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RF communication system for professional swimmers

Final Report

Group 5

EPS-PRJ-EPS-E10

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Preface

History of the project

“Wireless communication system for swimmers” is one of the 27 projects in the European Project Semester 2010. The project has been set by the Danish swimming league Sigma and is to be tackled by a small team of international Students.

Our group is working on the third phase of the project. From the last groups report we can see that the first group looked at which components to use in their time on the project and the second group developed these ideas and added some basic coding for the final electronic device.

The last group to work on this project submitted their final report in June 2005. No work has been done to update this since that time. We do not have the information of when the first group started the project and we have not received the final prototype they produced in their semester.

Acknowledgements

During the project we received help from a number of different people and here we would like to thank them. Firstly Thanks to Emil for the guidance throughout the project and the help introducing us to topics we previously had little or no experience of. Secondly we would like to thank all the people who participated in the tests we run for the vital feedback that allowed us to critically analyse the final designs. We would also like to thank all tutors who taught at the start of the semester as all members benefited by learning a lot of new skills and processes during this time.

Lastly thank you to all members of our EPS group who have worked hard and contributed to the final outcome of this project.

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Thursday 2nd December 2010

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2. Introduction

Our team has been brought together through the European project semester (EPS) run through IHK and prior to this no members of the team had ever met before. The EPS programme is designed to bring student together from all over the world to participate in one of a wide range of different available projects. These projects ranged from the very practical designing of a hydraulic pole hammer to the theoretical designing of a marketing strategy for a new dairy product.

All members selected 3 of 27 available projects that they would be interested in and then the university distributed the students into international groups of between 3 and 5. Because of this all the other on the project felt that they had skills that would contribute to the final project. 5 students with different skills were assigned to this project for the duration of the semester. The EPS programme is designed to help build skills working in a project team with people from different countries. For this programme English is the common language used and this is supported with English lessons which also form part of the final grade.

This is the final report for project group 5 working on the project titled "wireless communication system for professional swimmers". In this report we look at the final group summary of what has been accomplished over the last semester working at IHK and we will compare that to our initial ideas of what we hoped to achieve.

So as not to bog down this report with large amounts of supporting research, we will include in depth discussions of all our research in the appendix and then refer to it through the following sections.

3. Project work

3.1.Project Specification

At the start of this project semester the group was required to expand the initial task statement into a specification for the overall project. The first stage of this was to form a statement of what was interoperated from the project brief. **Group 5 defined the task as "*To further developing a device which allows wireless one way communication between a swimming coach and multiple swimmers*".** From the start of the project members were realistic about the fact that 2 groups had already worked on this project and there was a huge amount of work to be done so finishing the project was unlikely to be possible over the time on the project. Instead a number of goals were decided upon which were realsitic to accomplish by the end of the semester. These were:

- Develop a first prototype electronic setup applicable to the project
- Develop product form to second physical prototype stage ready for manufacture
- Work to combine 2 areas of the project in some sort of initial prototype for the project

The group also produced a written specification that the product should aim to satisfy. This is the complete specification.

This project will be looking to build upon the last semesters project work by reviewing their work and correcting their mistakes. By doing this, it is hoped that the project is brought closer to the initial specification and to a further developed conclusion.

The environment that this project must be designed for is use within a swimming centre. This means that the receiver unit (on the swimmer) will be used in chlorinated water daily. This can be used multiple times and for periods of up to 2 hours. The transmitter will be used poolside but for extended periods of time and so will need a battery life of up to 8 hours. The pool is 50m long so the and 25m wide this means that the furthest distance a swimmer can be from poolside is 55.9m. Therefore the maximum range of this product should be 65m to account for the coach being 10m away from the edge of the pool. The bulk of communication will be in the 15m-45m range.

This product should be capable of accurately transmitting vocal instructions from a single instructor to up to 8 swimmers either individually of as a group through a wireless connection. The swimmer should be able to understand the instructions of the coach clearly.

The size and the weight of the receiver unit should be small enough as to not disturb the movement of the user. The unit however must also be big enough to house all of the electronic components. The transmitter unit can be much larger as its primary function is ease of use however it must still be small enough to be carried easily by the coach.

The materials should be selected with the environment in consideration but should also take the use with the athlete into consideration. The product should also be ROHS compliant and use materials that are as eco-friendly as possible without compromising the other areas of the design.

The price should be minimised where possible but care should be taken to ensure that this does not affect the quality of the design more than is absolutely necessary. The final cost of this project should reflect that of a piece of specialised electronics equipment. A rough guide would be less than 750€ for a set of 8 headsets and 1 transmitter.

The durability and reliability of this product should be quite high as it is expected to become a regular and relied upon training aid for the swimming team. Because of this no more than 10% of the receiver devices should fail before 2 years and the majority should last for 3 years in full service.

3.2.Team structure

Having reviewed the previous groups project it was possible to see that at least 2 groups have worked on this previously. The group was given a copy of the final report from the previous team to work on this project and from that it is possible to see the makeup of the last team. The last group was made up of 4 electronics specialists and 1 marketing specialist from 5 different countries. Because of this the last project had a very strong bias towards the electronic development of the product and little work was done on the physical design.

This semester there are 4 different nations represented but also 4 different backgrounds. Alexander Hughes comes from the United Kingdom and studies product design in Nottingham. Dowhan Kim studies electronical engineering in South Korea. Two team members come from Spain: Ricardo López Cabañero and Sergio Ortiz Domenech, who study respectively mechanical design and telecommunications. Finally, the last team member, Gatien Manzac, comes from France and studies general engineering.

The combination of these backgrounds allowed the team to instantly separate the two main areas: the electronic form one part and the mechanical design form another.

At the start of this semester all team members used Belbin analysis to to try and profile what sort of team member they are and see where they will be best suited to fitting into a group. We were very lucky with the way that out group was structured as according to this we had a members that was very strong in 1 or more of the traits that are important in a functioning group. What was even more positive about this was that between the group 6 out the total 7 important traits needed were covered. The one the that wasn’t present was a member with strong skills in leadership. To overcome this problem it was agreed at the start the group would not elect a specific leader and instead meet more regularly and manage activities as a group.

This has been very successful through the semester, we have maintained a schedule of at least two group meetings per week dedicated purely to managing the time of each member and from this we have managed to keep the team well focused and directed without the need for a individual elected leader.

3.3.Distribution of Tasks

Because of the natural split in the team it was decided that an effective way to divide the main tasks would be to split the group into two separate sides. The two electronics specialists were assigned to developing the electronic side of the project and the two industrial designers were assigned to developing the casing that would be required to house the electronics. The final member has skills in both sides of the project as well as some supporting areas and so the role of Gatien was to coordinate between the two sides and work on supporting requirements such as battery selection and waterproofing research which required the knowledge of each side of the project to be able to accomplish.

Once the decision to split the team like this was made, the group made a list of the major jobs that needed to be done and divided them between the members assigning responsibility for the completion to different members. This ensured that each area was well managed and monitored through the course of the project. A copy of the tasks distribution can be found in **Appendix 12.1**.

3.4.Gantt chart

At the start of this project the group decided to make a Gantt chart to help with time management. Because the group had a lot of different tasks and because elements of the project were inter dependant it was very important to have clear goals and deadlines which all members of the group could work to. Initially the group broke down the main task into the 3 sub sections described in the specification and then from there each sub section was broken down further into the individual components and supporting research that was required to complete them. The Gantt chart is included in **Appendix 12.2**.

This chart was reviewed 6 times over the course of the semester in meetings devoted specifically to checking the groups progress compared to what had originally intended. Although members agreed that the chart could be amended if the group got ahead or behind schedule, the times we had allotted for each task were accurate and largely everyone managed to stick to the plan. The biggest weakness which resulted in the group finishing behind schedule was that the electronics components required were heavily delayed. This meant the electricians were not able to start the electronics side of the project as early as would have been ideal. Although the group aimed to lessen the impact of this on our project by re assigning the electronics members to jobs in research there was still a lot of time wasted. The reason for the delays on this electronics equipment was probably due to the fact that the components selected were all very new and probably being produced in small numbers currently.

Producing this time plan was a very positive step for the group and it helped a lot through the length of the project.

4. The system

This section of the report is intended to present and give an overview of the full system and the functions of every part of it. It is composed of two parts, one for emission (coach device) and other for the reception (swimmer device). The figure below shows a schematic of the main parts of the system. Every part is going to be explained in detail afterwards.

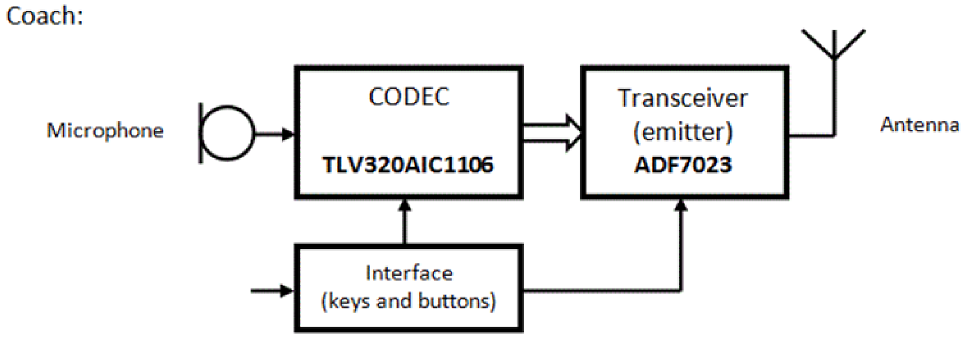


Figure 1 : Coach device

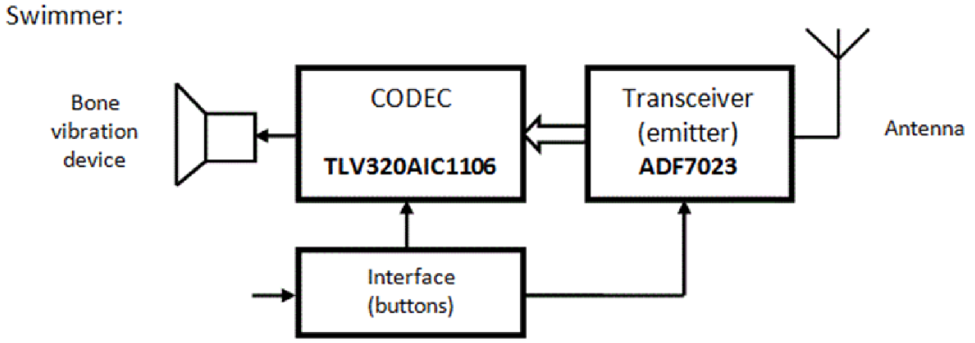


Figure 2 : Swimmer device

Coach device

As you can see in the figures, both devices of the system are made mainly of two complex electronic parts: a CODEC and a transceiver.

In the coach device the first part it's the microphone, which works as an input for the signal to the communication system. Next it's found the CODEC, that it's the part that discards any frequency not suitable to be voice and amplifies and converts the analog signal captured by the microphone to digital samples. Now the signal it's ready to next steps. After the CODEC, the transceiver (set as a transmitter) prepares the voice samples into packets and sends them through the antenna to the swimmers device.

Swimmer device

The swimmer device is very similar in what about concerns electronic parts. First the antenna and the transceiver (set as a receiver), that debuilds the packets and outputs the data previously sent by the coach's transceiver. Next the CODEC converts the digital voice samples to an analog signal and prepares it for the next step. Finally, the bone vibration system is the part trough the swimmer is able to hear the coach voice.

4.1.The microphone

The microphone is the transducer that converts the sound pressure waves made by the voice of the coach electrical signal (voltage difference). After some research, we found an electret microphone with noise cancelling that fits into our technical specifications (specially operating voltage). It's the Kwnoles Acoustics MD9752NSZ-1. For testing purposes was used a microphone built in a computer headset.

4.2.Microphone Amplifier

According to the datasheet of CODEC, we are capable to get a microphone gain with 23.5 dB by building an external circuit for microphone. Capacitor values of C1 = 0.22uF and resistor values of R1 = 2 kΩ, R2 = 34 kΩ, and R3 = 510 kΩ are applied. See **Section 4.8.2** to obtain more information about the application note of the microphone with gain of 23.5 dB.

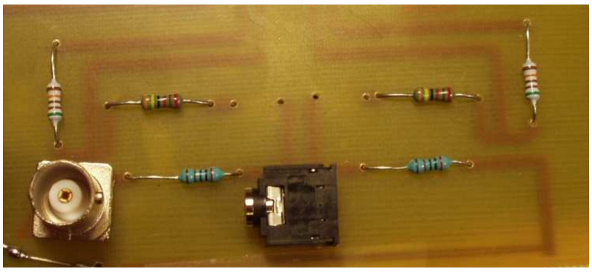


Figure 3 : Microphone amplifier

4.3.CODEC (TLV320AIC1106PW)

4.3.1. What is CODEC?

CODEC is a device or computer program capable of encoding and/or decoding a digital data stream or signal. The word CODEC is a portmanteau of 'compressor-decompressor' or, more commonly, 'coder-decoder'. In this project, CODEC is used in coding analog signals into Pulse-code modulation (PCM) and decoded them back. It is designed to meet Consultive Committee on International Telegraphy and Telephony (CCITT) G.714 requirement.

4.3.2. General idea of Pulse-Code Modulation (PCM)

PCM stands for Pulse-code modulation that is a method used to modulate analogue signals to digital signals.

As shown in **figure 4**, we can encode analogue signals as binary numbers, since the number of quantized values is 16 (2^4), we call it 4-bit PCM.

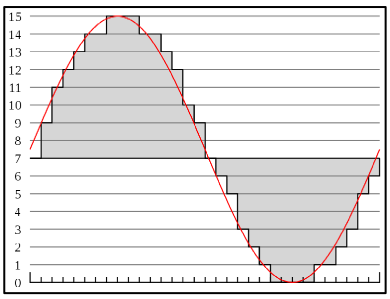


Figure 4 : Sampling and quantization of a signal (red) for 4-bit PCM

The 8-bit PCM is also produced in same way but different numbers of quantized values, 256 (2^8) in this time.

(ref. http://en.wikipedia.org/wiki/Pulse-code_modulation)

4.3.3. Master Clock and External Clock divider for PCMSYNC

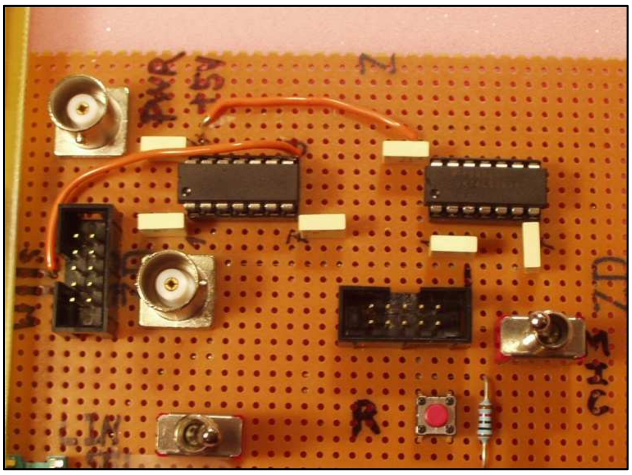


Figure 5 : Clock divider circuit

According to the data sheet, the group needs to supply pulse (2.048 MHz) for master clock and also need to use Divided by 256 clock divider to generate 8 kHz pulse for PCMSYNC, which is derived from the master clock. Master clock will be delivered from a function generator (Agilent 33220A) of a school laboratory, and the clock divider will be made of Dual 4-bit binary counter (DM74LS393N). Dual 4-bit binary counter consists of 8 toggle flip-flop modules. Frequency is divided by 2 when it passes through a toggle flip-flop, therefore a frequency is divided by 256 (2^8) when it passes 8 toggle flip-flops. **Figure 6** shows PSPICE diagram of it.

See **Section 4.8.1** to get more information about simulation results.

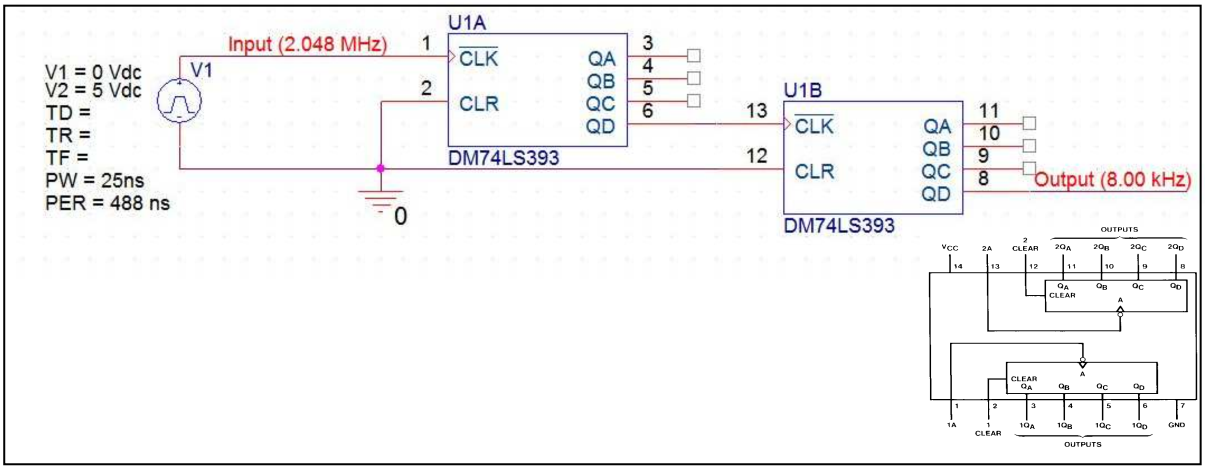


Figure 6 : PSPSICE diagram and connection diagram of Dual 4-bit binary counter

4.3.4. Features of TLV320AIC1106

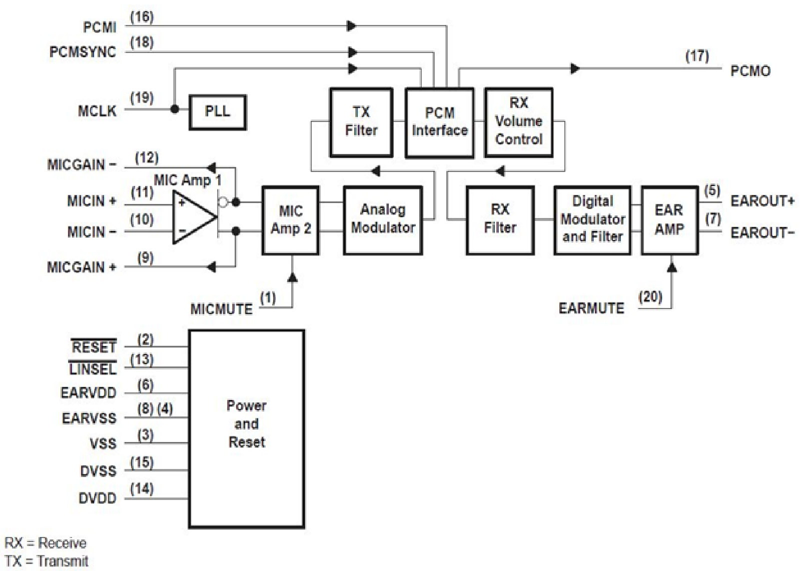


Figure 7 : Functional block diagram of CODEC (TLV320AIC1106)
(ref. CODEC (TLV320AIC1106) datasheet

This CODEC (TLV320AIC1106) is designed to perform the encoding analogue-to-digital (A/D) conversion, receive decoding digital-to-analogue (D/A) conversion, and filter transmit and receive signals for voice-band communications systems.

In **figure 7** shown in above, there is a functional block diagram of CODEC that will be used. It consists of several modules in a chip. These modules are necessary to construct the final device, unless a CODEC is used, each module will have to be built separately.

Specific features of TLV320AIC1106

- 20 I/O pins
- Operation voltage range : 2.7 V to 3.3 V
- Microphone amplifier
- Transmit / Receive filter
- Analogue / Digital modulator
- Input : analog or PCM
- Output : PCM or analogue

See **Section 4.8.1** to obtain more information about simulation results of CODEC.

4.3.5. Limitations

Since the delivered CODEC modules are SMD type and also too small to connect other components in a standard-dot PCB board, an extension circuit is needed. The group hoped to build a PCB board with Cadence layout software using, however it was impossible to build it since there was not related parts in its library and even in Texas Instruments web pages. There was no choice but building a circuit board by hand or by other drawing software.

4.3.6. Developing Strategies

Since all related circuits of CODEC were made of analogue components, it is important to be careful about noises might come from junctions, routing, and common ground problems. First of all, in the case of building extension circuits **(cf. figure 8, figure 9)** for CODEC, since there was not related Cadence layout library, we used Adobe illustrator CS4 instead. Prototype boards were developed by etching kits in IHK.

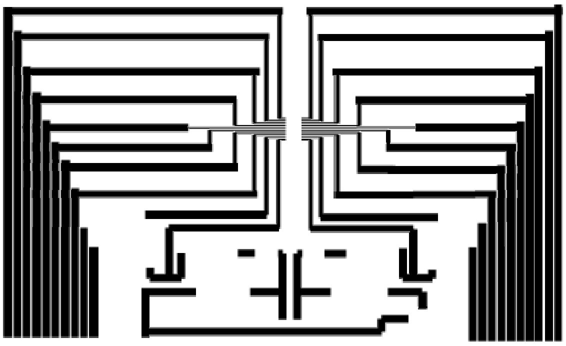


Figure 8 : Extension circuit for CODEC (TX)

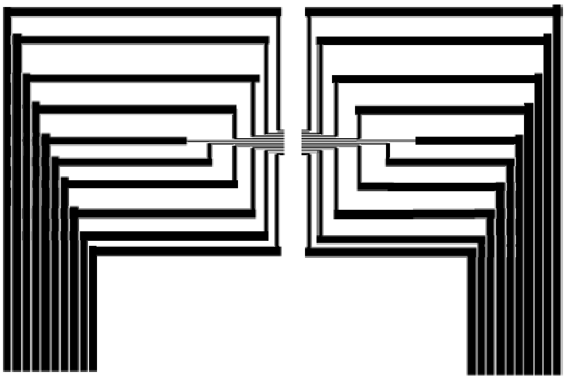


Figure 9 : Extension circuit for CODEC (RX)

The flowing steps represent how we have built extension boards for CODEC.

- Design a circuit diagram with PSPICE
- Draw extension lines for CODEC with Illustrator CS4
- Produce extension board at the school etching laboratory
- Install decoupling capacitors (100 nF) to prevent unexpected peak from the external power supply – pin 6, 14, 15, and $V+_{mic}$
- Install a pull-up resistor (10 kΩ) in parallel to Reset button to deliver clear Schmidt trigger to pin 2

It is important to keep in mind that the circuit might produce some high frequency noises because of edges of its wires.

To give clear pulse signals to a prototype circuit of CODEC easily, a function generator, Agilent 33220A is recommended to use. In practical product, it will be altered to quarts and a clock divider.

Specification of a function generator (Agilent 33220A):

- Mode : Square
- Frequency : 2.048 MHz
- Amplitude : 3.5 V
- Lo level : 0 V
- Duty cycle : 50 %

Dual 4-bit binary counter is used as Clock divider. See chapter 3.3.3 to obtain more information about Clock divider. Developing Clock divider methods (using a dual 4-bit binary counter – DM74LS393) are by following

- Routing circuit as simple and short as possible to minimize interferences of the high frequency
- Install decoupling capacitors (100 nF) in parallel to VCC+, and to pin 1 to prevent unexpected peaks from the external power supply and a function generator
- Connect pin 6 to 13
- Set clear at Low (0V) allow toggle for T flip-flops

4.3.7. Requirements and Specifications

The following system requirements are required to build a prototype circuit of CODEC.

- **Requirements**
  - Main Components: 5 * CODEC (TLV320AIC1106PW),
    2 * Dual 4-bit binary counter (DM74LS393N)
  - Hardware: 1* Function generator (Agilent 33220A)
    1* Oscillator (Agilent DSO7014A)
    1 * Power supply
    1* Component box
    1 * Soldering kit
    1 * Etching kits (Light box, Etching tank, Developer)
  - Software: Cadence SPB 16.2 (PSPICE)

Adobe Design premium CS4 (Illustrator, Photoshop)

- **System Specifications**
    - o Frequency: 2.048 MHz (MCLK) / 8 kHz (PCMSYNC)
    - o Voltage: +2.0 V (V_{MIC}) / +3.0 V (DVDD/EARVDD) / +5.0 V (VCC+ @ Clock divider)
    - o Impedance: 16 Ω (earphone)

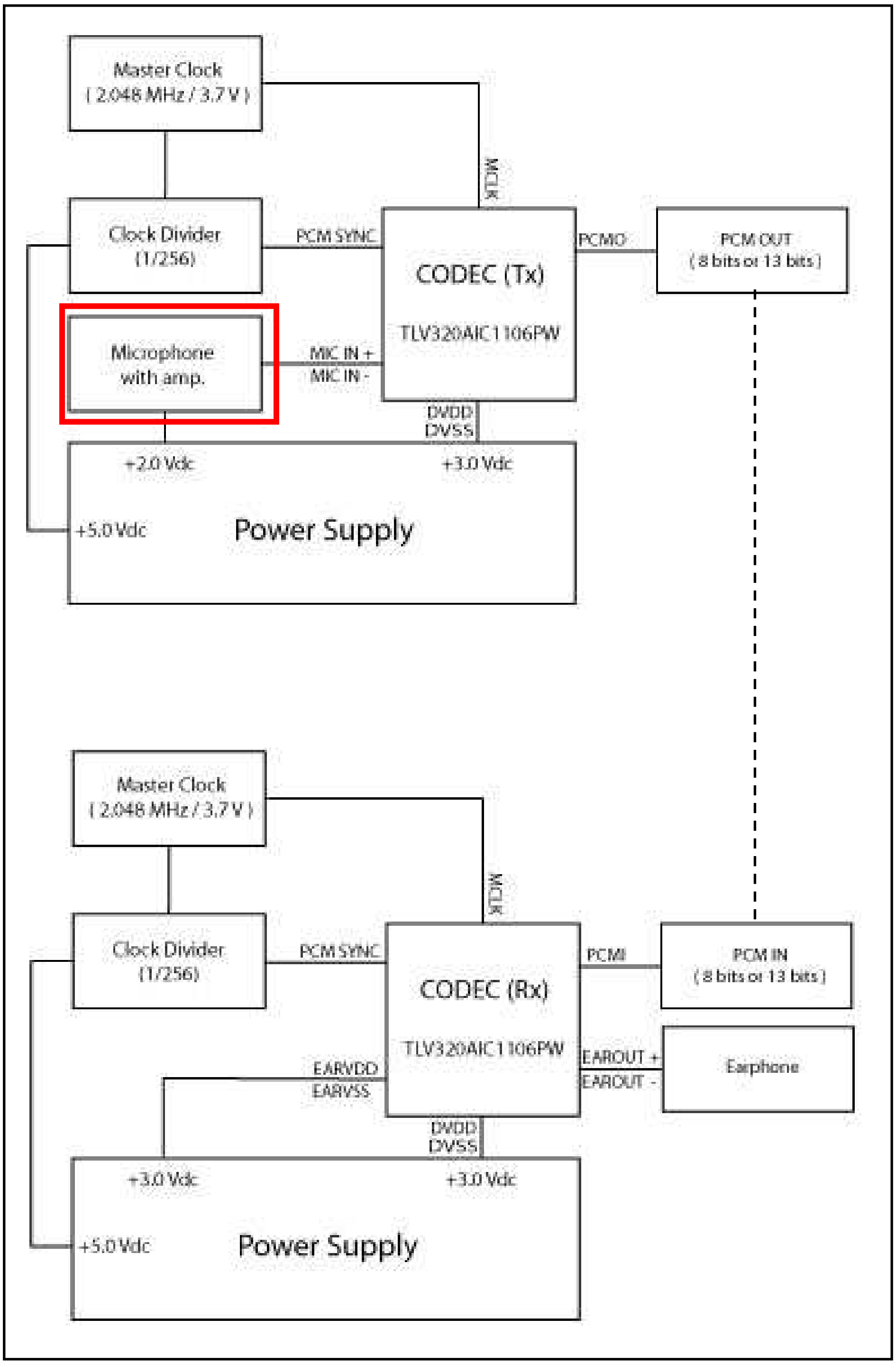


Figure 10 : Specified block diagram of CODEC(Tx/Rx)

4.4. The transceiver

The transceiver is the part responsible to make the wireless communication between the coach and each swimmer device successful. A transceiver is device that can work as a transmitter or as a receiver (or both). Usually transceivers have shared circuitry for both functions in the same integrated circuit or housing.

After several weeks to set the final technical specifications of the project by our supervisor and the lag that it implies in the research and development of the project, it was decided that the most suitable transceiver (combined with the groups wishes of using a CODEC instead of a standalone DSP) was the Analog Devices' ADF7023. The same transceiver is going to be implemented in the coach and the swimmers' devices.

The Analog Devices' ADF7023 is a very low power, high sensitivity, multi modulation transceiver designed for operation in the European license-free ISM frequency band at 868 MHz. It is suitable for circuit applications that operate under the European ETSI EN300-220. Data rates from 1 kbps to 300 kbps are supported. It also includes a built in 8-bit RISC communications processor, that performs the radio control and the useful and powerful packet management feature (that avoids the using of a separate microprocessor or DSP).

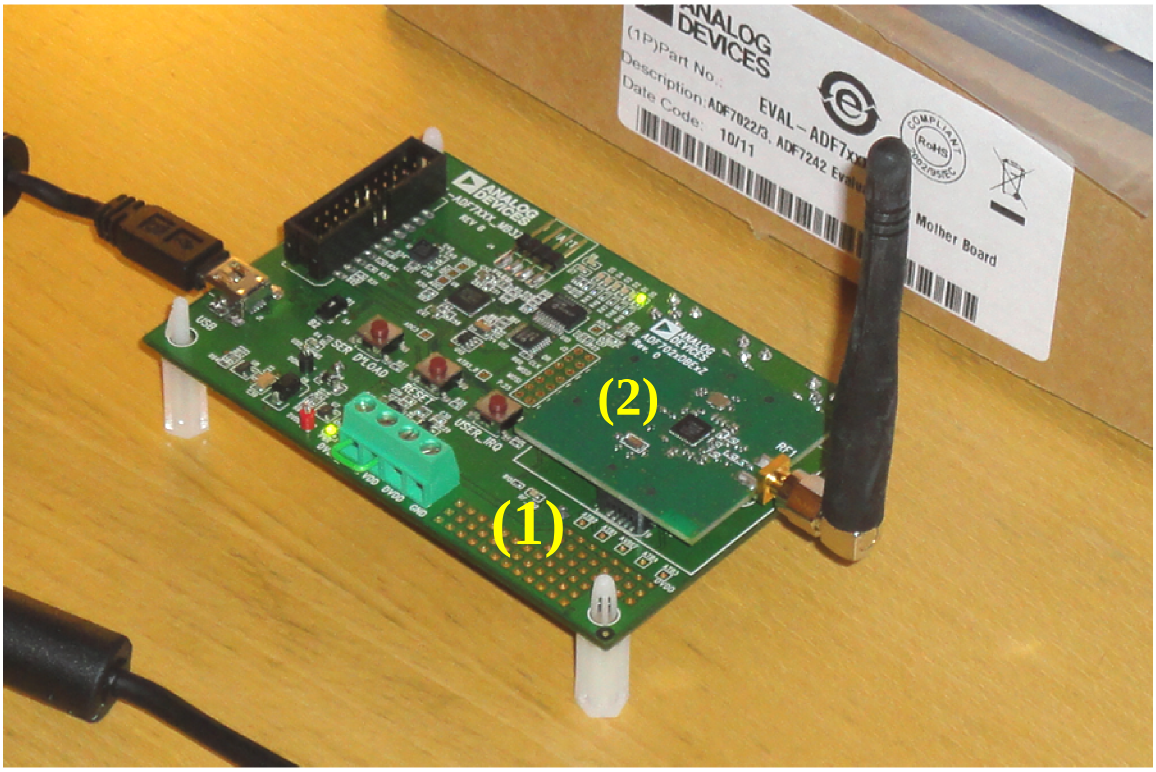


Figure 11 : . ADF7022/3 evaluation kit motherboard (1) and ADF7023 evaluation kit (2) attached

4.4.1. Frequency

As a carrier frequency for the modulated data the group decided to use the frequency of 868 MHz for two main reasons.

The first and most important is that it's in a European license free band of the radioelectric spectrum, called ISM band (industrial, scientific and medical) defined by the ITU-R in 5.138, 5.150, and 5.280 of the Radio Regulations.

And the second one is that after a few days of research, it was discovered that a carrier frequency near 1GHz should be enough to be able to be received through a small column or quantity of water surrounding the swimmer device (for example when swimming in the surface of the pool) but also because it is not as high to make the electronics design and building of a final prototype too expensive and complex in development.

Moreover the research also found out that the frequency of the carrier it's also high enough to allow the use of relatively small antennas for the devices.

4.4.2. Modulation

The data sent by the transceiver will be modulated in GFSK (Gaussian Frequency Shift Keying). GFSK is a modulation where a logical high (“1”) it’s represented by an increment in the frequency of the carrier and a logical low (“0”) it’s represented as a decrement.

