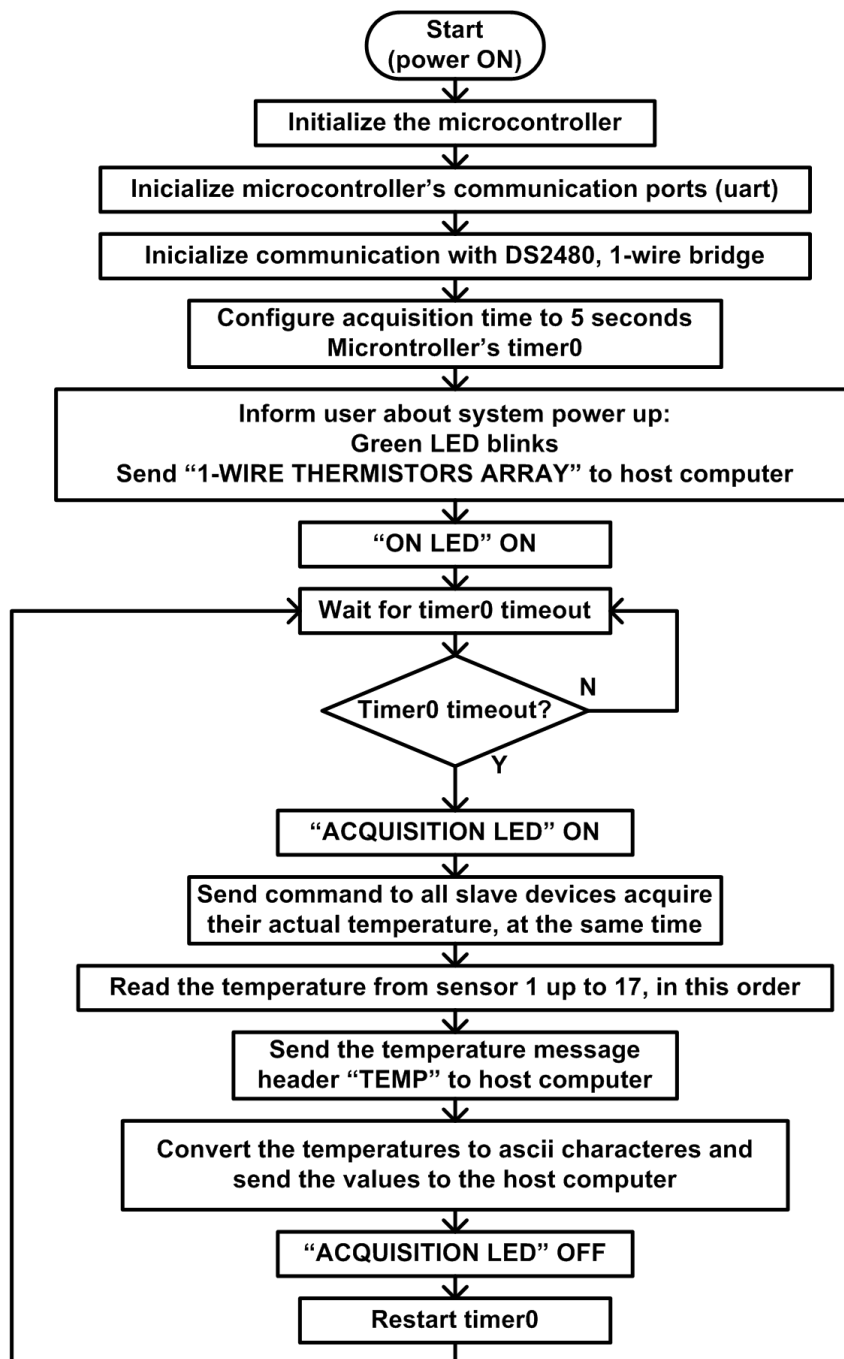


Figure 4.26: Thermistors acquisition software algorithm

```

#!/usr/bin/python2.4
import string
import serial
import time
import datetime
from string import atof
filename = "/AOB/data/termchain-data.log"
ser = serial.Serial('/dev/ttyS1', 19200, timeout=1)
FILE = open(filename,"a+")
data = range(17)
coef = range(17)
coef = (0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0)
begin = -2

#x = ser.read()          #read one byte
#s = ser.read(10)        #read up to ten bytes (timeout)

while 1<=2:
    line = ser.readline() #read a '\n' terminated line
    print line.strip()

    if line.strip()=='TEMP':
        begin = -1
        today = datetime.datetime.now()
        datestring = today.strftime("%02e,%2m,%4Y,%2H:%2M:%2S")

        if begin > -1 and begin < 17:
            tmp = line.strip()
            data[begin] = atof(tmp)
# adicionar correct. de temperatura aqui
            data[begin] = data[begin] + coef[begin]
            begin += 1

        if begin== -1:
            begin += 1

        if begin == 17:
            begin = -2
            dataline = "%s,%f,%f,%f,%f,%f,%f,%f,%f,%f,%f,%f,%f,%f,%f,%f,%f" %
            (datestring, data[0], data[1], data[2], data[3], data[4], data[5], data[6],
            data[7], data[8], data[9], data[10], data[11], data[12], data[13], data[14],
            data[15], data[16])
            print dataline
            FILE.writelines(dataline)
            FILE.writelines("\n")
            FILE.flush()
ser.close()
FILE.close()

```

Table 4.12: source code for reading thermistor chain data.

Appendix A

Technical specifications

Name	Array16
Description	Underwater vertical array designed for the AOB2 buoys, with 16 hydrophones.
Sensors	Hydrophones: 16 Thermistors: 17
Sensor locations	Hydrophones: ◇Distance from the top thimble to the first hydrophone: 5.55m ◇Distance between hydrophones: 4m ◇Distance from the top thimble to the last hydrophone: 65.55m Thermistors: ◇Distance from the top thimble to the first thermistor: 5.55m ◇Distance between thermistor: 4m ◇Distance from the top thimble to the last two thermistors: 65.55m
Mechanics, Dimensions and Weight	Total Length: 67.5m Estimated weight in air (excl. ballast): 50 kg Estimated weight in water (excl. ballast): ~12 kg Ballast's weight: 8 kg Top thimble inside diameter: 14mm Bottom thimble inside diameter: 14mm Strength member made of Dyneema Strength member diameter: 6mm Strength member breaking load: 1500 kg Protection sleeve mesh made of Polyamid
Hydrophones+pre-amp	Outside Case: ◇Diameter: 33.4mm ◇Length: 129mm Hydrophone: Reference: SQ26 from Sensortech Frequency response: flat from 1Hz to 28kHz Storage and operating temperature: -30°C to 60°C Pre-Amplifier: Gain: 36dB
<i>continued on next page...</i>	

	-3dB Bandwidth: 108.27Hz up to 52.796kHz Output voltage range, referenced to ground: $\pm 5V$ Differential preamp output voltage range: $\pm 10V$
--	---

Table A.1: analog 16-hydrophone and temperature sensor array technical specifications.

Appendix B

Equipment checklist

Array	
3 × Top connectors spare o-rings	☐
3 × Dummies for the impulse connectors	☐
1 × Shackle to connect the array to the buoy	☐
1 × Shackle to connect the array to the bottom weights	☐
1 × Lead weights plus holding band (8kg)	☐
1 × Isolation tape	☐
1 × Plastic cable ties + plier	☐
AOB2	☐
1 × Thermistors master electronic card	☐

Table B.1: equipment checklist.

