



Intelligent Sensing Anywhere



**Faculdade de Ciências e Tecnologia
Universidade de Coimbra**



Remote Vital Signs Monitoring

Instrumentation Module

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Master of Biomedical Engineering

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Instrumentation Module

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The mind stretched to a new idea never goes back to its original dimensions.

Oliver Wendell Holmes Jr.

ABSTRACT

The financial and physical constraints actually practiced on the healthcare level and the increasing number of elderly people, once baby boomers approach retirement, will create a tremendous strain, most probably leading to a seizure of healthcare systems.

Innovative wireless communication technologies combined with the overloading of healthcare providers opens a profitable new market segment possibly solving this problem.

The creation of a mobile care system facilitating a constant and secure supervision of the patients, allowing their ability to continue a daily routine, is the objective of this project. Its construction is based on the use of short and long-range wireless technologies to remotely transmit physiological data real-time enabling continuous care.

This thesis is focused in the hardware architecture, schematic and PCB design of all the modules involved in the remote vital signs monitoring system.

RESUMO

As limitações físicas e económicas exercidas actualmente na prestação de cuidados de saúde e o aumento da população idosa levarão a um esforço tremendo que pode originar a ruptura dos prestadores de cuidados de saúde.

A inovação verificada a nível das tecnologias de comunicação sem fios combinada com a conjuntura actual dos sistemas de saúde abre um rentável segmento de mercado que pode solucionar este problema.

Este projecto visa a criação de um sistema de cuidados de saúde portátil que permita uma contínua e segura monitorização dos pacientes, evitando a alteração da sua rotina diária. O sistema baseia-se na utilização de tecnologias sem fios de curto e longo alcance, transmitindo sinais fisiológicos para uma central de enfermagem continuamente e em tempo real.

Esta tese fornece uma descrição da arquitectura do sistema a nível de hardware, dos esquemáticos e PCB layouts de todos os módulos envolvidos na monitorização remota de sinais vitais.

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To all my colleagues and friends for the good work environment; their support and friendship so helpful in critical moments. I have to underline my project colleague, Nuno Varelas, for his ideas and his bright way of finding always a different approach when obstacles arise.

My special thanks to engineer Miguel Cardoso for having supported my learning in electronics field. I'm very grateful for his advices, patience and guidance along the course of the project.

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ACRONYMS

A/D	Analogue to Digital
AC	Alternate Current
AES	Advanced Encryption Standard
BAN	Body Area Network
CAD	Computer-aided design
CAE	Computer-aided engineering
CCC	Centro Cirúrgico de Coimbra
CE	Conformité Européenne
CEI	Centro de Electrónica e Instrumentação
CMOS	Complementary Metal-Oxide Semiconductor
CPU	Central Processing Unit
DC	Direct Current
DCE	Data Communication Equipment
DRC	Design Rules Check
DTE	Data Terminal Equipment
EAGLE	Easily Applicable Graphical Layout Editor
ECG	Electrocardiogram
EDA	Electronic Design Automation
EDR	Enhanced Data Rate
EEPROM	Electrically Erasable Programmable Read-Only Memory
ETSI	European Telecommunications Standard Institute
FCC	Federal Communications Commission
FET	Field-Effect Transistor
FPGA	Field Programmable Gate Array
GGSN	Gateway GPRS Support Node

GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GSN	GPRS Support Node
Hb	Haemoglobin
I/O	Input / Output
I ² C	Inter Integrated Circuit
IC	Integrated Circuit
IEEE	Institute of Electrical and Electronics Engineers
INFARMED	National Authority of Medicines and Health Products (Portugal)
IPC	Association Connection Electronics Companies
ISA	Intelligent Sensing Anywhere
ISM	Industrial, Scientific and Medical
LAN	Local Area Network
LED	Light Emitting Diode
MAC	Media Access Control
MIPS	Million Instructions per Second
MOSFET	Metal Oxide Semiconductor Field-Effect Transistor
OE	Output Enable
OSI	Open Systems Interconnection
PAN	Personal Area Network
PC	Personal Computer
PDA	Personal Digital Assistant
QoS	Quality of Service
RAM	Random Access Memory
RMS	Root Mean Square
RTC	Real Time Clock

R&D	Research & Development
SGSN	Serving GPRS Support Node
SIG	Special Interest Group
SMS	Short Message Service
SPI	Serial Peripheral Interface
SpO ₂	Saturation of peripheral Oxygen
USB	Universal Serial Bus
WLAN	Wireless Local Area Network

1 - INTRODUCTION

1.1 - Domain and motivation

Telemedicine generally refers to the use of communications and information technologies for the delivery of clinical care, where distance is a critical factor, creating a bridge that reduces spatial distance. It goes from a simple call between physician and patient to a complex real time conference between specialists using satellite technology and video equipment. It has an objective of facilitating and optimizing the distribution of human resources and professional competences. [1][2]

Health monitoring is a part of this large concept of telemedicine, consisting in the collection of the variables measured in the human body followed by the transfer and storing of the information. This physiological data should be adequate to fundament the decision making in medical care. The data are operated by healthcare providers whom can be alarmed by the system and intervene in case of distress, being these systems nominated as telecare [3].

There are several factors supporting the changing from conventional to remote monitoring systems, e.g. fewer and reduced duration of hospitalizations, fewer office and emergency room visits and the access constraints to central healthcare units from the rural areas, the elderly and physically challenged people, facilitating greater independence for the patient and avoiding inconveniences of travels and job interruptions. Besides that, home remote monitoring is the most accurate way to obtain physiological data, once the subject is less stressed, so these measurements are not changed by the so called white coat effect (i.e distortion in physiological measures caused by the unfamiliar hospital environment).

In the healthcare providers point of view, the best informed decision making as a result of continuous monitoring and more efficient outreach case management are the most visible benefits gained with remote monitoring. With the increasing of elderly people, who are susceptible to a higher risk of chronic diseases and require continuous care, remote health monitoring can be possible the only economically viable way to avoid the overloading of healthcare providers (regarding financial budget and human resources) and make healthcare accessible to everyone.

1.2 - Objectives

This project aim is developing an accurate system able to acquire, process and transmit vital signs using wireless technologies. The system should be divided in 3 mainly modules: acquisition, transmission and terminal module.

The acquisition module is organized in a (Wireless) Body Area Network (BAN), consisting in a set of mobile sensors, which monitor unobtrusively physiological parameters and communicate through low range wireless technologies (Bluetooth or Zigbee) [4] [5], transmitting data from the body to the transmission module. The system should be interoperable, allowing to add or remove any sensor, in order to obtain the best results to the specific application in which it is being used. The disposition of the sensors should be disposal ergonomically, allowing the user the independence of movements.

The transmission module should support both low and wide range wireless technologies to communicate with both acquisition and terminal modules, respectively. This module should also be portable to decentralize the monitoring of the patient and continue is daily life where he wants to be - at home, at leisure and productively at work or school.

The terminal module should be capable of showing the data round the clock and personalizing the alarms of each patient so the healthcare professional can intervene in case of distress. This module must also store all the measures in a database so the vital signs data will be remotely accessible via Web application. Monitoring-session reports should be created automatically with all relevant information and the data should be statistical treated in an individual patient log. In the end the interface must be user-friendly to minimize the transition impact to the user.

1.3 - Document Structure

This document is divided into 10 chapters where each chapter represents a block with different subjects and developed work.

The present chapter introduces the project domain, motivation and objectives.

Chapter 2 concerns the project management. It refers the project team member and supervisors and the project planning.

Chapter 3 is divided in two main chapters. First the reader is provided with the state of the art of vital signs remote monitoring systems available in the market, crucial to define the project requirements and strengths. Then a brief summary is done about the work developed in other project, Look4MyHealth.

The fourth chapter reports the main previous concepts and technologies studied, required to the beginning of the project development.

Chapter 5 provides the reader with background information about the communication technologies involved in the system and the monitoring scenarios in which each of them are used.

Chapter 6 describes the system's hardware architecture. Only the modules in which the student had intervention are focused.

Chapter 7 refers to the hardware design. The description of the design process and some components features are presented and the basic rules followed to design PCB layouts are briefly approached, pointing out the tolerance of some rules and specific cases when they are not applied. Only the modules designed by the student are explained and not the totality of modules employed in the project.

Experimental tests and system features studied in the prototypes are referred in chapter 8, required to the certifications and marking process, briefly described in the last topic of the chapter.

Chapter 9 refers to the personalized solution develop to a healthcare unit.

The last chapter, the tenth, concludes the project report. The actual status of the project is approached, possible future developments are suggested and a final personal appreciation regarding the project is transmitted.

2 - PROJECT MANAGEMENT

2.1 - Project Team Members

The team is composed of 7 elements: three Biomedical Engineering graduation students, three project coordinators and two technical supervisors.

The students had as main scope the projection and development of the system and the coordinators and supervisors the management and orientation of the work developed by the students.

Table 1 - Project Team Members.

Name	Contribution	Contact
Tomé Matos	Student	tomermatos@gmail.com
Nuno Varelas	Student	nunomsv@gmail.com
Rafael Simões	Student	rafaelsimoesengbiomedica@hotmail.com
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Professor José Basílio Simões	Coordinator	jbasilio@lei.fis.uc.pt
Professor Jorge Landeck	Coordinator	landeck@lei.fis.uc.pt
Engineer Paulo Santos	Supervisor	psantos@isa.pt
Engineer Lara Osório	Supervisor	losorio@isa.pt

2.2 - Project Supervising

2.2.1 - Supervising at CEI

The Electronics and Instrumentation Centre (CEI) has been created in the Physics Department of the University of Coimbra. Schoolmasters, researchers and technicians members of the CEI work on a wide range of research areas including Atomic and Nuclear Instrumentation, Biomedical Instrumentation, Plasma Physics Instrumentation, Microelectronics, Optical Signal Processing and Telemetry and Industrial Control.

The supervision at CEI was conducted by the Professor Carlos Correia and was focused in the first semester of the project, at multidisciplinary levels. The student acquired theoretical background through literature review benefiting the supervisor's assistance in case of interpretation difficulties or resources problems.

Informal meetings were held throughout all the duration of the project development in order to inform the supervisor about the work progress.

2.2.2 - Supervising at ISA

ISA (Intelligent Sensing Anywhere) is a spin-off company of the University of Coimbra that was founded in 1990. The technologic based company integrates a R&D unit that works on the development of complete solutions, which include hardware, firmware and software, for a wide range of application areas: telemetry solutions for the utilities, industrial telemetry and logistics, building management systems, environmental monitoring and control and more recently, in the healthcare and medical field.