This type of modulation is an improved version of the FSK (Frequency Shift Keying). In GFSK the data stream is filtered through a gaussian filter before modulating the signal. Doing this procedure the resulting energy spectrum of the modulated signal is decreased significantly compared with the regular FSK and makes possible to transfer at higher data rates and makes the signal stronger against noise problems.

The GFSK (Gaussian Frequency Shift Keying) modulation is used because it has been proven to perform better in a noisy environment than ASK (Amplitude Shift Keying, or OOK; On-Off Keying).

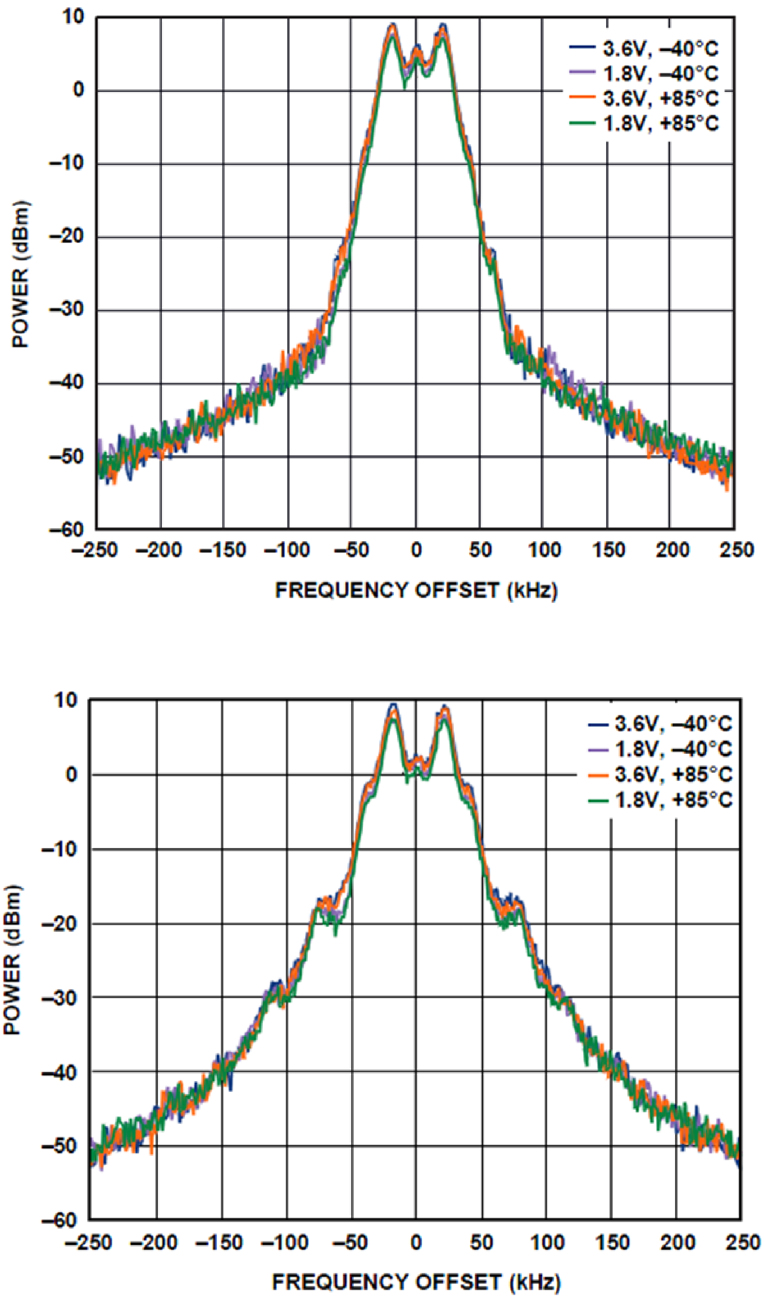


Figure 12 : Comparison between transmit spectrum of GFSK modulation (top) and FSK modulation (bottom)

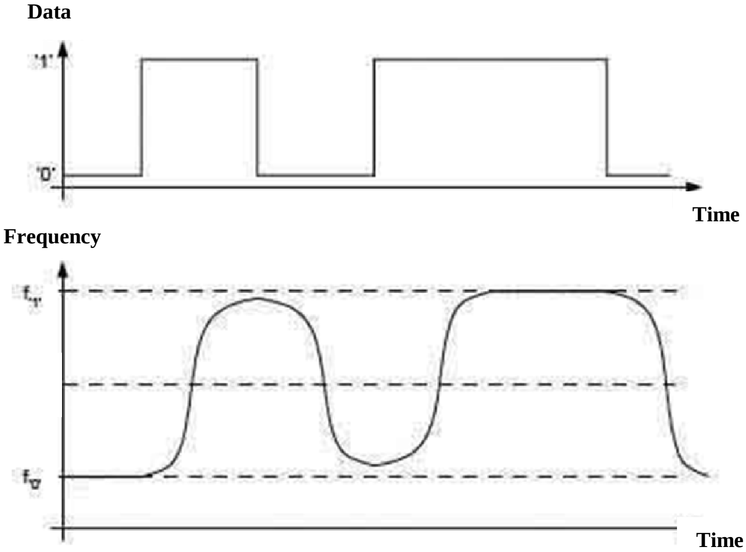


Figure 13 : Detail of the result after the gaussian filter

4.4.3. Packet management

The ADF7023 transceiver has a built-in communications processor, specifically an 8 bit RISC architecture processor, can be configured to be used with a wide variety of packet-based radio protocols.

In transmit mode, preamble, sync word, and CRC can be added by the communications processor to the data stored in the packet RAM for transmission.

In receive mode, the communications processor can be used to qualify received packets based on the preamble detection, sync word detection, CRC detection, or address match and generate an interrupt. On reception of a valid packet, the received payload data is loaded to packet RAM memory.

Afterwards are explained the main features that will be used by the achievement of the communication system.

Figure 14 : Structure of a packet

4.4.3.1. Preamble

The preamble is a mandatory part of the packet that is automatically added by the communications processor when transmitting a packet and removed after receiving a packet.

It is necessary to have preamble at the beginning of the packet to allow time for the receiver recovery circuitry to settle before the start of the sync word.

In receive mode, the ADF7023 can use a preamble qualification circuit to detect preamble and interrupt the host processor. After the preamble is detected and the end of preamble has been reached, the communications processor searches for the sync word.

4.4.3.2. Synchronization word

The synchronization word is used by the receiver for byte level synchronization, while also providing an optional interrupt on detection. It is automatically added to the packet by the communications processor in transmit mode and removed during reception of a packet.

In receive mode, the ADF7023 can provide an interrupt on reception of the sync word sequence programmed in the registers. This feature can be used to alert the host processor that a qualified sync word has been received.

4.4.3.3. Payload management

The host processor writes the transmit data payload to the packet RAM. The location of the transmit data in the packet RAM is defined by the TX_BASE_ADR value register (Address 0x124). The TX_BASE_ADR value is the location of the first byte of the transmit payload data in the packet RAM.

On reception of a valid sync word, the communications processor automatically loads the receive payload to the packet RAM. The RX_BASE_ADR register value (Address 0x125) sets the location in the packet RAM of the first byte of the received payload.

4.4.3.4. Addressing

The ADF7023 provides a very flexible address matching scheme, allowing matching of a single address, multiple addresses, and broadcast addresses. The address information can be included at any section of the transmit payload.

In receiver mode, the address data is then compared against a list of known addresses that are stored in BBRAM. The format and placement of the address information in the payload data should match the address check settings at the receiver to ensure exact address detection and qualification.

4.4.3.5. CRC (Cyclic Redundancy Check)

A cyclic redundancy check (CRC) is a hash function designed to detect accidental changes in the transferred data.

In transmission, the transceiver calculates a short fixed-length binary sequence known as the CRC code for each packet payload and attaches it to the packet itself.

In receiver mode, when a packet is received the calculation is repeated and if the new CRC does not match the one calculated earlier, then the payload contains a data error. If the CRC calculation returns the same code, the data is assumed to be error free.

An optional CRC-16 can be appended to the packet. A default polynomial is used if PROG_CRC_EN = 0 in the SYMBOL_MODE register. The default CRC polynomial is:

$$g(x)= x^{16} + x^{12} + x^5 + 1$$

Figure 15 : CRC-CCITT polynomial

Any other 16-bit polynomial can be used if PROG_CRC_EN = 1. An interrupt can be generated on reception of a CRC verified packet.

4.4.3.6. Postamble

The communications processor automatically appends two bytes of postamble to the end of the transmitted packet. On the receiver, if the received packet is valid, the RSSI (Received Signal Strength Indicator) is automatically measured during the first postamble byte, and the result is stored in the RSSI_READBACK register.

4.5.Interface

The interface for the final devices is an essential part of the design as this forms the bridge between the electronic systems and the person using it. A good or poor interface can greatly affect the quality and usability of the final device. The reasons for choosing different set ups for the interface are discussed at length in section 6.2 and 6.1. All reasons for using specific set ups are explained. During this project there was not enough time to develop a working electronic interface for the devices however the format that will be used has been tested and finalised

4.6.Antenna

The choice of antenna will be different for both the coach and the swimmer device. This selection is discussed at full length in **Section 6.1**.

4.7.Bone speaker

Similar to the antenna this section is discussed at much more length in **Appendix 12.4**.

4.8.Testing

4.8.1. CODEC

The aim of CODEC testing is to demonstrate weather CODEC modulates analogue signals and delivers PCM signals to PCMO. CODEC testing was started when CODEC chips (TLV320AIC1106PW) were delivered to us and installed in an extension PCB. CODEC testing was processed by following steps; Clock divider, testing microphone amplifying, and Pulse-code modulation (PCM) testing.

Clock divider

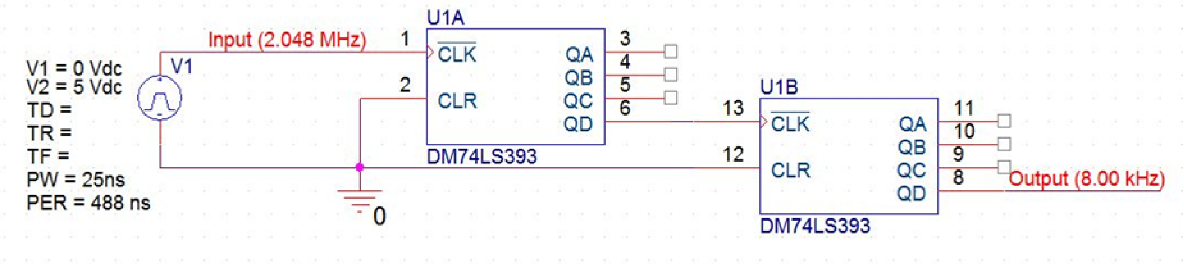


Figure 16 : Circuit diagram to build a Clock divider

Measuring specification:

Input signals : Pulse wave (2.3V/0V)

Frequency : 2.048 MHz (period : 488ns)

Simulation results:

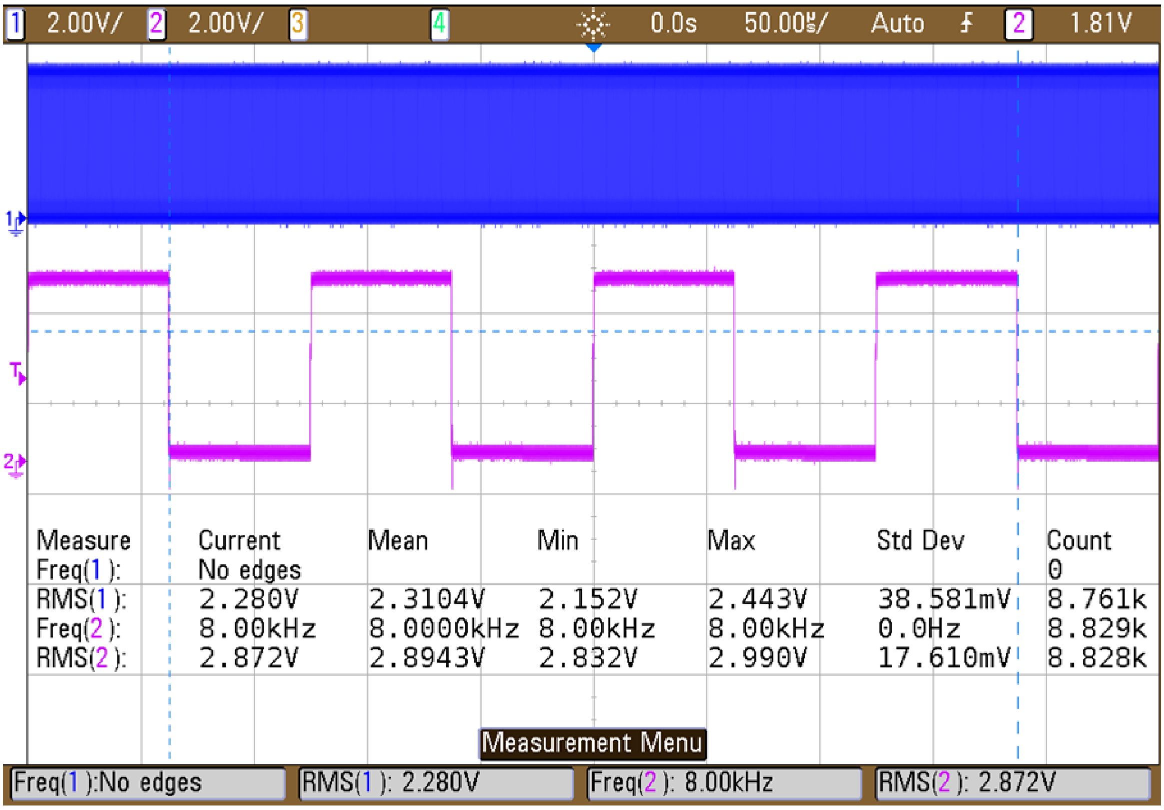
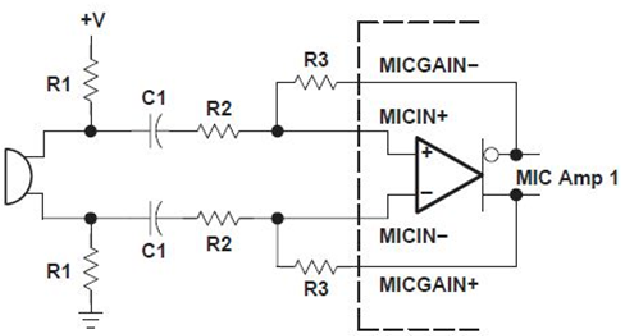


Figure 17 : Results for Clock divider (divided frequency from 2.048 MHz to 8.00 kHz)

4.8.2. Microphone polarization



R1 = 2 kΩ

C1 = 0.22 µF

$$\text{MIC Amp 1 Gain in dB} = 20\ \log\left(\frac{R3}{R2}\right)$$

microphone interface

	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{IO}	Input offset voltage	See Note 3	−5		5	mV
I_{IB}	Input bias current		−250		250	nA
C_i	Input capacitance			5		pF
V_n	Microphone input referred noise, psophometric weighted	MIC Amp 1 gain = 23.5 dB, See Note 4		2.9	4	μV_{rms}
	MICMUTE		−80			dB

NOTES: 3. Measured while MICIN+ and MICIN− are connected together. Less than a 0.5-mV offset results in 0 value code on PCMOUT.
4. Configured as shown in Figure 3.

Figure 18 : Application note of Microphone polarization

Measuring specification:

Input voltages : 1.5 Vdc

Frequency ranges of input source : 20 Hz < f < 2000 Hz

Testing results

Since there is no output pin of amplifying gain of 23.5 dB in CODEC, there is no way to figure it out. However, a blue line represents an analogue signal from input sources, and the pink line shows a line of CODEC with microphone polarization.

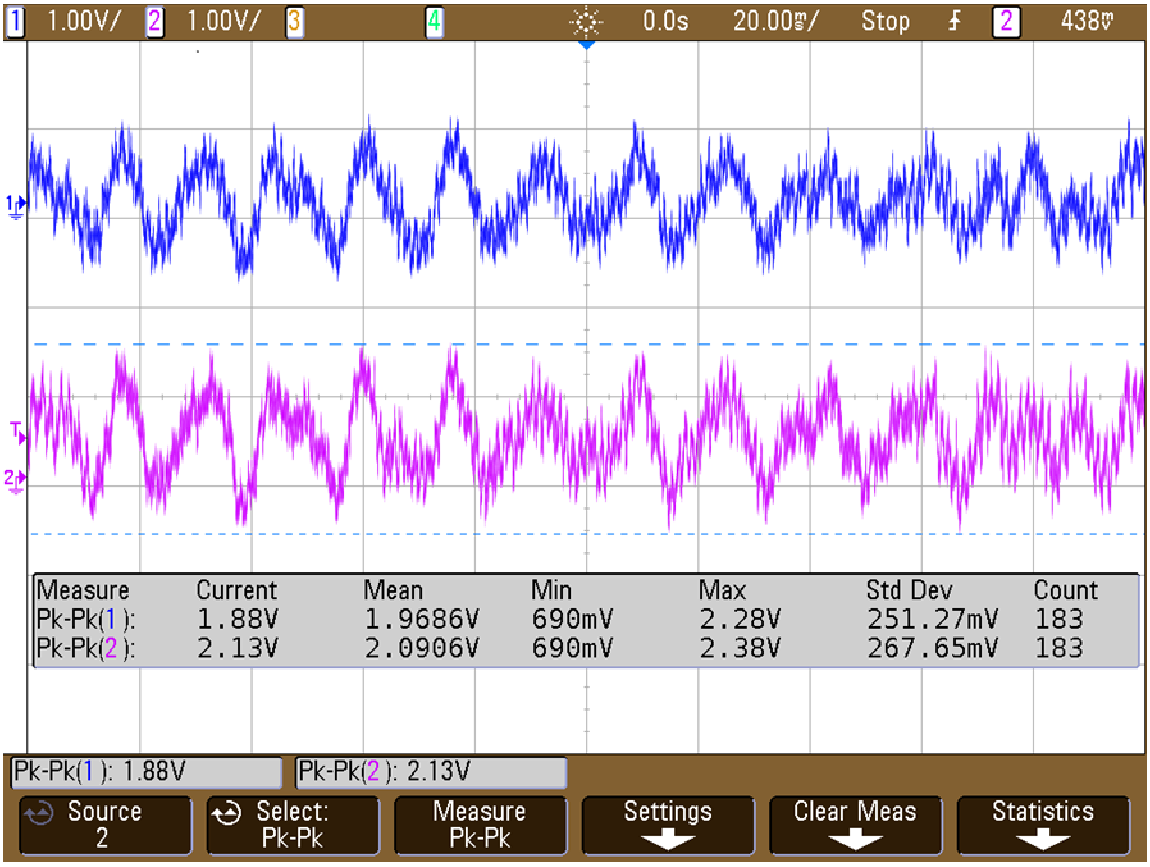


Figure 19 : Simulation results of microphone polarization

4.8.3. Transceiver

The testing of the transceiver began (late October) after the group received the Analog Devices ADF7023 transceiver evaluation kits and the correspondent mother boards for testing how everything should work work for the coach device and the swimmer device.

As commented earlier in the software section, the software is very powerful and for some settings overwhelms our knowledge of telecommunications and telematics involved in a transceiver.

Later it is explained how it's correctly set up the "Evaluation software" for testing a communication system made of two transceivers (coach device and swimmer device).

4.8.3.1. Using the "Evaluation software"

First, Ensure the evaluation mother board with the desired daughter card is connected to the PC via USB cable before running the software.

1. Run the ADF7023 software.
2. Once the software is running press Connect USB.
3. Wait until the BUSY signal above the Connect USB button is turned off before pressing any further buttons on the software interface.
4. After this enter state PHY_ON by pressing the command CMD_PHY_ON.

Once you follow these steps, the transceiver should be in the state PHY_ON ("awake" and ready for more commands). You can check it at the right bottom of any tab or in the radio states diagram of the "commands tab".

Figure 20 : Current state indicator (right bottom of any tab)

After getting ready one transceiver, you can decide if you want to use another transceiver in the same computer or repeat the process for another transceiver in another computer.

4.8.3.1.1. Connecting two Evaluation Platforms to one Computer

1. On one of the motherboards set switch S4 to position B1 (board 1). On the other board set switch S4 to position B2 (board 2). Connect both boards to the PC with USB cables.

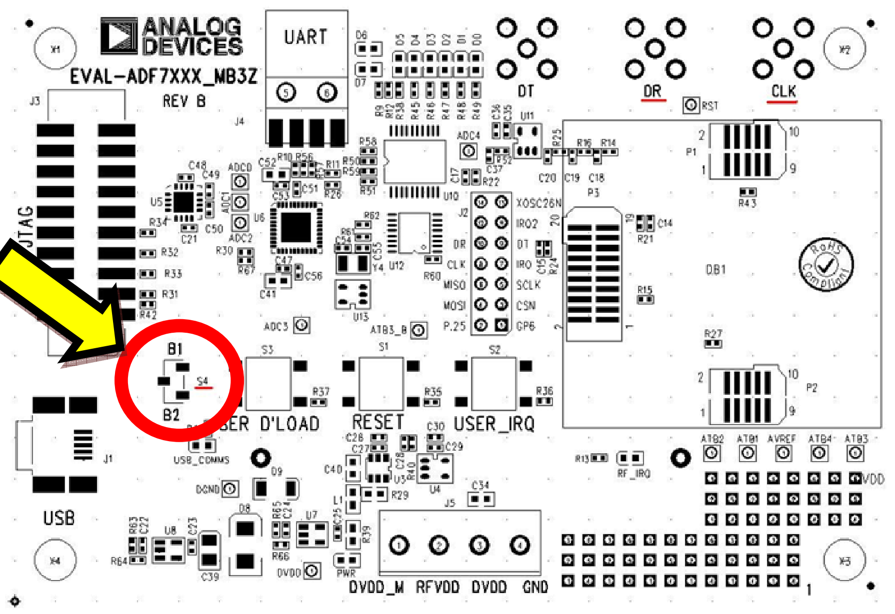


Figure 21 : Position of the switch S4 in the mother board

2. Open two instances of the evaluation software. On one front panel select board 1 and press Connect USB. On the other front panel select board 2 and press Connect USB.

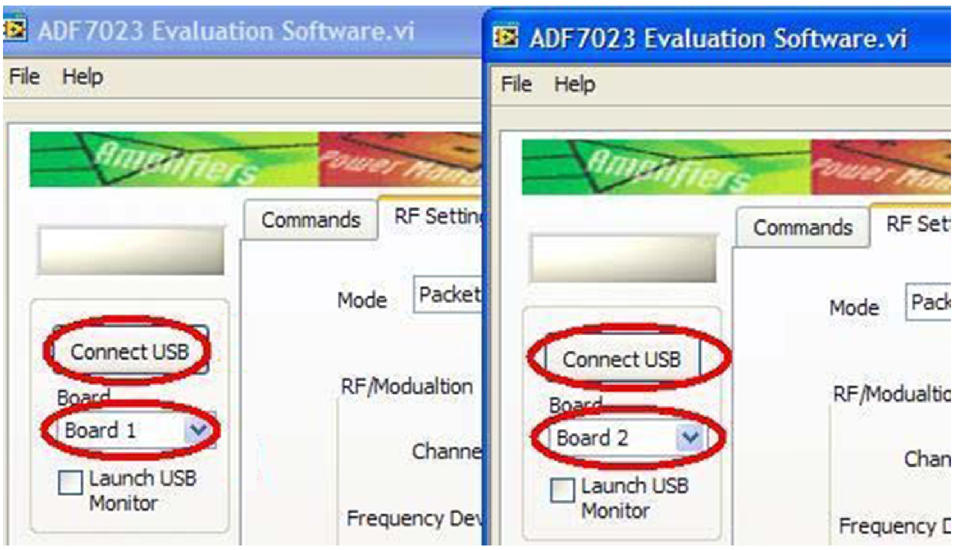


Figure 22 : Connecting two motherboards in one computer

4.8.3.1.2. Setting a board in "receiving" mode

1. In "RF Settings Tab" select the SPORT Mode. Press "Update Needed" if highlighted. This writes the settings to BBRAM and then does a CMD_CONFIG_DEV.

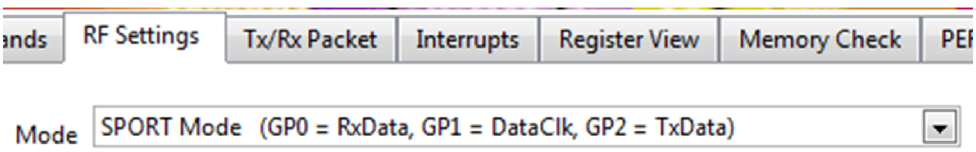


Figure 23 : Selecting SPORT mode for "receiving" transceiver

2. At the bottom buttons, press CMD_PHY_RX. The part now enters PHY_RX. To exit PHY_RX press CMD_PHY_ON.

While in PHY_RX with SPORT mode enabled, the received data demodulated by the ADF7023 will appear at the DR SMA connector on the mother board. A clock synchronized with the demodulated data will appear at the CLK SMA connector.

4.8.3.1.3. Setting the other board in "transmitting" mode

First of all, ensure the part is in PHY_ON state.

1. Set Tx Test Mode to "Transmit Carrier"

Figure 24 : Transmission Test Mode to "Transmit Carrier"

2. Press CMD_PHY_TX to enter transmit mode (continuous carrier transmission). Press CMD_PHY_END_TX to exit transmit mode and return to PHY_ON

Now the two transceivers are ready to be tested, one as a receiver and the other one as a transmitter.

4.8.3.2. Testing settings

After several working days getting familiar about how works the transceiver and solving some troubles, the best results and the closest ones of our specifications were obtained with these settings:

- RF/modulation:
  - Channel frequency: 868,0000 MHz
  - Frequency deviation: 200,0 KHz
  - Data rate: 300,0 kbps
- Transmitter:
  - Modulation scheme: GFSK
- Receiver:
  - IF bandwidth: 200 KHz
  - Demodulation scheme: GFSK
  - Expected max RF freq error: 100,0 KHz

Note: The settings that are not appearing above were set as default.

4.8.3.3. Testing results

As far as is known, the device will need at least 64 kbps of data rate to transfer the digital voice signal in real time between the transceivers but there was a big problem, the transceivers were needed to be tested but the CODEC part of the device wasn't ready yet.

The solution was using a fake digital data stream. It was made by the function generator, creating a square wave unipolar signal of 64 KHz of frequency.

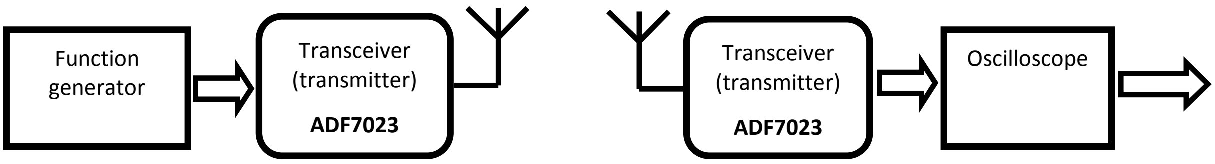


Figure 25 : Testing. Block diagram

The group found the solution worked, but not at the speed that was needed to make the communication system viable. Actually it works with acceptable error margins until about 40 KHz, being the perfect performance at a low 20 KHz.

Probably the problem it's just a matter or radio settings of the transceiver. Because of the short time available to test them, our lack of deep knowledge and skills about transceivers and the lack of help we found, it wasn't known very how to fix them and make them work faster.

The packet management testing was not a problematic feature. The group tested this early because it worked as planed in the (brief) user guide provided with the motherboards.

However, there was time to learn and keep testing before the final presentation.

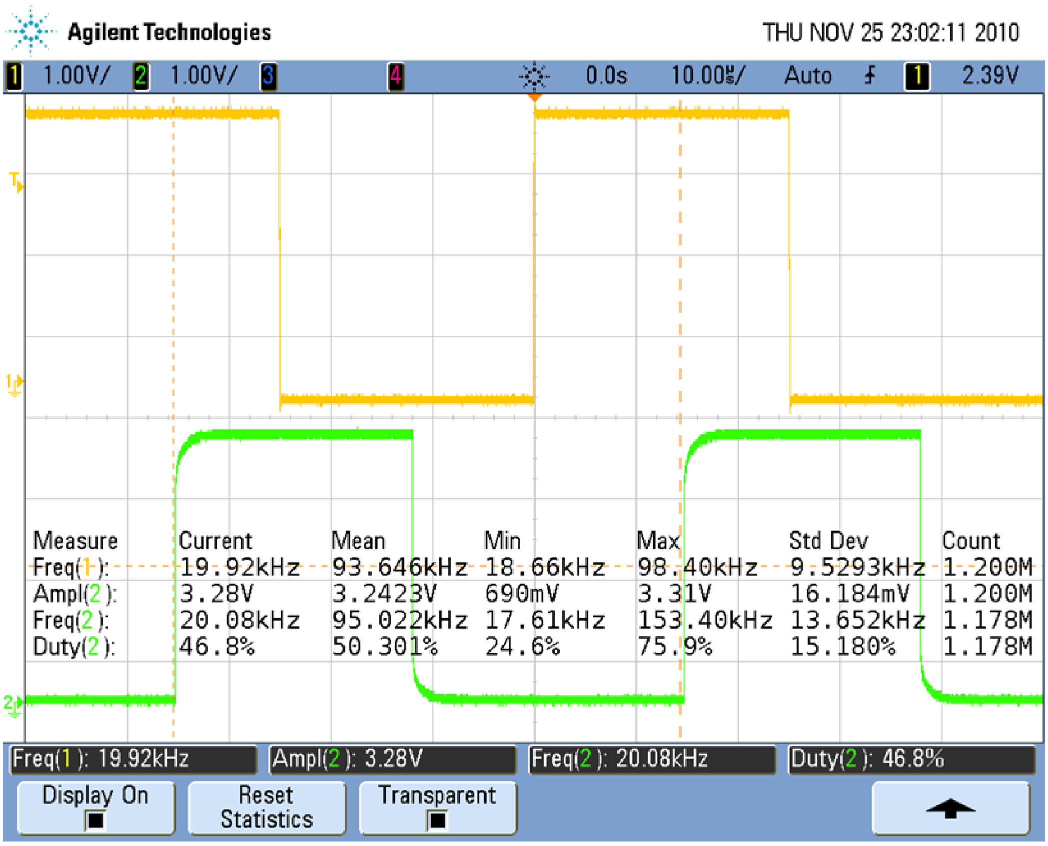


Figure 26 : Sending fake data results. Fake data (above). Output data (below)

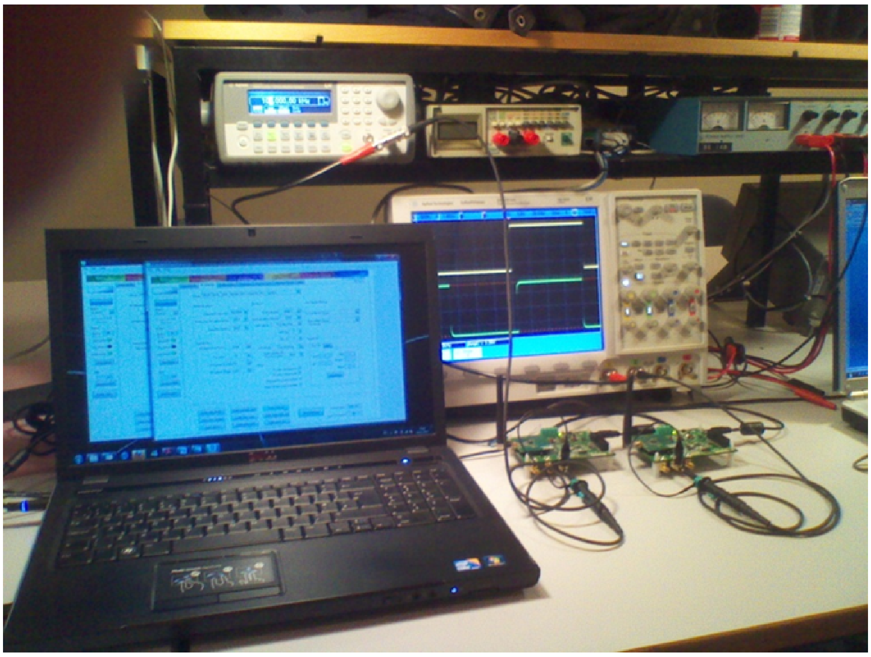


Figure 27 : Overview of the testing

5. Software

5.1.Codec

To design and develop PCB board properly, programs for circuit designing, Cadence SPB 16.2, and Adobe Illustrator CS4 are needed. Cadence SPB 16.2 is used in designing circuit diagrams of components and PCB circuit layout. As there is no related layout library of CODEC(TLV320AIC1106), Adobe Illustrator CS4 is used in designing extension circuits of it.