Appendix C

Pre-amplifier electronics calculus

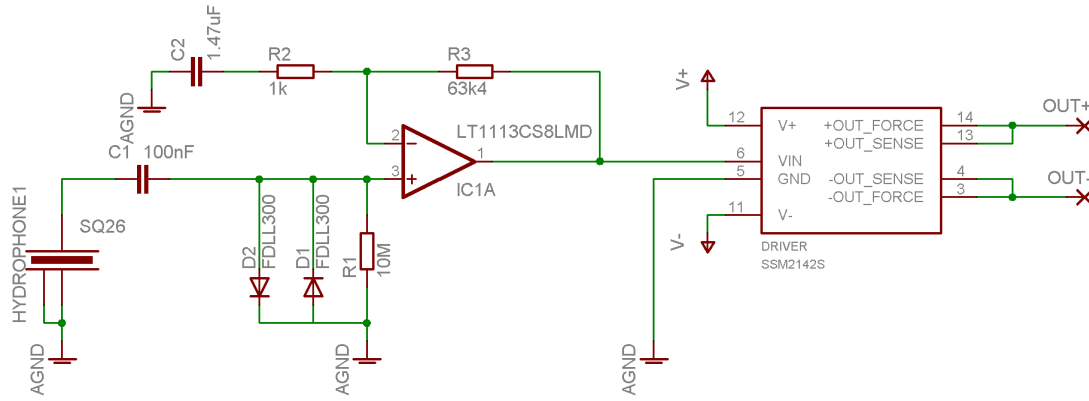


Figure C.1: Pre-amplifier circuit

C.1 Output voltage range

Power supply voltage: $\pm 9.3V \leq V_{SIN} \leq \pm 35V$

Voltage Regulators: $V_S = \pm 8V$

LT_1113 output voltage range:

$$V_S = \pm 8V \Rightarrow V_{Range-lt1113} = \pm 6.8V$$

SSM2142 output voltage range, referenced to ground:

$$V_{Range-ssm2142} = \pm 5V \quad (0.1\% \text{ distortion})$$

Output voltage range, referenced to ground:

$$V_{OUT} = \pm 5V$$

Differential output voltage range:

$$V_{OUT-dif} = \pm 10V$$

C.2 Pre-amplifier gain

Assuming that the lt1113 is an ideal op-amp and ignoring C_1 :

$$A_{ideal} = 1 + \frac{\frac{R_3}{R_2}}{1 + \frac{1}{j\omega C_2 R_2}}$$

$$f_{HP-3dB} = \frac{1}{2\pi C_2 R_2} = \frac{1}{2 \times \pi \times 1.47 \times 10^{-6} \times 1000} = 108.27Hz$$

$$f \rightarrow 0Hz \quad \Rightarrow \quad A_{IDEAL} = 1 \quad A_{IDEAL_dB} = 0dB$$

$$f \rightarrow 108.27Hz \quad \Rightarrow \quad A_{IDEAL} = 0.7079 \times 64.4 \quad A_{IDEAL_dB} = -3 + 36.17dB$$

$$f \rightarrow +\infty \quad \Rightarrow \quad A_{IDEAL} = 1 + \frac{R_3}{R_2} = 64.4 \quad A_{IDEAL_dB} = 36.17dB$$

Which is the same as a high-pass filter with 1 pole and -3dB cutoff frequency at $108.27Hz$. Including capacitor C_1 gives,

$$A_{ideal} = \left(1 + \frac{\frac{R_3}{R_2}}{1 + \frac{1}{j\omega C_2 R_2}}\right) \times \frac{1}{1 + \frac{1}{j\omega C_1 R_1}}$$

$$f_{HP-1} = \frac{1}{2\pi C_1 R_1} = \frac{1}{2 \times \pi \times 100 \times 10^{-9} \times 10 \times 10^6} = 0.16Hz$$

$$f_{HP-2} = \frac{1}{2\pi C_2 R_2} = \frac{1}{2 \times \pi \times 1.47 \times 10^{-6} \times 1000} = 108.27Hz$$

$$f \rightarrow 0Hz \quad \Rightarrow \quad A_{IDEAL} = 0 \quad A_{IDEAL_dB} = -\infty dB$$

$$f \rightarrow 0.16Hz \quad \Rightarrow \quad A_{IDEAL} = 0.992 \quad A_{IDEAL_dB} = -69.49dB$$

$$f \rightarrow 108.27Hz \quad \Rightarrow \quad A_{IDEAL} = 45.592 \quad A_{IDEAL_dB} = 33.17dB$$

$$f \rightarrow +\infty \quad \Rightarrow \quad A_{IDEAL} = 1 + \frac{R_3}{R_2} = 64.4 \quad A_{IDEAL_dB} = 36.17dB$$

Assuming taht the opamp has a finite and frequency dependent gain:

$$A_{VOL_typical} = 3400(V/mV) = 130.63dB$$

$$f_{p_lt1113} = 1Hz$$

$$\omega_{p_lt1113} = 2\pi rad/s$$

$$a = a_{opamp} = \frac{A_{VOL_typical}}{1 + \frac{j\omega}{\omega_{p_lt1113}}}$$

$$A_{pre_amp} = \frac{a \left(\frac{1}{1 + \frac{1}{j\omega C_1 R_1}} \right)}{1 + a \left(\frac{\frac{R_2 + \frac{1}{j\omega C_2}}{R_2 + R_3 + \frac{1}{j\omega C_2}}}{1} \right)}$$

When $f \rightarrow +\infty Hz$:

$$A_{pre_amp} = \frac{a}{1 + a \left(\frac{R_2}{R_2 + R_3} \right)} = \frac{64.3988}{1 + \frac{j\omega}{2 \times \pi \times 52796}}$$

$$\begin{aligned} f \rightarrow 0 Hz & \Rightarrow A_{pre_amp} = 0 & A_{pre_amp_dB} = -\infty dB \\ f \rightarrow 0.16 Hz & \Rightarrow A_{pre_amp} = 0.992 & A_{pre_amp_dB} = -69.49 dB \\ f \rightarrow 108.27 Hz & \Rightarrow A_{pre_amp} = 45.592 & A_{pre_amp_dB} = 33.17 dB \\ 108.27 Hz < f < 52.796 kHz & \Rightarrow A_{pre_amp} = 1 + \frac{R_3}{R_2} = 64.4 & A_{pre_amp_dB} = 36.17 dB \\ f \rightarrow 52.796 kHz & \Rightarrow A_{pre_amp} = 45.592 & A_{pre_amp_dB} = 33.17 dB \\ f \rightarrow +\infty & \Rightarrow A_{pre_amp} = 0 & A_{pre_amp_dB} = -\infty dB \end{aligned}$$

C.3 Bandwidth

$$108.27 Hz \leq B_{pre_amp} \leq 52796 Hz$$

The upper cutoff frequency depends on the opamp open-loop gain, which is dependent of temperature.

$$\text{Temperature range:} \quad 0^\circ C \leq T_{amb} \leq 70^\circ C$$

$$\text{Opamp open-loop gain:} \quad 800(V/mV) \leq A_{VOL} \leq 3400(V/mV)$$

$$\text{Pre-amp upper cutoff frequency:} \quad 12423.4 Hz \leq f_{3dB_{LowPass}} \leq 52796 Hz$$

C.4 Noise

LT1113	
Input Noise Voltage Density @ 1Hz	50 $\eta V/\sqrt{Hz}$
Input Noise Voltage Density @ 10Hz	17 $\eta V/\sqrt{Hz}$
Input Noise Voltage @ 0.1Hz $\rightarrow$ 10Hz	2.4 μV
Input Noise Voltage Density(Typical) ($E_{whitenoise}$) @ 1000Hz	4.5 $\eta V/\sqrt{Hz}$
Input Noise Voltage Density(Maximum) @ 1000Hz	6 $\eta V/\sqrt{Hz}$
Input Noise Current Density ($I_{whitenoise}$) @ 10Hz and 1000Hz	10 $fA/\sqrt{Hz}$
Corner Frequency(f_{nc})	120 Hz

Table C.1: lt1113 noise characteristics.

Hydrophone bandwidth:

$$1 Hz \leq B_{hyd} \leq 28 kHz$$

Pre-amp bandwidth:

$$108.27Hz \leq B_{pre_amp} \leq 52796Hz$$

Noise bandwidth:

$$\begin{aligned} B_{NOISE} &= \frac{1}{|A_{pre_amp_max}|^2} \int_0^{+\infty} |A_{pre_amp}|^2 d\omega \\ &\approx \frac{1}{|64.3988|^2} \left(\int_0^{2\pi 5000} \left| \left(1 + \frac{\frac{R_3}{R_2}}{1 + \frac{1}{j\omega C_2 R_2}} \right) \times \frac{1}{1 + \frac{1}{j\omega C_1 R_1}} \right|^2 d\omega + \int_{2\pi 5000}^{+\infty} \left| \frac{64.3988}{1 + \frac{j\omega}{2 \times \pi \times 52796}} \right|^2 d\omega \right) \\ &\approx 82779Hz \end{aligned}$$

For the noise calculus, it was considered that the noise bandwidth is equal to the input signal bandwidth (hydrophone bandwidth).