In the particular case of the student involved in this thesis, two elements of ISA supervised the project: Professor José Basílio Simões, as the project coordinator and Engineer Paulo Santos, as the technical supervisor. The supervising at ISA initially consisted of periodic meetings that involved the supervisors and took place in the ISA's installations. The project evolution at short and long term was discussed during the meetings, as well as the system's requirements and architecture.

Once the individual tasks of the student were defined, informal and periodic sessions of clarification with the technical supervisor were held. The supervisor gave the student practice explaining regarding the project evolution and clarified the doubts that arose during the work progress.

In the second semester of the project, the student continued his work in the company facilities, benefiting of a closer accompaniment of his work by the technical supervisor and the other colleagues inside the company.

2.3 - Project Planning

The project was mainly divided in 3 functional areas: hardware, firmware and software.

Tomé Matos was responsible for the hardware development of both acquisition and transmission modules and Nuno Varelas the embed firmware into the hardware developed. The creation of a user interface to visualize the data and a database to store all the information was the task assigned to Rafael Simões.

The project started with the analysis of the development done the year before - since this is a continuance project - and what should be the directives and requirements to follow the project during this year. As an engineering system, this project required the acquisition of some technical knowledge and the management of software programs.

In the first semester the attention was divided also with other project, Look4MyHealth, consisting in the collection of physiological data, such like abdominal perimeter, weight and arterial pressure of the patient, as a control method for cardiovascular diseases before the first appointment with the physician. This project also aims to create a national database to study the arterial pressure problems and create credible statistical results, something that does not exist yet.

The first oral presentation took place in February 2008 and marked the end of the first phase of the project.

After this, the students started to work entirely in the Remote Vital Signs Monitoring system. In the hardware development there was a large redefinition of the process since the circuits designed before were dropped and one electronic module in use in another project inside the company was adopted. This module

allocates specific sockets to allow the communication using wire or wireless networks. Since the hardware development had this delay, which was not expected at the beginning of the project, the embedded firmware started to be created in a demoboard and later was transferred to the designed modules.

Later, *Centro Cirúrgico de Coimbra (CCC)*, a well know and accredited private healthcare unit located in Coimbra, demonstrated their interest in the system and a particular solution started to be developed to this case, reaching with this the final aim for this academic year.

3 - KNOWLEDGE ACQUISITION

Before starting this project and after reading the thesis of the students who had been involved in the same project last year, the first step was to get theoretical knowledge about the subject implicated in this project and after that, when necessary, continue deepen specific knowledge. Thus, the knowledge acquisition cannot be restricted to the initial development of the project but it was spread all over this academic year and in this chapter just will be mentioned some aspects of this learning.

3.1 - Electronic concepts

3.1.1 - Power Supply

Whether AC or DC, the supply voltage provides the necessary power to operate the circuit. It requires an energy source and will modify the energy to provide the necessary voltages and currents required by the circuit. This power supply must guarantee circuit operation within a set range (a nominal value with a tolerance), be stable over the operating temperature range, be stable over time, and provide the necessary voltages and currents required by the electronic circuit or system.

A fixed power supply that is to operate indefinitely without being recharged or replaced will operate from either the domestic or industrial mains power supply or from a generator. A portable power supply utilizes batteries, whether disposable or rechargeable (from a fixed power supply). In addition, voltage must be converted from AC input to DC output (using a transformer and diode-based rectifier circuit or a switched-mode power supply), from DC input to AC output (using an inverter, for example, to operate mains powered electronic equipment from a car battery) or even using a DC-DC converter to increase or decrease the voltage supply. We will only deal with this last type of conversion because is the only one used inside the project. [6]

3.1.1.1 - DC-DC Converter

DC-DC converters are electronic devices used whenever we want to change DC electrical power efficiently from one voltage level to another. DC-DC conversion uses linear or switching regulators to do this conversion. Linear regulators are less expensive, more reliable and much simpler but inefficient, because they convert the dropped voltage into heat dissipation. Thus, since linear regulators are not applied in this project, just switching regulators were studied more deeply. [7]

A switching regulator is a circuit that uses a power switch, an inductor, and a diode to transfer energy from input to output. There are three reasons to use switch regulators in spite of linear ones. They can be more efficient, they lost few energy in the transfer - since smaller components and less thermal management is required - and finally because the energy stored by switcher can be transformed to output voltages that can be greater than input (boost), smaller (buck), negative (inverter). But there are some concerns about switching regulators: they can noisy and require energy management in the form of a control loop - nowadays the solution to this control is integrated in switching-mode controller chips. [7]

Buck Regulator

Figure shows a buck regulator circuit, also known as a step-down regulator since the output voltage (V_o) is lower than the input voltage (V_i).

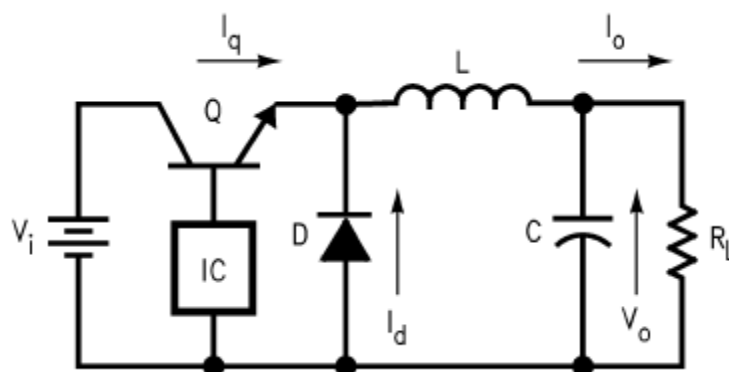


Figure 1- Buck Regulator Circuit. [8]

As we can see there are only for main components: the switching power MOSFET Q, the flywheel diode D, the inductor L and the output filter capacitor C.

A control circuit (often a single IC) monitors the output voltage, and maintains it at the desired level by switching Q on and off at a fixed rate (the converter's operating frequency), but with a varying duty cycle (the proportion of each switching period that Q is turned on). When Q is turned on, current begins flowing from the input source through Q and L, and then into C and the load (R_L). The magnetic field in L therefore builds up, storing energy in the inductor - with the voltage drop across L opposing or "bucking" part of the input voltage. Then when Q is turned off, the inductor opposes any drop in current by suddenly reversing its EMF, and now supplies current to the load itself via D. [9]

Boost Regulator

This second type of regulator is capable of boosting the input voltage, transferring the energy stored in the inductor into the capacitor. The basic boost converter is similar to the buck converter, only the components are arranged in a different way in order to step up the voltage, as shown in figure. Again the operation consists of using Q as a high speed switch, with output voltage control by varying the switching duty cycle. When Q is switched on, current flows from the input source through L and Q, and energy is stored in the inductor's magnetic field. There is no current through D, and the load current is supplied by the charge in C. Then when Q is turned off, L opposes any drop in current by immediately reversing its EMF - so that the inductor voltage adds to (i.e. "boosts") the source voltage, and current due to this boosted voltage now flows from the source through L, D and the load (R_L), recharging C as well. [9]

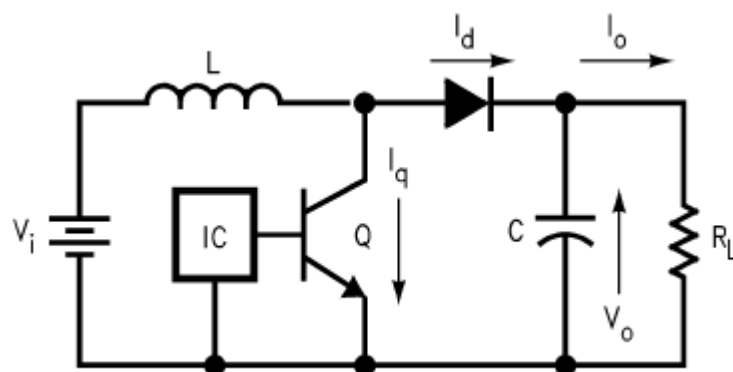


Figure 2 - Boost Regulator Circuit. [8]

3.1.2 - Batteries

A battery consists of one or more electrochemical cells that convert chemical energy to electrical energy. Batteries will be classed as either disposable or rechargeable, where: [10]

1. Disposable batteries transform chemical energy into electrical energy and when the energy has been taken from the battery it cannot be restored. These are “use once” batteries and are carefully disposed of (in accordance with the required legislation) when the battery can no longer provide electrical energy. A range of battery types is available and the type of battery would be chosen for the required application. Battery types include alkaline and silver-oxide.

2. Rechargeable batteries also transform chemical energy into electrical energy, but the energy can be restored by the supply of electrical energy to the battery. These batteries can be recharged and so can be used multiple times. A range of battery types is available and the type of battery would be chosen for the required application. Battery types include nickelcadmium (NiCd), nickel-metal hydride (NiMH) and Lithium-ion.

3.1.3 - System Clock

Almost all electronic circuits and systems require stability and precise timing for the circuit operations, achieved with one or more clock signals. These clock signals are needed to generate the required clock frequencies and to operate at the required power supply voltage levels, and must remain stable (in the generated frequency) over variations in the power supply voltage, over the operating temperature range, and over time. [11] [12]

A clock is generated using one of three types of circuit: RC network, quartz crystal or resonator modules.

For simple clocks, an RC network connected to suitable circuitry within the IC is sufficient. However, accurate timing can be difficult because of tolerances in the values for the resistor and the capacitor.