Schematics designed with PSPICE

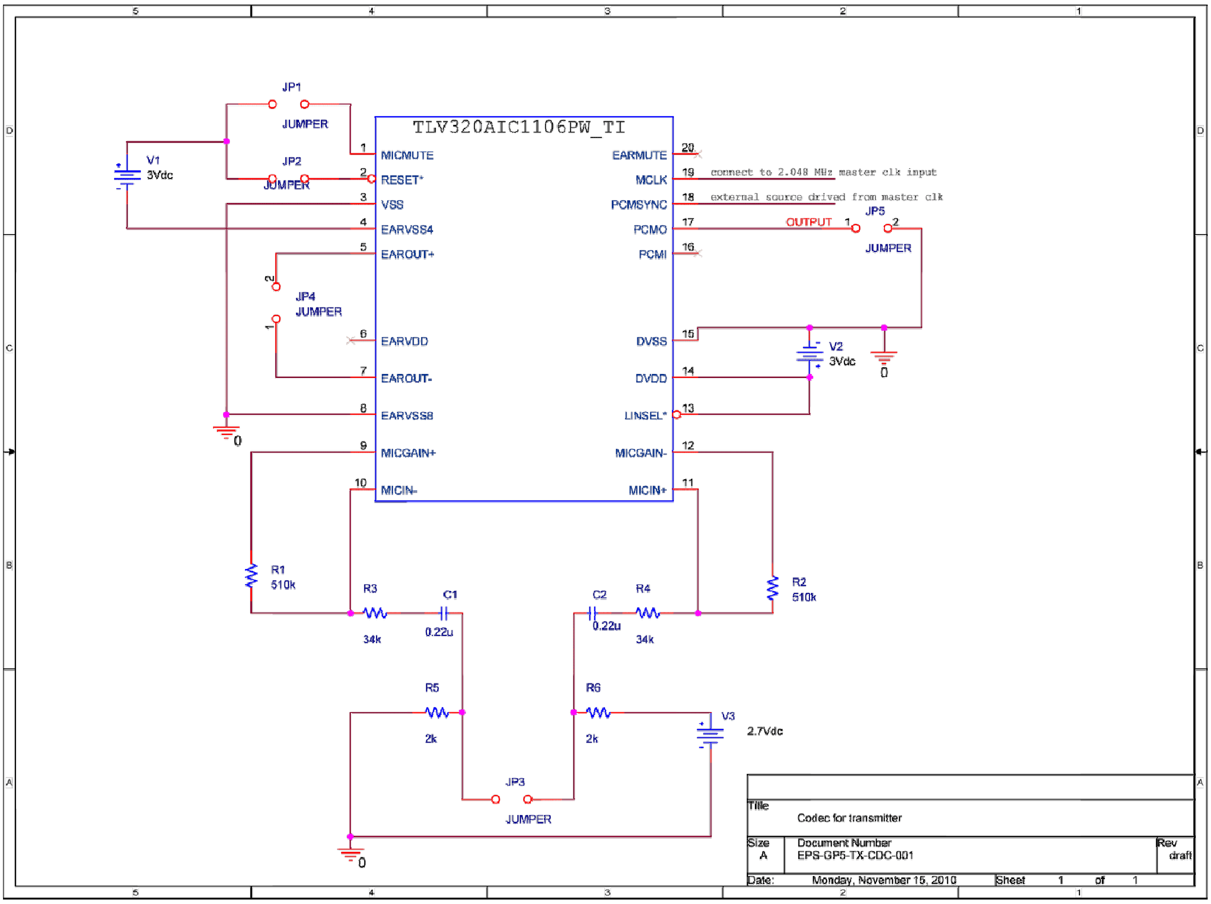


Figure 28 : Schemtaic of the Texas Instruments TLV 320AIC1106

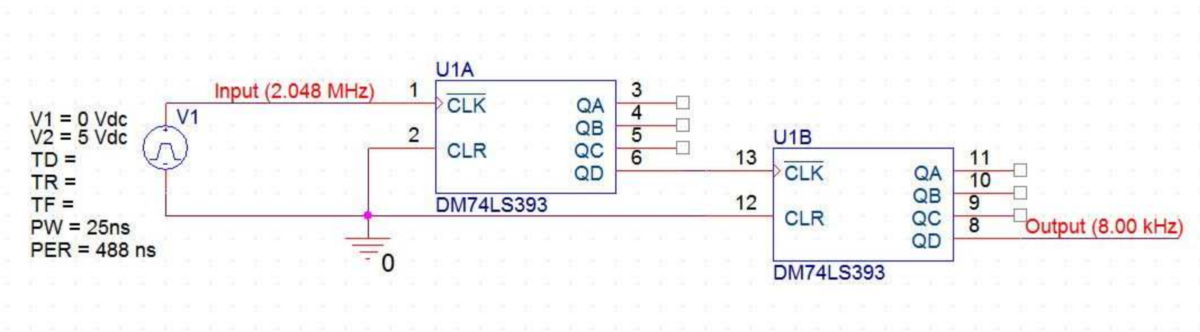


Figure 29 : Schematic of the 256 times divider

Extension circuits designed by Adobe Illustrator CS4

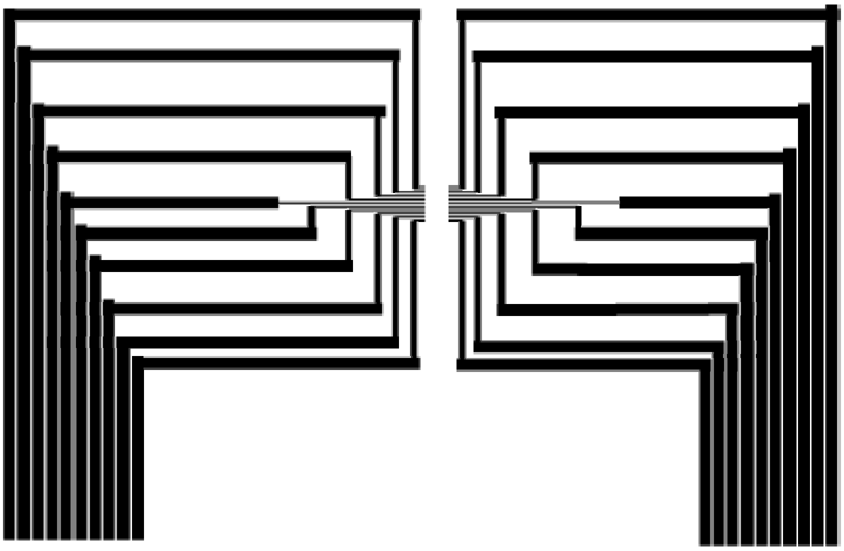


Figure 30 : Extension circuits of receiving CODEC

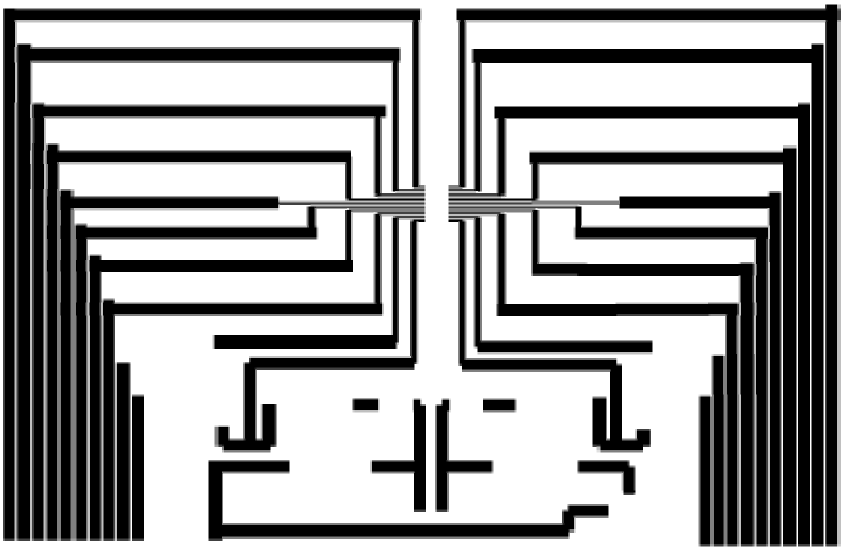


Figure 31 : extension circuits of receiving CODEC

5.2.Transceiver

The selection of components made the development of the devices mainly by hardware but for the testing of one of the main components, the transceiver, was used the software included with the development kit. It was very tough to use because it came without any kind of manual and the user guide which was really bad. Also the software is very buggy and it hangs every once in a while.

This software it's called "ADF7023 Evaluation software".

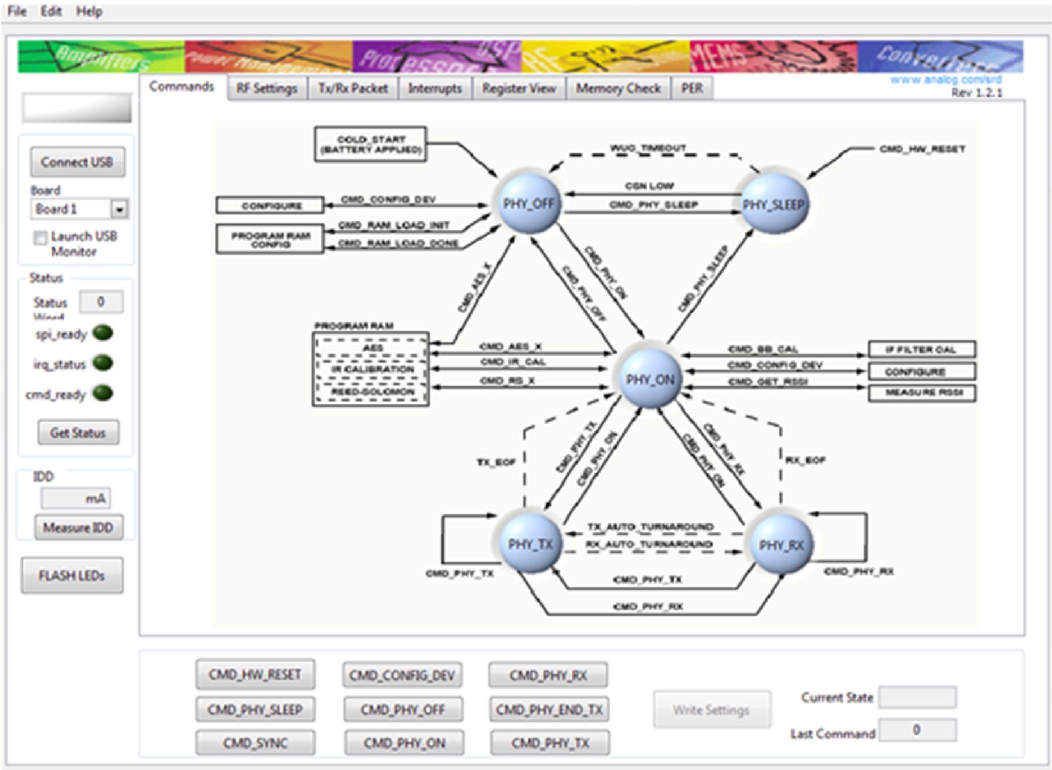


Figure 32 : Screen capture of the "Commands" tab

Although the software it's in an early stage of development and the lack of help to use it and configure correctly the transceiver, (probably because the ADF7023 it's a very new product itself and in the market only since spring 2010) it was proved to be very powerful and useful to test the transceiver.

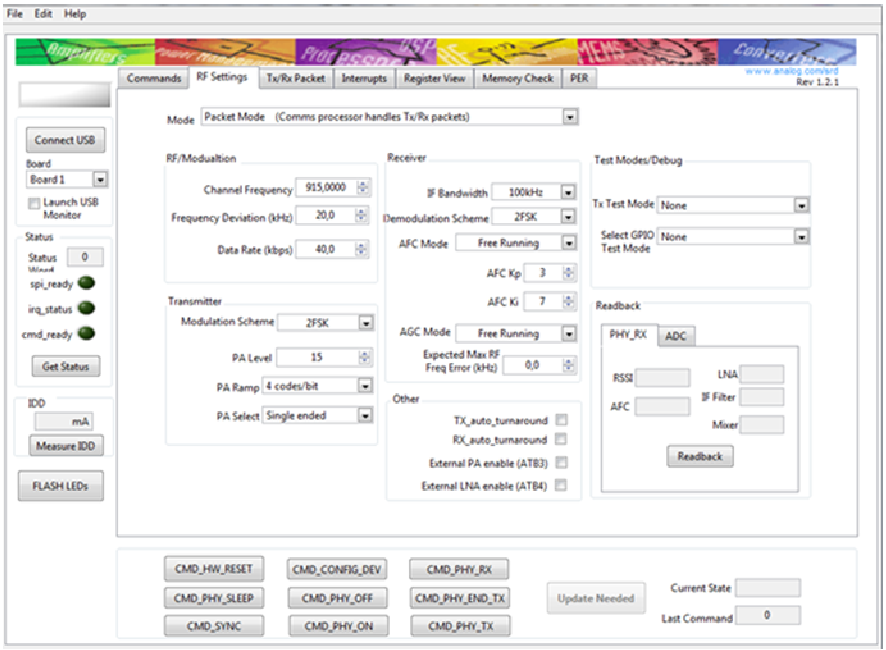


Figure 33 : Screen capture of the "Radio frequency settings" tab

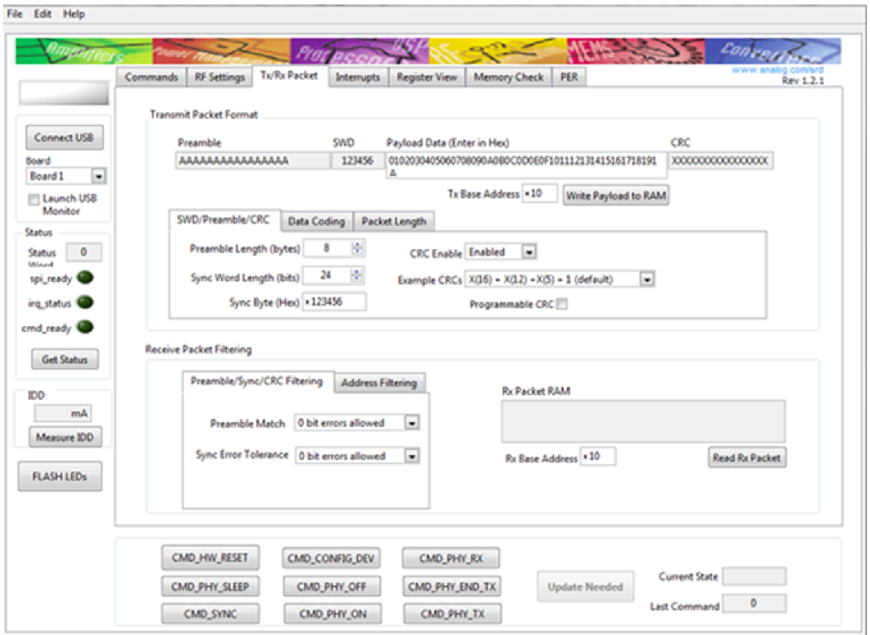


Figure 34 : Screen capture of the "Transmission/Reception packet settings" tab

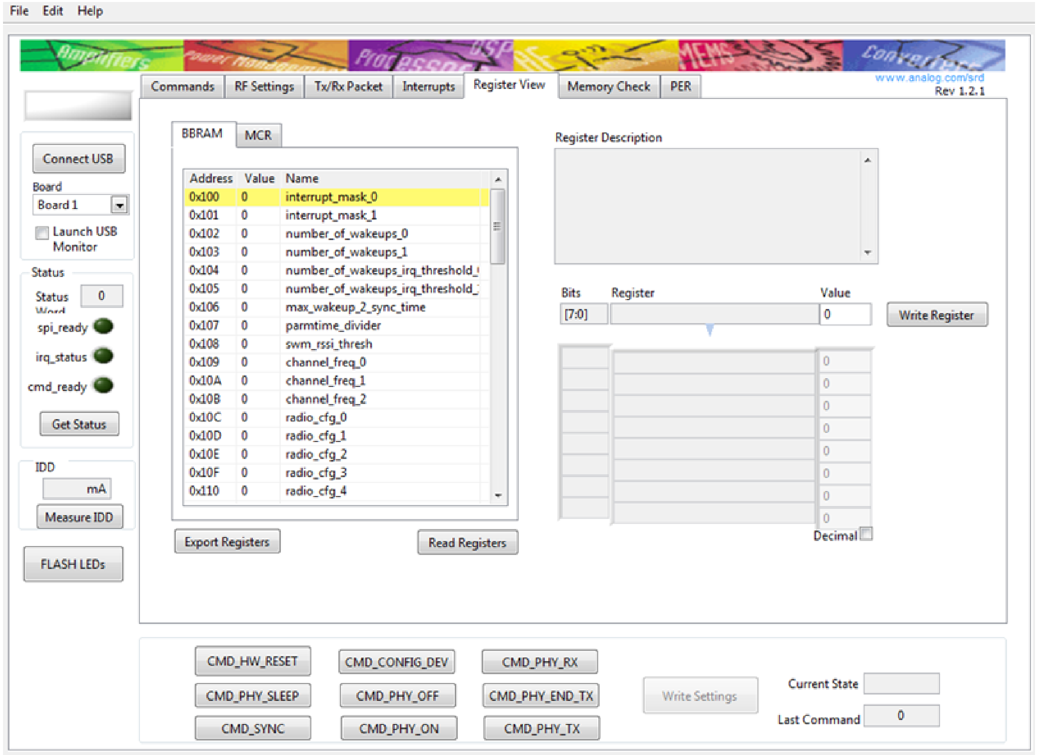


Figure 35 : Screen capture of the "Register view" tab

6. Other Components

6.1. Antenna

The antenna is a crucial part of the RF transmission. After some researches, it appeared that designing one needs knowledge and notions quite complex, especially in the electromagnetic area. This part details the different options choose for the several parts of the project.

Coach antenna

For the coach device, the simplest idea is to use a whip antenna (**Fig. 36**). Indeed, this kind of component can be found easily in the trade. Otherwise, the coach device does not have the same design requirement than the one for the swimmers. Ad a monopole antenna on the side of the coach device is a suitable solution for the data transmission to the swimmer receiver.

It is also good to notice that whip antennas radiate equally in every direction in a horizontal plane.

Figure 36 : Whip antenna

The wavelength is crucial to determine the size of the antenna and is given by the formula:

$$\lambda = cT = \frac{c}{\nu} \quad [1]$$

where:

c = light speed (299 792 458 m/s)

ν = frequency of the signal (in our case: 868 Mhz)

The size of the antenna is directly linked to mechanical properties of vibration and resonance of the device. The most efficient size is when the movement amplitude at the end of the whip is the most important. As shows the **Fig 37**, the antenna enters its first state of resonance when its length equals to the quarter of the wavelength. With the relation [1] it is now possible to know the length of the antenna:

$$L = \frac{\lambda}{4} = \frac{c}{4\nu} \quad [2]$$

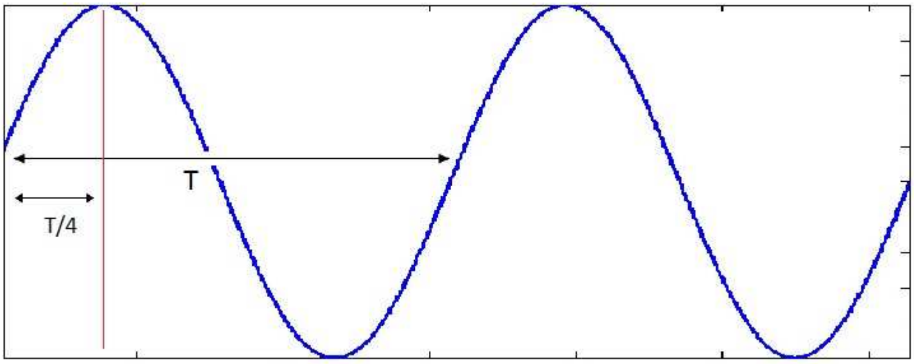


Figure 37 : Sinusoidal signal

After calculation, the antenna needed to be used in the coach device should measure 8.63cm.

Swimmer antenna

The main specification about the swimmer antenna choice was the space available in the device. The investigations were focused on tiny antennas, such as chip antennas (**cf. Fig 38**). As a matter of fact, this kind of antenna is mainly used in hand-held devices or Bluetooth devices and they are known to be the smallest antennas available on the market.

Figure 38 : Chip antenna

For the swimmer device, after looking in several catalogs, the ANT-868-CHP-x was chosen to be eventually implanted in the final product and as it can be checked on the **Fig 39**, the size of the antenna is reasonably small for the space available in the swimmer device shell.

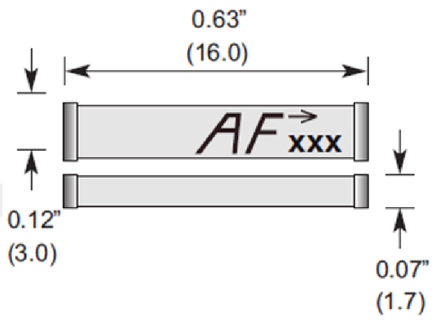


Figure 39 : Chip antenna's dimensions

6.2.Power supply

The different devices need power supply to work without being plugged. To fulfil this specification, different options were considered during the project.
The power supply section can be divided in two parts; one for the coach’s device and another for the swimmer device. For both, the battery has to be rechargeable and as small and lightweight as possible.

Regarding on the performance and characteristics, two different kind of battery were analysed: the Lithium-Ion and Lithium-Polymer battery. Indeed, those two types of power supply are really effective, relatively cheap and can be found pretty easily on the market.

Especially in the swimmer device, the space is quite restrictive and a flexible battery is the best choice. After several discussions, the Li-Poly type was chosen for both devices because of the flexible cell.

A Li-poly battery delivers voltage from about 2.7V (discharged) to about 4.23V (fully charged) and has to be protected from overcharge. An overcharged Li-Poly battery would probably cause explosion or fire; this is why the power consumption needs to be precisely calculated and the battery removed as soon as the voltage drops below approximately 3V.

6.3.Power supply charging

It is absolutely critical that every precaution is taken when charging your LiPo battery back. Lithium polymer chargers use a different algorithm than any other type of battery charger. For this reason, a lithium polymer charger must be used when charging your LiPo battery back. Using a charger that is not specifically designed for LiPo batteries will damage the battery and could result in an explosion or fire.

Lithium polymer battery packs do not develop a "memory" as NiCad batteries do and there is no worry about fully discharging LiPo battery packs before charging them. A LiPo battery will be especially hot immediately after use, another important point is to wait until the battery has reached ambient temperature before charging.

Current and voltage are the two variables that must be determined when charging LiPo batteries. The voltage should be set to the nominal voltage of the LiPo battery pack and the current should never exceed a 1C charge rate.

Even if most LiPo chargers automatically detect the voltage (or cell count) of the LiPo battery pack, it is always a good idea to double check, or confirm that the charger detects correct the voltage pack to avoid any problem with this very sensitive kind of power supply.

For the future, the best solution would be to use an inductive power supply charging. Because of the waterproof requirement, it would be easier charge the battery with such a system and let the device sealed with the battery and the electronics inside.

Inductive charging uses the electromagnetic field to transfer energy between two objects. A charging station sends energy through inductive coupling to an electrical device, which stores the energy in the batteries. Because there is a small gap between the two coils, inductive charging is one kind of short-distance wireless energy transfer.

Induction chargers typically use an induction coil to create an alternating electromagnetic field from within a charging base station, and a second induction coil in the portable device takes power from the electromagnetic field and converts it back into electrical current to charge the battery. The two induction coils in proximity combine to form an electrical transformer.

6.4.Power consumption

Knowing the different components of the products allows defining the device power consumption for the coach device and the swimmer device (cf. **Table 1 and 2)**. With the voltage supply and the device using time it is possible to determinate the current consumption and the capacity, which is necessary for a battery choice.

A 1.25 safety factor is applied to the theoretical value to avoid a total discharge of the different batteries during the utilization but also to compensate for the self discharge of the power supply and to adapt the solution depending on the availability of the market.

Table 1 : Power consumption of the coach device

Load	current consumption / mA	x	hours of supply / h	=	capacity / mAh
Microphone WM – 034BY	4	x	3	=	12
TLV320AIC1106	7	x	3	=	21
ADF7023	32,1	x	3	=	96,3
			theoretical battery capacity		129,3
			practical battery capacity		161,6

Table 2 : Power consumption of the swimmer device

Load	current consumption / mA	x	hours of supply / h	=	capacity / mAh
ADF7023	12,8	x	3	=	38,4
TLV320AIC1106	7	x	3	=	21
Bone speaker	178	x	3	=	534
			theoretical battery capacity		593,4
			practical battery capacity		741,8

Battery and power supply charging choices:

Source: http://www.all-battery.com

To adapt the voltage delivered by the battery to the one needed by the components, a voltage adapter could be used.

<u>Coach device</u>

To reach the 161.6 mAh needed, an association of two cells in parallel is necessary:

Polymer Li-Ion Lipo Battery 3.7V 80mAh

Table 3 : Swimmer battery specifications values

Rated Capacity (mAh)		80
Model Number		30133
Nominal Voltage (V)		3.7
Dimensions (mm)		21(length) x 12(width) x5(thickness)
Impedance (m-Ohm)		<= 50
Cell Weight (g)		2.4
Max. Charge Current		1 C
Max. Charge Voltage (V)		4.2
Max. Discharge Current (mA)		80
Cut-off voltage (V)		2.75
Operation Temperature	Charge	0~+45 ^{o}C
	Discharge	-20~+60 ^{o}C
Storage Temperature	<= 1 month	-10~+35 ^{o}C
	>=6 month	-5~+30 ^{o}C

Swimmer device

To reach the 741.8 mAh needed, an association of two cells in parallel is necessary:

Polymer Li-Ion Battery 3.7V 430mAh

Table 4 :430mAh coach battery specifications values

Electrical	3.7V, 430mAh
Max charging rate	430mA (1C)
Max Dis-Charging Rate	900mA (2C)
Dimensions (mm)	48(length) x 30(width) x 3(thickness)
Cell Weight (g)	11

Polymer Li-Ion Battery 3.7V 300mAh

Table 5 : 300mAh coach battery specifications values

Electrical	3.7V, 300mAh
Max charging rate	300mA (1C)
Max discharging rate	300mA (1C)
Continuous discharge current	60mAh
Dimensions (mm)	40(length) x 15(width) x 5.6(thickness)
Cell Weight (g)	4

Power supply charging choice

TLP-2000 Tenergy Universal Smart Charger for Li-Ion/Polymer battery Pack

Features and Benefits

- Smart universal charger for Li-Ion and Li-Polymer battery pack with capacity > 500mAh
- 4 Voltage selections at 3.7v 7.4v 11.1v and 14.8v
- Charges pack made of 1 to 4 cells
- Universal 100V - 240V AC input for worldwide power usage
- 500 mA constant charging current.
- Automatic charging stop when battery pack is fully charged , or when each cell 's voltage reaches 4.2V peak
- LED indication: Red means " In Charging " and Green means " Full " or "open circuits "
- With Tamiya Conncetor
- Weight: 4.5 oz
- Dimension: 1.5" x 1" x 4"
- Price: $20.85

6.5.Water resistance

Water resistance is defined as the in DIN8310 as the ability to resist the penetration of water inside the device. DIN 8310 is the standard that watches are tested against to determine the level of water resistance they comply with. This is the appropriate scale to measure the two different devices water resistance against. The change as a product is immersed further under the surface of water is pressure and this is the reason that some devices can be waterproof to 10m but no further.

Pressure is measured in Bar, 1 Bar can be defined as 1 kg of force being applied across each cm^2 of our bodies. 1 Bar is also the pressure a person standing at sea level will be subjected to under the force of the atmosphere. As the person climbs higher into the atmosphere the pressure decreases however as the person is submerged in water and starts to go deeper the pressure will increase. For the purpose of being in the same units as DIN 8310 it is important to convert working in Bar to atmospheres. The conversion rate is 1 bar = 0.980665 atmospheres or atm.

Here is a rough breakdown of what each level of water resistance means.

Level of Resistance	Classification	Application
0 atm	not water resistant	No water contact
3 atm	water resistant	Rain
5 atm	water resistant 50m	Bathing
10 atm	water resistant 100m	Swimming
20 atm	water resistant 200m	Free diving

As you can see from this table, the receiver device should achieve a rating of 10atm or high to be suitable for its intended environment.

Although the team did not have the time or the facilities to test to this standard, it is something that will be essential in the further development of the final product.

7. Product Form

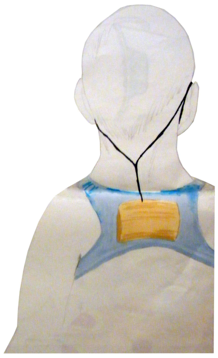
The form is split into two parts, the receiver and the transmitter. The majority of the design work went into the receiver (swimmers device) as the functionality of this part is much more critical to the overall success of the project. First the development of the receiver will be discussed broken down into the 5 stages of the design process that were passed through, secondly the development of the Coach device will be discussed as it passes through 3 stages of design. After this each final product will be discussed at length and the justifications of the main design points will be given.

7.1. Development

7.1.1. Receiver

7.1.1.1. Stage 1 development

At the initial stage of the project the group used the basic information gathered in the research phase to familiarise itself with the topic area and give a strong basis to design from. At this stage of the project the designers did not know whether the swimmers would be wearing goggles, swimming hats or nothing which meant that a wide range of ideas were developed to try and address all of these areas. The team at this stage also did not know how large the final electronics solution was likely to be and so casings for both very small circuits as well as very large circuits were developed with the majority of the designs focusing somewhere in the middle. In total the group produced more than 40 individual designs at this stage. Here are some of the most interesting designs that were developed and what the team thought of each one;



One of the first ideas generated was aimed as a solution to create a sort of Lycra or neoprene support to hold the device between the swimmers shoulders at the top of their back, The idea behind this design was to create a method of placing a very large unit on the swimmer with as little impact on their performance as possible. The electronics of the design are all housed in the main unit on the swimmers back while a single wire runs up to a bone speaker placed inside the swimmers hat. The main problem with this design is that while it minimises the impact of a unit that large there will still be a significant effect on the swimmer. It is hoped that the final product will be significantly smaller than this and so will not require such an extreme design.

Another design looked at was using an elasticised armband on the swimmer and using this to house the electronics. This design would be suitable for if the total size of the electronics required is smaller than the previous idea but still too large to mount on the head. The biggest problem with this idea is that while the unit is out of the way and will have a small impact on the swimmer, it requires a wire to pass up to the swimmers hat and our research has shown this to be extremely irritating to swimmers. It also has a chance that it will get tangled around the arm as the swimmer swims.

The next idea was the result of looking at ways to attach a headset to a swimmer using neither a swimming cap nor goggles. The product uses a sprung plastic band around the back of the head to locate the device and is supported by a secondary adjustable strap which runs over the top of the swimmers head. The group liked this design however we felt that it was over engineered if the swimmer was using either cap or goggles and so decided to review it once we had more information to work with.

This was one of many different ideas we had to place the unit on the back of the swimmers head. By doing this we can aim for the 2nd significant point of conduction on the skull and also minimise the effect on the swimmer significantly by keeping the unit out of the line of their stroke. The product is dependent on having a goggle strap for securing it and also on a swimming hat for support however given these two things it is the idea the group initially saw as having the most potential.

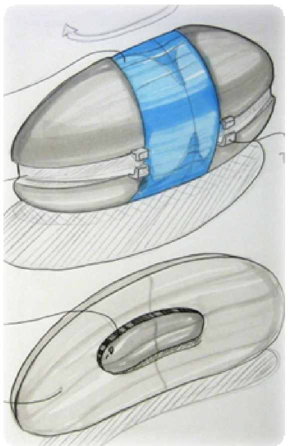
A blue sky thinking idea was to use detached bone speakers to allow the swimmer to place the speakers wherever they got the best connection. This design would be highly adjustable for the swimmer however we decided that this was a bad thing because it would require a lot more time and effort than a simply put on and swim type device and also the speakers could slip under the swimmers cap.

Finally the team designed a product that would stay on the head much the same as traditional headphones however converted to work with the bone conduction technology. This idea was well received however more development is needed to properly asses its potential.

Although this section has looked at 6 different designs there were many more very individual designs all of which were evaluated in a group meeting and the best points of each listed to be carried forwards to the next round of development.

7.1.1.2. Stage 2 development

By the time the team moved onto this stage of design the questions that had been given to Sigma had been replied to and the research on caps and goggles had developed a lot further. Because of this it was known that the product would have the support of both goggle straps and a swimming cap and so the development of these designs took this into account. Another consideration that was introduced in this stage was the need for the product to be able to work with swimmers that have long hair. In this stage the designers developed a total of 13 different designs and looked at variations that could be made to each one of them. By this stage the idea for a device mounted on the back of the head had a lot of favour so the designs that were developed had a strong bias towards this, however the group did take 5 through that utilised different placement. Here are 4 of the designs that were looked at.



This design is extremely simple and yet was also the one that was the most popular within the team. Simply this product is held in place by the goggle strap and supported by the cap with all the electronics and the bone speaker contained inside it. Because of the positioning of the strap at the back of the head it meant that this product could easily interact with one of the best points for bone conduction. One of the other points about this design that made it so popular was that it will be extremely easy for the swimmers to attach and remove it from their own swimming goggles which is something a lot of the other designs fall down on. Another added benefit of this device is that it is probably one of the easiest ones to manufacture. The group looked at several different ways of applying this design and came up with a number of variations including a flexible design and a huge number of different shapes it could take.