$$\begin{aligned} f_{min} &= 1Hz \\ f_{max} &= 28kHz \end{aligned}$$

Individual noise values

lt1113

$$\begin{aligned} E_{nlt1113} &= E_{whitenoise} \sqrt{f_{nc} \times \ln \left(\frac{f_{max}}{f_{min}} \right) + (f_{max} - f_{min})} \\ &= 120 \times 10^{-9} \sqrt{120 \times \ln \left(\frac{28000}{1} \right) + (28000 - 1)} \\ E_{nlt1113} &= 769.326\eta V \end{aligned}$$

Ignoring the $1/f$ noise:

$$E_n = E_{whitenoise} \sqrt{(f_{max} - f_{min})} = 120 \times \sqrt{(28000 - 1)} = 752.981\eta V$$

The near results are because $(f_{max} - f_{min}) \gg f_{nc}$

The $1/f$ noise may be ignored.

$$\begin{aligned} I_{nlt1113} &= I_{whitenoise} \sqrt{f_{max} - f_{min}} \\ &= 10 \times 10^{-15} \sqrt{28000 - 1} \\ I_{nlt1113} &= 1.67329\rho A \end{aligned}$$

R1

$$\begin{aligned} E_{nR1} &= \sqrt{4KTR_1(f_{max} - f_{min})} \\ &= \sqrt{4 \times 1.38 \times 10^{-23} \times (25 + 273) \times 10 \times 10^6 \times (28000 - 1)} \\ E_{nR1} &= 67.865\mu V \end{aligned}$$

R2

$$\begin{aligned}
E_{nR2} &= \sqrt{4KTR_2(f_{max} - f_{min})} \\
&= \sqrt{4 \times 1.38 \times 10^{-23} \times (25 + 273) \times 1000 \times (28000 - 1)} \\
E_{nR2} &= 678.655 \mu V
\end{aligned}$$

R3

$$\begin{aligned}
E_{nR3} &= \sqrt{4KTR_3 \times (f_{max} - f_{min})} \\
&= \sqrt{4 \times 1.38 \times 10^{-23} \times (25 + 273) \times 63400 \times (28000 - 1)} \\
E_{nR3} &= 5.404 \mu V
\end{aligned}$$

Individual output noise values**E_{n-out}LT1113**

$$E_{n-outlt1113} = \left(1 + \frac{R_3}{R_2}\right) E_{nlt1113} = \left(1 + \frac{63400}{1000}\right) 769.326 \times 10^{-9} = 49.54 \mu V$$

E_{In-out}LT1113

$$\begin{aligned}
E_{I_n-outlt1113} &\approx \left(1 + \frac{R_3}{R_2}\right) \times R_1 \times I_{nlt1113} = \left(1 + \frac{63400}{1000}\right) \times 10 \times 10^6 \times 1.67329 \times 10^{-12} \\
E_{I_n-outlt1113} &\approx 1.0776 mV
\end{aligned}$$

E_{n-out}R₁

$$E_{n-outR_1} = \left(1 + \frac{R_3}{R_2}\right) E_{nR_1} = \left(1 + \frac{63400}{1000}\right) 67.865 \times 10^{-6} = 4.3705 mV$$

E_{n-out}R₂

$$E_{n-outR_2} = \frac{R_3}{R_2} E_{nR_2} = \frac{63400}{1000} 678.655 \times 10^{-9} = 43.03 \mu V$$

E_{n-out}R₃

$$E_{n-outR_3} = E_{nR_3} = 5.404 \mu V$$

Output noise value

$$E_{n-out}R_3$$

$$\begin{aligned}
E_{n-out} &= \sqrt{E_{n-outlt1113}^2 + E_{I_n-outlt1113}^2 + E_{n-outR_1}^2 + E_{n-outR_2}^2 + E_{n-outR_3}^2} \\
&= \sqrt{(49.54 \times 10^{-6})^2 + (1.0776 \times 10^{-3})^2 + (4.3705 \times 10^{-3})^2 +} \\
&\quad + (43.03 \times 10^{-6})^2 + (5.404 \times 10^{-6})^2} \\
&= 4.5019\text{mV}
\end{aligned}$$

Appendix D

Pre-amplifier electronic schematics and PCB

This appendix presents the schematic, the PCB components layout and the PCB layout for the hydrophone pre-amplifier circuit. The following pages are organized in the following order: schematic, PCB components layout, PCB board layout and component order list.

D.1 Schematic

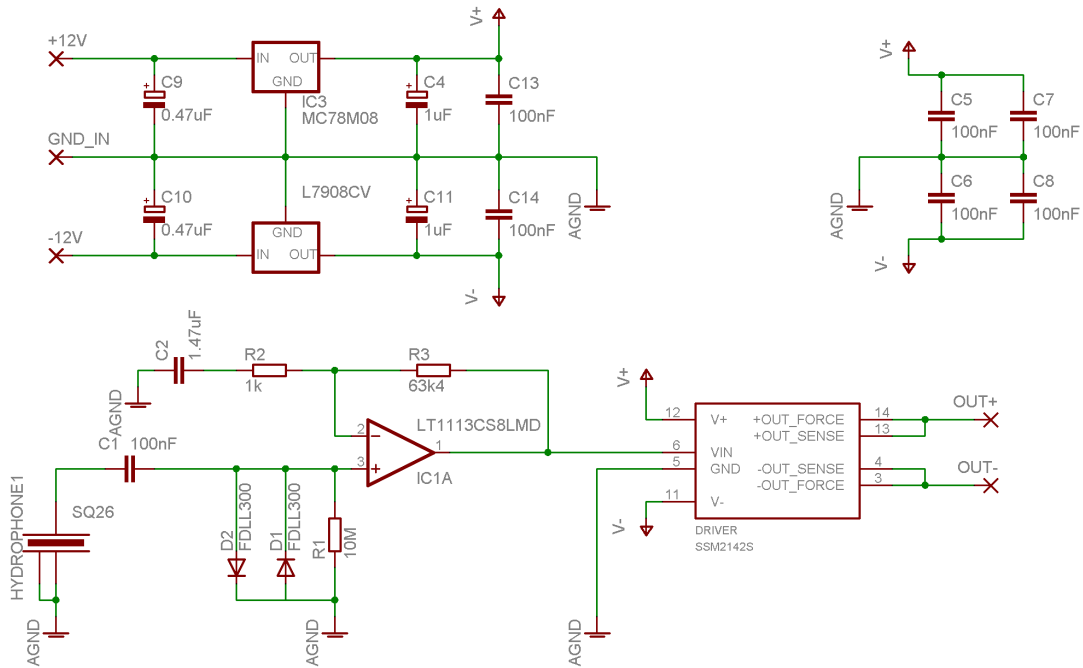
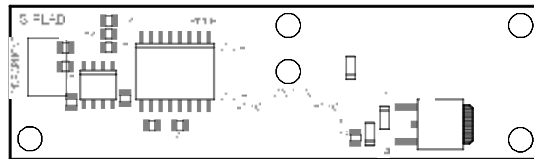


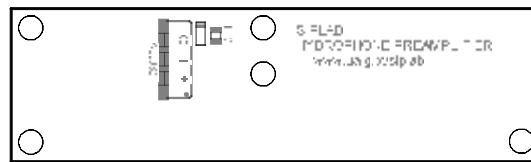
Figure D.1: Hydrophone pre-amplifier

D.2 PCB and components layout



22-11-2006 18:15:49 C:\development\eagle siplab projects\Array2\Preamp-final-4laye

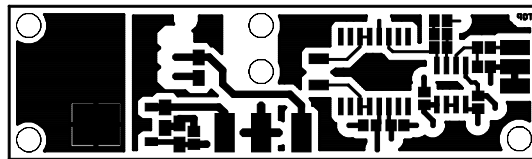
Figure D.2: pre-amplifier top components placement.



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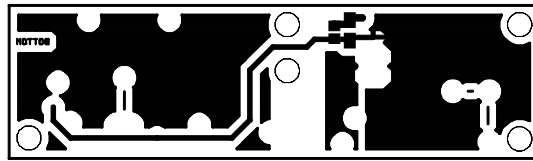
Figure D.3: pre-amplifier bottom components placement.

D.3 PCB layout



22-11-2006 18:17:11 mirrored C:\development\eagle siplab projects\Array2\Preamp-

Figure D.4: pre-amplifier top pcb layout.



22-11-2006 18:18:07 C:\development\eagle siplab projects\Array2\Preamp-final-4laye

Figure D.5: pre-amplifier bottom pcb layout.