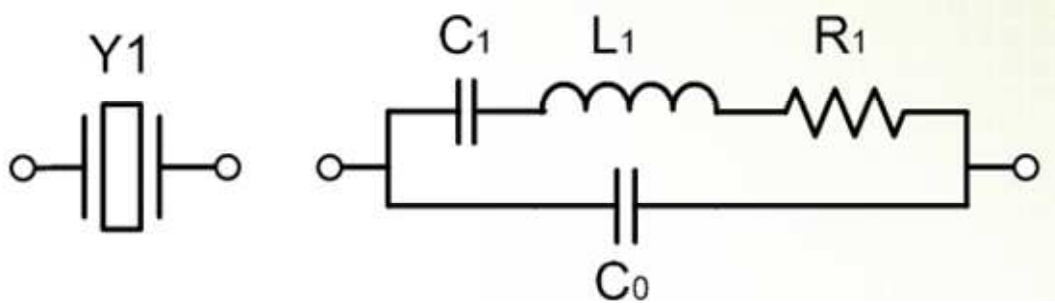


Figure 3 - Crystal equivalent circuit: R1, L1 and C1 represent the quartz and C0 represents the case capacitor at the crystal terminals. C1 is a function of the stiffness, L1 the mass of the quartz and R1 (ESR) the losses of quartz and package. [13]

A quartz crystal (available in either a through-hole or surface-mount package) connected to suitable circuitry within the IC provides more accurate clock. The terminal device is connected to circuitry internal to the IC, so that the crystal creates an oscillatory electrical signal. Figure 4 shows an example of a surface-mount package 7.3728 MHz oscillator module in cut tape case. This is in a metal 4-pin package even if just two of them are connected. The other two can either be unused (not connected) or used in some modules for a clock enable signal.



Figure 4- 7.3728 MHz oscillator module in 4 pads package: top (left) and bottom (right) views.

Resonator modules, which are complete clock signal generators, are made out of layered ceramic (instead of quartz, as with a crystal) and are available in either through-hole or surface-mount packages.

3.1.4 - System Reset

At some point during the operation of a digital circuit or system, there will be the need to reset the circuit into a known state. This is particularly important when the power supply is first switched on to an electronic circuit as the state of the circuit is not then known. Circuits typically include a reset input connection in the pins of their ICs to reset internal connections within the design. The reset signal will be designed to occur when: [10]

- the power supply is initially switched on;
- any time during the normal circuit operation when the circuit must be reset for normal circuit operation.

When the power supply is initially switched on, the power supply voltage will rise to a level at which the IC will start to operate correctly (the power supply threshold voltage), as shown in Figure 5. When this threshold voltage has been reached, the circuit will operate correctly. During the device power-up, the device should be held in its reset state (i.e., the reset input is asserted). After the threshold voltage has been reached, the reset should be removed. The top graph of Figure 5 identifies the power supply voltage rise (in time), and the bottom graph identifies the reset (reset as it is active low here) signal being asserted (logic 0) and removed (logic 1).

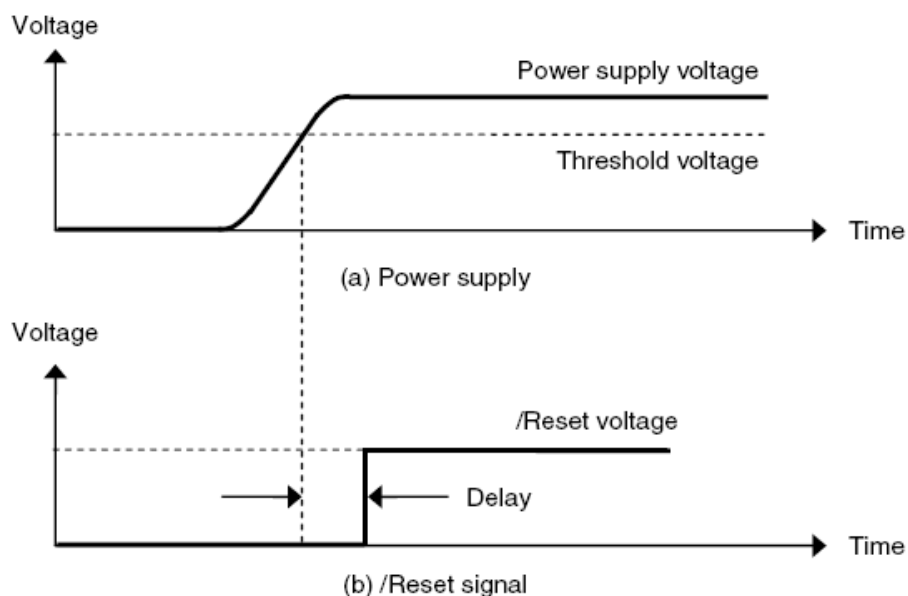


Figure 5 - Power Supply Threshold Voltage. [6]

3.1.5 - Printed Circuit Board (PCB)

A Printed Circuit Board (PCB) consists of an electrically insulating base made up of one or more layers of electrical conductors, onto which conducting metal tracks are patterned to form electrical connections, in which electronic components are mounted to the top, and sometimes the bottom of the insulating base to create a complete electrical circuit. [14]

PCBs are rugged, inexpensive and can be highly reliable. They require much more layout effort and higher initial cost than either wire-wrapped or point-to-point constructed circuits, but are much cheaper, faster and consistent in high volume production. A big part of electronics industry's PCB design, assembly and quality control needs are set by standards that are published by the Association Connecting Electronics Companies (IPC).

3.1.6 - Integrated Circuit (IC)

An IC is an electronic circuit fabricated on a die of semiconductor material, usually silicon based. The die is normally housed within a package although individual bare dies are available.

3.1.6.1 - Microcontroller

A microcontroller is a functional computer system-on-a-chip, integrated in a single in circuit, commonly with the following features:

- central processing unit (CPU) - ranging from small and simple 4-bit processors to complex 32- or 64-bit processors;
- discrete input and output bits, allowing control or detection of the logic state of an individual package pin;
- serial input/output such as serial ports (UARTs);
- other serial communications interfaces like I²C, Serial Peripheral Interface (SPI) and Controller Area Network for system interconnection;
- peripherals such as timers and watchdog;

- volatile memory (RAM) for data storage;
- EEPROM or Flash memory for program and operating parameter storage;
- clock generator - often an oscillator for a quartz timing crystal, resonator or RC circuit;
- many include analogue-to-digital converters;
- very low speed that guarantees little power consumption, making them ideal for low power and long lasting battery applications.



Figure 6 - A PIC 18F8720 microcontroller in an 80-pin TQFP package.

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, remote controls, office machines, appliances, power tools and toys. By reducing the size, cost and power consumption compared to a design using a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to electronically control many more processes.

3.1.6.2 - Level Translator

Nowadays most of electronic systems need voltage level translations in their signal lines, allowing devices with different voltage supplies to communicate with each other.

Dual-supply devices are designed for asynchronous communication between two buses or devices operating at different supply voltages. These devices use two supply voltages: VCCA to interface with the A side and VCCB to interface with the B side. For bidirectional level translators, data is transmitted from A to B or B to A, depending on the logic level at the DIR input. On devices with an output enable (OE) control input, the A and B buses effectively are isolated when OE is inactive. [15]

Dual-supply devices are available in a variety of bit widths and cover nearly every supply-voltage node in use today. These devices are flexible, easy to use, and can translate bidirectionally (up-translate and down-translate), which makes them an ideal choice for most level-translation applications. Their active current-drive capability makes them suitable for applications with long trace lengths and heavy output loads.

3.2 - Product Development Process

3.2.1 - Product management

The process undertaken to develop a product is the means by which a design can be developed from an initial concept through to realization as a product.

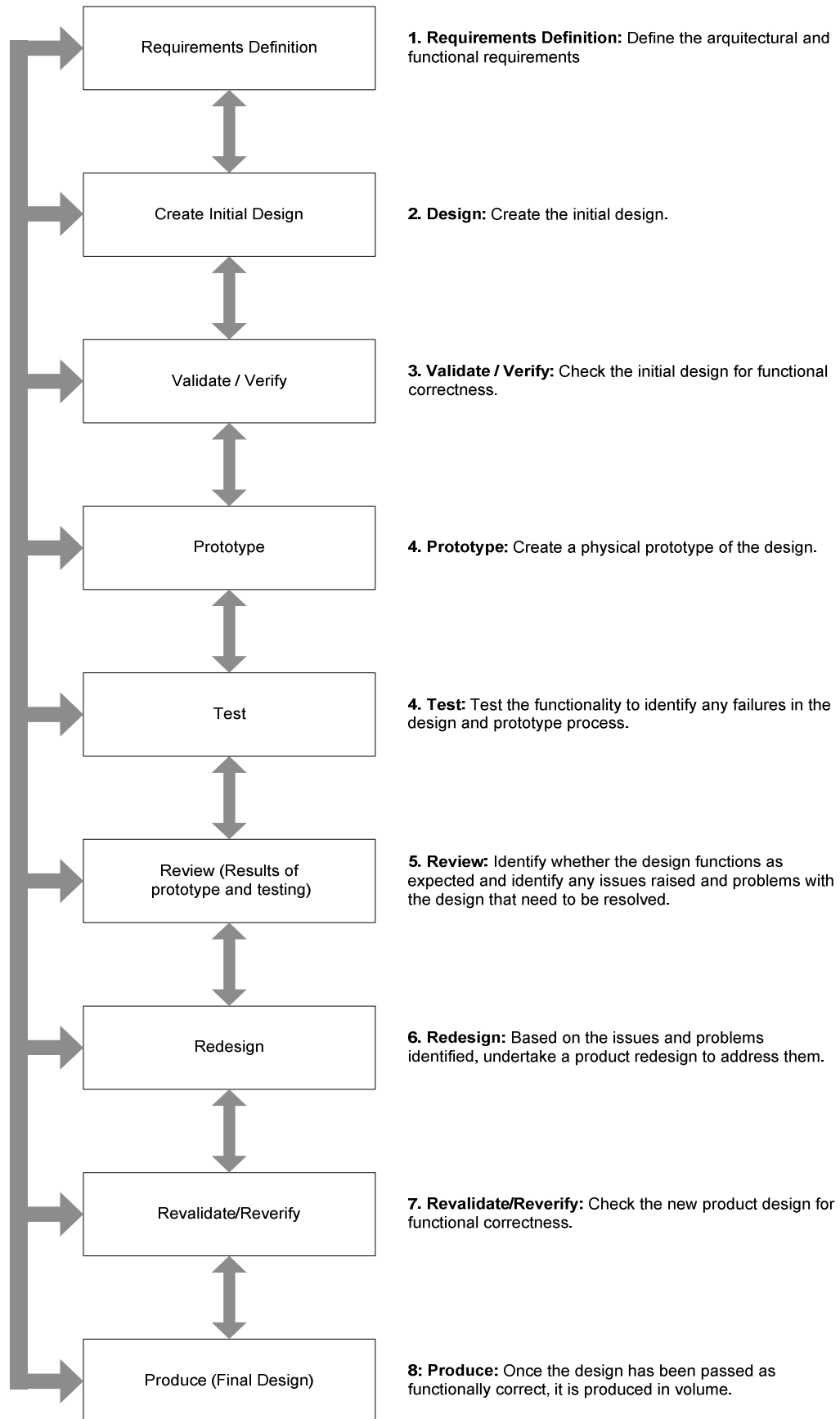


Figure 7 - Product Development Process Flowchart.