This design is very similar to the previous one however it has been designed for the double strap swimming goggles. This idea was based as a cross between the previous design and aiming to incorporate some of the benefits of the detachable speaker system seen in the initial ideas section. This design means that the lengthy preparation time and risk of the speakers slipping is almost completely eliminated and provides a solution that allows the swimmer some flexibility in positioning the speakers. We were all keen on this idea however one thing that stood out as a problem was the attaching it to the goggles. Ideally this product would just stay attached to one strap however that is impractical for the swimmers. We thought of a lot of different ways of addressing this problem such as remove-able straps and quick fix solutions however we eventually decided that this may be difficult to make work.

The next design that was developed was another variation of the back of the head concept however this design looked at creating a solid housing for the electronics and attaching the bone speaker to the bottom using a small arm. The benefit of this device was that it could be attached and removed from the goggles easily however the arm helped reach the ideal spot for bone conduction. The arm was sprung towards the head of the user to help get the best possible connection.

The main problem with this idea was that when testing we found it was very difficult to apply it to someone with long hair as it didn't leave space for a pony tail to fit into the cap. Because of this it will be very difficult to take the design on any further unless it can be modified to work better with long hair.

The final design is a headset idea that aims to locate a bone speaker at the back of each ear. This point of bone conduction is better than any that the back of the head devices can access and the low profile of the headband will have very little impact on the swimmer. Another advantage of this idea is that the total size of the unit is spread around the whole head and so it will not feel like having a something large on the back of the users head. The arm that goes around the back of the head is sprung and the whole system works on a one size fits all basis. To secure it a number of clips are on the inside of the head band and these attach to the strap of the goggles. This product would be easy to attach or remove however the major problem with it for our group will be trying to design and manufacture a much more complicated shape which will require a significantly more advanced ergonomics study to achieve a satisfactory result.

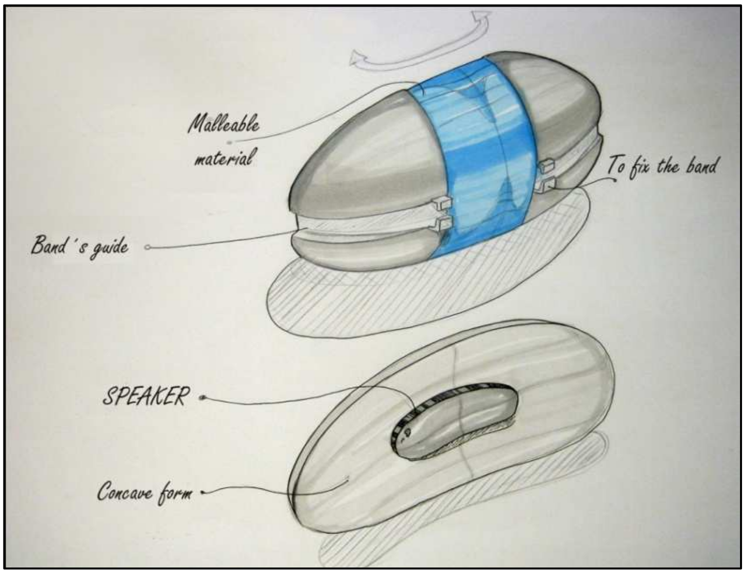
It is worth pointing out at this stage that the designers also looked at the previous groups suggestion of a silicone or flexible resin around the electronics however it is hard to do any designs for this until the designers have a much better idea of the total size of the electronics that will be used.

7.1.1.3. Stage 3 development

The stage of development we are currently working at is the selection of the designs we want to develop to solid form prototypes. Certainly at least 2 variations of the simple back of head approach should be tested and if possible a basic version of the headset idea would be good to test at the pool. Over the next 2 weeks we will refine the best ideas and Produce CAD models which can be printed to solid forms. These are two of the concepts we will be developing over the next two weeks.

RECEIVER UNIT

CONCEPT 1: Try to find the best connection between the device and the head.



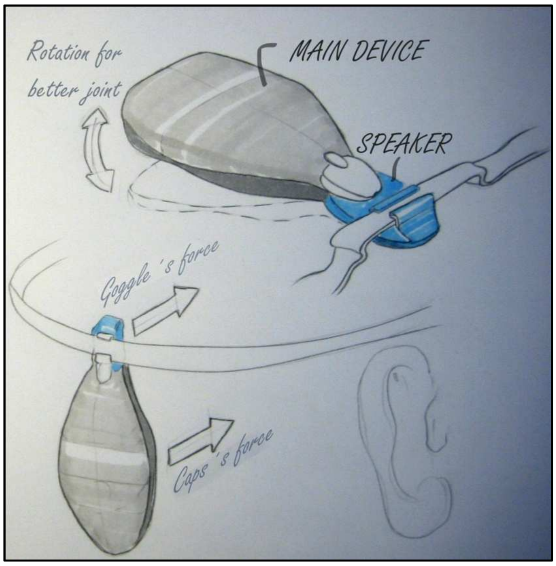
Advantages:

- Bender for a better fixing.
- Concave form.
- Smooth forms improve the performance.

Disadvantages:

- Three parts could be divided with use.
- Zones without touching the head.

CONCEPT 2: Separate the main device from the bone speaker.



Advantages:

- Use goggle´s force just for the speaker.
- Cap´s force to join the main device with the head.

Disadvantages:

- Design more difficult.

7.1.1.4. Stage 4 development

In this stage of development the designers modelled the best ideas from the previous stage using CAD software. The ideas were selected were quite different and gave the group a good contrast in the testing. The ideas selected for development in this stage were;

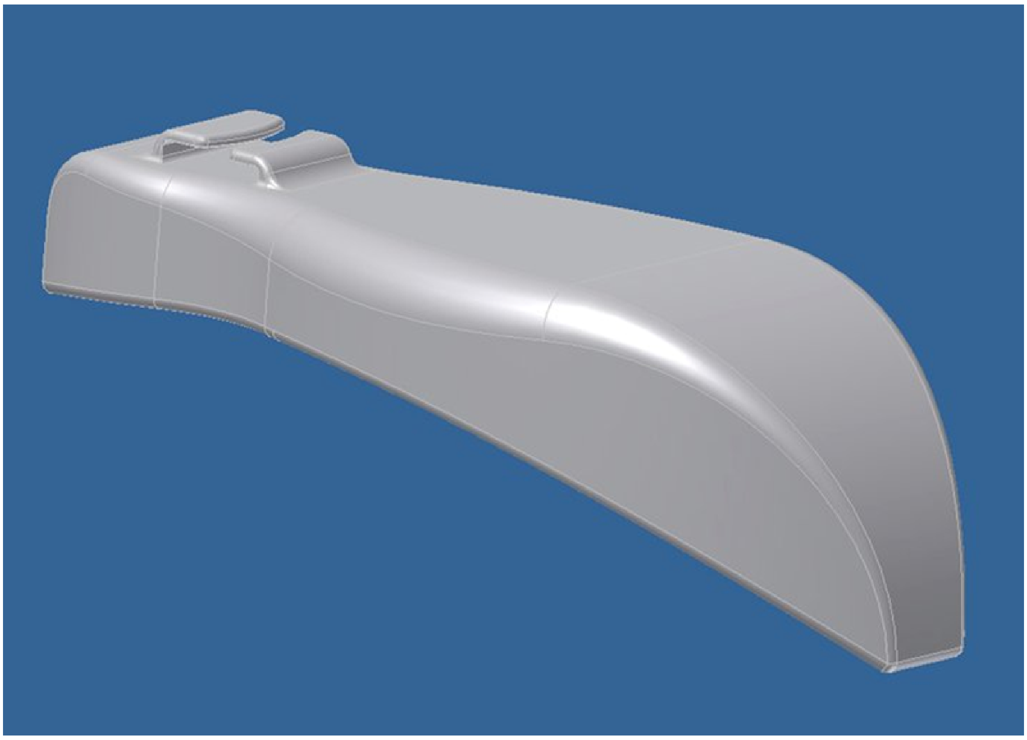


Figure 40 : Elongated device CAD model

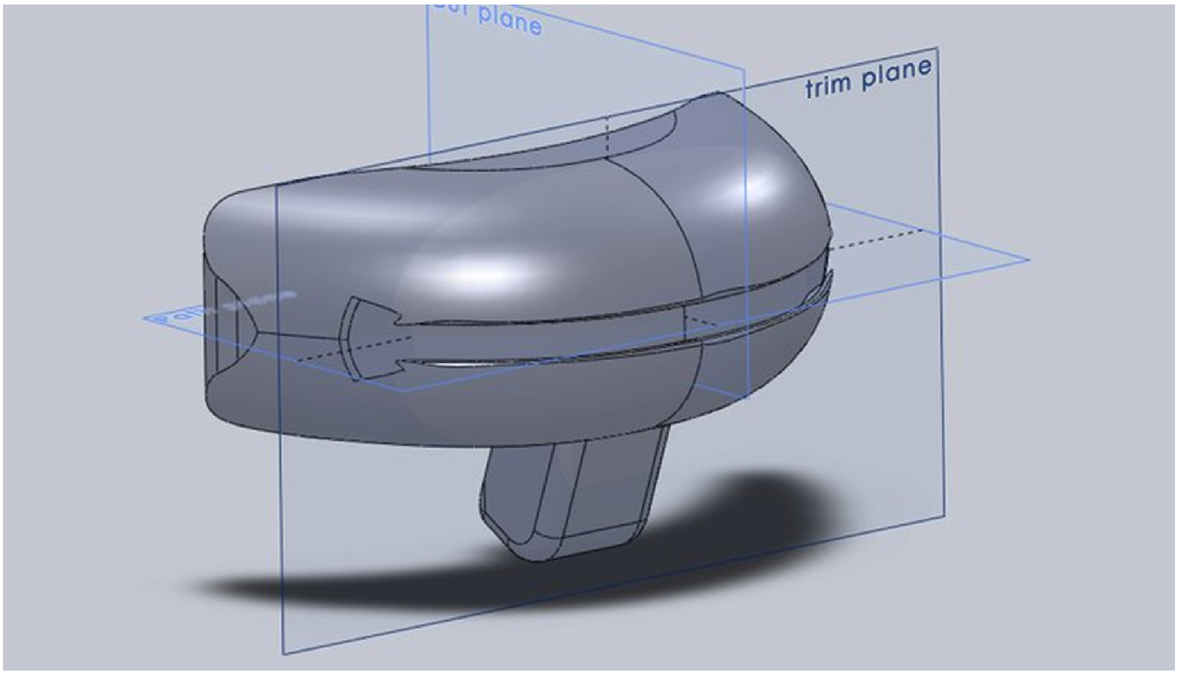


Figure 41 : External Speaker Device CAD model

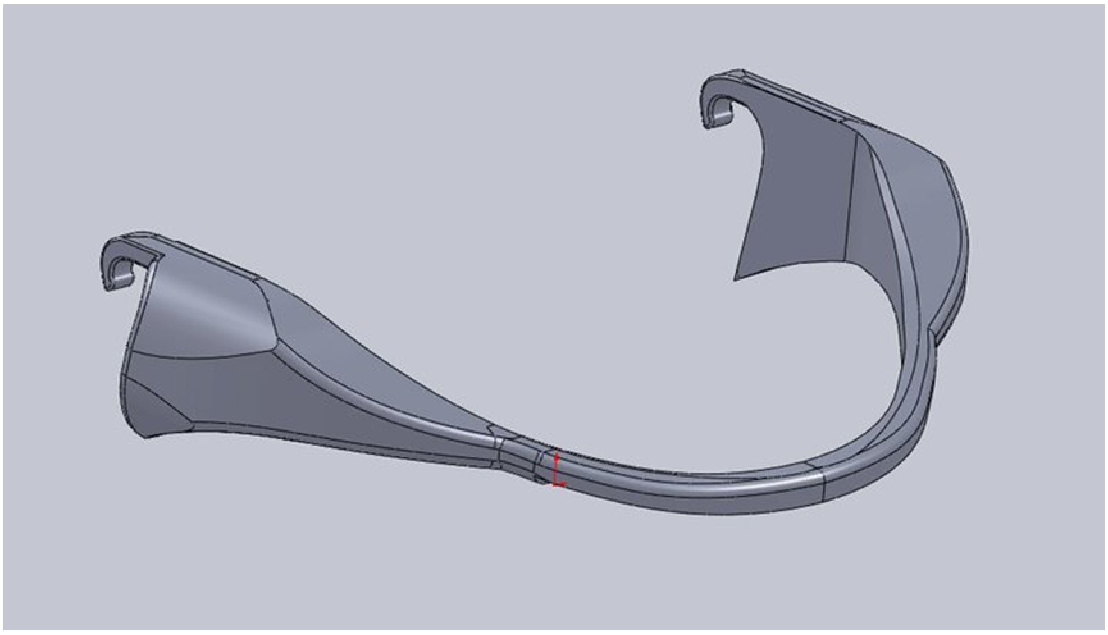


Figure 42 : Headset CAD model

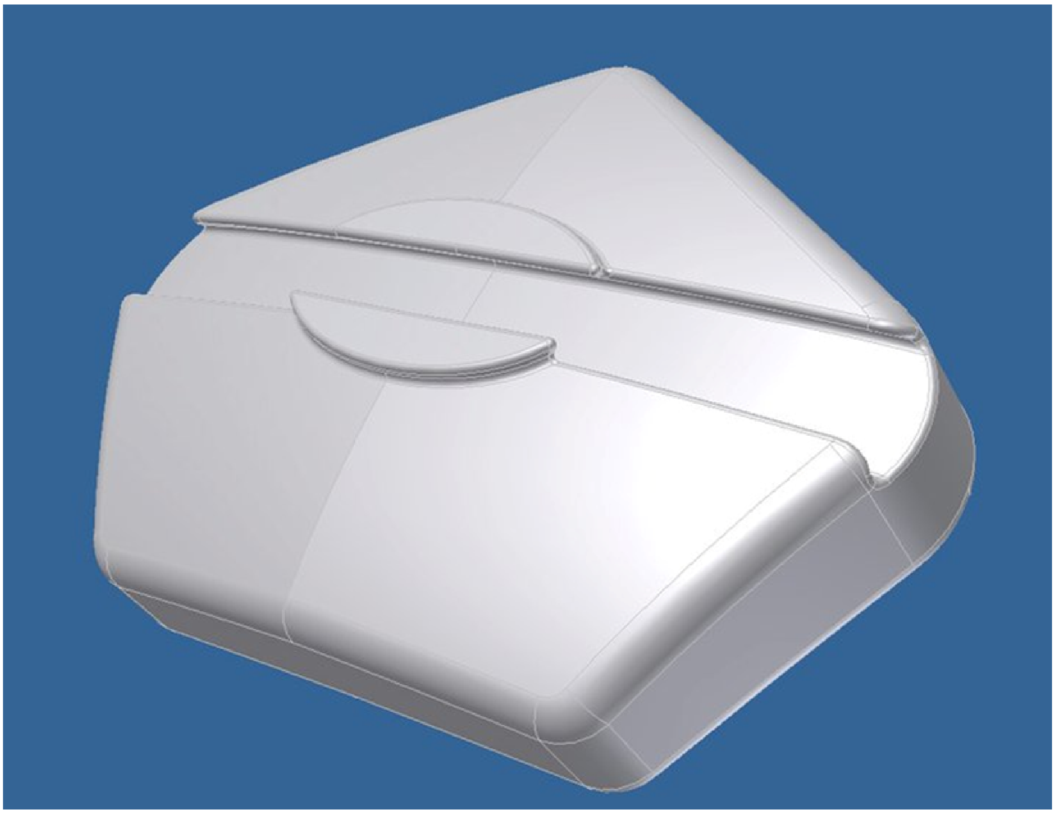


Figure 43 : Diamond CAD model

Each model was produced using the ergonomics research (discussed later) and also fitted to a CAD model head we used for reference during this stage. This was the first time any of the ideas had been converted into a 3D model and so a lot of development had to be done of areas of the devices which had not been considered in the drawn ideas. The main thing that was added to the designs in this stage was the exact dimensions for being compatible with the goggles used and also the swimmers head. Once these models were finished they were all passed onto Emil to be produced as 3D form Prototypes.

These Prototypes gave the group a lot of feedback on the designs and brought up a lot of points that had previously not occurred to the group. Here are the physical forms that were produced in this stage.

Long Speaker Device

Figure 44 : Elongated model photograph

This device used two external clips to go round the goggle strap and aimed to mount the bone speaker directly beneath the strap for maximum contact with the swimmer. The electronics are housed in the area that hangs below the strap and are all encased inside the shell of the product. This initial device is low profile and looks as if it will add a minimal amount of drag to the swimmers which is important in their training. The clips hold the product very securely although it can be relatively difficult to put the strap into the fixing. The other major problem with this device is that the length of it means that the swimmer cannot easily tilt their head back without the device causing some discomfort.

External Speaker Device

The ergonomics of this device meant that the first observation was how well it fitted to the back of everyone’s head. This device is significantly bigger than any of the other devices and because it has such a large surface area in contact with the back of the swimmers head it means that it had to be shaped on 2 planes to ensure a comfortable fit. The detail that had to go into achieving this was very high and so these measurements were useful to retain for fine tuning the final model. The second major point was that this product was very large compared to the other models. Because of this it appeared that it would have a very large effect on the swimmer due to its bulkiness. The external mounting of the speaker proved to be a good idea as this gave a good amount of contact for

Figure 45 : External speaker photograph

transmission of the vibration, however it negated the problem of using so much internal space to house the bone speaker. Finally this product used a groove cut into its surface to slot the strap into. Although the fit was not as secure as the previous device, it proved very easy to put the strap into the groove. One disadvantage of this method however was the cut for the strap took away space that could be used inside the product.

Headset

Although this device used a lot of ergonomics data to create, it was a completely different set to the previous device as the path of the headband follows a very different path. This was by far the hardest model to get the shape right on and unfortunately the calculations for attaching round the ear proved to be inaccurate and so the prototype does not fir as well as hoped for. This device was also criticised as its use of 2 bone speakers would significantly increase the power consumption and would not improve sound quality enough to justify this. This product would be significantly harder to manufacture and the only real advantage is that it will produce the lowest amount of drag from these final ideas and the increased sound quality could be useful for the swimmer. These advantages however do not outweigh the disadvantages and the design does not have the scope at this strange to evolve to minimise these weaknesses. For this reason this design will be left at this stage and will not be developed further.

Figure 46 : Headset photograph

Diamond

The final model that was developed to this stage was the diamond, This model used a version of the groove cut method to hold the strap in place although this time a shallower groove was tested out, this meant that less space was taken from the internal space available. This product was quite small and very low profile. Because of this it looked like

Figure 47 : Diamond model photograph

a good solution to the problem. In development it was assumed that because of the products small contact surface area, the ergonomics component of the design would be smaller. In testing however this product proved to be uncomfortable as it was not curved enough to fit the head easily. The benefits and weaknesses of this design appear to be the opposite to the benefits and weaknesses of the second design, "External mounted speaker" and so the next stage of development will look to combine these two designs into 1 and give a more suitable final outcome.

Some dry testing of these model was done using a set of goggles and a swimming cap and it was decided that the in the next stage of design the external speaker and the long speaker device should be developed further. The long speaker design should be altered to allow better movement for the swimmer and the external speaker design should be merged with the diamond device to get the best benefits of both.

7.1.1.5. Stage 5 development

In this stage of development the two designs that were selected in the previous stage have been drastically modified to provide products that should match the initial requirements. At this stage the designs are going to each be produced in the form that they would each finish in. This means that where the models were previously produced as solid blocks to test the basic form, this time they must be produced with sufficient space to allow the electronics to fit inside and should also be produced with the final method of manufacture in mind. These designs are also required to conform to the requirements set for waterproofing. Here are the revised CAD models exploded to show the new detail added.

External Speaker

Long Speaker Device

External Speaker

As you can see the model here is radically different to the model it was based on in the previous section. The bulky device has been trimmed down to a slim shape that barely exceeds the maximum height of the bone speaker. The profile has also been stretched slightly upwards to help guide it into the natural curve of the swimmers head and further reduce the drag that will be felt. The groove for the goggle strap was kept the same as in the initial device because although it now takes up an even bigger percentage of available internal room, the benefits of how well the previous design worked outweighed this problem. The internal cavity has just enough space to fit all of the pieces that will be required in the final product and this space has been maximised by hollowing out the door that fits onto the front of the device to seal it. The waterproofing is based around using a rubber ring between the two layers to create a water tight seal.

Long Speaker Device

As described in the testing section the group then dry tested these two products against each other to ascertain which product would be the most suitable for use with the swimmers. As seen in the previous CAD model this design was developed as extensively as the model we finally selected. The decision to bring two models to a final stage like this was to give us the best possible choice when we came to making the final decision. This product could have easily been used for the final device and in the feedback we got from testing there was very little to separate the two products.

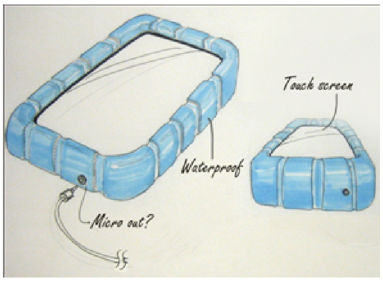
We dry tested this product with 20 different volunteers using both the swimming cap and the goggles in each test and the results show that the volunteers slightly preferred the external speaker device based on the fact that it stayed in place easier and it was easier to attach to the strap. Because of this the External speaker device has been carried forwards to be used as the final design.

7.1.2. Transmitter Unit

Because the transmitter or coach device is much less critical in terms of design it meant that the group spent that majority of its focus on making sure that the Swimmers receiver device was as well developed as it could be. Because of this it meant that the Coach device only went through 2 phases of design. This is not to say however that significant thought did not go into selecting a design that would fit the purpose effectively.

7.1.2.1. Stage 1 Development

In the first stage of design the team drew out a large number of ideas that could be implemented into the coach device and made about 10 initial ideas for forms that the device could take. It was agreed that this device should have a good level of waterproofing however it is far less critical than than the waterproofing of the receiver device. During the initial design process a lot of methods of channel selection were discussed with the electronics side of the project and this helped set some limitations for the format of the interface. Here are 2 of the different ideas that were considered for this section.



Touch Screen

The first idea is a touch screen device that is protected by a rugged rubber outer case. The outer casing comes further forwards than the front of the screen and so should protect the unit from any fall resulting in an impact on a flat surface. This design could however be vulnerable to drops on edges or corners. As the floors in pools are usually tiled it means that any fall could easily damage this product. Because of this a touch screen idea may be a liability and the gains of using it are unlikely to be sufficient to justify the extra cost or risk. The device incorporates a built in internal microphone and also a 3.5mm jack socket which allows the coach to add in an external microphone and attach this to a headset. This could be very useful in minimising the disturbance of the equipment on the coaches actual job which should be monitoring the swimmers.

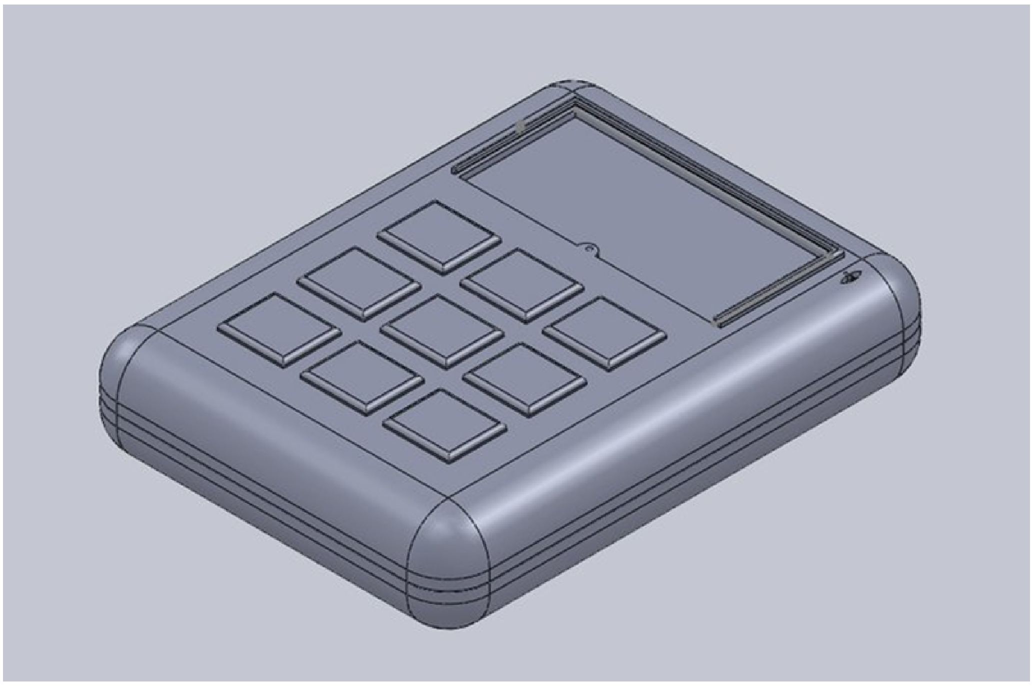
Twist Button

The second design went away from the touch screen device and instead focused on keeping the equipment much smaller. This would be with the intention that the coach can attach it to their clothes as they move around the pool. In an effort to minimise the size the most space efficient manner of adding a channel selector was to use a twist switch instead of individual buttons. The big drawback of this is that 2 swimmers cannot be selected at the same time and it can often be difficult for the coach to see which swimmer they have selected. This would serve to distract the coach from their main job and thus the design is flawed. Another weak point in this design is that if the transmitter unit is kept significantly smaller than the previous design then there may not be room to house sufficient batteries which would harm the devices usability. By making this product very small it will increase cost and decrease performance for a benefit that is quite low on the list of priorities for this product. For that reason this design will not be continued.

Out of all the designs done for this piece of equipment all were very similar to the touch screen one but incorporated various different features which separated them. Some of the features were good ideas and these were saved and noted while some of the ideas were poor and discarded. Because the devices were all very similar it meant that we were able to merge all of the best ideas in to a single design. This was the design we decided to carry forwards into the next stage of development.

7.1.2.2. Stage 2 Development

In this stage a design was decided upon which did not have the same drawbacks as the touch screen device shown before but that would also be very intuitive for the coach to use and would provide minimal distraction. Because the function of this device is quite simple it was decided that the product should also be simple and although the design is well thought through there are very few unnecessary frills added to the design. Here is the design once we had put it through Solidworks 3D modelling software.



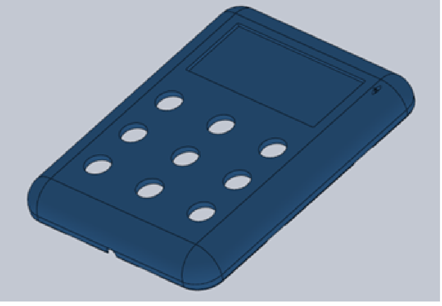
This design incorporates a number of features aimed at making the device as intuitive as possible for the coach to use. After a group meeting on the design and some refinements to the sealing method used the design was passed onto Emil to be printed in 3D. At the time of submission of the report the group is waiting for the model to be printed due to some small delays. The final specification will be discussed at length in the following section.

7.2.Final Product

In this section we review the final product form for both the receiver and the transmitter. All important design decisions will be discussed at length and the final devices will be critically analysed.

Coach

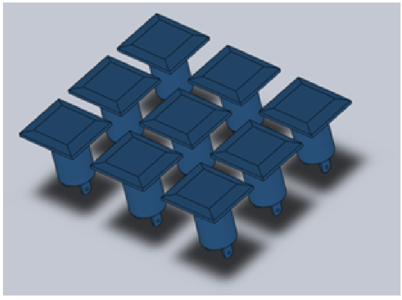
There are a number of different parts making up the final construction. The overall design of the device is quite small however there are a few features that could be explained further to give a better idea of the thinking behind certain design decisions. Here is a breakdown of each of the components used in the device.



Front Cover

This is the most complex part of the coach device, the front cover includes a number of different features to make the coaches job easier. The first thing that is worth discussing is the overall size of the product (25x90x110) this size was selected after some testing with different sizes and was considered by the team members to be the biggest the device could be and still be easily manageable by the coach. The device was required to include 9 buttons on the front and also incorporate a small space for some written notes to be made by the coach. This was an idea that was carried over from the previous ideas section and will add value to the coach holding this device with them. The buttons will be attached to an m12 thread and will protrude about 15mm inside the device, for this reason it is difficult to mount electronics under the space where the buttons are mounted. Instead batteries will be mounted in this space and the antenna will be mounted alongside the buttons inside the device. The electronics will be mounted at the top of the device where no internal space is taken up by other components. To mount the electronics some small pillars have been introduced and each has a 3mm screw thread from the top. This will allow the boards we use to be mounted onto the pillars easily. The 9 buttons will be spaced evenly in a grid format on the bottom half of the device. The bottom edge of the side will feature a ridge that will slot into the other side of the shell and will aid with the waterproofing, this ridge will also have slots cut into it to help locate the rubber seal. 4 m6 screws posts are located on the underside of the device and these will match up to the same thing on the back of the other half of the shell.

Selection Buttons



For this feature the group has chosen to use green push on/push off buttons that use an LED to signal when they are in the on position. The first 8 buttons will all feature a number on the front corresponding to which swimmer channel they select and the 9th button will be a select/deselect all button used to quickly select or deselect all the channels at once. The reason that these light up buttons were selected was because one important goal of the coach's device was that it is intuitive and takes a minimal amount of concentration away from the main task. By giving such a clear display of which swimmers are selected and by making it so easy to change the selection the device will be exceptionally easy for the coach to use at the same time as paying sufficient attention to the swimmers.

Back cover

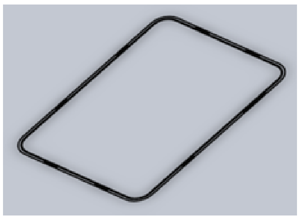
The back cover of the device is basically a blank version of the front half however there are a couple of differences that are worth mentioning, On this side of the device the ridge that was mentioned is reversed as a matching groove useful in making the final device waterproof. Although we assume that the coach device will need minimal water protection, for the sake of ensuring the expensive electronics stay safe we have decided to make this device waterproof to roughly 10atm. The seal used on the outside of the device will also be complimented by a sealed bag around the internal electronics.

The screw holes on this side of the device are heavily recessed and give access for the 4 m6 screws to be inserted into the required holes. The columns to support these holes are supported and attached to the side of the device.

Note paper

An idea that came up in a previous idea and was decided to be brought forwards was the inclusion of a small amount of note paper which can be attached at the top of the device. This paper will fill a space that would otherwise be wasted and will add value to the product as it will now also give an area to make small notes and reminders for the training session. This post it note style pad will sit into a small recess on the devices surface.

Seal



the seal runs around the entire join and will be compressed as the two sides are tightened together. There are a number of slots cut into this seal which will aid in locating it on the device and ensure it does not move through the products life time. The seal is made from a soft rubberised foam and is laser cut to the exact dimensions required.

Microphone

The group made the decision that to free up the coach from having to speak into the device, an external microphone should be used. The microphone that was selected is intended to be used on a headset to allow the coach free movement and hands free to perform other tasks.

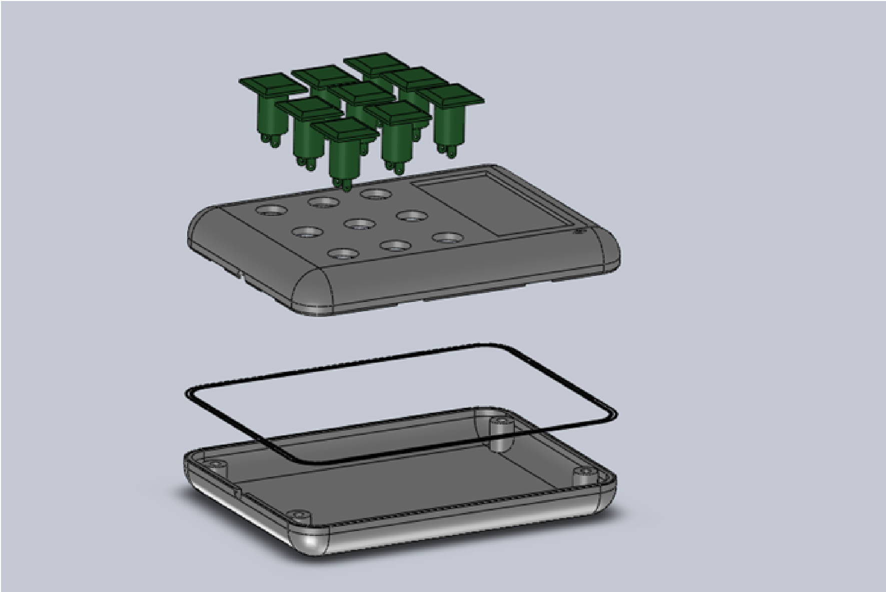
Screws

This device will use 2 different screws in its construction, firstly 4 M6 screws will be used to hold the two sides of the shell together and secondly 6xM1 3mm will be used to secure the electronic boards to the support columns inside the device. This will have no seal over them as they may need to be removed if a fault occurs however they will be sealed at the join by the rubber seal component.