D.4 Component order list for pre-amplifier board

Quant.	Component	Referenc	Value		Vendor:
1	Resistor	R1	10M Ω	0805, 1%, 250ppm	Farnell: 9238115
1	Resistor	R2	1k Ω	0805, 0.1%, 5ppm	Farnell: 1108863
1	Resistor	R3	63.4k Ω	0805, 0.1%, 10ppm	Farnell: 1140998
2	Capacitor	C2 (paralelo)	1uF	0805, 25V, 10%, cerámico	Farnell: 8805687
2	Capacitor	C2 (paralelo)	0.47uF	0805, 25V, 10%, cerámico	Farnell: 8805679
7	Capacitor	C1,C5,C6,C7 ,C8,C13,C14	100nF	0805, 50V, cerámico, 10%	Farnell: 9406387
2	Capacitor	C4,C11	1uF	Case A, 35V, tantalum ,10%	Farnell: 3037897
2	Capacitor	C9,C10	0.47uF	Case A, 35V, tantalum ,20%	Farnell: 967269
1	Voltage regulator	L7908CV	L7908CV		Farnell: 9756248
1	Voltage regulator	IC3	MC78M08		Farnell: 1087192
2	Diode	D1,D2	FDLL300	Low leakage, high conductance	Farnell: 9843779
1	opamp	IC1A	LT1113	LT1113CS8LMD	Linear Tech(credit card) www.linear.com
1	Balanced line driver	DRIVER	SSM2142	SSM2142S	Farnell: 9426329
1	hydrophone	Hydrophone1	SQ26		Sensortech, www.sensortech.ca
1	PCB	PCB	PCB		www.pcbtrain.co.uk

Figure D.6: pre-amplifier component order list.

Appendix E

Thermistor master card technical details

E.1 DS18B20-PAR addresses

THERMISTORS DS18B20-PAR

Nbr in the box:	Nbr in the array:	Address (64 bits):	type
T1	-	8E000000DBAF0328	Sample
T2	-	C5000000DBBE1B28	Sample
T3	-	B5000000DBA7A028	Sample
T4	-	74000000DBBE8B28	Sample
T5	-	B6000000DB9F7C28	Sample
T6	-	26000000DBB5B128	Sample
T7	-	C4000000DBBDB528	Sample
T8	-	3A000000DBA4D328	Sample
T9	-	81000000DBC63328	Sample
T10	-	B8000000DBBE1728	Sample
T11	-	88000000DBB66E28	Sample
T12	-	9E000000DBB7DA28	Sample
T13	-	3B000000DBAEAC28	Sample
T14	-	2F000000DBC4F528	Sample
T15	-	62000000DBA12828	Sample
T16	-	D9000000DBC48728	Sample
T17	-	C9000000DBB7A028	Sample
T18	-	60000000DBB4CF28	Sample
T19	-	1E000000DBBD8428	Sample
T20	-	A9000000DBAAE728	Sample
T21	-	77000000DBB95228	Sample
T22	-	74000000DB9F9928	Sample
T23	-	C9000000DBADD328	Bought
T24	T17	DA000000DBA72728	Bought
T25	T1	35000000DBADFE28	Bought
T26	T2	2F000000DBB11C28	Bought
T27	T3	27000000DBC0DD28	Bought
T28	T4	FD000000DBC3C728	Bought
T29	T5	C2000000DBC29328	Bought
T30	T6	60000000DBB38028	Bought
T31	T7	D0000000DBBD0B28	Bought
T32	T8	D4000000DBB85028	Bought
T33	T9	39000000DBAC8D28	Bought
T34	T10	E6000000DBA96228	Bought
T35	T11	C5000000DBB5F828	Bought
T36	T12	6B000000DBC59828	Bought
T37	T13	E1000000DBC22C28	Bought
T38	T14	64000000DBBF0A28	Bought
T39	T15	2B000000DBA97B28	Bought
T40	T16	82000000DBBEF928	Bought