It is very important to interlink the different steps, from concept through production and testing, allowing information to be passed among the steps, making possible to deal with the problems and issues in together.

Other departments inside the company (or even outside, in the case of a consulting company) should work in parallel with the development department to guarantee the better route in the product development

The marketing department is entrusted to identify the market requirements and the steps required to develop a product that will be a commercial success. The sales department is incumbent of studying what should be the cost to design, manufacture and test the product; what can be the sale price and convert the idea into a set of documentation.

3.2.1.1 - Electronic Systems Development Process

Applying the product development process strategy to the particular area of electronic systems it is possible to analyse with more detail three key steps to be successful: [16]

- Design: the first step is create a suitable design specification for the required circuit, then construct the circuit schematic (the components used and connections between those components), to meet the initial design specification, and finally develop the PCB layout. Figure 8 represents a flowchart of the steps taking in account in this phase.
- Manufacture or prototyping: the manufacture of the printed circuit board itself must adhere to the design specifications. The two main steps are manufacturing the PCB base (insulating base with metal interconnect) and electrically and mechanically connecting the electronic components to the PCB base (the insulation and electrical connection is usually done according to specialized companies with the appropriate machinery).
- Test: the purpose of testing the design and manufactured PCB is to ascertain whether or not the design is working. Testing is undertaken at a number of points during the design and manufacture. Testing

includes both simulation testing of a model of the PCB design prior to manufacture to determine the functional correctness of the design and physical testing of the manufactured PCB to take the electrical measurements to determine the functional correctness of the manufactured design. [10]

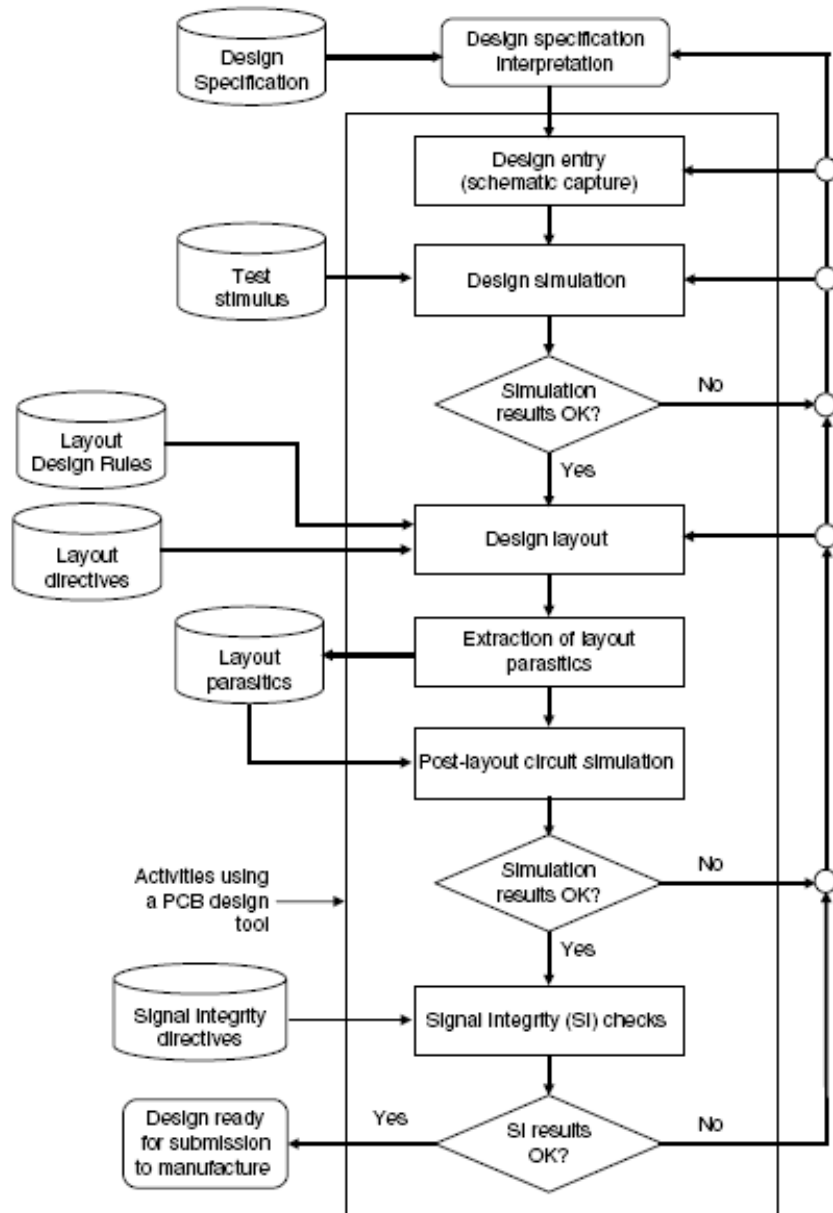


Figure 8 - Design's phase flowchart of electronic systems development. [6]

3.3 - Development Environment

Nowadays a large range of electronic design tools are available for designing both circuit schematics and PCBs, running on the main operating systems. In order to choose which tool is the more appropriate, must be analysed some technical characteristics: the ability to create and edit schematic documents representing the circuit diagram; the ability to create PCB layouts either manually or using automatic place and routing and finally the ability to simulate the design functionality using a suitable simulator. Other than technical characteristics, when choosing a design tool should be considered other elements, like what operating systems are needed for the software tool to operate, what are the licensing arrangements and if there is any maintenance fee; as well as how easy is to learn how to use that specific design tool and what are the documentation and training available to the user for that learning.

The following table presents some of the most well-know design tools and respective currently used and respective companies

Table 2- Examples of design tools software.

Design Tool Name	Company
Allegro PCB Design	Cadence Design Systems Inc.
Board System	Mentor Graphics
EAGLE	CadSoft
Orcad	Cadence Design Systems Inc.
Altium Designer	Altium
Expert PCB	CADRoom
McCAD	EDATools
Express PCB	Express PCB
Ultiboard	National Instruments

3.3.1 - Altium Designer

Presently, the design tool commonly used at ISA for schematics capture and PCB design is Altium Designer, from the Australian CAD/CAE software company Altium. This software allows, in a single electronic product development system, to conceive a variety of activities from concept to completion: system design and capture, physical PCB design, FPGA hardware design, embedded software development, mixed-signal circuit simulation, signal integrity analysis and PCB manufacturing.

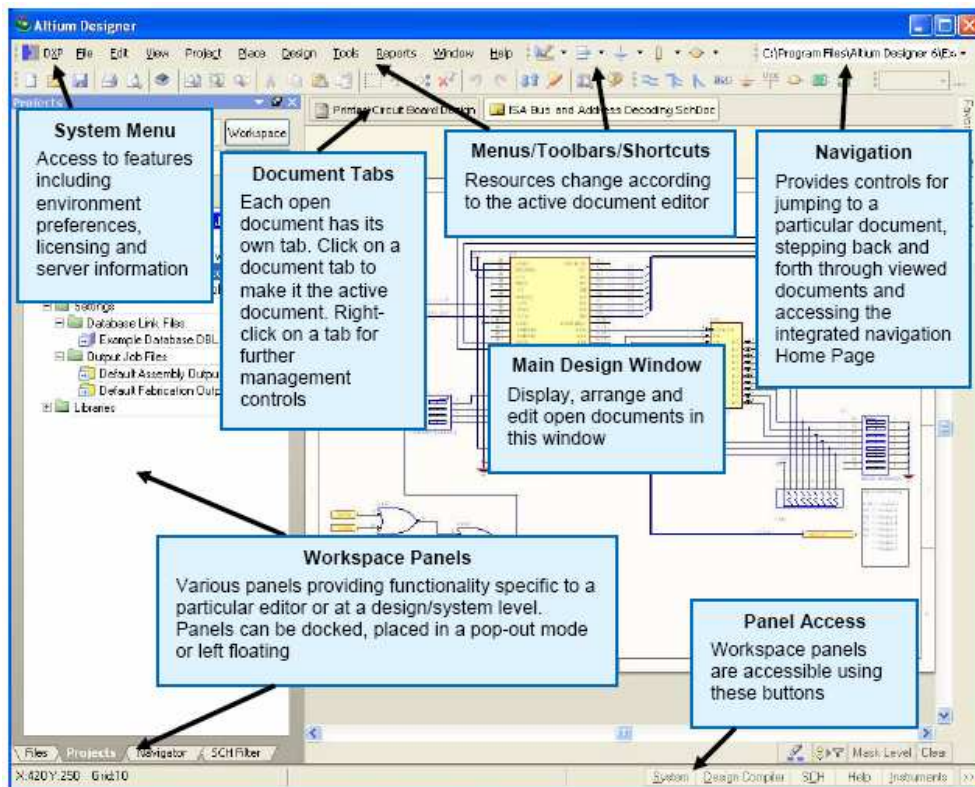


Figure 9 - Altium designer environment and some of his key elements. [17]

Other important features of Altium Designer are the translator and importer technologies, allowing to import or export design files from previous versions or alternative software packages. Incorporated in the software, there's an automatic and unified tool which handles both the schematic and PCB parts of the project, as well as manages the relationship between them.

Finally Altium Designer software brings together a set of tutorials and documentations that makes easier and pleasant the discovery and utilization of this software.

4 - RELATED WORKS

This chapter is divided in two main sections. Firstly the state of the art analysis tries to resume the most important systems that have been developed to monitor remotely vital signs. After, a brief description of the Look4MyHealth project is done, completed by the project specifications report, available in the attachments.

4.1 - State of the Art

Through this state of the art it is pretended to summarize the most outstanding systems in the remote monitoring vital signs field. The system differs according to the type of applications to which they are destined.

4.1.1 - Wealthy

Wealthy project intended to develop a wearable solution for providing vital signs continuous remote monitoring of user, appealing to the flexible and intelligent technologies that will fit in the human body.

The solution propose to help patients in rehabilitation or people who work in environments with extreme conditions of stress, assuring a continuous and intelligent monitoring, that would improve the autonomy and security of the user.

This project developed a prototype that allows the monitoring of ECG, respiratory activity, temperature of the body and detention of position and movement of the body, through sensors integrated in the fabric the prototype.