Transmission Button

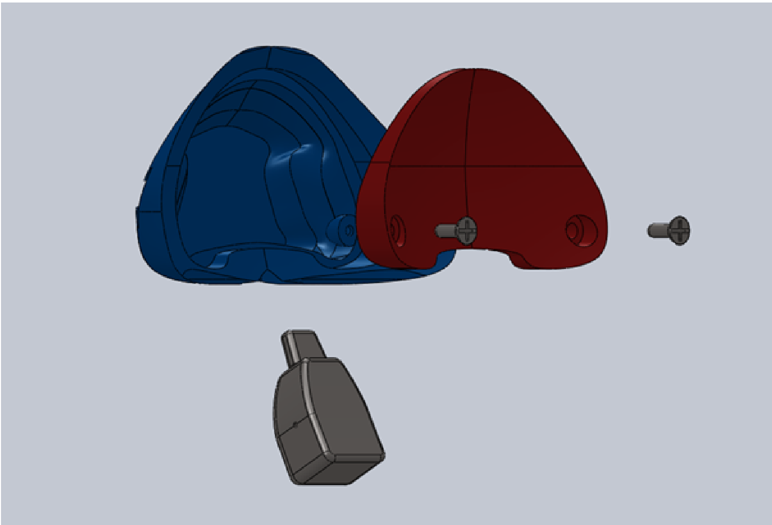
To save battery power it is required that the device includes a transmission button; this is located on the side of the device and is a push to make switch. Whilst this is pressed a transmission will be sent to all the swimmers selected on the key pad.

The final device provides an easy solution to all of the problems posed in the initial brief. By using this, the coach will be able to focus on their main job and the device will aid as a simple and effective additional tool in their training arsenal. Here is an exploded view of the overall finished product including the buttons which will be purchased from an independent supplier.



Swimmer

Here is a picture of the exploded final version of the swimmer device.

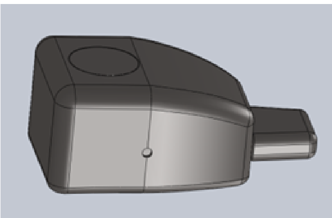


As you can see it is made up of a number of different components each of which have been coloured differently to help differentiate between them. Each of the parts has been designed then reviewed and redesigned a number of times to reach the final product seen here. The overall design was based around taking the best parts from both the external speaker device and also the diamond device. As you can see this is radically different from either and looks like a product that could easily be used by the swimmers. The driving force behind this design was creating something that would be as low profile and sleek as possible while still maintaining just enough room to house all of the electronics. The final design does this extremely well and is on the very boarder line of fitting all the components inside. This is an ideal design as it means that no space has been wasted. Here is a review of each of the parts and how they all fit together to create the final device.

Screws

The device uses 2 x 3mm stainless steel screws which are each counter sunk into the back doors surface to ensure that no edges irritate the swimmer. As the final device aims to be charged through induction there is no need to be able to remove the back panel after construction and so once the screws have been put in at the assembly stage, a small amount of silicone is used to seal over the heads. This aids with the waterproofing and will make the device more comfortable for the swimmer.

Bone speaker



The bone speaker as discussed in section 11.3 of the appendix has been attached in a fitted recess under the bottom of the main device. This speaker is sealed into place using a hard silicone to minimise the absorption of the vibrations and to effectively seal the bottom of the product. The bone speaker carries on the curve from the product and fits securely against the users head giving clear transmission of the sound output from the device.

Antenna

The antenna is a surface mounted patch antenna which is secured to the back face of the device. Because space is so tight in this product this is the only realistic option for an antenna.

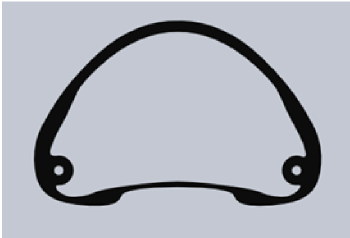
Chips

Both chips requited by this product are very small and require only a tiny amount of space. These will be attached to a small board shaped to the profile of the cavity with the necessary additional components built in and will be secured with 3 clips to the outside edges.

Battery

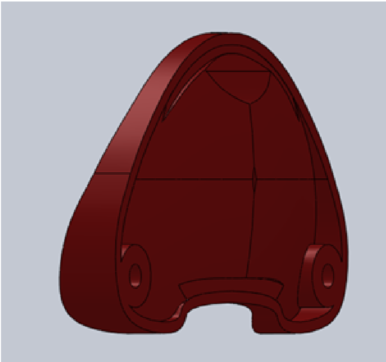
As a lithium polymer battery it is possible to mould this component into the shape required for the application. In this case the battery is required to be moulded to the curve on the inside of the door where it is mounted with a small amount of adhesive prior to final assembly of the product.

Seal



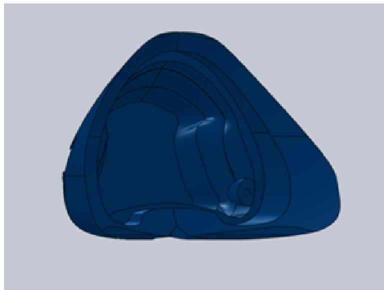
The seal is created to run around the same path as the back door fits into. The seal will be laser cut from soft rubberised foam and will be approx 0.5mm thick. This seal will be held in place with small amounts of adhesive and when the device is closed it will squash out to form an effective seal between the two components. It is important to also note that the seal will run around each of the screw holes to ensure that water does not come in via this route either.

Door



The door used to seal the back of the device is calibrated to the ergonomics research done for the project. When in place the door will be almost invisible as it continues the curve started on the main shell piece and simply slits into its place. The reason the sides go down so far instead of curving with the profile of the door is because by keeping a flat surface it makes the sealing much more efficient and less susceptible to failures caused by tiny errors in manufacturing. To make sure that this doesn't waste too much space the door has been cut to a thickness of 1.8mm inside the area of the seal. This gives a cavity where the battery will be able to fit into the final device. The two screw holes are bigger than the thread of a 3mm screw so that as the screws bite into the hole on the second piece it will pull this tight and create a better seal for the product. Finally the place for the screw heads has been recessed so that the back of the device will be smooth for the swimmer and will avoid causing any irritation.

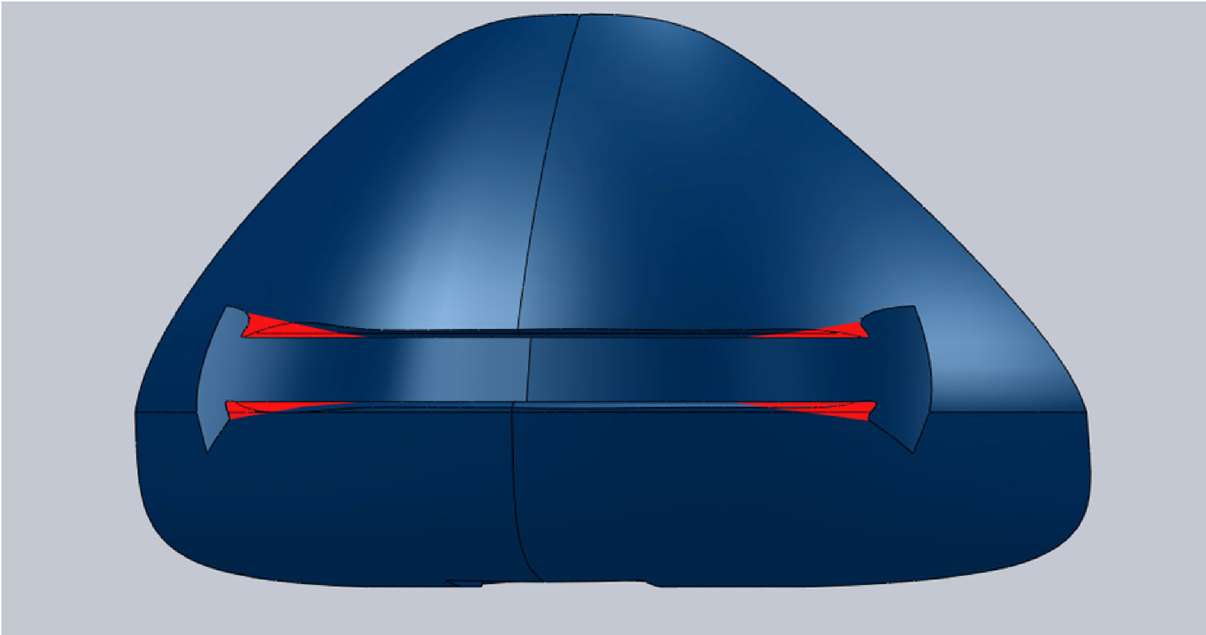
Main Piece



The main shell of this product has been refined down from a much larger device and the group believes that this is the smallest possible size the final device could be made and still retain a good functionality. The shape of this component has been altered since the design stage and is now taller to help the curve of the product merge with the natural curve of the swimmers head. This will help to reduce the effect of drag on the product. In the research stage it was discovered that even something as minor as putting the goggle strap over the swimming hat instead of under it could add 2% drag to the swimmer.

The curve of the inside of the device has been reused from the large model as this was well researched and received a lot of positive feedback when used on a much larger device. As this device is smaller, the accuracy of these stats become less important however by using such well researched data it means that the final product will have a very comfortable secure fit on the swimmers head. The method of coming to these measurements is discussed in the following ergonomics section.

The channel on this device was an exact copy of the channel initially designed for use on the bigger model, however, after a lot of positive feedback on the ease of using a channel of these dimensions it was decided that it should be kept for this model. As the model is smaller the channel is shorter and also due to the research in the durability section the ends of the channel have been slightly reshaped. The picture here highlights in red the alteration that was made to this.



The next point of the design is the cavity at the bottom of the main shell into which the bone speaker will fit. In order to ensure a clean smooth surface between the device shell and the bone speaker, a thin wall at the front of the cavity was shaped to fit accurately to the curvature of the bone speaker. In manufacture the bone speaker will be mounted directly to this wall using a brittle adhesive and then when this has set a relatively hard silicone will be used to fill all the gaps around the speaker and produce a water tight seal. The benefit of attaching like this, in addition to guiding the speaker, is that through this brittle join the vibrations from the speaker will be able to propagate into the main shell and help to increase the transmission surface area across the entire device. Above the bone speaker mounting cavity is a channel cut through into the main electronics cavity. This allows the electrical connection to be made with the power supply and additional electronics.

Over all this design effectively addresses the requirements of the specification and serves as an innovative solution to the initial problem. The next few sections will review different aspects of the design in more detail. Finally here is an additional exploded view with all the components inside the product. This shows how all of the pieces will fit in the final construction.

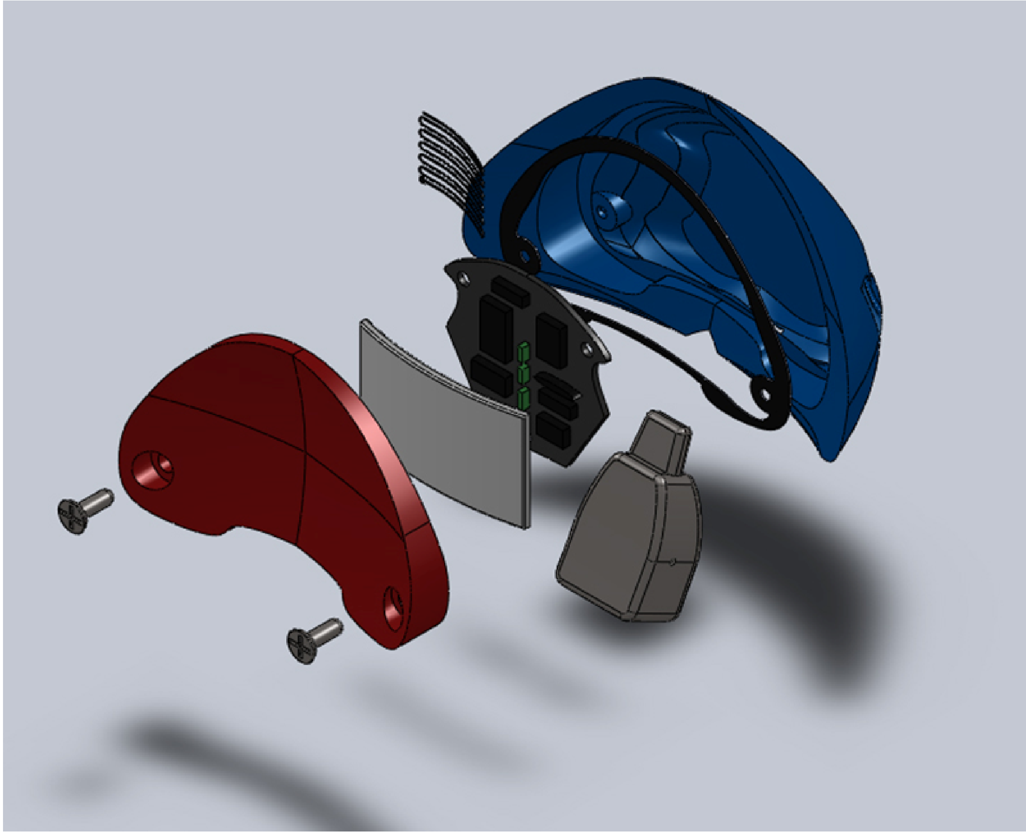


Figure 48 : exploded view of the final product

7.3.Ergonomics

This section will look at the detailed ergonomics work that went into producing the final curves used on the product. Because the device that the research was originally intended for was quite large it was important that it was fitted to the users head across 2 different planes. To get suitable measurements for the product a large number of different card curves were cut at different radius. All the X axis forms were made 110mm long as this is the length needed for the final model and likewise the Y axis forms were all cut to 50mm. To get a number of samples each on had a uniform curve cut into it to a different depth.

The aim of this exercise was not to find the shape which the most people liked but to find a shape that would suit the largest range of people. To do this each curve was tested on our series of 40 volunteers who rated each shape 1 to 4 on comfort 4 being highest. Here is a sample of one of the people that was asked.

Y Axis

Cut depth (mm)	10	15	20	25	30	35	40
Review	2	2	3	4	2	1	1

X Axis

Cut depth (mm)	20	25	30	35	40	45	50	55	60	65
Review	1	2	2	3	3	4	4	3	1	1

As you can see from these results, the person was most comfortable with a Y axis cut of 35mm and an X axis cut of 45-50mm. It also shows that if the decide is curved too tightly it becomes uncomfortable faster than if it is out by the same amount in the other direction. When plotted in a graph we can see a standard distribution curve of the range of peoples preferences. From this we can see that to account for the majority of people the device should be slightly shallower cut than is average. The person shown here is typical across the Y axis however slightly larger on the X axis. The final results showed that we should select a x axis curve of 40mm and a Y axis curve of 25mm. by selecting this the worst rating for each would be a 2 and by eliminating the 10% most extreme results the lowest ranking was a 3.

Similarly the Y axis had a lowest ranking of 3 to start with and by eliminating the most extreme 10% the vast majority rated the curve as a 4. To test that this combination of curves was correct a card jig that covered both axis was constructed and tested on the same 40 people all of which said the 2 curves felt comfortable on the back of their head.

7.4.Water Resistance

As described in the previous water resistance section the final receiver product must be capable of withstanding 10atm of pressure to pass the waterproofing requirement. To achieve this, the final receiver device incorporates a rubber seat that passes around the entire join between the door and the main device. This seal is extended to for a full loop around all of the screws and is made in one solid piece to avoid any leaks. When the screws are tightened this seal is squashed between the two layers and the seal is formed. Currently we are unable to test the device to see whether this method of sealing conforms to the specified level however some basic tests at low depths have shown positive results. If the seal should start to fail before it reaches the depths we need it to be functional at then a groove and ridge can be added around the path of the seal to aid with the sealing and should this fail an additional screw could be added at the top of the device however this would take a significant amount of space up which is required for the electronics.

The coach device is not required to have the same level of sealing as the receiver and so we chose to finish this to be resistant to about 5atm. For this we have designed the device with a channel and ridge that runs right the way around the join between the two halves of its construction. Like in the previous device a rubber seal will follow this and help seal it from any leaks. The coach device requires a lot of buttons and switches on its surface and so for this reason it would be hard to finish it to the level that is required of the receiver. In addition to this rubber seal the internal electronics will be sealed inside a bag to protect them. This bag is suitable for up to 10atm which is more than enough for the device.

7.5.Materials

For the swimmer device the group decided to select ABS as its primary material choice. This is for a number of reasons; firstly because the product is required to be used in chlorinated water it was important to select a polymer that displays a good chemical resistance to chlorine. The second important factor that meant the group favoured this polymer was that ABS displays good scratch and impact resistance. This is extremely important as the final products (as specified in the brief) should be targeted to last around 3 years with failure rates in the first 2 years below 10%. To achieve this target the plastic needs to be durable and although ABS is more expensive than some of the other options it is necessary if the group is to meet this target. Finally as discussed in the manufacturing section, the process selected for producing these components will be injection moulding. As a thermo plastic whit good flow properties ABS is compatible with this method of construction.

For the coach device the group was stuck between using ABS again or using a cheaper alternative such as HDPE or PC. In the end the decision was made to use ABS again due to the fact that the actual components being used in the product are relatively cheap however the product is expected to be aimed at a relatively high price. Because of this quality was put ahead of saving money and ABS was selected again for its scratch resistance which will help prolong the life of the product.

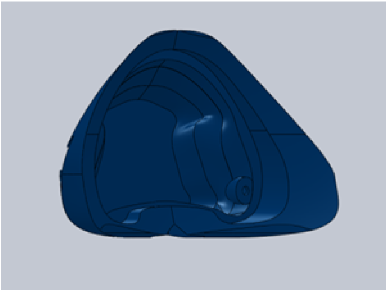
7.6.Manufacturing

As it said in the section before, the two pieces which constitute the case will be made of ABS plastic. Two standard 3mm screws will be used for join both parts. To assure a slight movement in the bonespeaker for a correct location in the back of the head, it will be introduce through the slot in the main part of the device. This part is a little bit wider than the part of the bonespeaker which is introduced in the casing. Silicone will then be used to seal both components.

First of all, two moulds will be needed for producing the main parts from thermoplastic using injection moulding. Electronic components will be ordered directly to the company which produces them, with the appropriate changes made in the programming. This will be the same for the screws and the bonespeaker.

With all components manufactured, an assembly line will be used to facilitate the manual construction process.

Shown below are the two parts which are needed to be built. The rest of the components will be ordered from the appropriate companies. The reason that the cost section displays a 6.500€ set up cost for the injection moulding is because mould manufacture costs are proportional to workshop time needed to produce them. In this case the design is very complex and so will take a long time to manufacture the moulds.



MAIN CASING:

Function: To hold the electronic parts and provide the possibility to hold the device with the goggle´s band.

Units: One.

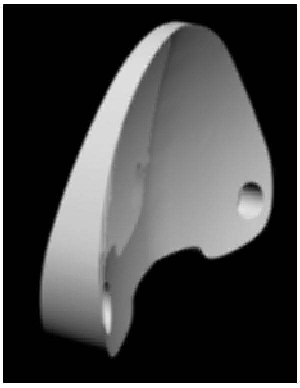
Dimensions: 110 x 55 x 35mm

Assembly: With two screws to join it with the back cap and using silicone to fix the bonespeaker.

Manufacturing: Injection moulding.

Material: ABS

Requirement: Rigidity, water resistant.



Door:

Function: Close the device making pressure assuring waterproofing.

Units: One.

Dimensions: 100 x 35 x 10mm approx

Assembly: Two screws to join it with the back cap component. To ensure a permanent hold these will be secured with locktight glue and silicone will be used to seal over the heads.

Manufacturing: Injection moulding.

Material: ABS

Requirement: Rigidity, water resistant.

7.7.Methods of Use

In the beginning of the project, a wide amount of research was done. In this search, a lot of swimming goggles were seen. Paying attention to the different sizes of the goggle’s band. Considering that this part is made of a malleable material, the slot of the device has a dimension which can be attached to most of the swimming goggles.

A common use of the device is detailed next.

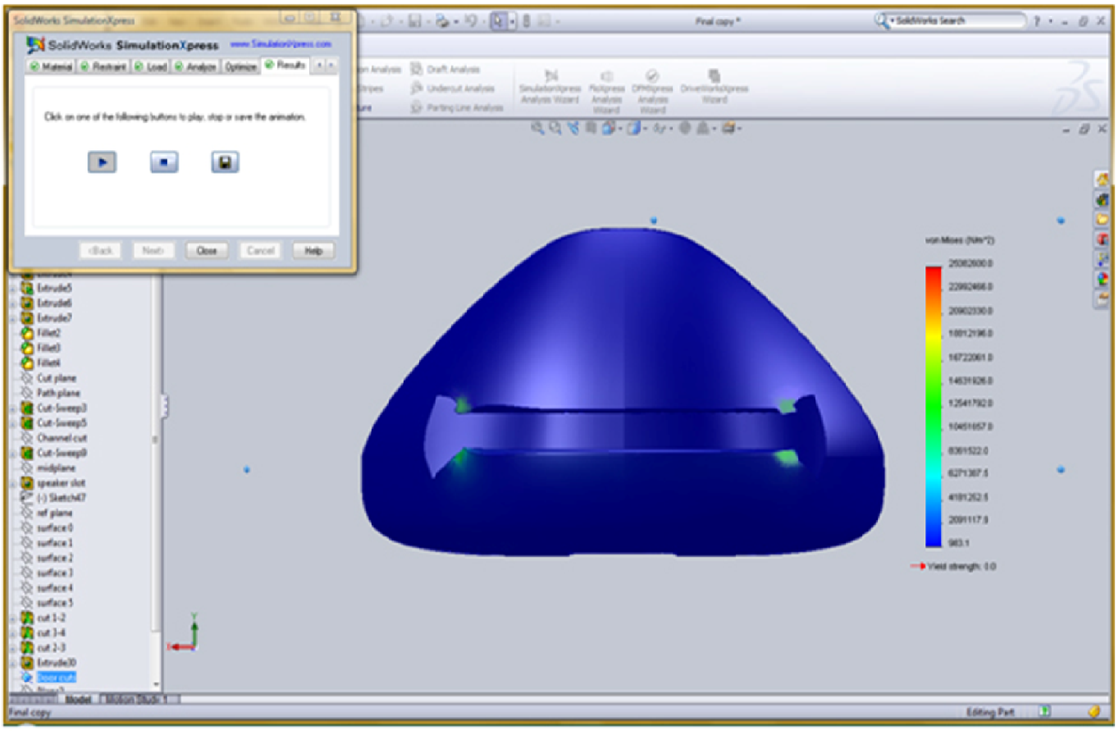
1.- Cross the goggle´s band trough the back groove of the device.

2.- Put the goggles assuring that the bone-speaker is making a correct pressure in the back of the head.

3.- Put your swimming cap.

7.8.Durability

By using Solidworks fatigue calculation software it is possible to predict what stresses will be put on the product over its lifetime and ensure that the construction and material choice is sufficient to withstand the 3 year lifespan defined in the initial specification. Here is a graphical representation of how well our product will fare over its lifetime.



For this the material was selected as ABS and the forces considered were general wear and tear around the edges as well as the goggle strap being put in and out of the band strap a total of 3,285 times. This is assuming the product is used 3 times a day and 365 days a year. The conclusion from Solidworks was that the edges of the channel would break within the first year. This is shown by the green areas in the picture above, the blue areas will not break under normal usage. This has been rectified by reshaping the channel slightly to reduce the catch of the band on the ends of it. The revised model will stand up to the stresses for a minimum of 5 years. This is however is assuming no big drops or times getting trodden on and so the actual product lifespan is likely to be closer to the specified 3 years.

7.9.Location

As discussed in the **Appendix section 12.3** there are a number of different sites that conduct the sound from the bone speaker better than others. The final receiver device is designed to effectively combine with the zones located on the back of the head to transmit a clear signal to the inner ear. As you can see in the appendix the zone selected by us is not the best at conducting the vibrations however due to the ease of access it was selected over the more conductive zone behind the ears. We did a significant amount of experimentation around this site and found that the transmission at this point would be easily sufficient for our product to work. A large benefit of selecting this zone is that the goggle strap passes close to it and allows us a point to anchor the device to.

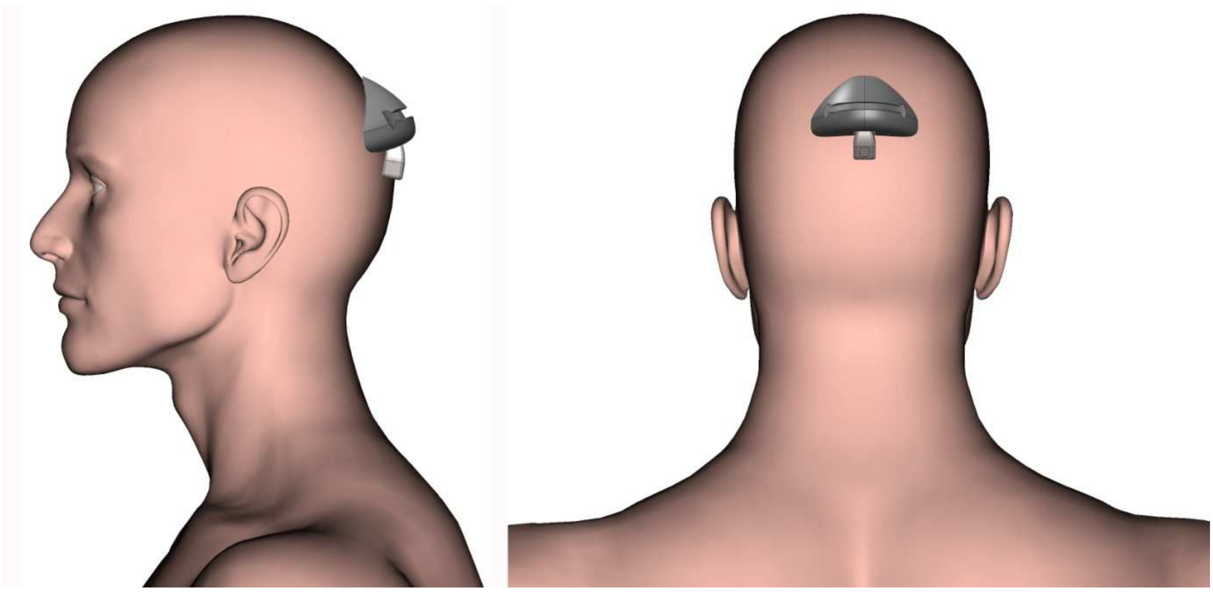


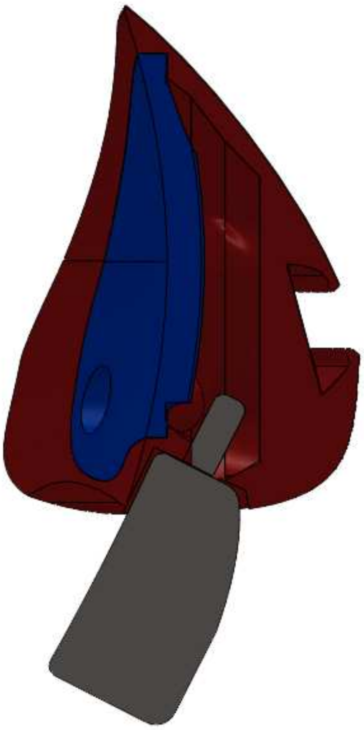
Figure 49 : Final CAD head models

7.10. Testing

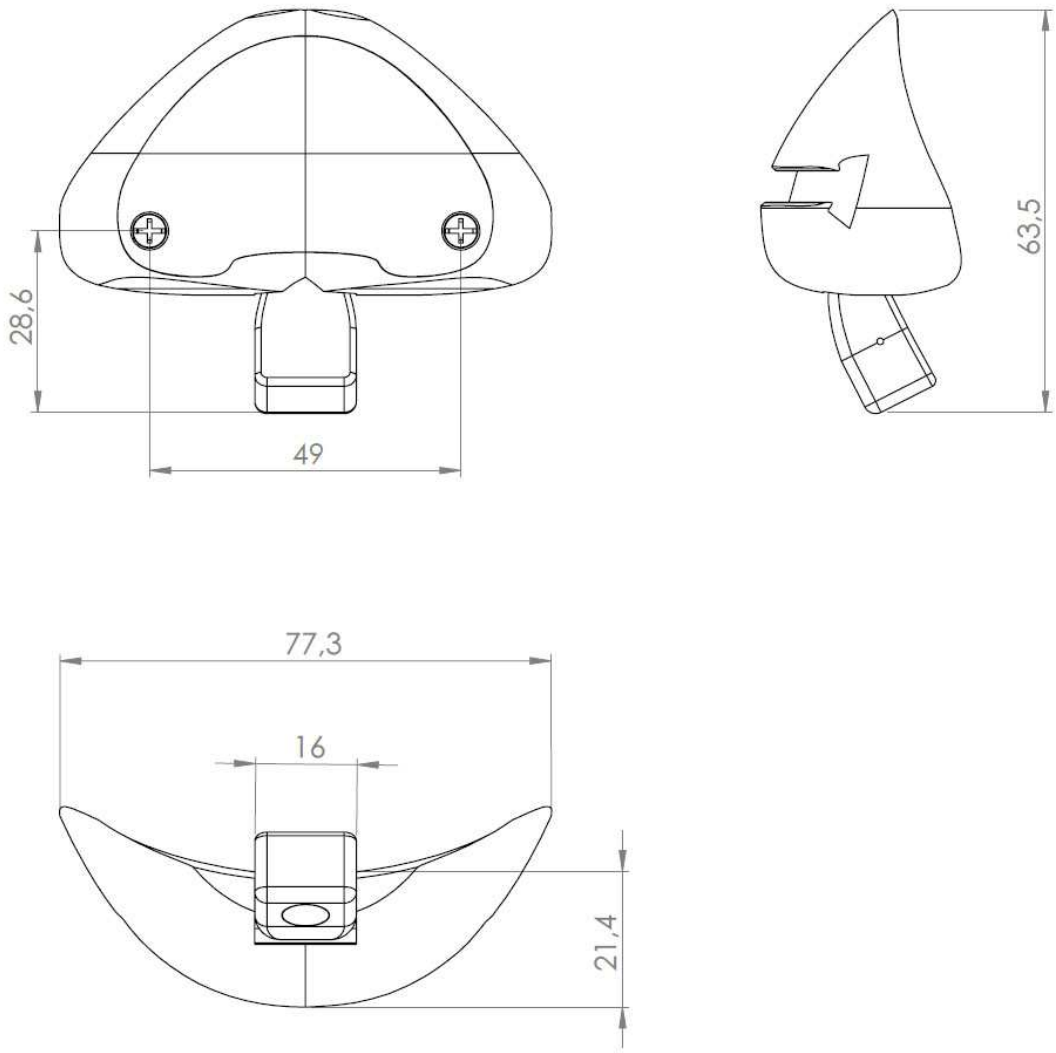
The testing that has been referred to through this section has often be referred to as dry testing. This is because although the final receiver unit is intended to be used in the pool, the most time effective way to test the device during stage 4 development was to get a sample group of people to wear it as if they were about to go swimming with it and to give us their immediate reactions. Because of the level of detail that was actually required at this stage going to the pool and trying to get a large enough group of people to collect significant data from would have been a poor investment of time. A test on the final complete device would have been good to go to the pool for however due to time constraints the group was unable to do this before the end of the project. To try to lessen the impact of this on the group it was decided a second dry test would be done on the final device to get some final observations and feedback. If the project were to be continued more through testing would have been carried out and there would have probably have been 1 further stage in the products development to rectify and areas that perform poorly on the final device. In the initial dry tests carried out during phase 4 of the development, a sample of 20 people both male and female were asked to put the device on with minimal instructions to get feedback for the designers. Having looked at the results there is a clear preference towards the externally mounted speaker device and it is possible to see that they felt this device was more comfortable and was easier to get set up. The area it performed weaker than the other device was pressure felt under the speaker area and thus it is likely to have poorer sound transmission. This can be negated by increased amplification of the signal carefully balanced against maintaining a suitable battery life.

The second round of dry testing was much more geared towards refining the final design and due to time constraints, only members of our team participated in this. The results were not logged however notes were taken and the consensus was that the final product fitted our initial brief well and the device looked good. The only major criticism was that under some extreme circumstances and rough treatment the device could slip on the back of the swimmers head. This is something that is discussed in the final design summary for the receiver device.

7.11 Render



7.12 Blueprint



8. Cost

The total cost of this product is a combination of a number of different components and will be dependent on the scale of production that is implemented. Because we are unsure of the strategy Sigma intend for this product it is difficult to make a prediction of the numbers that will be produced. Here is a breakdown of all the costs in the product calculated for a full set of 8 swimmer devices and a single coach device;

Plastic;	= 5€
Batteries;	= 81.8€
Electrical components;	= 257.5€
Microphone;	= 12€
Seals;	= 12€
Bone speaker;	= 76€
Coach Buttons;	= 35.5€
Antenna;	= 121€
Construction;	= 18€
Injection moulding per set;	= 12€

Set up costs

Process set up;	= 600€
Injection moulding set up;	= 6500€

The set up costs for the injection moulding process are very high and for this reason the higher the number of units produced the lower the individual cost will be. This graph shows how the cost drops away as number produced increases.