Figure E.1: DS18B20-PAR addresses

E.2 PIC18F6620 software flowcharts

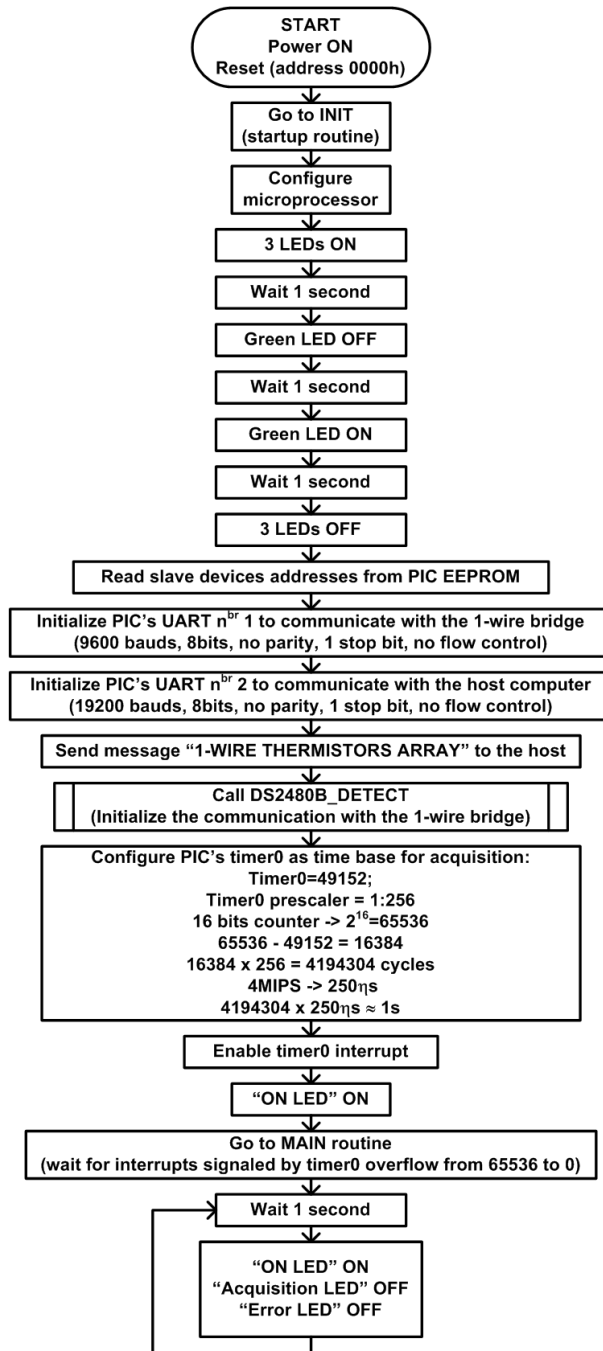


Figure E.2: Power ON

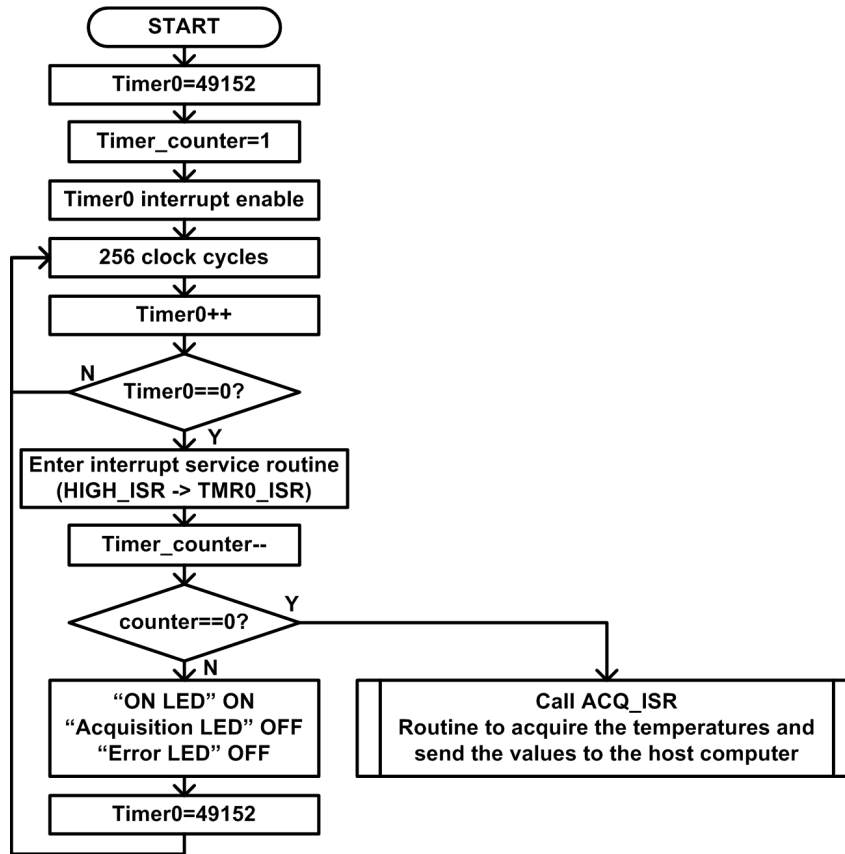


Figure E.3: Timer0 interrupt

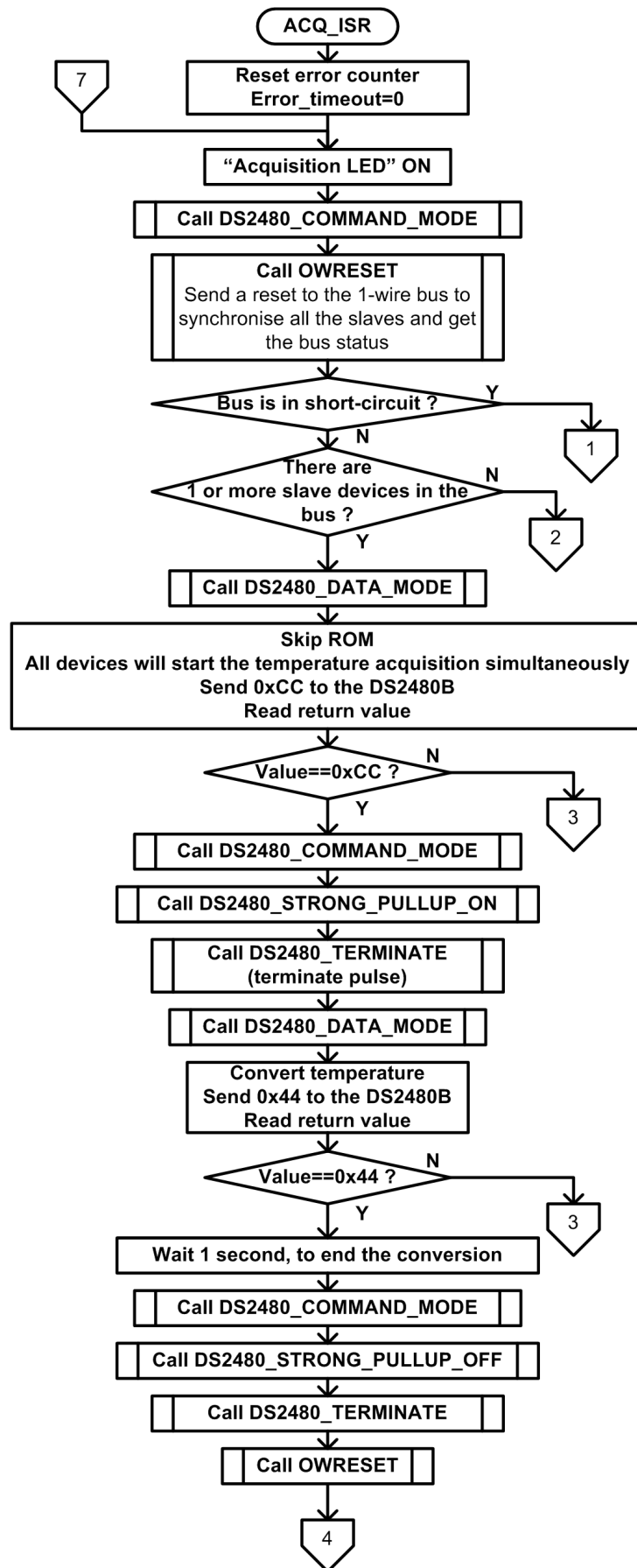


Figure E.4: Acquisition routine flowchart(1 of 4)

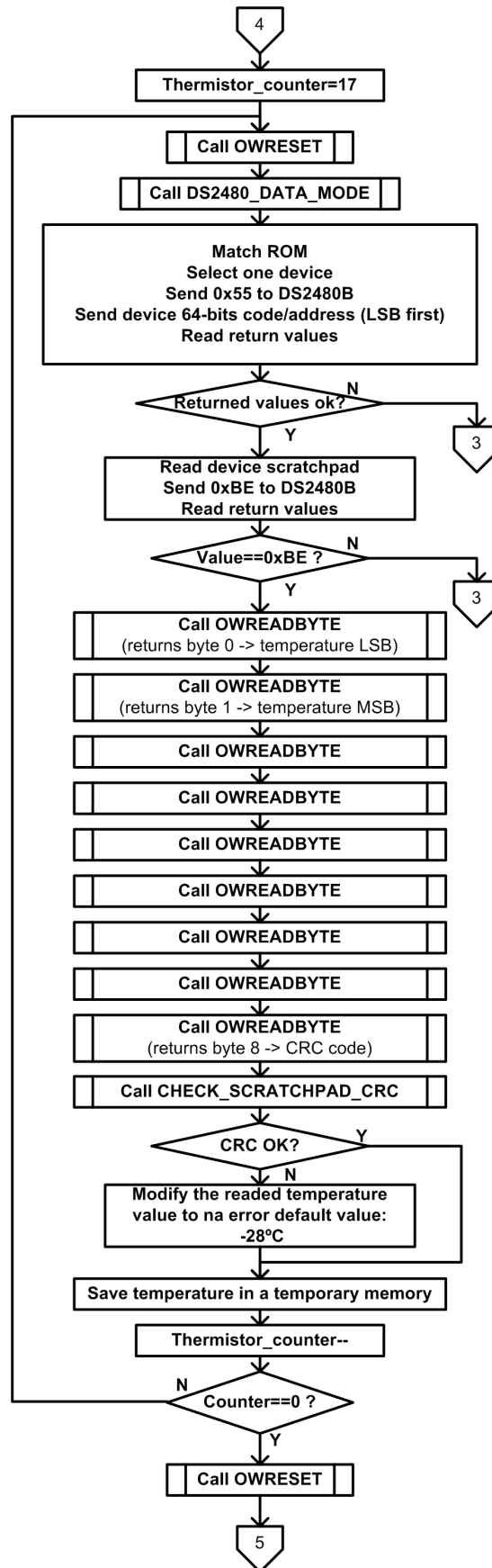


Figure E.5: Acquisition routine flowchart(2 of 4)

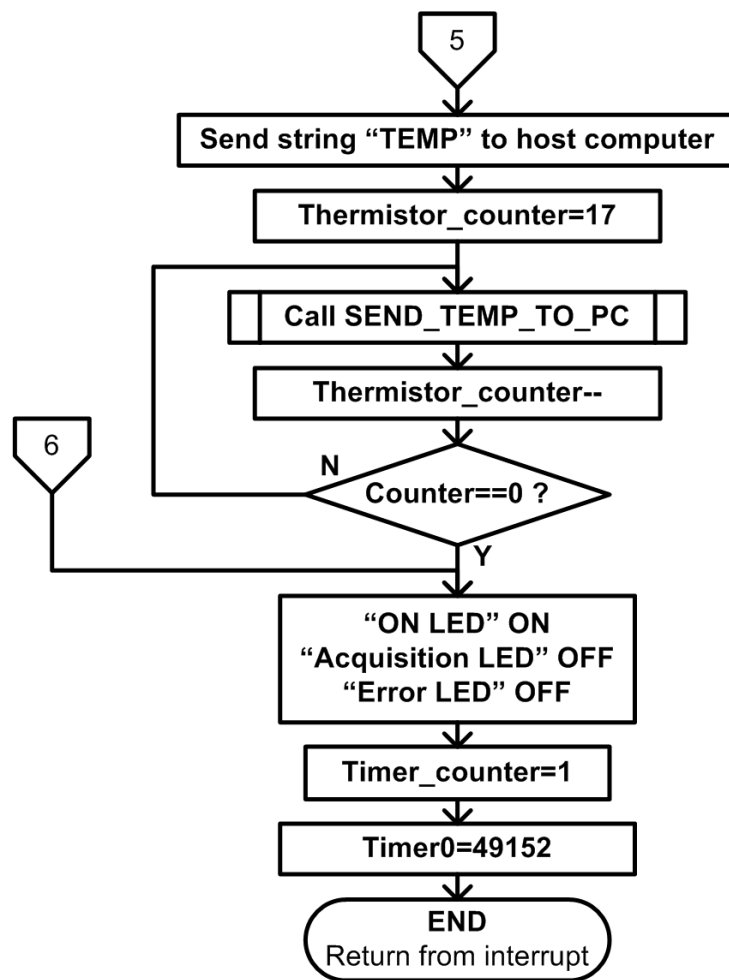


Figure E.6: Acquisition routine flowchart(3 of 4)