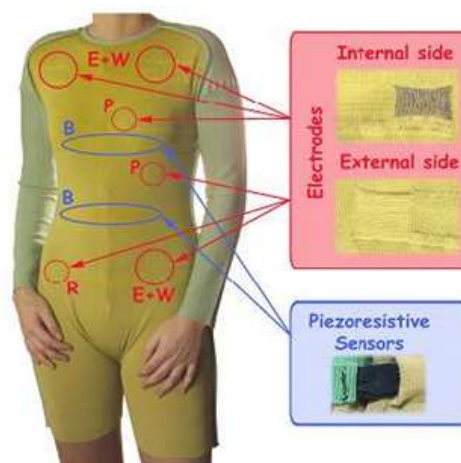


Figure 10 - Prototype developed in Wealthy project. [18]

The acquired data are collected in a portable electronic device, of reduced dimensions, with capacity to effect an initial processing of parameters key and to send the information for a remote clinical unit, through technology GSM/GPRS.

The project has been already prototyped but it has not been yet validated from a clinical point of view.

4.1.2 - SmartShirt

The Sensatex is a North American company who commercializes SmartShirt, a T-shirt with capacity to acquire biometrical information. This product incorporates staple electrum-optics fibers, which creates connection to acquire and to transmit physiological signals to a small controller or PDA.

Following the information is transmitted by technology without wires (in this case Zigbee technology is used) for a local station (PC) to analysis and processing; and it is finally transmitted through Internet for a central unit.

This solution allows the monitoring of the cardiac rhythm, ECG, respiratory frequency, temperature and detection of movement and position. The system is interoperable, allowing the incorporation of other variables.

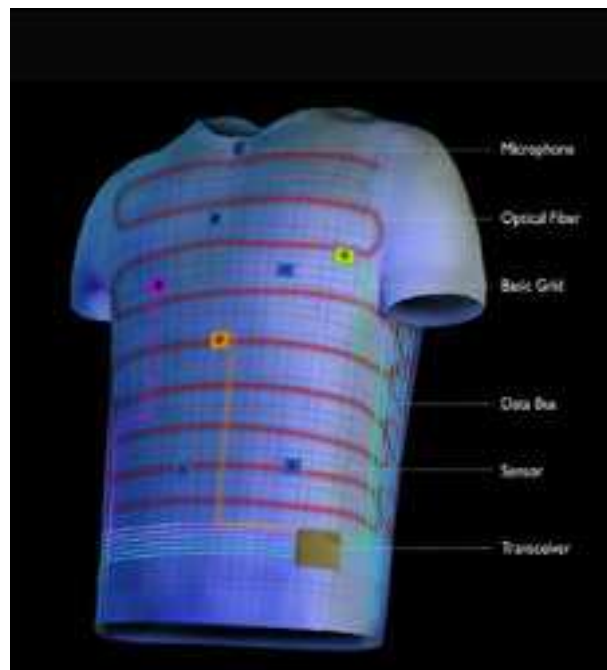


Figure 11 - Smartshirt model. [19]

The Sensatex identified three possible applications for the SmartShirt:

- First Responder SmartShirt: solution for the forces of security and intervention,
- Health SmartShirt: solution suitable for remote monitoring of ill people, allowing the transmission of the information to a healthcare provider;
- Athletic SmartShirt: solution developed for athletes, with the objective of optimizing trainings and performance.

Concerning the suitable solution for healthcare, the Health SmartShirt, it comprises both hospital monitoring, supporting post-operative patients, and telehomecare monitoring, designed for the elderly.

4.1.3 - Ring Sensor

The solution is developed by the investigation laboratory of Biorobotics “D’Arbeloff” and by the Department of Mechanical Engineering, from MIT, under the scope of wearable health monitoring devices.

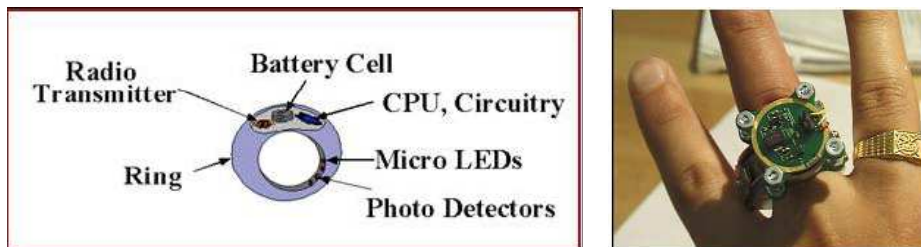


Figure 12 - Sensory Ring - in the left image the architecture and in the right a prototype picture. [20]

Sensory Ring is applied in patient’s finger under the form of a ring, with the ability of monitoring cardiovascular related vital signals, such as cardiac rhythm and its variability, oxygen saturation (SpO_2) in the blood and an estimative of the arterial pressure.

The functioning mode is the one generically used in pulse oximetry, where two LEDs are mounted in the ring, illuminating the base of the finger

After the acquisition of data, its transmission to a mobile phone or PDA is done 433, 92 MHz frequency. Later, data are transmitted to a datacenter through Internet, being visualized by a healthcare professional.

The transmission of data using low-power radio frequency was developed in the laboratory in set with the algorithm to minimize the consumption of the LEDs; enabling the use of the sensor for more than one year using only one lithium battery of 3 V.

4.1.4 - AMON

Project AMON - Monitorial Medical Advanced had as main objective to develop a monitoring device, to use over the pulse of the sick person, allowing the collection and analysis of cardiac vital signals: cardiac beating, oxygenation of the blood, arterial pressure, ECG and temperature.

The AMON is a clinical equipment conceived for high risk patients who need constant monitoring register of their vital signals.

The system allows the emission of alarms when identifies abnormal vital signals, possess panic button and allows reception of written messages of remote operators, as well as take a monitoring autonomy of 24-hour.

This autonomy is obtained through a well-taken energy management, in which samples are transmitted only from 2 in 2 minutes.

The analysis of the collected data use the clinical algorithms installed in the device, which realizes a preliminary diagnosis and later send the data for Telemedicine Centers, using GSM/GPRS technology.

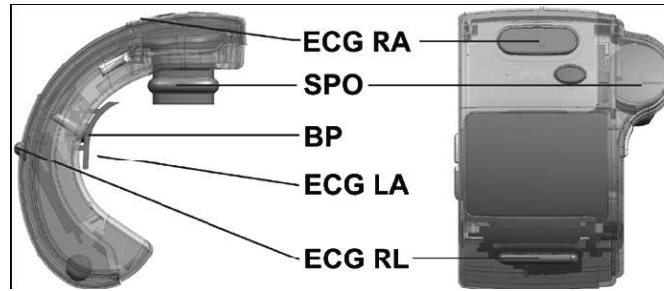


Figure 13 - AMON system. Sensors on the left image: SpO2, ECG with a measure point (RA - right arm, LA - left arm and RL - right leg), arterial pressure, physical activity and temperature. On the right one prototype of the system is shown.

4.1.5 - Health Buddy

The Health Hero Network develops and commercializes the system Health Buddy®. The Health Buddy serves of interface between the patients (in its own house) and the healthcare professionals, aiding the monitoring in chronics illnesses people.

The system includes monitoring technology, database with clinical information of the sick people; support tools via Web and health control programs.

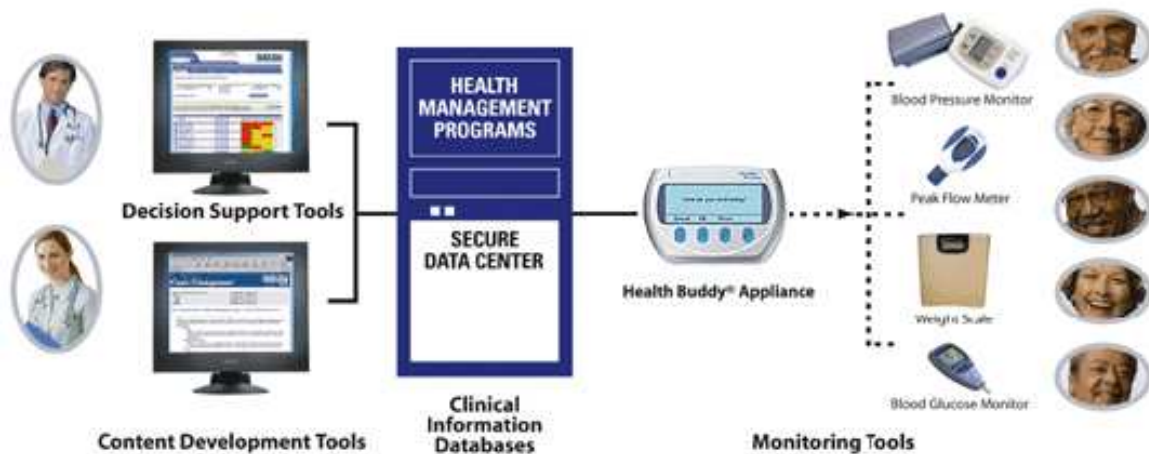


Figure 14 - Health Hero Network. [22]

This system allows to monitoring a variety of peripheral medical devices, such like blood glucose and arterial pressure connected to the Health Buddy Appliance.

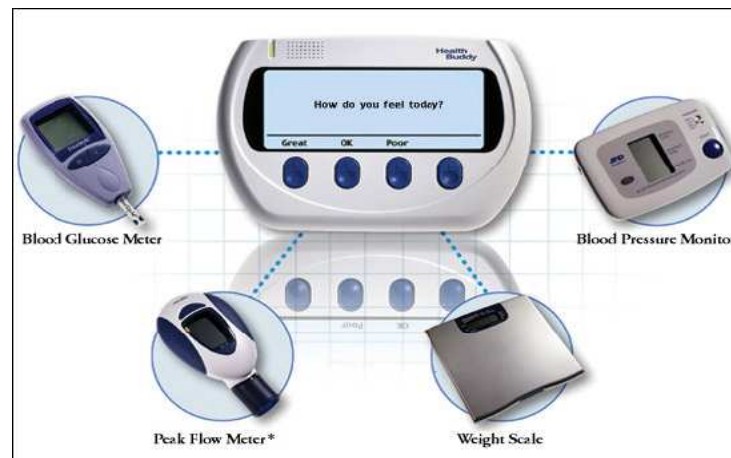


Figure 15 - Health Buddy Appliance. [22]

Several questions are still asked to the patient about the actual symptoms. The combination between the monitoring and the answers given allows the efficient control of his healthcare status.