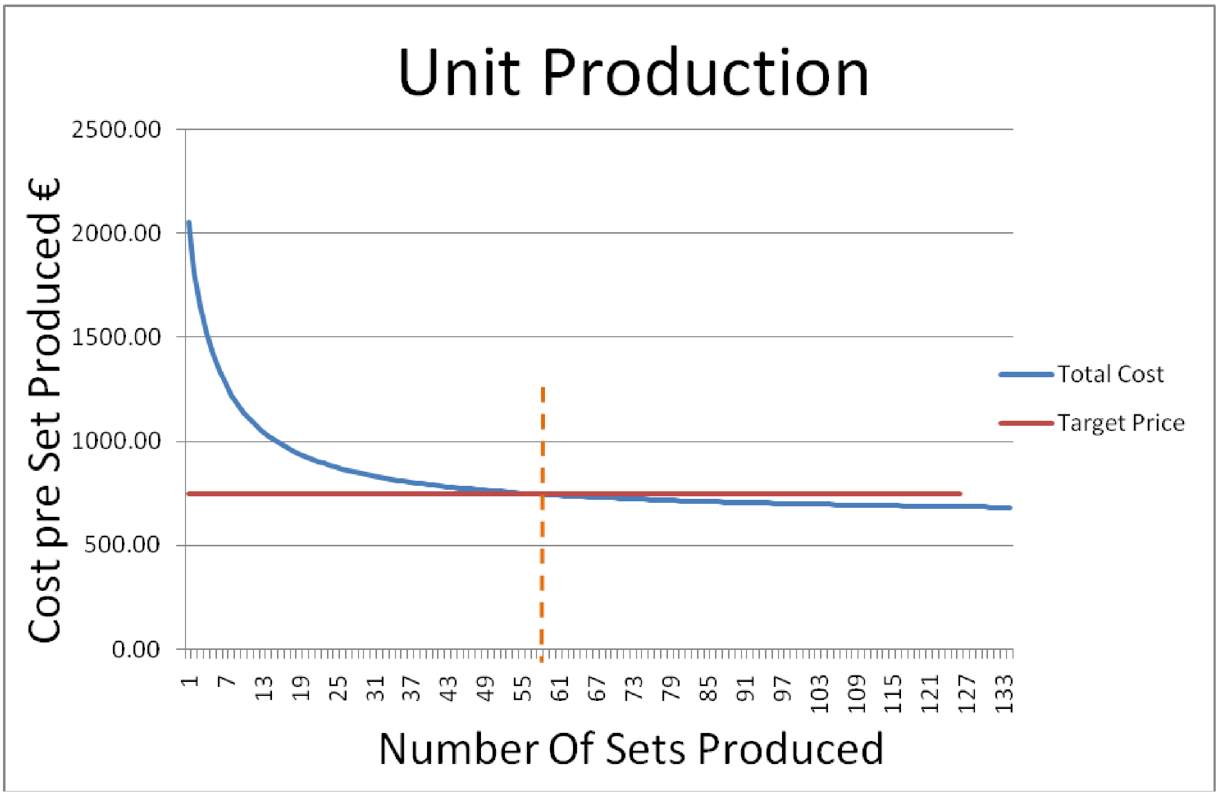


Figure 50 : Unit production table

From this we can see that it is going to be very costly to produce less than 20 units. Assuming that at least 59 full sets are produced then we can set the retail price of a full set at around 750€ with a replacement receiver retailing at 89€ and a replacement transmitter retailing at 95€ and sales will still cover the cost on manufacture. This is in line with our initial brief which stated that the final product should cost less than 750€ for a full set of devices.

The two highest costs in the device are the electrical components and the antenna. The selection of the antenna was made based on the space requirements in the swimmer device and in order to reduce costs a different antenna was selected for the coach device where space was not such a critical issue. Here is a breakdown of the Electrical costs.

Prices

Testing:

Part	Quantity	Price (unit)	Price (total)
TLV320AIC1106 (CODEC)	5	-	free (samples)
Testing PCB for the CODEC	-	-	free
EVAL-ADF7023DB2Z (evaluation kit) (transceiver)	2	75€	150€
EVAL-ADF7xxxMB3Z (evaluation kit motherboard)	2	100€	200€
Cables and others	-	-	free (borrowed)
TOTAL			**350€**

Final product

Coach device:

Part	Quantity	Price (unit)	Price (total)
Knowles Acoustics MD9752NSZ-1 (microphone)	1	12€	12€
Texas Instruments TLV320AIC1106 (CODEC)	1	5,5€	5,5€
Analog Devices ADF7023 (transceiver)	1	2,5€	2,5€
PCB, resistors, connectors and others	-	-	25€*
L-com HG903RD-SM (antenna)	1	8,5€	8,5€
TOTAL			**53,5€**

Swimmer device:

Part	Quantity	Price (unit)	Price (total)
Antenna Factor ANT-868-CHP-x (antenna)	1	16€	16€
Analog Devices ADF7023 (transceiver)	1	2,5€	2,5€
Texas Instruments TLV320AIC1106 (CODEC)	1	5,5€	5,5€
PCB, resistors, connectors and others	-	-	15€*
Huaying International HY-00001 (bone speaker)	1	1	2€
TOTAL			**41€**

Note: * indicates estimated

9. Suggestions for following groups

9.1.Wireless charging

Due to a lack of time, the group was not able to look into developing the induction charging device however the previous group did some basic research into this subject: This is a subject area that would be valuable for the next group to research further into. Because of this it is important that the information collected by the first group is not wasted and passed onto the next group. The last groups work on this subject is included in **Appendix 12.10**. We take no responsibility for this work.

9.2.Develop shell

Although the shell for the receiver has been developed to a point where the members all feel that it would be ready to go into production, the transmitter unit could still be developed further to give a better overall project. Things that could be developed are combining the buttons with a working interface system for the electronics side, working on methods of making the device more portable for the coach, and also research into whether the space at the top of the device, currently occupied with a small note pad, could be used more efficiently.

Currently the product struggles to get below the £600 per full set price limit our group set. The next stage in the products development should be to reduce this number to £4,500 and work to bring down more costs through better design.

9.3.Test Electronics

As main problem we had that the evaluation kit for the CODEC that we finally found more suitable for our design and requirements seemed to be not in stock in any retailer or distributor. We would be grateful if our supervisor had advised us earlier of this fact to have time to search for another solution.

That implied that we only got free samples of the CODEC itself, and they were SMD components so weld them over an PCB was extremely difficult due to the tiny dimensions of the CODEC.

Although we actually succeeded in designing and making our own PCB board for testing the CODEC in a short time, it was proved as a fountain of problems due to high frequency requirements and it didn't work well.

Summarising, we suggest to following groups that select this project to follow the path of making the devices with a CODEC and a transceiver but finding another CODEC with similar characteristics ensuring that it's correspondent evaluation kit is available.

9.4.Induction Charging

This semester the group has been heavily focused on progressing the main body of the project as far as is possible within the time and because of this the group has not looked into Induction charging in anywhere near the depth that would be needed to start making progress in this area. In Appendix 12.9 we have included the last groups initial work into this area and from this we hope that the next team to tackle this project will be able to develop this further.

10. Conclusion

The EPS programme has helped all members become much more comfortable working in an international team and being responsible for running their own project. Through this project the team has had a lot of different deadlines to work on top of managing a challenging project where different setbacks have to be overcome to reach the final goal. Although the project did not reach the stage of having the final circuits built, the team feels that they have done very well given delays in acquiring the electronics and the amount of additional work that had to be done throughout the project time.

Because this project had such a big split between the electrical side and the casing side it has at times been a challenge not to separate these two sides too much. One way the group has overcome this is by not sticking rigidly to the side of the project we were assigned but instead switching between the two sides and learning about areas members were previously weak in.

Another big benefit that all members have experienced is the project management structuring that was taught at the start of the year. Out of the whole group Kai was the only one who had been formally taught these strategies of management before and so the team members gained a lot from this and were all able to see how they could be applied to the project.

The overall feeling from all the group members was that we were lucky to be assigned team mates that all worked well together and had similar expectations for the semester to one another. This has helped the members to get the most out of the project and has really added to the experience.

11. List of References

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  http://www.analog.com/static/imported-files/data_sheets/ADF7023.pdf
- Texas Instruments TLV320AIC1106 (PCM CODEC)
  http://www.ti.com/lit/gpn/tlv320aic1106
- Knowles Acoustics MD9752NSZ-1 (noise cancelling microphone)
  http://www.farnell.com/datasheets/302370.pdf
- L-com HG903RD-SM (antenna)
  http://69.84.140.50/multimedia/datasheets/DS_HG903RD-SM.PDF
- Antenna Factor ANT-868-CHP-x (chip antenna)

  http://www.antennafactor.com/resources/data-guides/ant-xxx-chp-x.pdf

- *Huaying International HY-00001 (bone speaker)*
  http://huayingint.en.made-in-china.com/product/TeOnqLpMYGUb/China-Bone-Conduction-Transducer.html

Others

Wikipedia, http://www.wikipedia.org

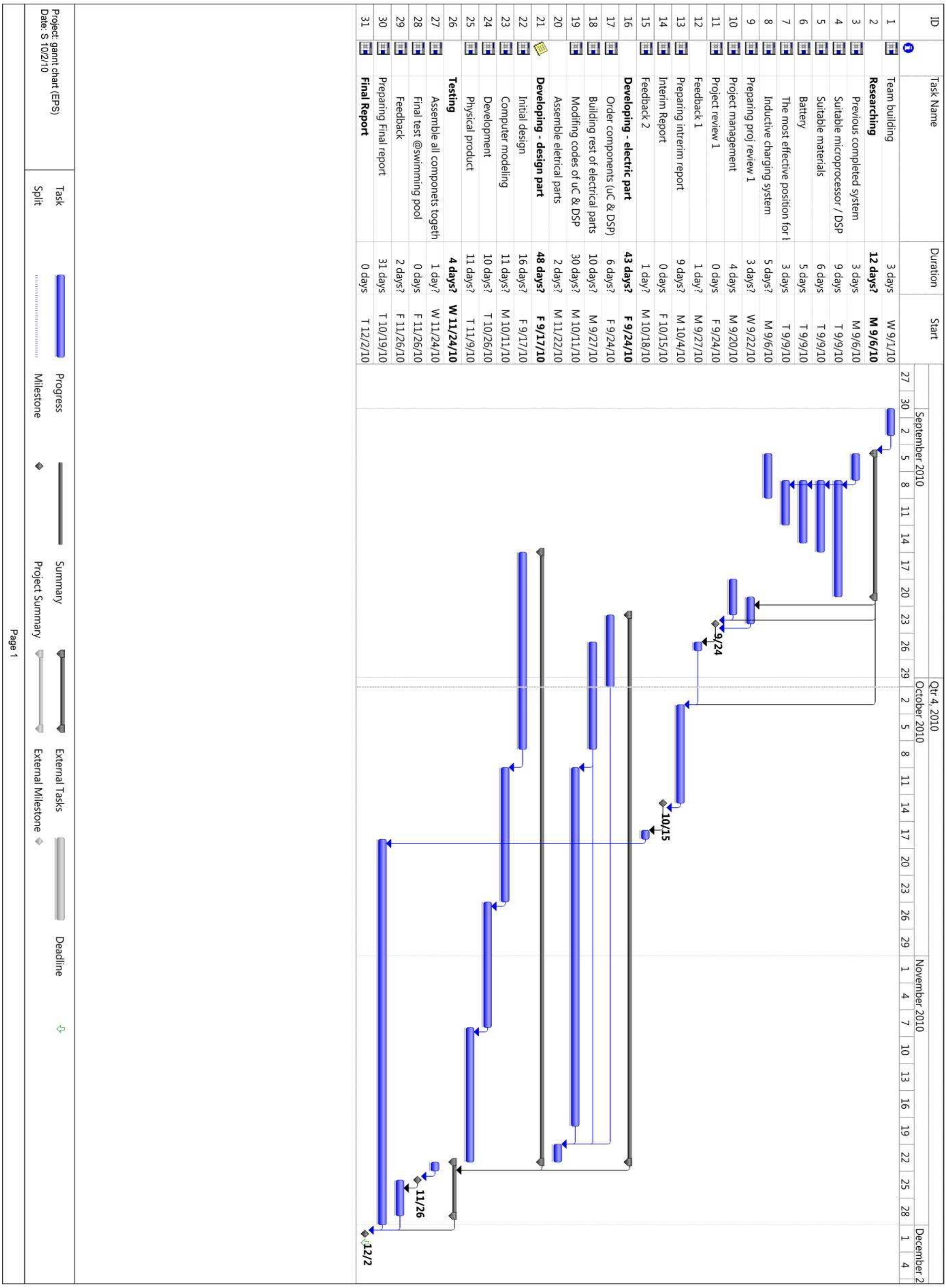
12. Appendix

12.1. Task Distribution

WBS \ OBS	Alex Hughes	Gatien Manzac	Kai Kim	Sergio Ortiz Domenech	Ricardo López Cabañero	Comments
Find suitable transceiver			S	R		
Find suitable microprocessor /DSP			S	R		
Create accurate programming codes			R	S		
Research location of the device	S				R	
Develop product form	R	S			S	
Work to optimize bone vibration technology				S	R	
Produce a working electronics prototype		S	S	R		
Produce a form prototype	R	S			S	

Find suitable materials	R		S		S	
Ensure that the final form prototype is waterproof	S				R	
Investigate effects of chlorine on the final product	S	R			S	
Research and implementation of a suitable battery		R	S	S		
(If there is time) Develop the inductive charging system	S	S	S	S	S	
Review the earlier complete system		S	R	S		We don't know yet if we need to build again some electronic parts

12.2. Gantt Chart

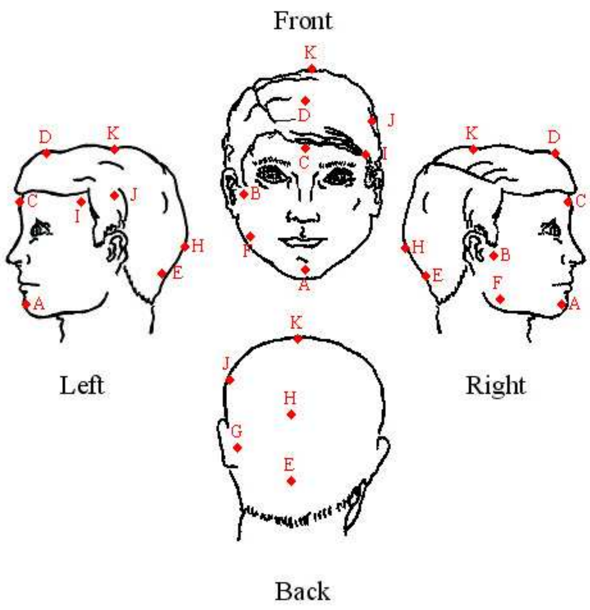


12.3. Location of Swimmer Device

One of the most important parts in the casing is where to place the receiver unit. Mainly, we need to focus on three aspects: hydrodynamics, bone conduction and comfort.

About the hydrodynamic, we have researched several swimming´s videos. We have noticed that, because of the form of the head, the less disturbing head´s zone for the training would be localized on the back´s surface between the ears.

According to some studios, we found one with a chart which indicates different parts of the head with measurements of the sound´s level. Results of the study indicate that the condyle (an articular prominence of a bone) is the most receptive location for a BC transducer because it generates the lowest overall threshold levels. The "best" effective location appears to be the **condyle**, followed by the **mastoid** and **vertex**. Although the jawbone ranked third, it was very difficult to hold the vibrator in place at this location. Next images show it more understandable:



A.- Chin
B.- **Condyle**
C.- FPz
D.- Fz
E.- Inion
F.- Jaw angle
G.- **Mastoid**
H.- Pz
I.- Temple
J.- T3
K.- **Vertex**

Rank ave			Sorted by rank ave		
A	Chin	10	B	Condyle	1.4
B	Condyle	1.4	G	Mastoid	3.3
C	FPz	9.2	F	Jaw Angle	3.5
D	Fz	6.8	K	Vertex	3.8
E	Inion	7.9	I	Temple	5.2
F	Jaw Angle	3.5	J	T3	6.2
G	Mastoid	3.3	D	Fz	6.8
H	Pz	9.5	E	Inion	7.9
I	Temple	5.2	C	FPz	9.2
J	T3	6.2	H	Pz	9.5
K	Vertex	3.8	A	Chin	10

loc/rank	1st	2nd	3rd
Chin	0	0	0
Condyle	8	2	1
FPz	0	0	0
Fz	0	0	0
Inion	0	0	0
Jaw Angle	2	4	2
Mastoid	1	2	3
Pz	0	0	0
Temple	0	1	0
T3	0	0	1
Vertex	0	2	4

Comfort would be the link between both aspects. So, according to that, we decided that Pz (H) or Inion (E) will be the place which satisfied our requirements. It is necessary to say that, making some tests with our bone speaker, we realized that there are no real differences between zones. At least big enough to impose over comfort and hydrodynamic.

12.4. Bone speaker

Bone conduction hearings are small devices that are designed in such a way that they can be fitted outside or inside the ear. Over the years, a variety of bone conduction devices types have been developed and introduced in the market, each having its own set of pros and cons. However, all of them work on more or less the same principle. Each one makes use of a sound amplifier and a speaker device.

Most of the devices suitable for our project come from hearing aids companies and is divided and those basic parts:

- Behind The Ear (BTE) Model: This is the most basic and oldest technology. It consists of a small, semi-circular plastic unit which, as the name suggests, needs to be placed behind the ear. It is connected to an additional plastic earmold which is fitted in the ear.

- In The Ear (ITE) Model: This type of system consists of a single unit that is small enough to be fitted in the outer ear.

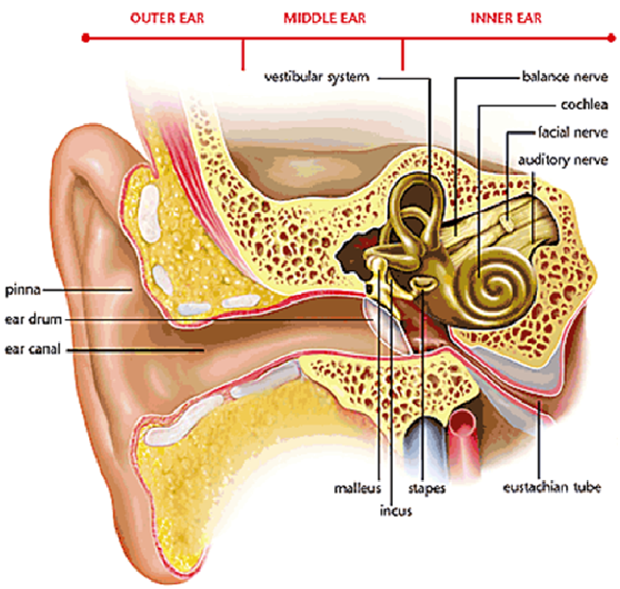
- In The Canal (ITC) Model: These are also custom-built according to the size of the person's ear canal. This hearing aid is placed in a manner that is similar to the way in which we cover our ears with earplugs while swimming.

- <u>Completely In Canal (CIC) Model</u>: As the name suggests, this type of device fits completely inside the ear canal. It is an advanced version of the ITC model and is hardly visible from outside.

For a better optimization of the product, various options were reviewed about the device location (cf. previously). For a great majority of those, a BTE model is preferable towards In-the-Ear (ITE) model for obvious reasons. The plan is finally to buy a bone conduction system and experimenting a remodelling with the project device in a lab at the university for some improvement and implanting.

12.5. The ear – Anatomy and function

The ears are paired sensory organs comprising the **auditory system**, involved in the detection of sound, and the **vestibular system**, involved with maintaining body balance/ equilibrium. The ear divides anatomically and functionally into three regions: the **external ear**, the **middle ear**, and the **inner ear**. All three regions are involved in hearing. Only the inner ear functions in the vestibular system.



The **external ear** (or *pinna*, the part you can see) serves to protect the tympanic membrane (eardrum), as well to collect and direct sound waves through the ear canal to the eardrum. About 1¼ inches long, the canal contains modified sweat glands that secrete *cerumen*, or earwax.

The **middle ear**, separated from the external ear by the eardrum, is an air-filled cavity (tympanic cavity) carved out of the temporal bone. It connects to the throat/nasopharynx via the Eustachian tube**.** This ear-throat connection makes the ear susceptible to infection (otitis media). The eustachian tube functions to equalize air pressure on both sides of the eardrum. Normally the walls of the tube are collapsed. Swallowing and chewing actions open the tube to allow air in or out, as needed for equalization. Equalizing air pressure ensures that the eardrum vibrates maximally when struck by sound waves.
Adjoining the eardrum are three linked, movable bones called "ossicles," which convert the sound waves striking the eardrum into mechanical vibrations. The smallest bones in the human body, the ossicles are named for their shape. The hammer (malleus) joins the inside of the eardrum. The anvil (incus), the middle bone, connects to the hammer and to the stirrup (stapes). The base of the stirrup, the footplate, fills the oval window which leads to the inner ear.

The **inner ear** consists of a maze of fluid-filled tubes, running through the temporal bone of the skull. The bony tubes, the *bony labyrinth,* are filled with a fluid called perilymph. Within this bony labyrinth is a second series of delicate cellular tubes, called the *membranous labyrinth*, filled with the fluid called endolymph. This membranous labyrinth contains the actual hearing cells, the *hair cells of the organ of Corti*. There are three major sections of the bony labyrinth:

1. The front portion is the snail-shaped **cochlea**, which functions in hearing.
2. The rear part, the **semicircular canals**, helps maintain balance.

3. Interconnecting the cochlea and the semicircular canals is the **vestibule**, containing the sense organs responsible for balance, the *utricle* and *saccule*.

The inner ear has two membrane-covered outlets into the air-filled middle ear - the **oval window** and the **round window**. The oval window sits immediately behind the stapes, the third middle ear bone, and begins vibrating when "struck" by the stapes. This sets the fluid of the inner ear sloshing back and forth. The round window serves as a pressure valve, bulging outward as fluid pressure rises in the inner ear. Nerve impulses generated in the inner ear travel along the vestibulocochlear nerve (cranial nerve VIII), which leads to the brain. This is actually two nerves, somewhat joined together, the cochlear nerve for hearing and the vestibular nerve for equilibrium.

All sounds (music, voice, a mouse-click, etc.) send out vibrations, or sound waves. Sound waves do not travel in a vacuum, but rather require a medium for sound transmission, e.g. air or fluid. What actually travels are alternating successions of increased pressure in the medium, followed by decreased pressure. These vibrations occur at various frequencies, not all of which the human ear can hear. Only those frequencies ranging from 20 to 20,000 Hz (Hz = hertz = cycles/sec) can be perceived.

In hearing, air-borne sound waves funnel down through the ear canal and strike the eardrum, causing it to vibrate. The vibrations are passed to the small bones of the middle ear (ossicles), which form a system of interlinked mechanical levers: First, vibrations pass to the malleus (hammer), which pushes the incus (anvil), which pushes the stapes (stirrup). The base of the stapes rocks in and out against the oval window - this is the entrance for the vibrations. The stapes agitates the perilymph of the bony labyrinth. At this point, the vibrations become fluid-borne. The perilymph, in turn, transmits the vibrations to the endolymph of the membranous labyrinth and, thence, to the hair cells of the organ of Corti. It is the movement of these hair cells which convert the vibrations into nerve impulses. The round window dissipates the pressure generated by the fluid vibrations, thus serves as the release valve: It can push out or expand as needed. The nerve impulses travel over the cochlear nerve to the auditory cortex of the brain, which interprets the impulses as sound.

12.6. Questions to Sigma

To go further in the project researches, we needed some specific details about the future using of the final product. The questions asked are the following:

- What percentage of the swimmers wears caps?

  ➔100% of the swimmers wear cap

This information is crucial for the design of the product. With this, we know now that we could use the pressure of the cap to maintain the device on the swimmer's head.

- What percentage of the swimmers wears goggles?

  ➔100% of the swimmers wear goggles.

Here as well, this piece of information allows us to notice the goggle's band and its utility in the solutions we could choose to fasten the device on the athlete's head.

- Is the product intended for use on all different strokes?

  ➔All the swimmers of the team are going to use our product, whatever their speciality

We have to be careful of the place which the device will be placed on and find one which will not interfere with the swimmer's performance.

- Characteristics of the water

  ➔The water used in the pool contains chlorine

This characteristic is very important for the choice of the external shell material.

- What is the maximum distance ever between a coach and a swimmer?

  ➔The swimmer won't be farer than 50 m

We know now that the radius of radio-transmission has to be at least 50m. This information will help us to define de components of the electronic part.

- Training schedule of the swimmers this product is intended for?

  ➔Trainings are going to be 2 or 3 hours long, twice a day.

This is crucial information for the battery choice. It has to be sufficiently powerful to allow exchange between coach and swimmers during the whole training.

12.7. Swimmer device – Another final version

Difficult decisions were taken to decide which one of the final models had the best characteristics to achieve the goals marked on the project. Some words are said in the 6.1 section trying to explain the differences between the models and how we came to the final decision through a survey. Here is a complete summary of the alternative model that was designed, This model had many unique innovative features and so a detailed summary may be useful to future groups working on this project.

Long Speaker Device

Trying to offer a different form to accomplish the specification of the project, this form was built elongated. As was decided in the development stage, bone-speaker is separated from the electronic part, in order to assure the best transmitting of the sound and focus the goggle´s band force in that part.

Figure 51 : Explode view of the elongated model

Different zones to hold the parts.

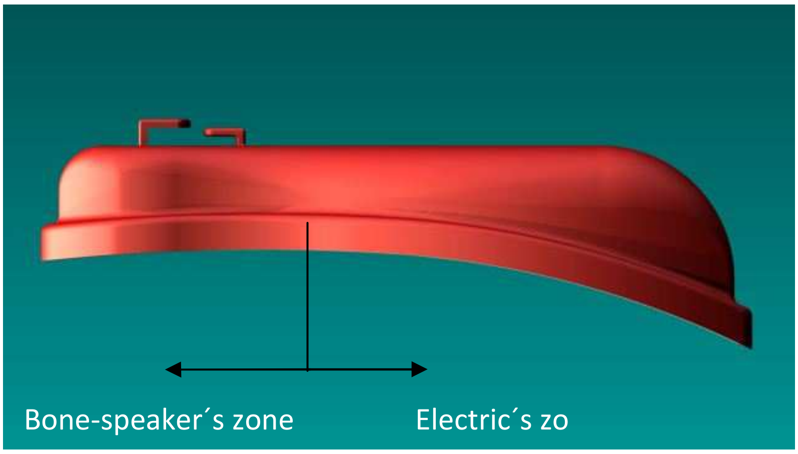


Figure 52 : Repartition in the elongated model

General dimensions of the device compared with the head.

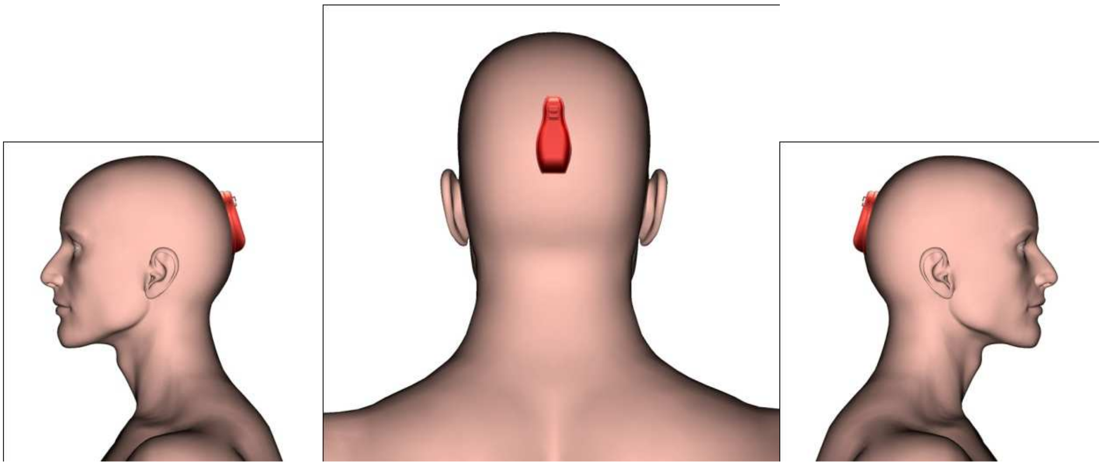


Figure 53 : Location of the elongated device

Characteristics of the parts.

Main piece

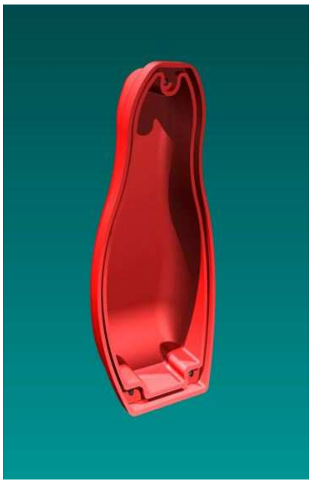


Figure 54 : Main piece of the elongated device

This piece is the most important part of the device (cf. **Fig. 43**). The top of the form, narrower, this will hold the bone-speaker. The bottom part will be used to house the rest of the components.

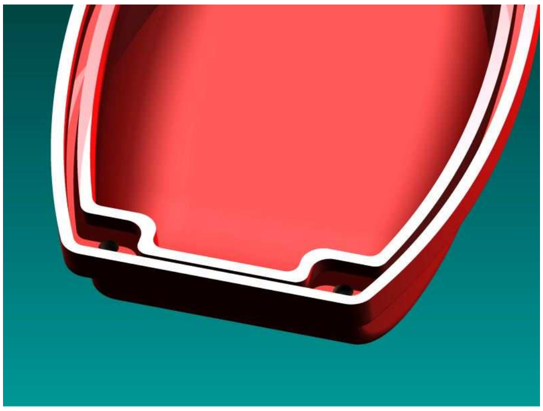


Figure 55 : Detail of the waterproofing channel

In the lateral (cf. **Fig. 44**), there is a slot to put the join part which will be fixed thanks to three 3mm stainless screws.

Material: Polycarbonate.

Manufacturing: Injection molding.

Dimensions: 80 x 25 x 23 mm.

Figure 56 : Goggle fastening

As said before, there are different goggle´s band sizes. To overcome that, two small steps had been designed to do easier the use with most of the bands (cf **Fig. 45**).

Join part

Figure 57 : Join part of the elongated model

Waterproofing has been the most difficult goal to overcome. This model is thought to use that piece between the two main parts and make pressure in the back piece (cf. **Fig 46**).

Material: Some kind of elastomer such as thermoplastic polyurethane (TPU) or silicone.

Manufacturing: Injection molding.

Dimensions: 78 x 23 x 1 mm.

Back piece

Figure 58 : Views of the elongated model back piece

This piece is used to seal the back of the device. It has been calibrated to the ergonomics research done for the project. It has a thickness of 1 mm, except for lateral, which has a thickness of 3 mm due to the waterproofing. The place for the screw heads has been recessed so that the back of the device will be smooth for the swimmer and will avoid causing any irritation. For a better sound´s transmitting, there is a little cavity in the top part which houses the bone-speaker.

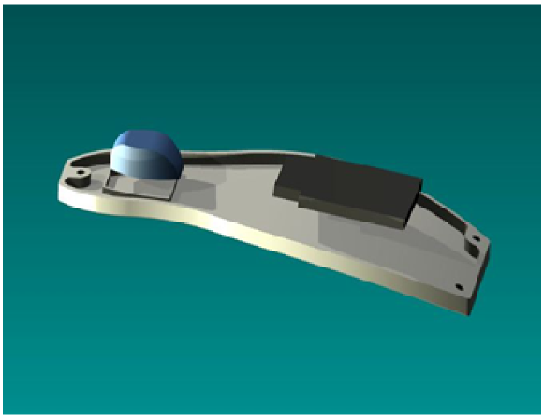
Material: Polycarbonate.

Manufacturing: Injection molding.

Dimensions: 78 x 23 x 1 mm.

Apart from this, three standard M1.6 x 5 mm stainless steel screws will be needed to do the force between the two pieces and the electronic parts.