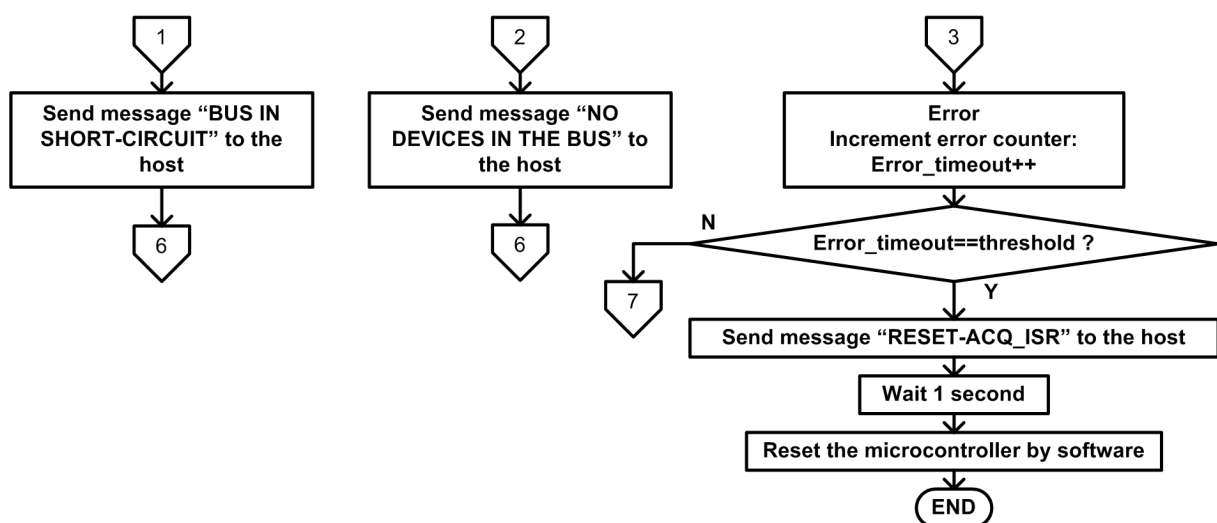


Figure E.7: Acquisition routine flowchart(4 of 4)