4.1.6 - Systems analysis

Some of the systems above described present some limitations. Few systems are not sufficient ergonomic to provide the desired mobility and total freedom of movements. Thus, one question to consider is to eliminate the largest amount of wires as possible.

Only some systems are interoperable, i.e. allow the integration or extraction of sensors (and consequently vital signs) depending of the particular application in which the system is applied.

In spite of having being remote monitoring systems some of the solutions do not transmit the data to the healthcare providers in real time. This does not allow a fast intervention by a qualified professional when an emergency occurs. The estimate time to a succeeded reanimation occurrence, after the patient collapse, is about 5 minutes. Thus, to safely proceed to the reanimation the system cannot have delays, once the healthcare professional should be informed about the situation and move until the occurrence spot.

4.2 - Look4MyHealth

As introduced in the project planning (see chapter 2.3 -), the students' attention was divided between the vital signs remote monitoring project and other tasks assigned by the company.

These tasks belonged to Look4MyHealth project, a system developed to the Healthcare Family Centres, and with the main aim of early detecting cardiovascular diseases. These screening exams are led by measuring some physiological parameters relevant to the diagnosis of cardiovascular diseases, as the arterial pressure, the weight and the abdominal perimeter. Any professionals are needed to complete the exam - except for the first time, for possible doubts - since a TFT attached to the system explain all the steps to realize it, saving essential human resources.

The students' tasks were to define the system architecture, which was submitted to several changes along the course of the project, to realize a market research regarding the hardware involved in the system and finally to complete the project specifications report.

System Architecture was implemented as follows, in Figure 16.

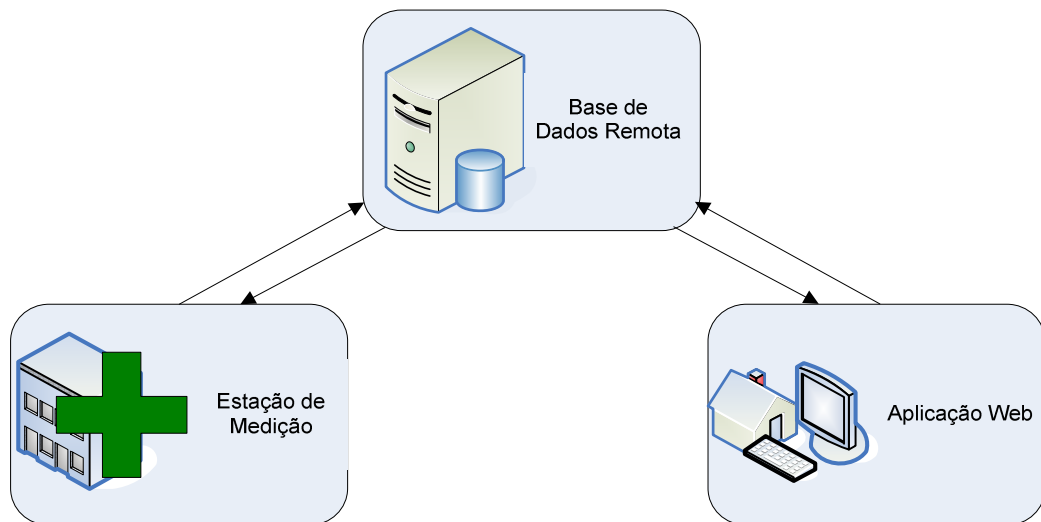


Figure 16 - Look4MyHealth General Architecture

It is divided into three distinct domains (explained from left to right):

- **Measure Station:** responsible by the parameters measure and their transmission to the Datacenter. The communication held by the transmission is UMTS.
- **Datacenter:** here all the patient sessions will be stored, comprising biological signs and other relevant information. Beyond this, it should control the accesses to each Web Application, making the information available.
- **Web Application:** Web portal that allows the visualization of the patient's historic. This is one of the main features of the system, the historical data allow the physician to study the evolution of the signs, making more informed decisions about the patient's diagnosis.

This project was briefly presented, once it does not belong to the main project where students were involved. It is explained in detail in attachment C.

5 - PROJECT REQUIREMENTS

5.1 - Communication Technologies

In this chapter the wireless and wire communication technologies chosen to integrate the system are briefly introduced to support the reader with background information about the system's architecture and execution.

5.1.1 - Short Range Wireless Communication

This type of communication is employed in the delivery of vital signs between the medical sensors and the transmission module. It should guarantee the freedom of movements by one side, and the integrity of the data across the transfer.

5.1.1.1 - Bluetooth

Bluetooth is a low cost, short range radio technology, intended to replace the cables connecting portable or fixed electronic devices [23]. By enabling a standardized wireless communication between any electrical devices, Bluetooth has created the notion of a personal area network (PAN).

Bluetooth communication technology presents the following potentialities:
[24]

- Low cost
- Low size
- Globally available and unlicensed band - 2.4 GHz.
- Authentication and encryption guarantees high security
- Protection against interference
- Point-to-point and point-to-multi point communication
- Low power consumption:

Bluetooth technology is divided in 3 power classes described in table.

Table 3 - Bluetooth power classes.

Class	Power	Range
1	100 mW (20 dBm)	100 m
2	2.5 mW (4 dBm)	10 m
3	1 mW (0 dBm)	1 m

The actual range for each power class may vary depending upon environmental factors where the Bluetooth device is used. Class 3 devices have a very limited range and not very common.

Bluetooth operates in the free ISM (Instrumental, scientific and medical) band using a shaped and binary frequency modulation to minimize transceiver complexity. It supports data rates up to 1 Megabit per second (Mbps) with Basic Rate mode or up to 2 or 3 Mbps with Enhanced Data Rate mode. [24]

It is possible to synchronize a group of device in what is called a piconet, which is the fundamental form of communication for Bluetooth wireless technology. The devices have one of two functions: only one device provides the synchronization reference and it is known as the master and the other devices are known as slaves. Bluetooth communication protocols allow a maximum number of 7 slaves managed by the master.

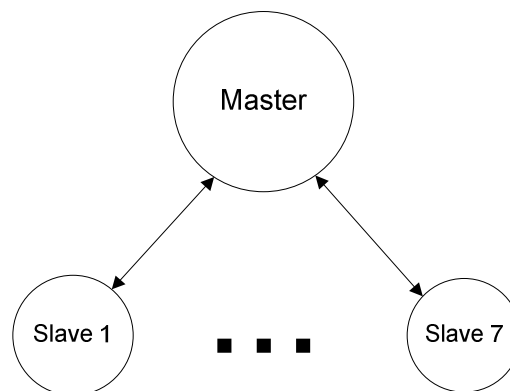


Figure 17 - Maximum piconet established in Bluetooth technology.

The Bluetooth uses an open and global specification defining the complete system from radio to the application level. The protocol stack is usually implemented partly in hardware and partly as software running on a microprocessor, with different

implementations partitioning the functionality between hardware and software in different ways.

5.1.1.2 - Zigbee

The ZigBee is a home-area wireless network, combining HomeRF Lite and the 802.15.4 specification, creating a low power, low-maintenance and highly reliable network [39]. The creation of a mesh network between nodes fills a market niche, since allows the short range of an individual mode to be expanded and multiplied, covering a much larger area.

Following the standard Open Systems Interconnection (OSI) reference model, ZigBee’s protocol is structured in layers.

The first two layers are defined by the IEEE 802.15.4 standard. The physical layer allows high levels of integration, being very tolerant and simple towards inexpensive implementations. The media access control (MAC) allows multiple topologies without complexity, turning it able to reduce the functionality, saving ROM or RAM memory.

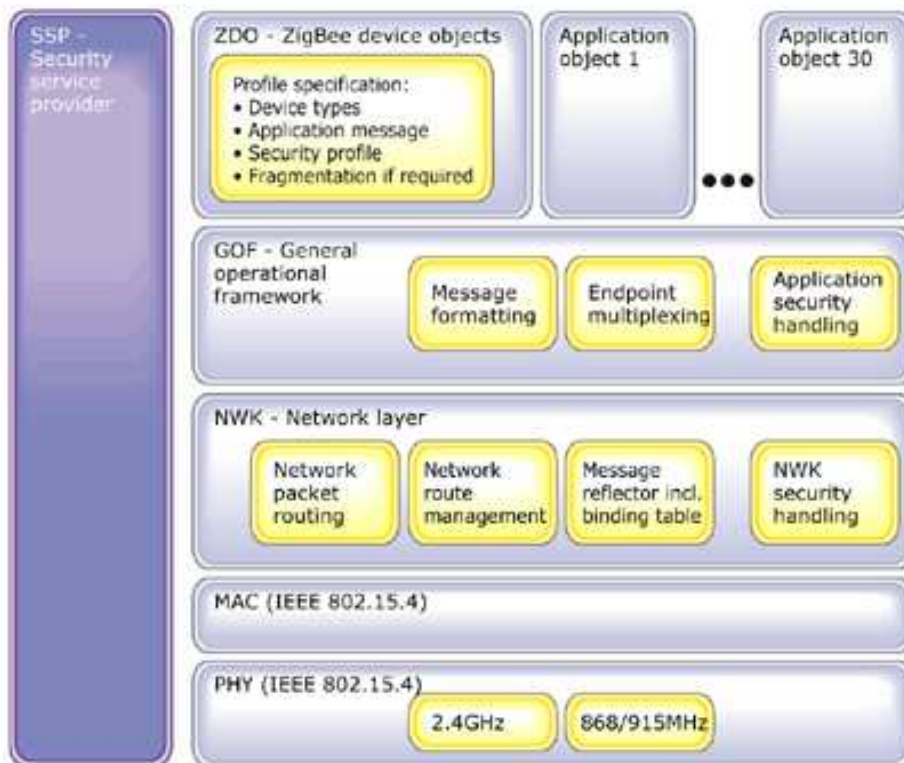


Figure 18 - ZigBee Architecture. [25]

The layers above the first two are defined by the ZigBee Alliance, an association of companies working together to provide the users with flexible, mobile and easy to use wireless intelligence. They focus on defining the network, security and application software layers, providing interoperability and conformance testing specifications and managing the evolution of the technology. [26]

Focusing in the Network Layer, this associates or dissociates devices using the network coordinator, implementing security and routing frames to their intended destination.