Assembly



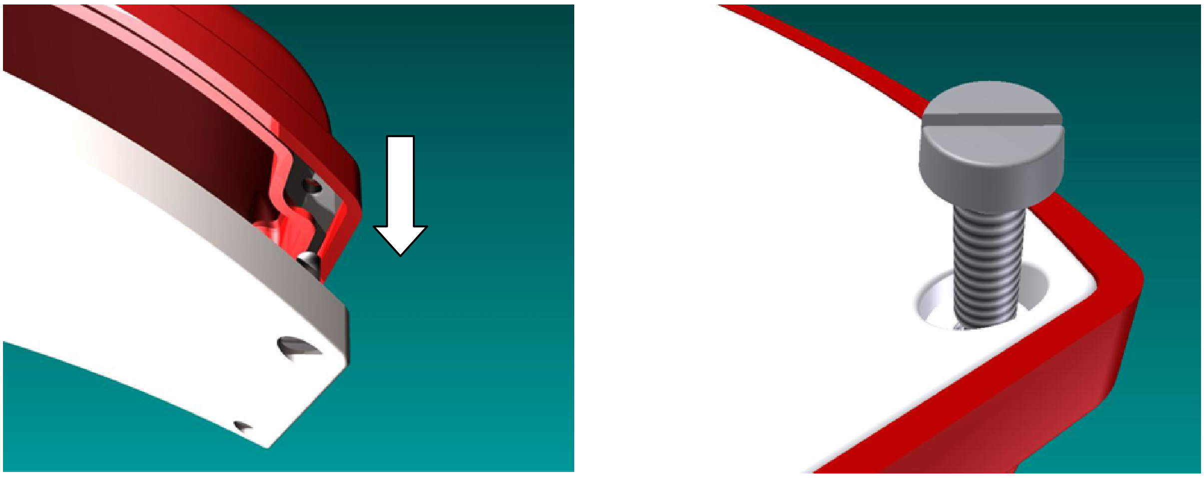
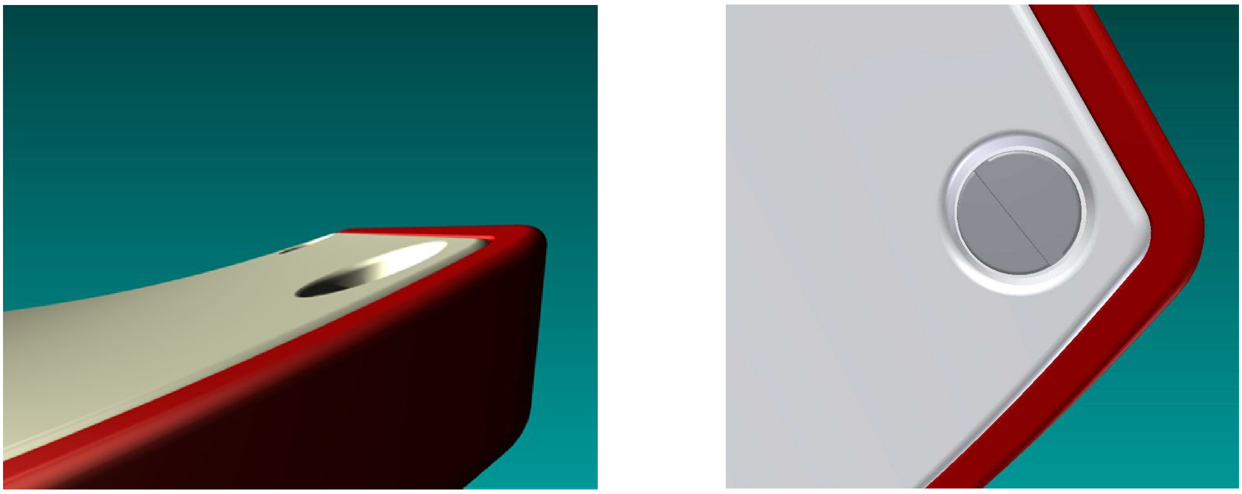



Figure 59 : Elongated model assembly process



Final sealing

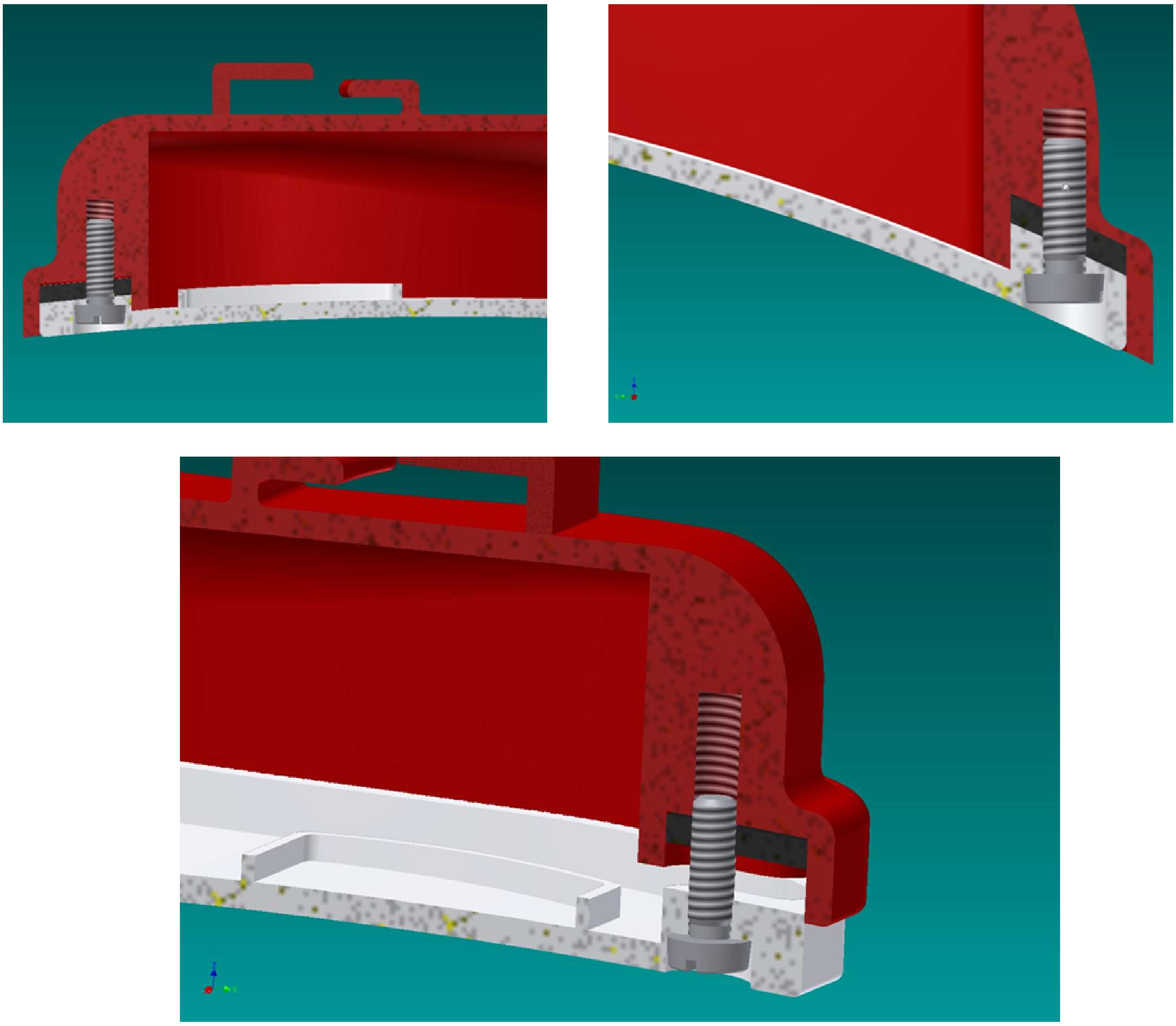


Figure 60 : Elongated model sealing

Although the design of this model is finished, the information about it it’s not as detailed as the chosen one, because the efforts of the team were focused on the main model.

12.8. Danish law about frequency in use

The frequency chosen for the carrier signal of the transceivers needs to be within legal limits of the Danish law.

After a very tough researching on the “National IT and Telecom Agency” (which is department under the Danish Ministry of Science Technology and Innovation) and the ”Experimenterende Danske Radioamatører og Radioamatørernes Forlag ApS” websites were found two important documents that helps us on complaining the radio electric requirements and certify that our system can be used legally in Denmark.

As a summary, that the frequency bands 868.000 – 868.600 MHz, 868.700 – 869.200 MHz and 869.700 – 870.000 MHz can be used legally in Denmark without demanding any type of license.

Note: Documents **“Notification on Danish air-interface no. 00 032 for low-power radio equipment with integrated or dedicated antenna intended for telemetry, remote-control purposes, alarms, speech and data transfer in certain frequency bands between 6 MHz and 246 GHz”** and **“EXTRACT Of Amateur Radio related provisions in Denmark relevant to radio amateurs using amateur radio stations during short stays in Denmark in accordance with CEPT recommendations T/R 61-01 or (05)06”** can be found in the annex.

12.9. Previous group, Induction Charging

Here is the work done by the previous group on the subject on induction charging. It is important to note that we take no responsibility for this work however it is important to include this for the following group.

<u>Inductive wireless charging</u>

Introduction

Solid-state charging can improve the handling of many electric devices. In particular affected are devices being used several times during the day and being recharged continually, like cell phones, electric toothbrushes, electric shavers etc. Beside it, there are other applications where the security of the operator is important. One example is electric cars, which have to be recharged in all weathers; another example is devices in explosive area, where sparks are not allowed. Another field of application results in devices, where no plug connectors are possible. In this group belongs on the one hand medical implants (pace maker, biotelemetry) and on the other hand absolute encapsulated, hermetic devices, e.g. for underwater application.

Wireless charging

Wireless charging is a method, where the energy for charging a battery is transferred without a plug connector (wireless) and without an electric contact (solid-state). The energy could be provided with following methods:

forms of energy	force component	modifier	output	range	efficiency factor
optical	radiation	LED solar cell	mW	m	< 1%
mechanical	motion	piezo modifier	W	um	80%
capacitive	voltage	electrode	uW	um	60%
inductive	current	coil	kW	cm	98%
electromagnetic field	wave	antenna	uW	km	< 1%

In practice the inductive transmission with two coils goes into action (transformers coupling).

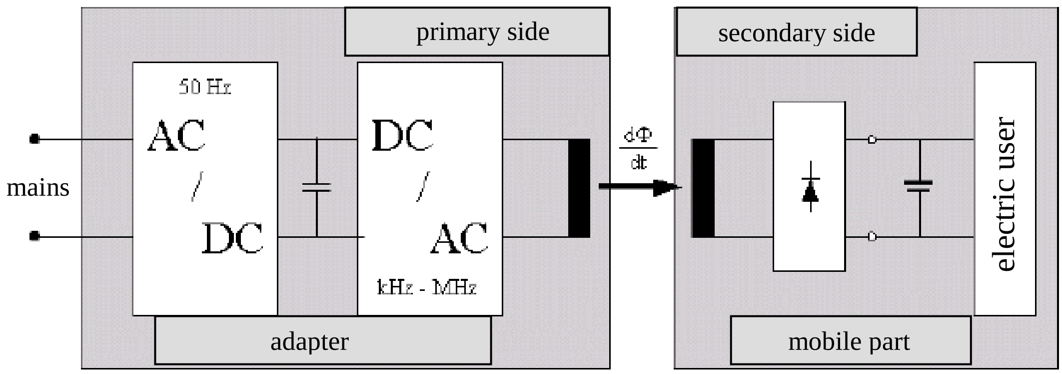


Figure 11.9: Block diagram of an inductive charger (11)

The contrast to a conventional transformer is only, that the primary and the secondary side are mechanical separated. For charging the mobile part is placed in the adapter. The electric power is transmitted between the two parts in an inductive way, i.e. without a direct electric contact. The distance is only about a few millimetres. After charge the primary side of the transformer remains stationary in the adapter. The secondary side is in the mobile part and is abstracted out of the adapter during using.

Advantages:

- No contact debit / wearing
- Potential-free
- Hermetic closed
- Error free

Disadvantages:

- Adapter and mobile part form a constructive unit

Examples for inductive wireless charging:

application	power	benefit
electrical toothbrush	mW	easy handling
implants	mW	no plug possible
medical devices	W	easy handling
electric cars	kW	handling, safety
hearing aids	mW	handling resp. implant
explosion protective device	W	solid-state, hermetic

While conventional charger consists of two functional blocks, charger and power control, the inductive wireless charging makes allowance for a third component, the wireless transfer way (power and control signal).

Transformers coupling

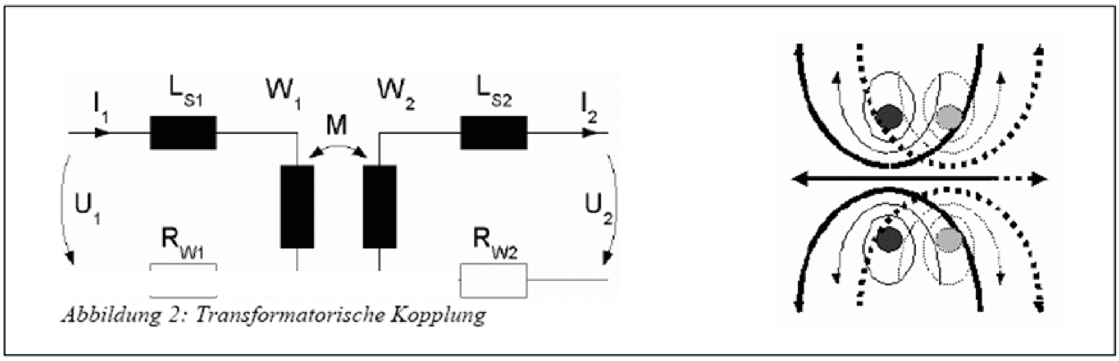


Figure 11.10: Transformers coupling (11)

The principle of transformers coupling is shown in figure 1.2. The transmitter consists of two coils, which are chained with their flow. The single inductivity divides in the one part, which is connected to the opposite field of the other coil (compare M and the bold line in figure 1.2) and the remaining rest (compare Ls in figure 1.2). As in the remaining rest only voltage drop and idle power accrues, it has to be very little opposite the main part.

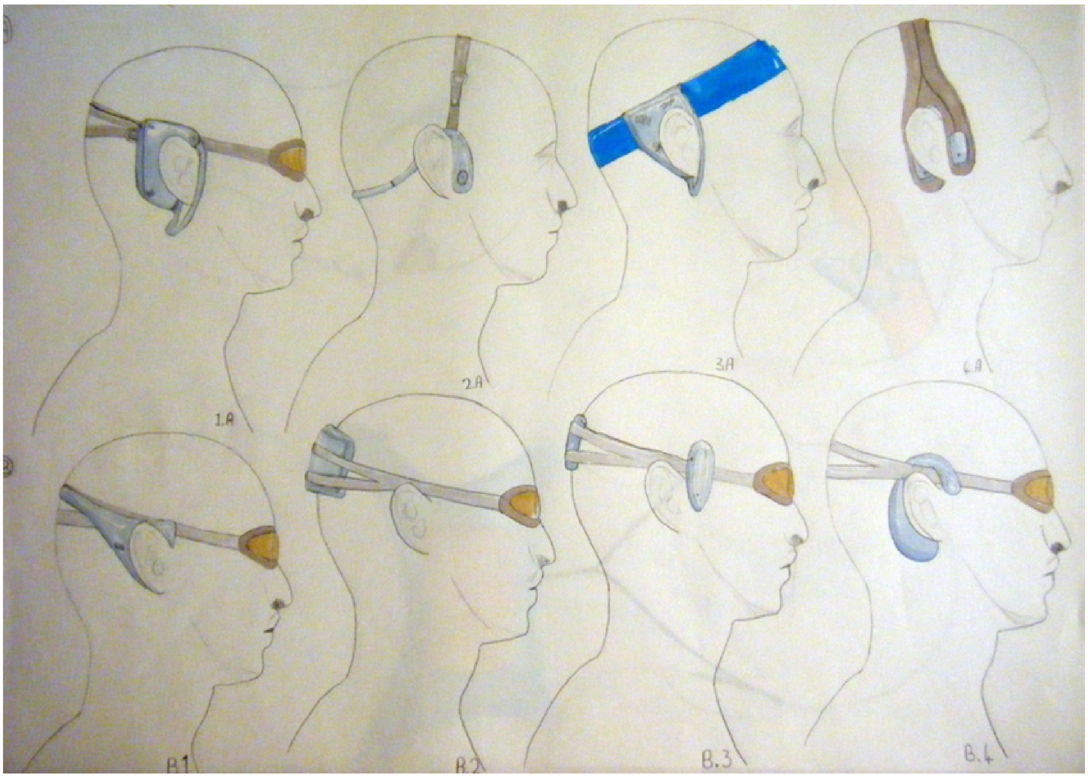
In many fields, like implants, there is a mechanical minimum distance of the coils and the precise covering is not in every time interlocking.

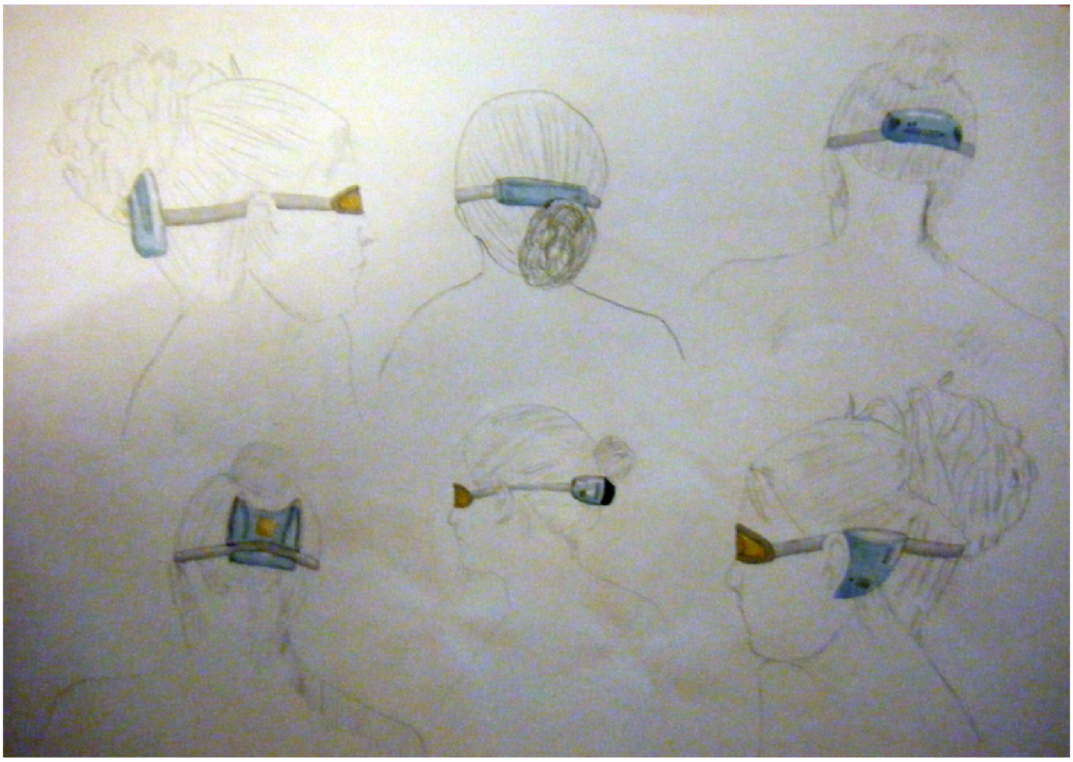
To describe how the order of the coils affecting the electrical transmission, the Neumann's equation is a general formula to describe this problem.

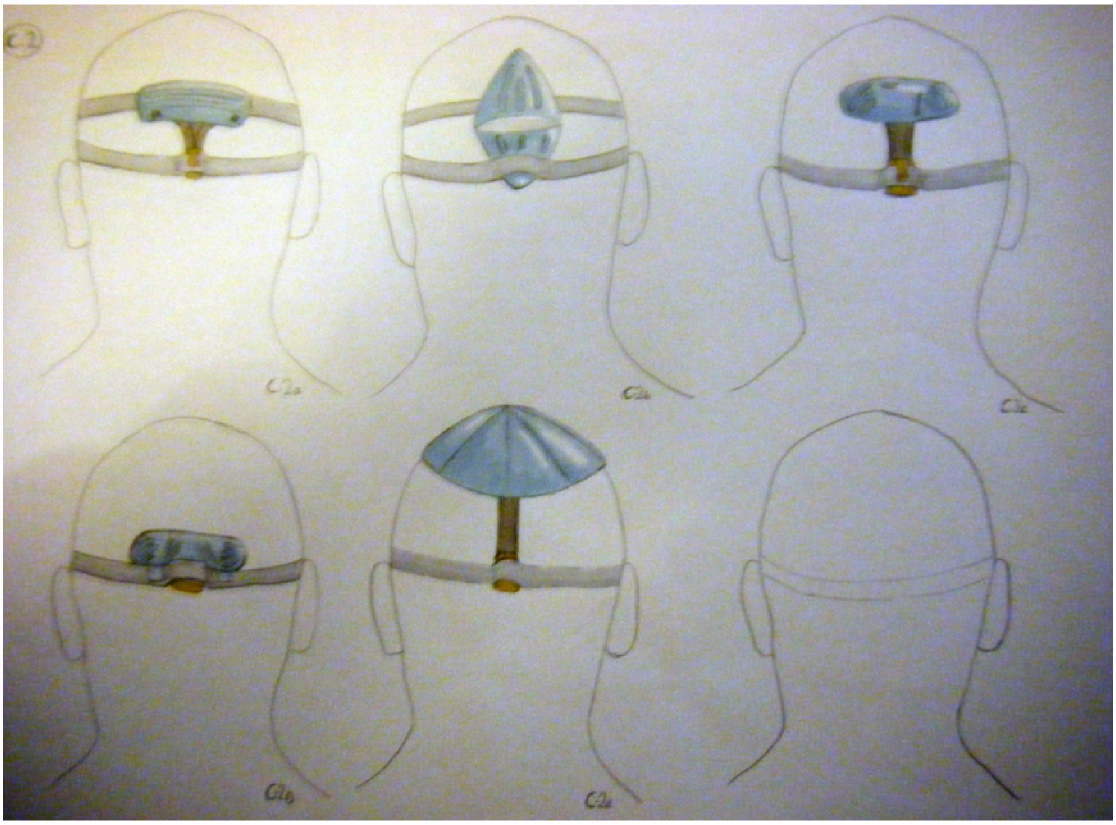
$$M = \frac{\mu}{4\pi} \oint_{I_1} \oint_{I_2} \frac{dI_1 \; dI_2}{r_{12}}$$

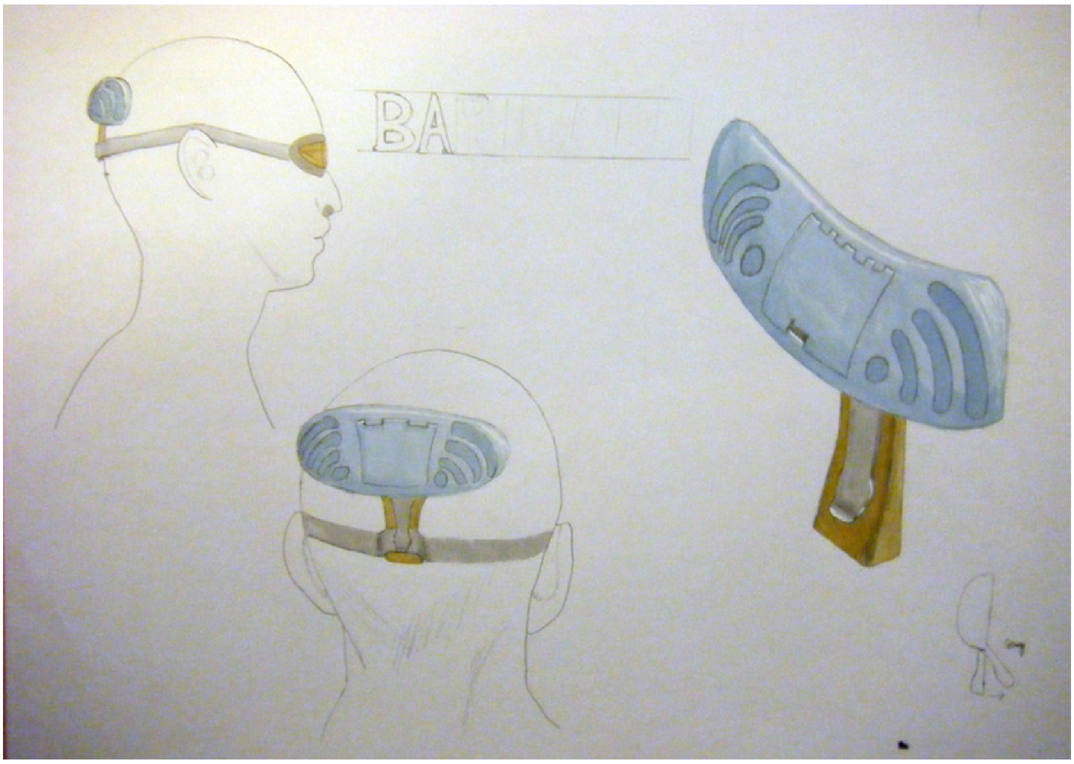
The Neumann's equation constitutes a ring integral over the power flow conductors (I). In practice this kind of calculation is not possible, so it depends mostly on empiric investigations.