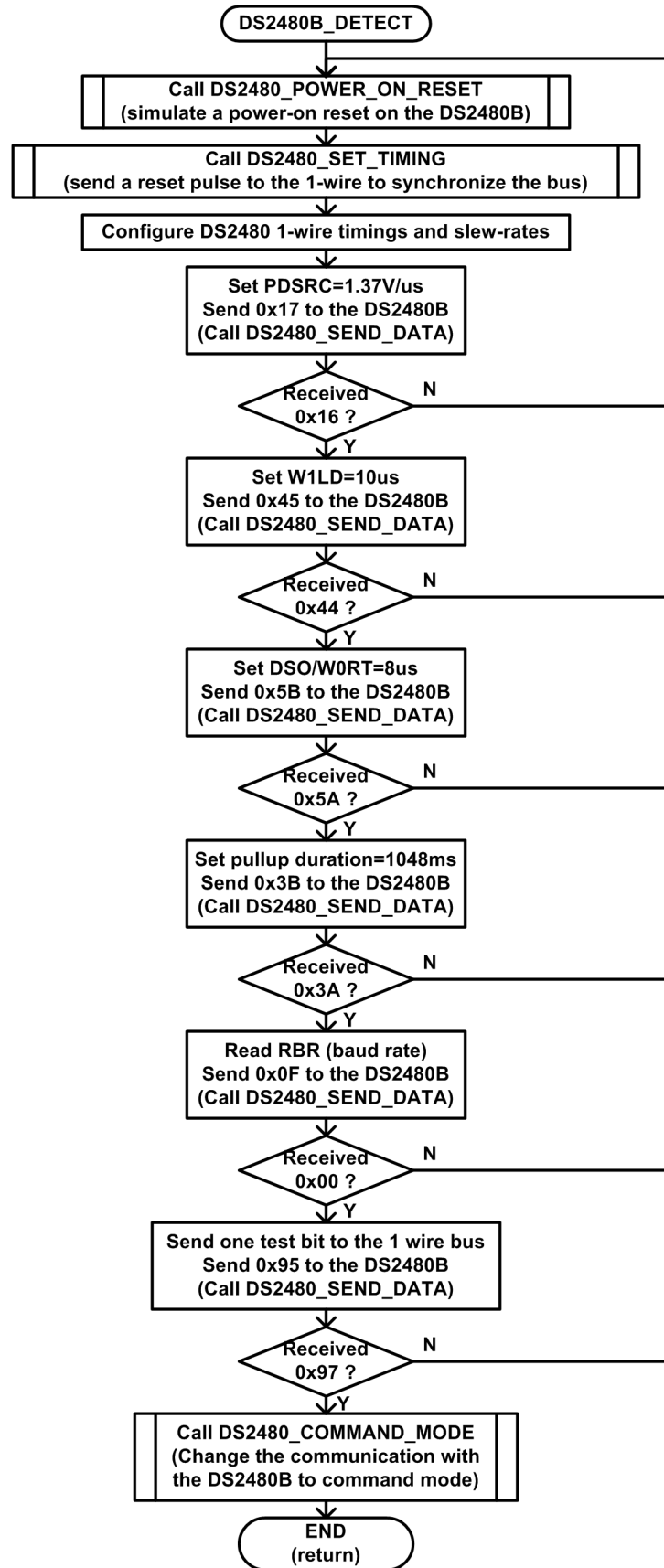


Figure E.8: DS2480B_DETECT subroutine

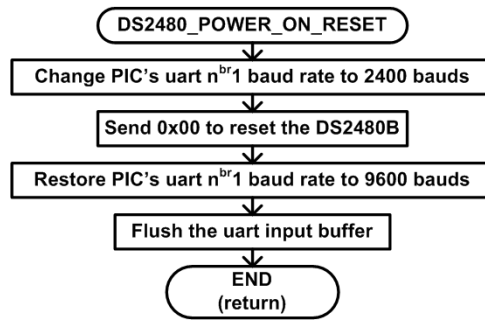


Figure E.9: DS2480B_POWER_ON_RESET subroutine

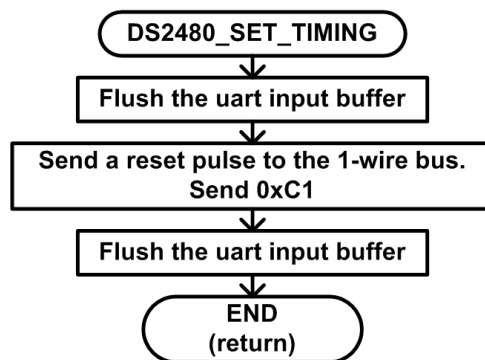


Figure E.10: DS2480B_SET_TIMING subroutine

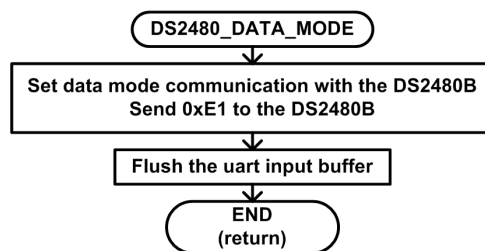


Figure E.11: DS2480B_DATA_MODE subroutine

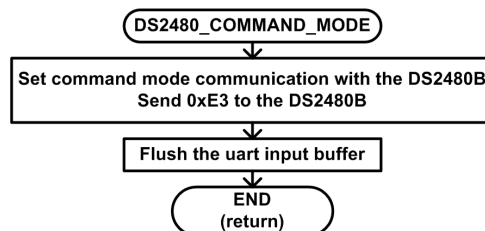


Figure E.12: DS2480B_COMMAND_MODE subroutine

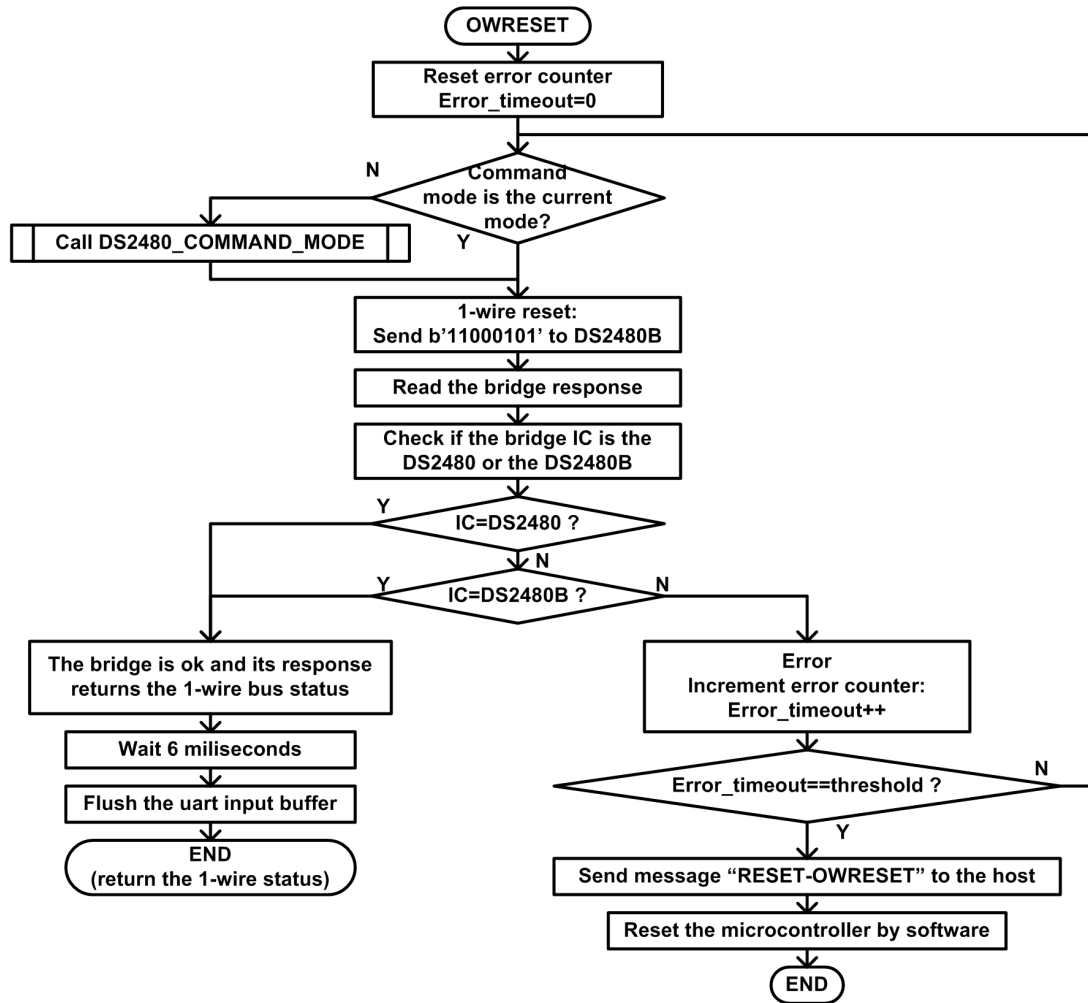


Figure E.13: OWRESET subroutine

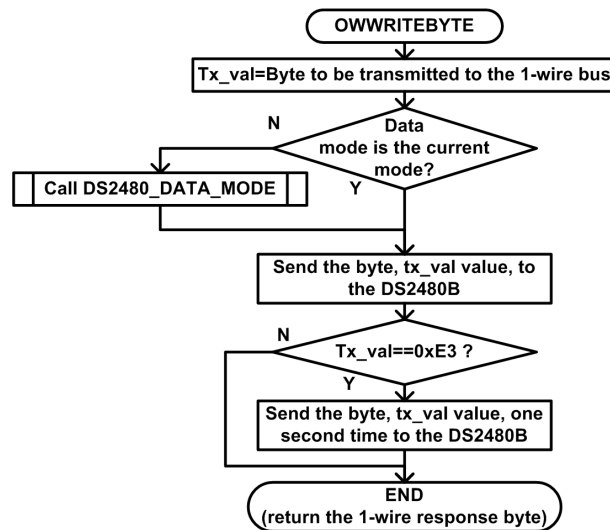


Figure E.14: OWWRITEBYTE subroutine

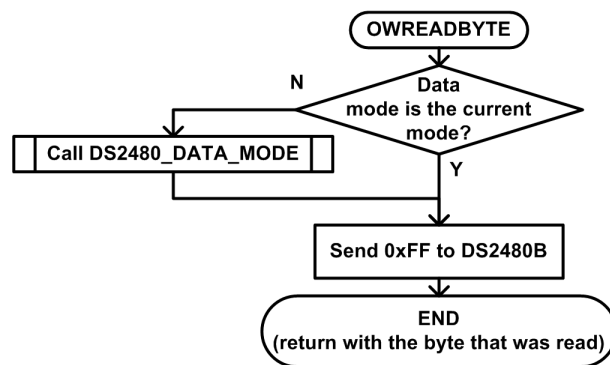


Figure E.15: OWREADBYTE subroutine

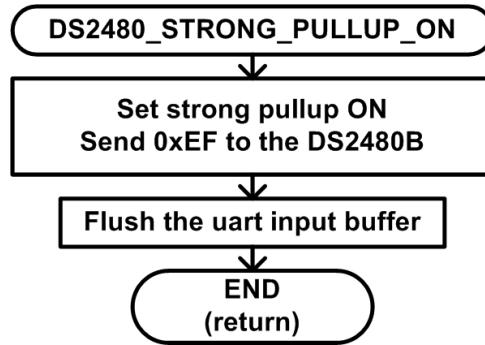


Figure E.16: DS2480_STRONG_PULLUP_ON subroutine flowchart

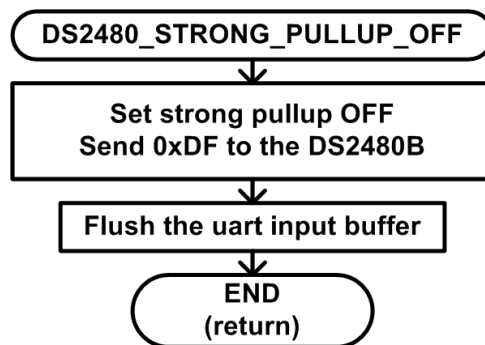


Figure E.17: DS2480_STRONG_PULLUP_OFF subroutine flowchart

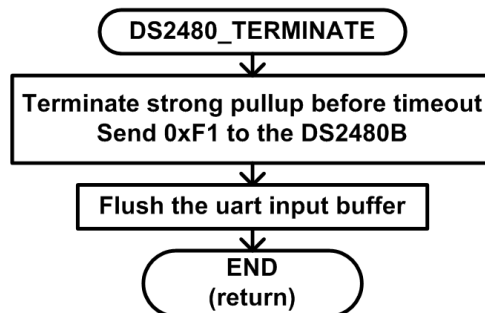
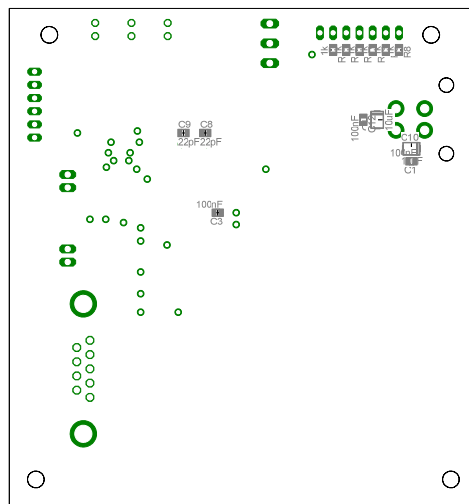


Figure E.18: DS2480_TERMINATE subroutine flowchart

E.3 Thermistors master PCB

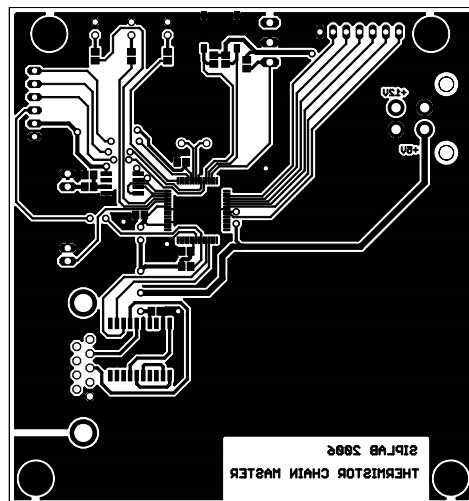
This appendix presents the PCB components layout and the PCB layout for the thermistors master circuit. The schematic for this card is on 4.24



23/05/2006 12:27:20 mirrored C:\development\leagle siplab projects\AOB2\Thermistor_chain\thermistor_master.brd

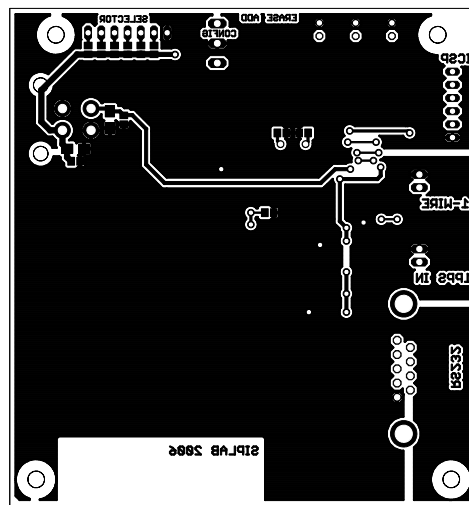
Figure E.20: thermistors master bottom components placement (not to scale).