The Network Layer supports multiple network topologies including star, cluster, tree and mesh, as shown in Figure 19.

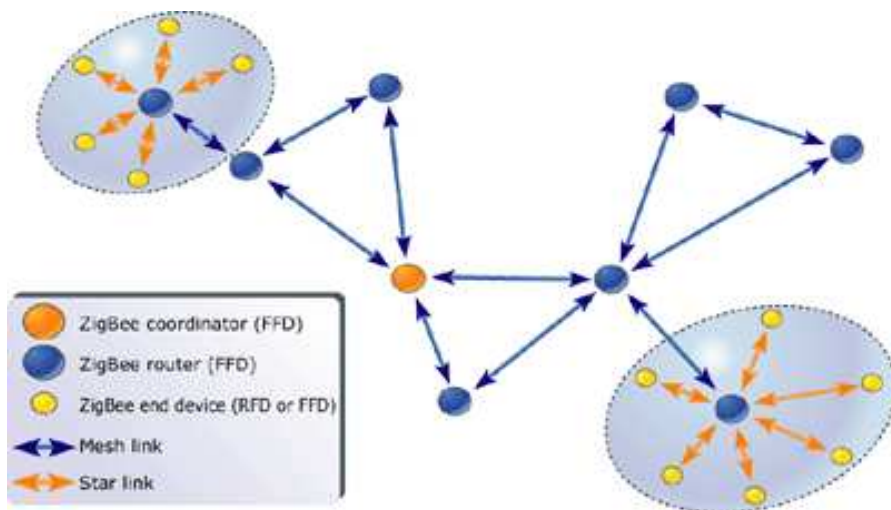


Figure 19 - ZigBee network model [26]

There are three categories of Zigbee devices identified in Figure 19 :

- **ZigBeeNetwork Coordinator**: smart node that automatically initiates the formation of the network tree and might bridge to other networks. There is an exact number of one ZigBee coordinator in each network and it is able to store information.
- **ZigBee Router**: Another smart node that links groups together and provides multi-hopping for messages, being associated with other routers and end-devices.
- **ZigBee End Devices**: contact with the parent node (either coordinator or router), being impossible to relay data from other devices. Working as a slave

device, it can be in deep sleep mode giving long life time. It is represented by the sensors, actuators, monitors switches, dimmers and other controllers.

In summary, the ZigBee technology communication presents the following features: [41] [42]

- 2.4 GHz and 868/915 MHz frequency band:
- low power consumption;
- Data rates up to 250 kbps at 2.4 GHz, 40 kbps at 915 MHz and 20kbps at 868 MHz;
- Low latency for low duty cycle devices like sensors and controls
- Fully hand-shaked protocol for transfer reliability
- Range between 5 and 50 meters (depending on the environment)
- Different topologies: star, peer-to-peer, mesh.

5.1.1.3 - Technologies Comparison

The bandwidth of Bluetooth is 1 Mbps, while ZigBee's is one fourth of this value. Bluetooth strength lies in its ability to allow interoperability and easy replacement; ZigBee is low cost and has longer battery life.

In terms of protocol stack size, ZigBee's 32 KB is about one-third of the stack size necessary in other wireless technologies (limited end devices stack size is as low as 4 KB).

Bluetooth is meant for such target areas as wireless USBs, handsets and headsets, whereas ZigBee is meant to cater to the sensors and other battery operated products.

5.1.2 - Long Range Communications

5.1.2.1 - Wi-Fi

Wireless Fidelity is the term usually suggested to Wi-Fi technology, comparing with audio recording term High Fidelity or Hi-Fi, but officially this term does not mean anything. Wi-Fi

Wi-Fi is a data transmission system designed to provide location-independent network access between computing device using radio waves rather than cables and supported by the IEEE 802.11 standard.

The 802.11 specification as a standard of WLANs was ratified by the IEEE in the year 1997. It provides for 1 Mbps and 2Mbps data rates and a set of fundamental signalling methods and other devices. Like all IEEE 802 standards, the 802.11 standards focus on the bottom two levels of the ISO model, the physical layer and the link layer, as seen in Figure 20. [27]

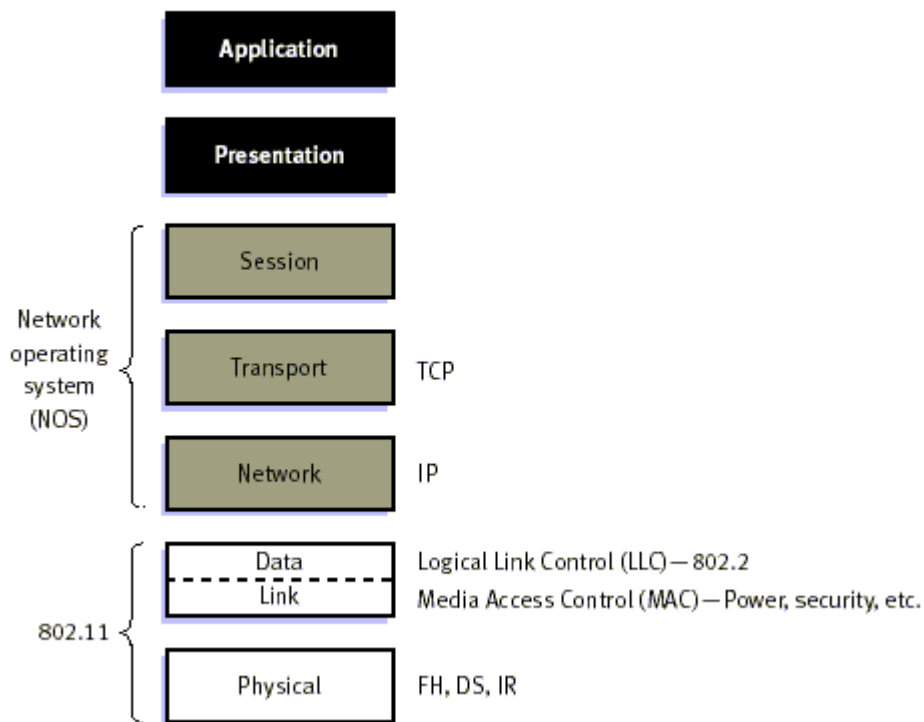


Figure 20 - IEEE 802.11 and the ISO Model. [27]

Wi-Fi technology is often submitted to revisions in order to optimize data rates, improve security and interoperability. Thereby, these are the more relevant set of standards in use at the moment:

802.11.a - enables high data rates up to 54 Mbps (effective speed: 30 Mbps). Up to eight communication channels can be used in the 5 GHz frequency band.

802.11.b - it is the most used standard where data rates can reach 11 Mbps (effective speed: 6 Mbps) and ranges up to 300 meters In line of sight.

802.11.d - it enables the connection to WLANs at international level.

802.11.e - regarding the data link layer this standard uses packets bandwidth and transmission delays in order to improve voice and video transmission.

802.11.f - it proposes the Inter-Access-Point Roaming Protocol to enable users to change their access point in a transparent way when travelling.

802.11.g - it is the second most common standard and offers data rates up to 54 Mbps (effective speed: 30 Mbps) using the 2.4 GHz frequency band.

802.11.h - it modify the conformity of the 802.11 standard to European Standard (HiperLAN2) regarding frequency and energy saving features.

802.11.i - based on the AES encryption it improves the transmission security.

In the last few years embedded Wi-Fi modules have become available which come with a real-time operating system and provide a simple means of wireless enabling any device which has and communicates via a serial port. This allows monitoring device, for example a portable ECG, to be created, communicating with other node inside the internet cloud.

In summary, the Wi-Fi purpose is to make information accessible in a easier way, ensuring compatibility and co-existence of devices eliminating cabling and wiring.

5.1.2.2 - GSM/GPRS

The Global System for Mobile Communications (GSM) radio technology is based on 200-kHz wide radio channels with a gross data rate of 270 Kbps and it is the most popular standard for mobile phones in the world. It operates in four different frequency ranges: most GSM networks use the 900 MHz or 1800 MHz bands while in the Americas the 850 MHz and 1900 MHz are employed because the other bands were already allocated; the countries where these technologies were first tested and implemented, like Scandinavia, operate at 400 and 450 MHz frequency bands. [28]

One of the advantages of GSM is that it offers a subscriber identity module (SIM), also known as a smart card. The smart card contains a computer chip and non-volatile memory and it is inserted into a slot in the base of the mobile handset. The memory on the smart card holds information about the subscriber that enables a wireless network and the smart card can be used in different handsets.

The general packet radio system (GPRS) provides packet radio access for mobile GSM and time-division multiple access users. In addition to providing new services for today's mobile user, GPRS is important as a migration step toward third generation (3G) networks. The GPRS specifications are written by the European Telecommunications Standard Institute (ETSI).

GPRS provide high-speed data rate services, reducing the time spent setting up and talking down connected and it is designed to support bursty applications such as e-mail, telemetry, web browsing, among other services.

GPRS architecture attempts to reuse the existing GSM network elements as much as possible but some new support elements, interfaces and protocols for handling packet traffic are required. The GPRS Support Node (GSN) is divided into Serving GSN (SGSN) and Gateway GSN (GGSN). The SGSN is connected directly to the base station network and controls access, tracks user mobility and implements various security functions. The GGSN is a gateway to external data networks and provides services such as authenticating external network access, quality of service (QoS) and tunnelling. The GGSN must furnish an IP address to each mobile terminal during all its connection to the GPRS network. These two nodes interact with the Home Location Register (HLR) node to obtain subscriber profile and authentication information.