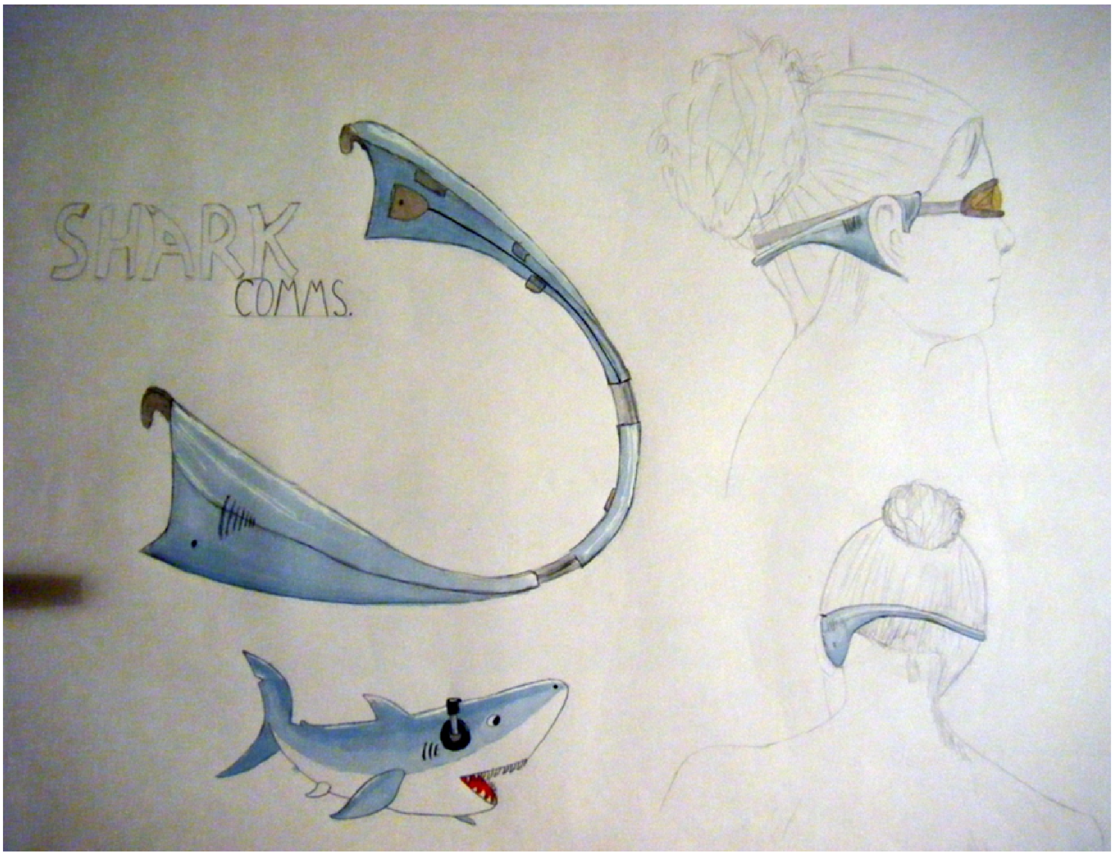
12.10. Supporting Drawings

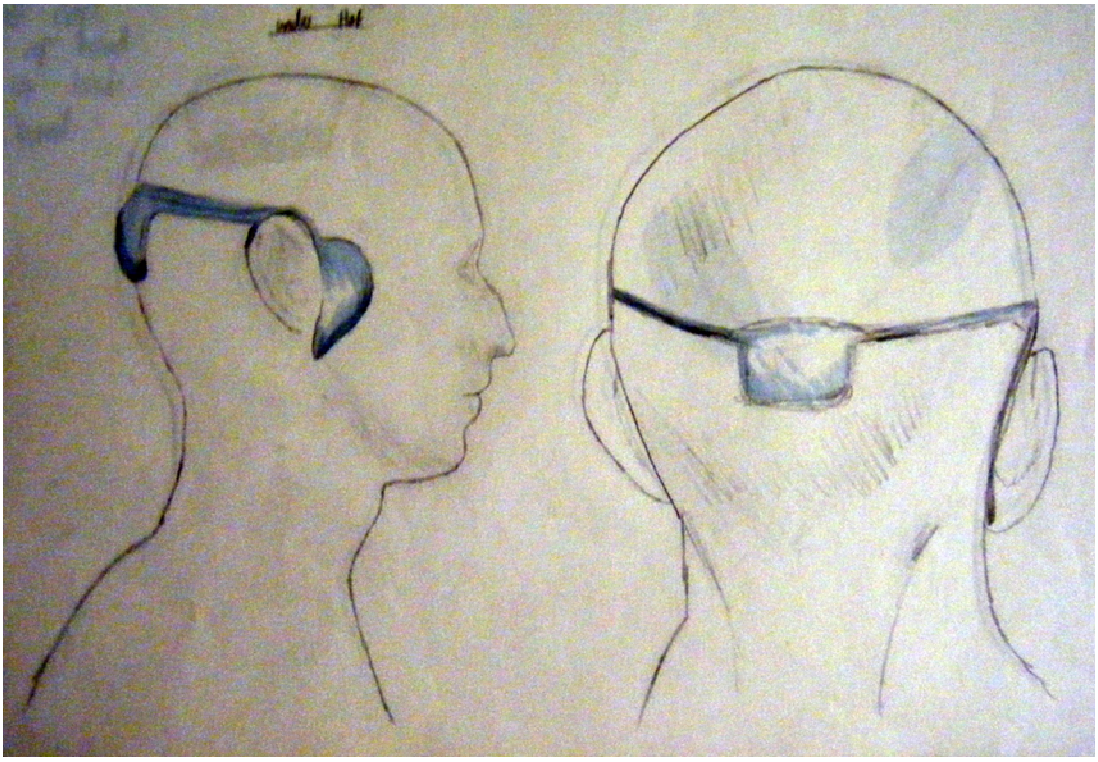


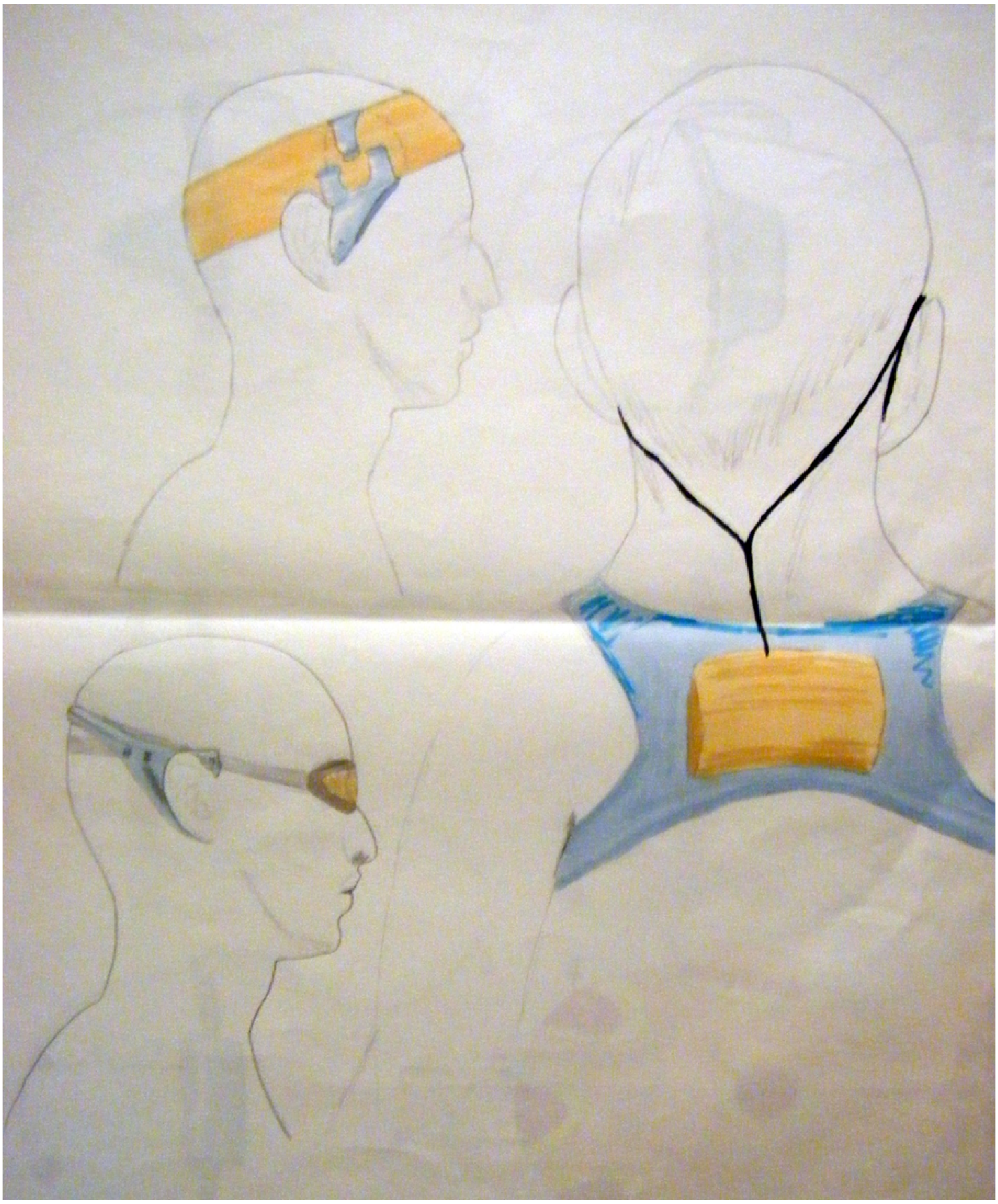


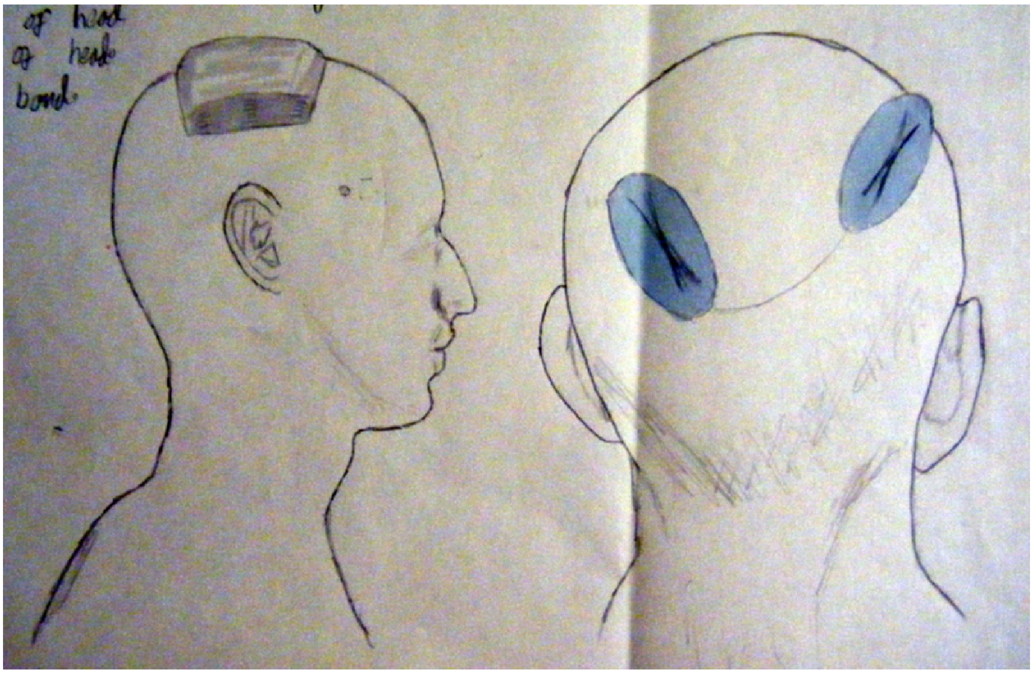


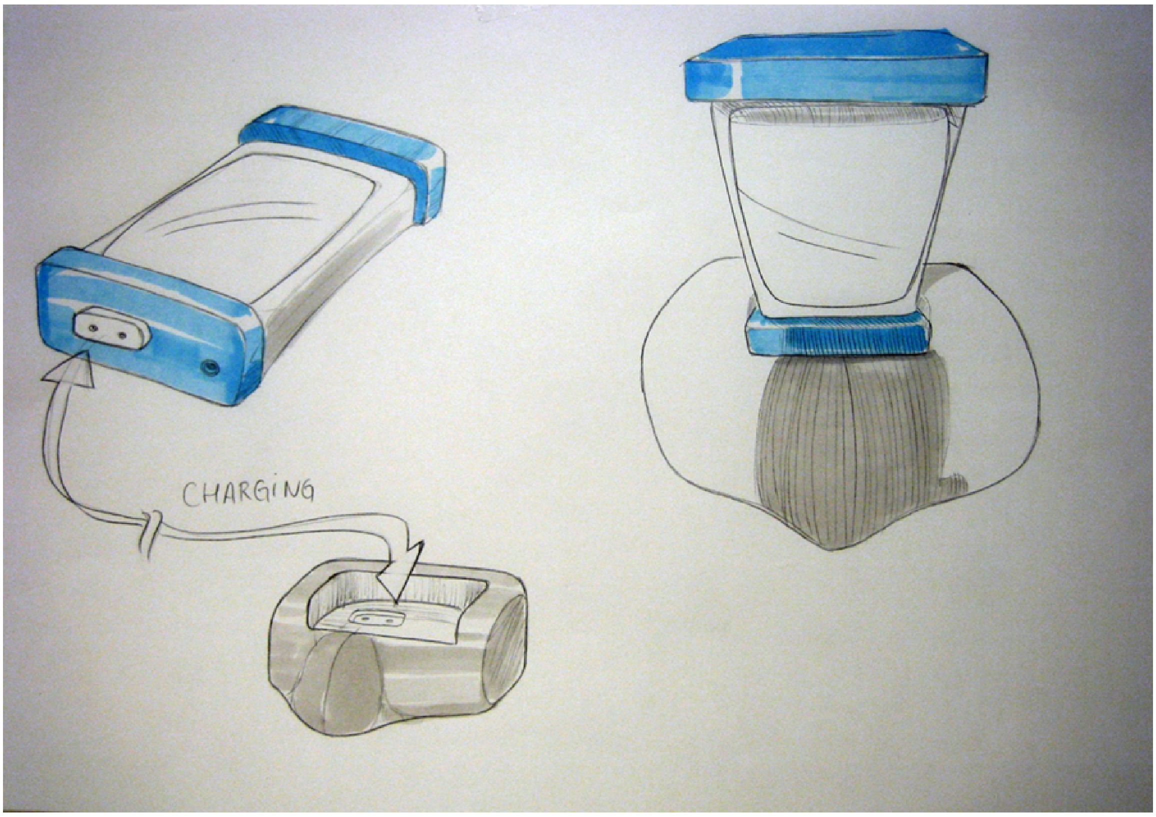

BA

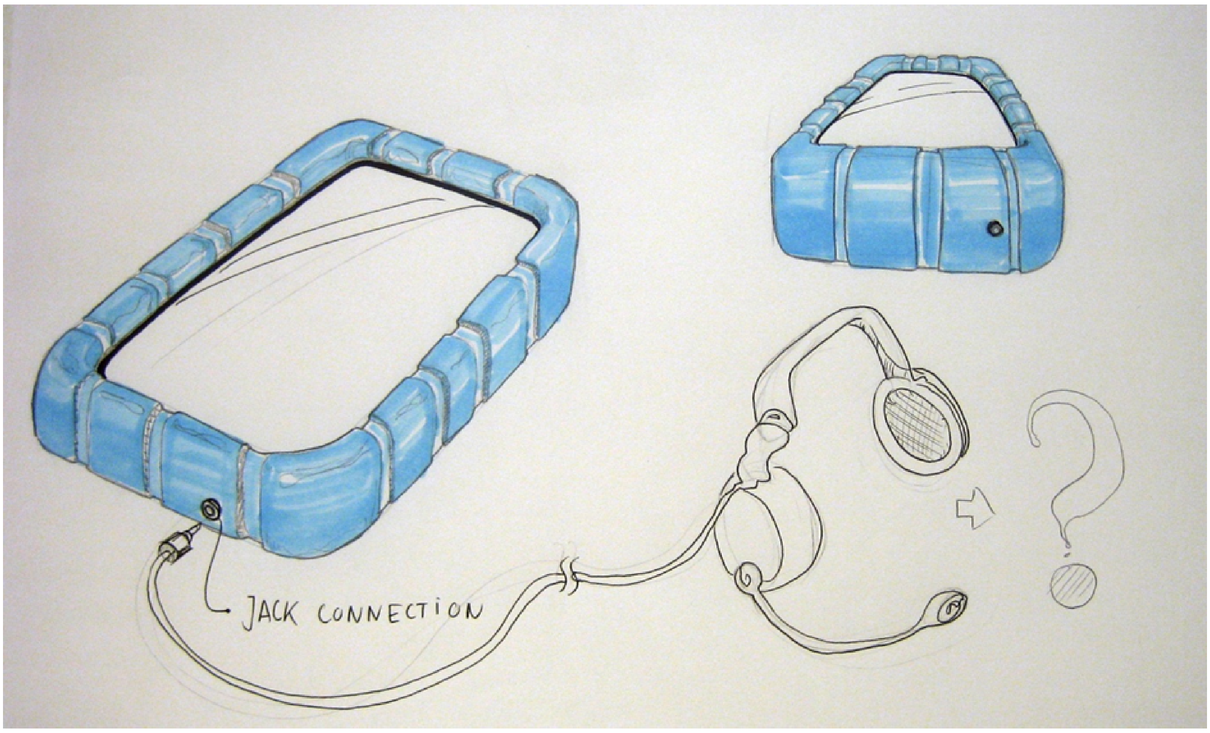

SHARK
COMMS.

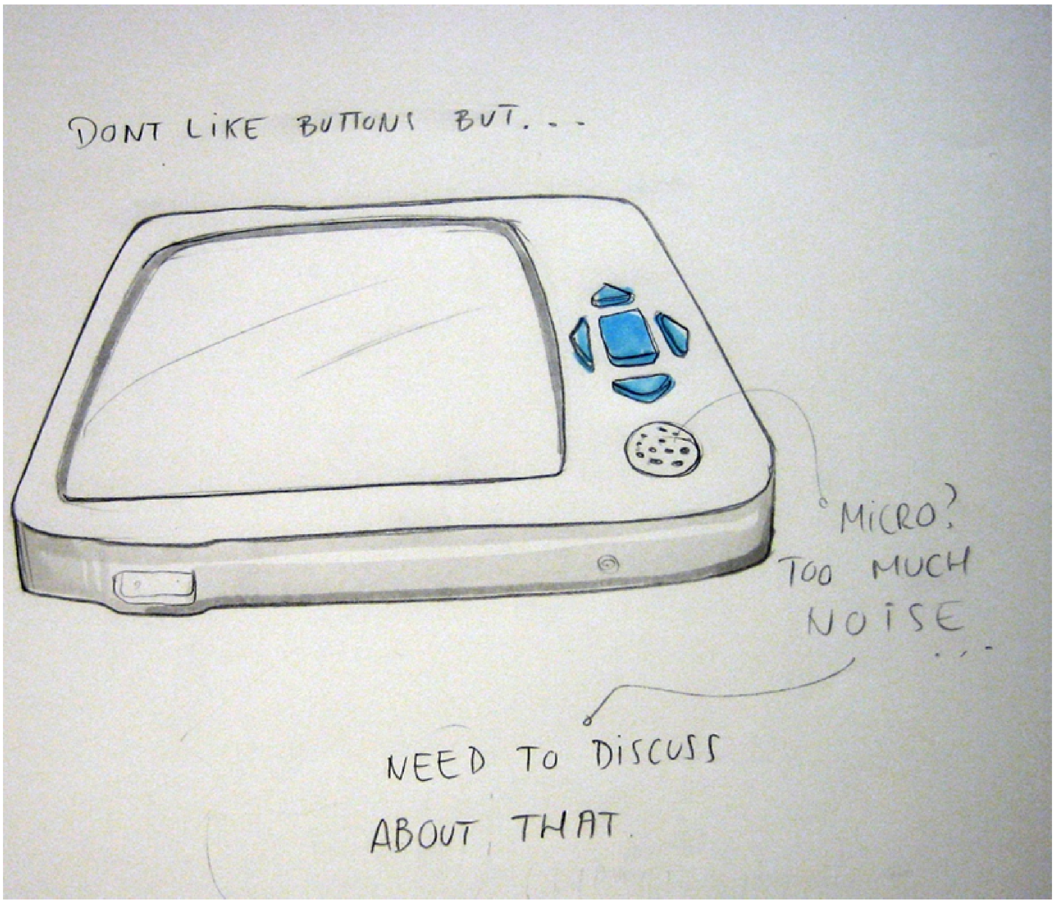




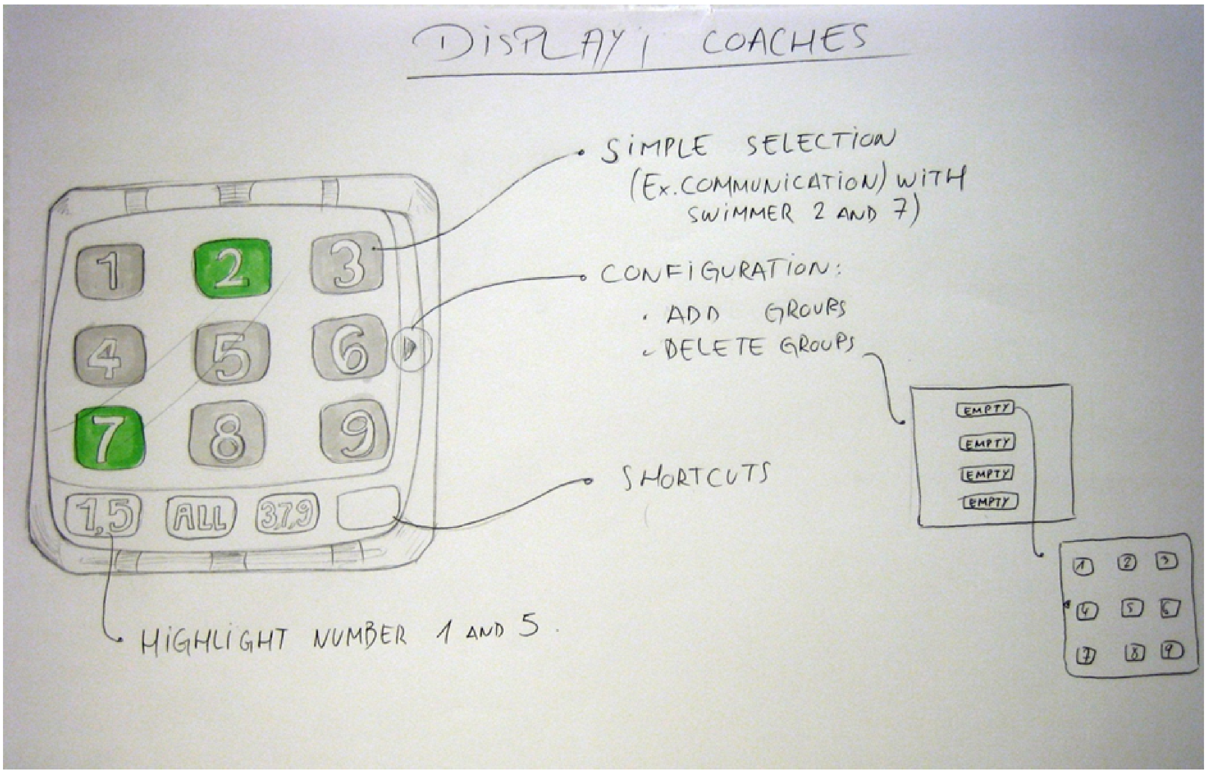

of head
of head
band.

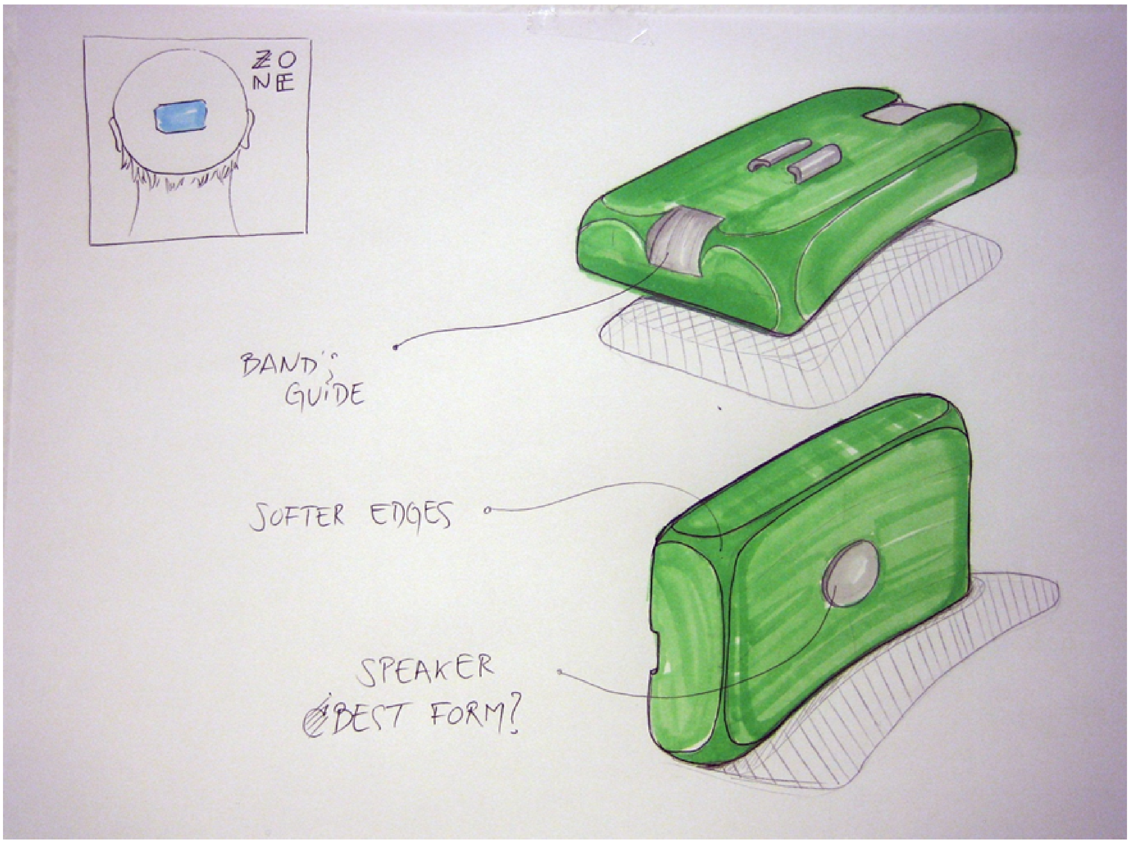

CHARGING

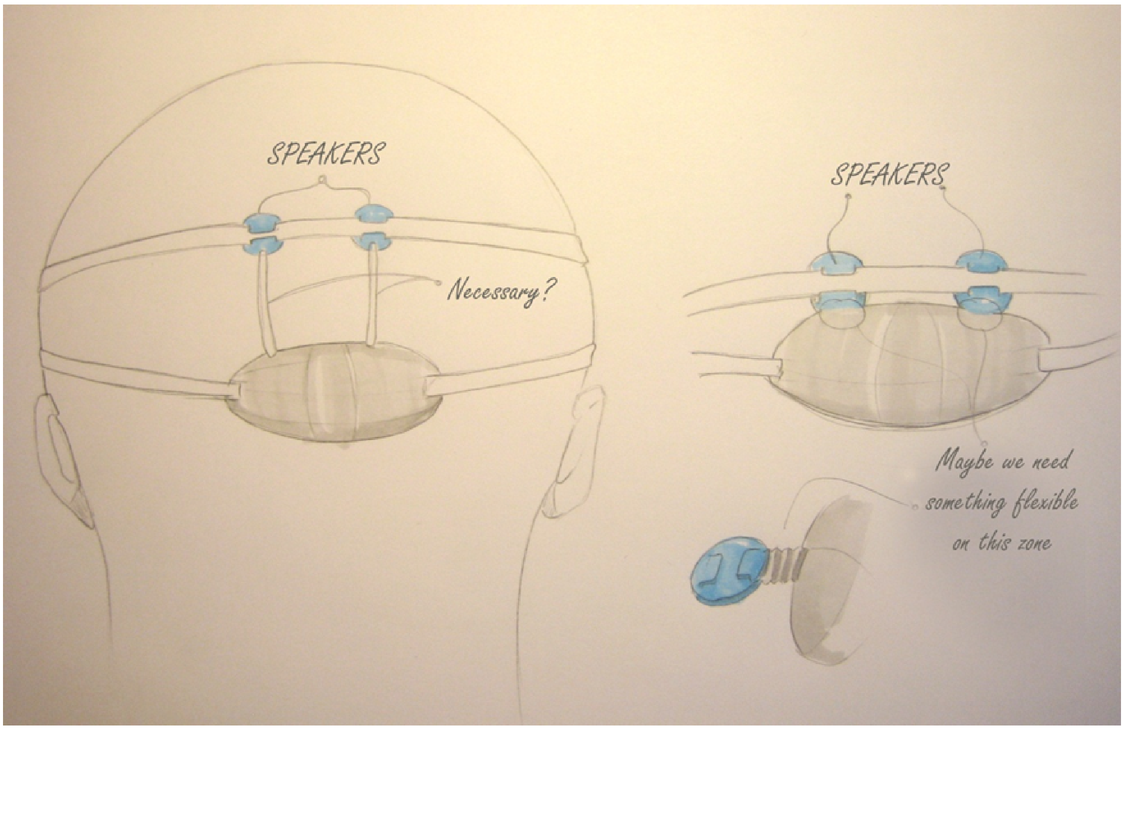

JACK CONNECTION

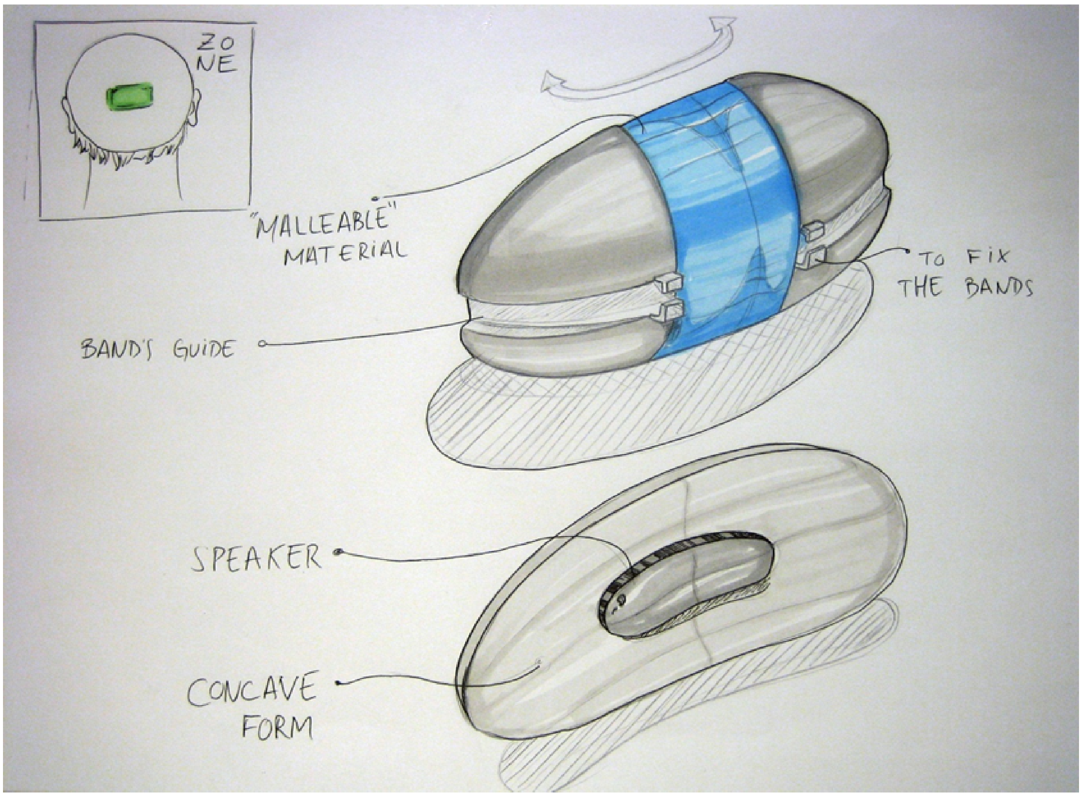

DONT LIKE BUTTONS BUT...
MICRO? TOO MUCH NOISE
NEED TO DISCUSS ABOUT THAT.

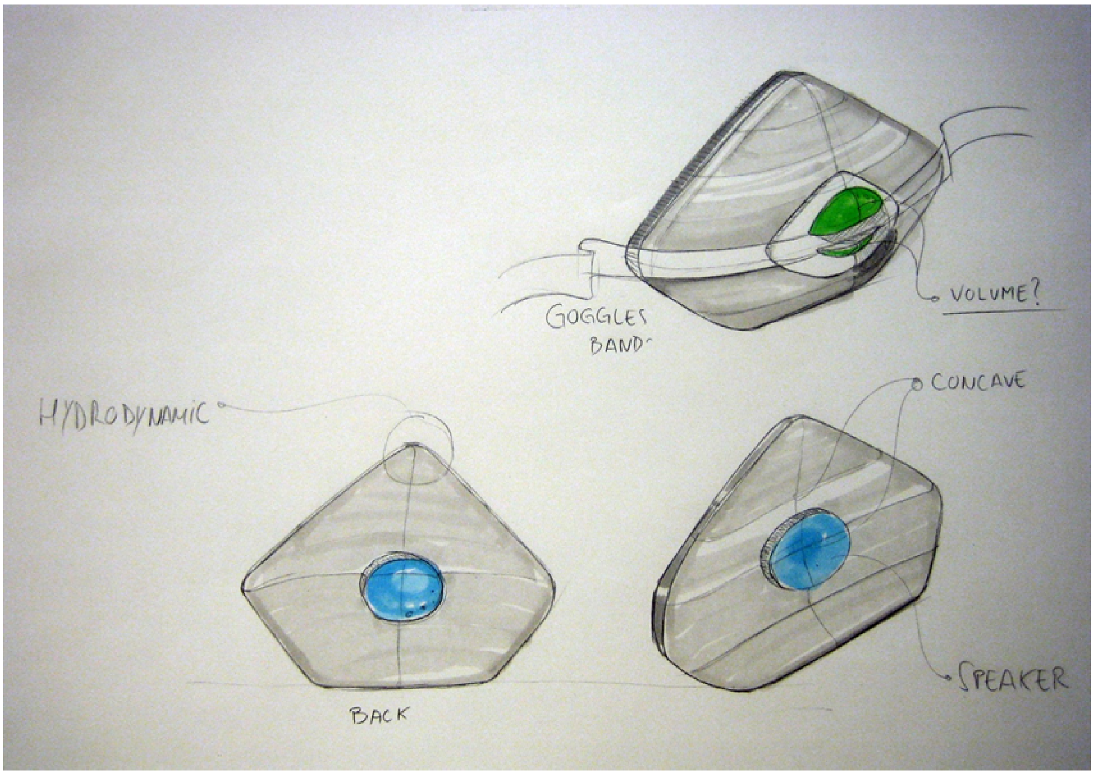
Appendix
18

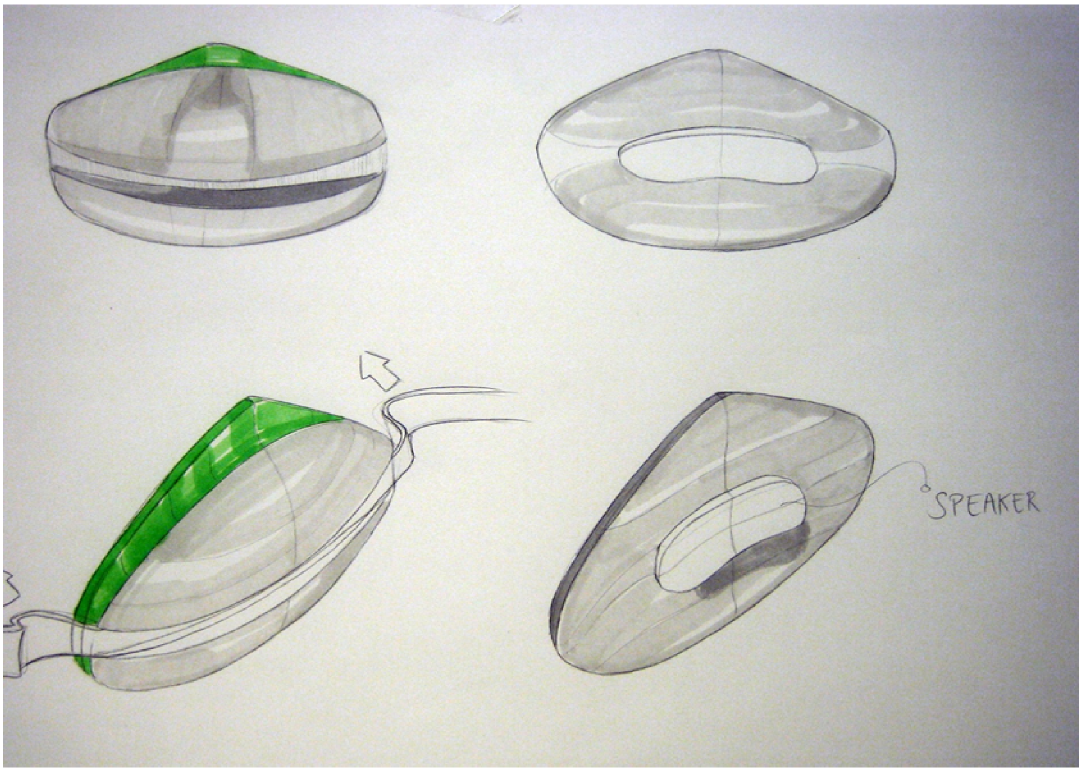

DISPLAY | COACHES
SIMPLE SELECTION
(Ex. COMMUNICATION) WITH
SWIMMER 2 AND 7)
CONFIGURATION:
· ADD GROUPS
· DELETE GROUPS
SHORTCUTS
HIGHLIGHT NUMBER 1 AND 5.
1
2
3
4
5
6
7
8
9
1,5
ALL
3,7,9
EMPTY
EMPTY
EMPTY
EMPTY


ZONE
BAND'S GUIDE
SOFTER EDGES
SPEAKER
¿BEST FORM?


SPEAKERS
Necessary?
SPEAKERS
Maybe we need something flexible on this zone


ZO
NE
"MALLEABLE"
MATERIAL
TO FIX
THE BANDS
BAND'S GUIDE
SPEAKER
CONCAVE
FORM


VOLUME?
GOGGLES
BAND
HYDRODYNAMIC
CONCAVE
SPEAKER
BACK



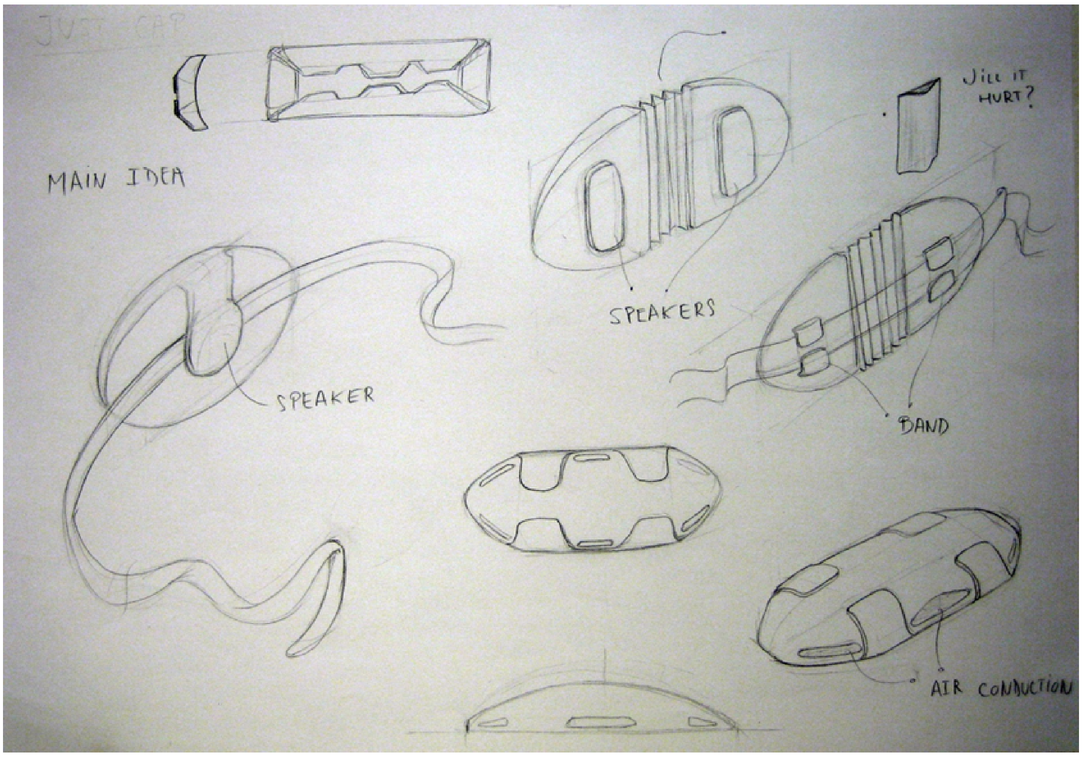


Figure 61 : Supporting drawings