E.3.2 Pcb layout



23/05/2006 12:24:54 mirrored C:\development\eagle siplab projects\AOB2\Thermistor_chain\thermistor_master.brd

Figure E.21: thermistors master top pcb layout (not to scale).



23/05/2006 12:23:30 C:\development\eagle siplab projects\AOB2\Thermistor_chain\thermistor_master.brd

Figure E.22: thermistors master bottom pcb layout (not to scale).

E.4 Component order list for thermistor master card

Qty	Value	Device	Parts
1		255SB	S1
1		F09HP	RS232-PORT
1		FE06-1	ICSP
1		FE07-1	DEVICE-SEL
2		L02P	1-WIRE, INPUT-1PPS
3		LED5MM	ERROR-LED, LED-ON, OK-LED
1		PIC18F66226-I/PT	PIC18F6622
2		SUBMINIATURE	ADD-DEVICE, ERASE-LIST
13	1k	R-EU_R0805	R2, R3, R4, R5, R6, R7, R8, R9, R10, R11, R12, R13, R14
1	4MHz	CRYTALHC49S	Q1
2	10uF	CPOL-EUB/3528-21W	C10, C11
2	22pF	C-EUC0805	C8, C9
1	100R	R-EU_R0805	R1
7	100nF	C-EUC0805	C1, C2, C3, C4, C5, C6, C12
1	4700pF	C-EUC0805	C7
1	CON_MINI_FIT_4	CON_MINI_FIT_4	POWER-SUPPLY-IN
1	DS2480B	DS2480B	1WIRE-IC
1	MAX203ECWP	MAX203ECWP	RS232-IC
1	PC104-DIM	PC104-DIM	US1

Figure E.23: component order list for thermistors master card.

Appendix F

Manufacturers and Suppliers

Parts	Suppliers	Contacts
Electronic components	RS-amidata	www.rsportugal.com
Hydrophones	Sensortech	http://www.sensortech.ca/
Impulse Connectors	Impulse	http://www.impulsent.com/home.html
Analog devices components	Avnet / Silica	www.rsportugal.com
Maxim components	Maxim	www.maxim-ic.com prototype orders (use the excel sheet to perform any order, the on-line request on the site doesn't work, the credic card validation always give errors).
Inox parts (Shackles, thimbles)	MGLInox	Conceição de Faro
Polyamid mesh	AUTEC	www.autec-vertrieb.de
strenght member cable	Sulcampo	Nautical equipment store in Olhão

Table F.1: list of equipment and parts suppliers.

Appendix G

Hydrophone-case mechanical specifications

Figures G.1 and G.2 respectively show the mechanical design of the hydrophone case and the case support (for attachment to the strenghtmember rope).

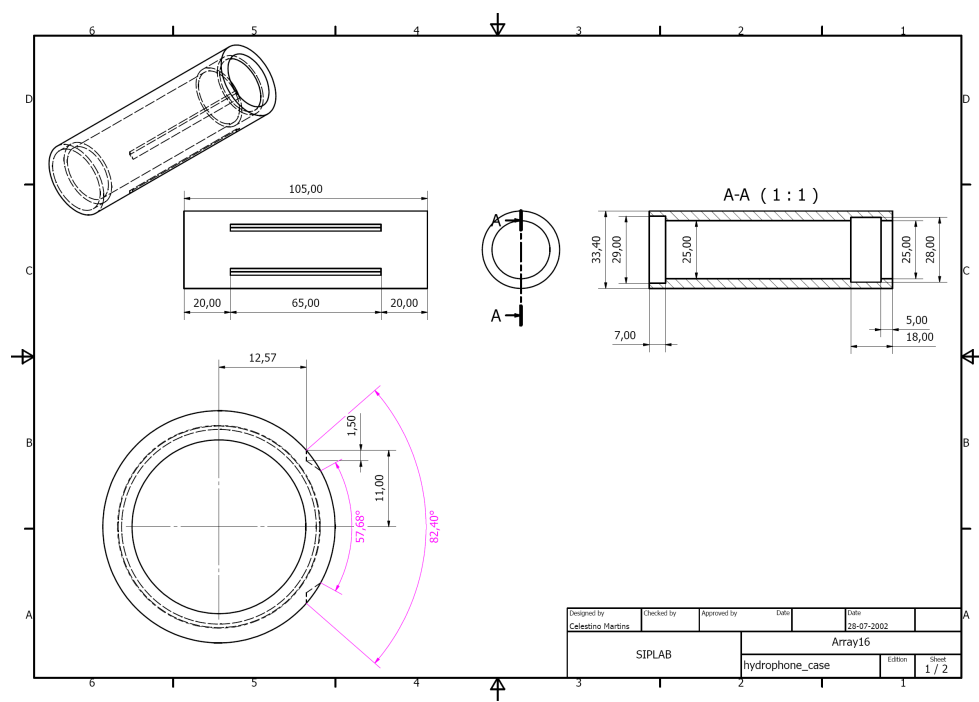


Figure G.1: hydrophone case mechanical design design.

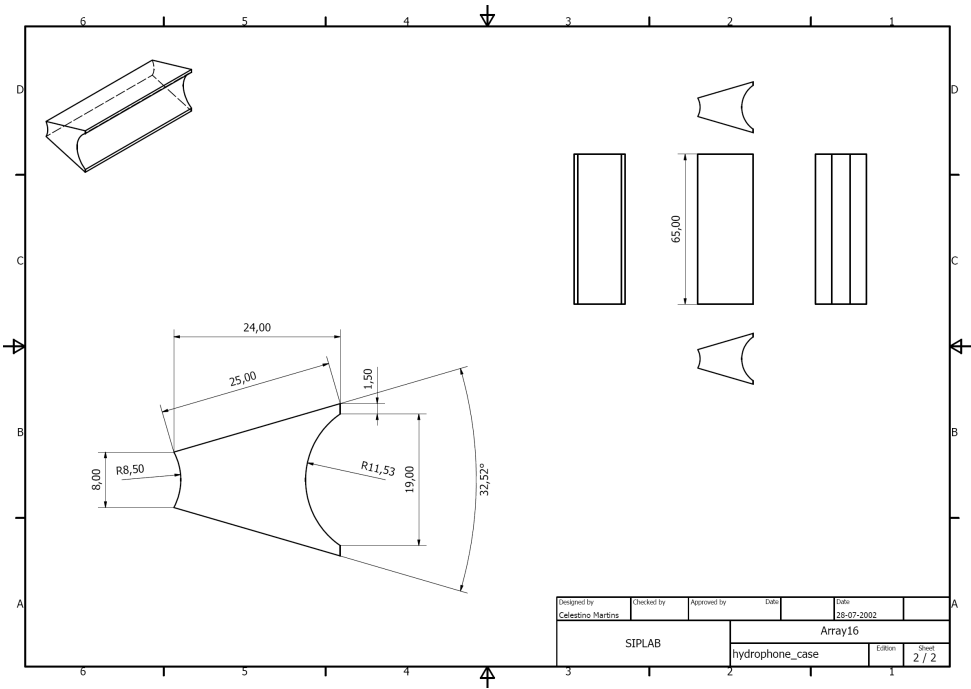


Figure G.2: hydrophone case support mechanical design.

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