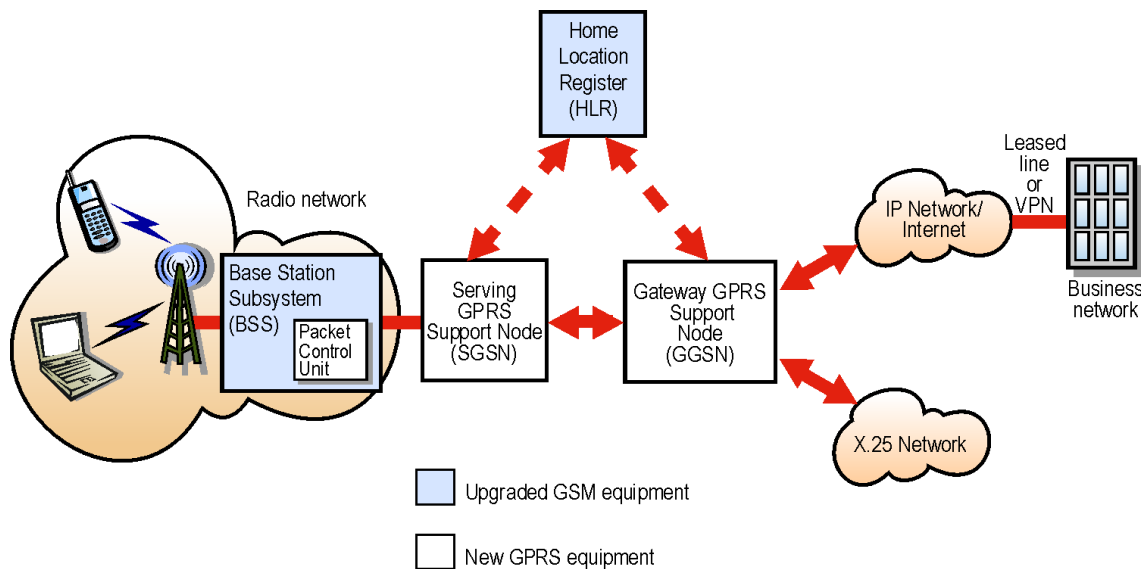


Figure 21 - GPRS Network. [29]

5.1.2.3 - Ethernet

Ethernet is the most widely-installed local area network (LAN) technology standardized as IEEE 802.3. Ethernet LANs consist of network nodes and interconnecting media. The network nodes fall into two major classes:

- Data Terminal Equipment (DTE): devices are either source the source or the destination of data frames, like PCs, workstation or file servers.
- Data Communication Equipment (DCE): intermediate network devices that receive and forward frames across the network. They can be either standalone devices such as repeater, network switches and routers or communications interface units such as interface cards and modems.

The simplest structure is the point-to-point interconnection where only two network units are involved and the connection may be DTE-to-DTE, DTE-to-DCE or DCE-to-DCE. The original networks were implemented with a coaxial bus structure and the maximum allowable length of the link was 500 meters.

However, the star-connected topology has been implemented in current networks, where the central network unit is either a multiport repeater (hub) or a network switch. All connections are point-to point links implemented with either twisted-pair or optical fibre cable.

The following figure shows the relationship between the OSI reference model and the IEEE 802.3 logical layers.

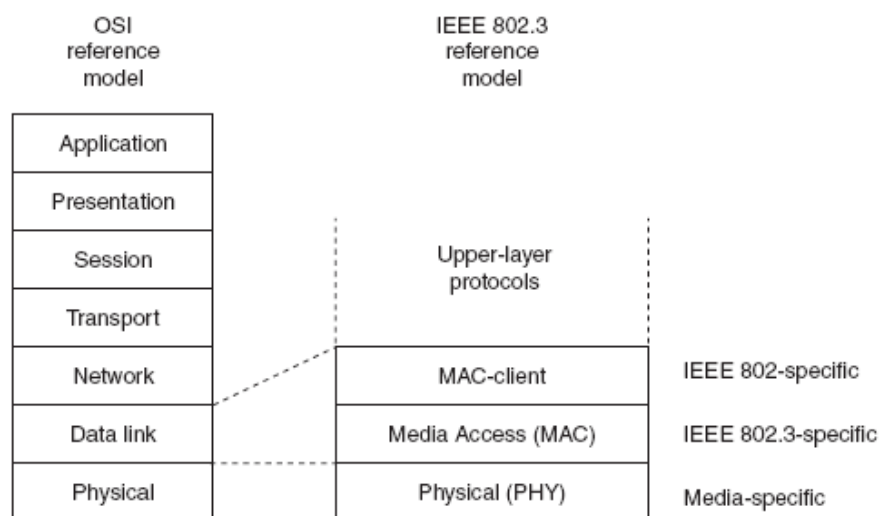


Figure 22 - Ethernet’s Logical Relationship to the ISO Model. [30]

In physical terms Ethernet cables vary both in speed and physical medium. The most common forms used are 10-BASE-T, 100-BASE-TX and 1000-BASE-T, running at 10 Mbit/s, 100 MBit/s and 1 Gbit/s, respectively.

Fibre optics variants of Ethernet are commonly used in structured cabling applications, used in datacenter applications, for example. Their strengths lie in performance, electrical isolations and distance, up to tens of kilometres with some versions. New developments guarantee a very high speed of almost 100 Gbit/s.

The ISO data link layer is divided into IEEE 802 sublayers: the Medial Access Control (MAC) sublayer and the MAC-client sublayer.

MAC-client sublayer may be a Logical Link Control (LLC) if the unit is a DTE or a bridge entity if the unit is a DCE. LLC provides the interface between the Ethernet MAC and the upper layers in the protocol stack of the end station, defined by the 802.2 standards. Bridge entities provide LAN-to-LAN interfaces between LANs that use the same protocol or even different protocols and are defined by IEEE 802.1 standards. [31]

6 - SYSTEM ARCHITECTURE

The definition of the remote monitoring system is the subject of this chapter. A general overview of the system is presented, with the division between the vital signs acquisition and transmission module, regarding internal organization and operations performed by each unit.

6.1 - Medical Sensors Equipment

Originally medical sensors equipment was projected to collect all the vital signs in an acquisition module to which each individual sensor would be attached via wire. This idea was developed during the last academic year and was continued until the first oral presentation, in February 2008. After, a new approach was taken to the development of the project: in this initial phase and implementation in the market the system would use medical sensors already available in the market and the design and construction of the sensors and the acquisition module was dropped. This decision was taken for two reasons: first the wires connecting each sensor to the acquisition module would reduce the patient mobility, one of the strong features of this system; and mainly because the certification and marking of the medical sensors would be too expensive and would delay a fast implementation in the market, since these process require a large amount of time and the company does not have a previous experience with medical products.

Another possibility was discussed and analysed: the connection of medical sensors already in the market to an acquisition module developed inside the project. This path would give an added value to the system: just using one wireless module that would establish the connection from the acquisition to the transmission module. But, after a contact with INFARMED - Portuguese regulatory authority that evaluates, authorises, regulates and controls medical devices - we acknowledge that even if the acquisition module would not have a direct contact with the human body (since the signal would be acquired with medical sensors already certified), this product would also need to be certified and authorized as a medical product. Thus, each sensor used in the project, at this phase, should be certified and have an individual wireless device that allow a direct communication with the transmission module. This

decision increases the interoperability of the system, once an individual sensor can be added or removed into a specific application, without changing the system's hardware.

Three vital signs were analysed and the respective modules chosen during this year but just one of them - pulse oximetry - was integrated in the system, as required in the project developed to *Centro Cirúrgico de Coimbra* (see chapter 9).

6.1.1 - Electrocardiograph

ECG is a crucial diagnostic exam in cardiovascular diseases, specialized in rhythm disturbances, changes in electrical conduction and myocardial ischemia and infarction. It records the electrical activity of the heart, using a simple and non-invasive procedure where a certain amount of electrodes are placed on the skin of the chest and connected a system that measures the electrical activity over the heart. As cardiac cells depolarize and repolarize, electrical currents are spread throughout the body because the tissues surrounding the heart are able to conduct electrical currents. These electrical currents are measured by the array of electrodes specified before recording what is called the ECG tracing.

A typical ECG tracing can be seen in the following figure.

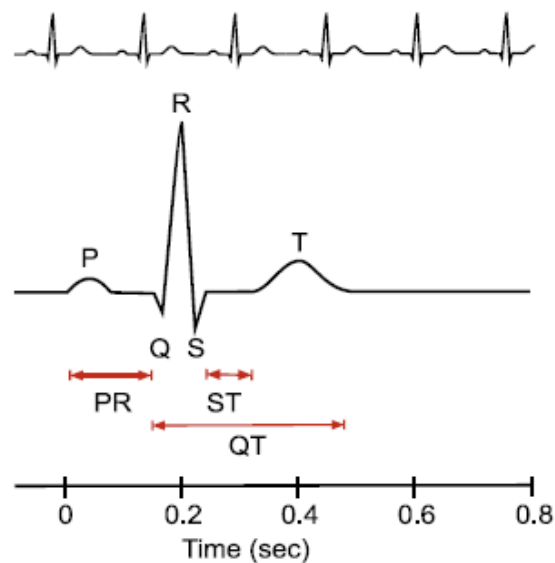


Figure 23 - ECG recording and components of the ECG trace [32].

In the enlargement of one of the repeating waveform the P wave, QRS complex and T wave can be detected. The P wave represents the atrial depolarization, QRS complex the ventricular depolarization (for both ventricles) that pumps the blood out of the heart and the period during which the ventricles are resting and receiving more blood is represented by the T wave.

Besides real-time monitoring, special algorithms are able to detect specific changes in ECG characteristics making possible the discovery of future cardiac diseases by the extension of cardiac events recording evaluation.

The device chosen to integrate the first prototype of the monitoring system is CardioBlue, an ECG event recorder with wireless communication, from the Hungarian company Meditech. This device was chosen due to the possibility of wireless data transmission with Bluetooth™, ability of recording 3 independent bipolar channels with 7 electrodes in the upper body, storage capacity up to 60 minutes (useful when the connection to the transmission module is not available).

CardioBlue also presents other features: [33]

- Power Supply: 1 AAA alkaline or rechargeable battery
- Sampling: 1200 Hz or 600 Hz
- Dimensions: (66 x 59 x 17) mm
- Weight: 49 g (approximately)



Figure 24 - CardioBlue ECG recorder.

Some contacts were held with two professors of Medicine's Faculty of University of Coimbra that advice and validate the option taken in the ECG sensor choose decision.

6.1.2 - Oximeter

Pulse Oximeter is a non-invasive medical device that indirectly measures the arterial oxygen saturation, i.e. the amount of haemoglobin that carries oxygen (in percentage) [34]. This measure is based in two physical principles: the presence of a pulsatile signal generated by arterial blood and the fact that oxygenated haemoglobin (O₂Hb) and reduced haemoglobin (Hb) have different absorption spectra [35].

An oximeter device uses a light emitter with red and infrared LEDs that shine through a translucent site with good blood flow (usually the finger or the lobe of the ear). Oppositely to the emitter there is a photodetector that receives the light that passes through the measuring site. This is achieved since the O₂Hb absorbs less light than Hb in the red region, while the reverse occurs in the infrared wavelength. With a higher increase of signal acquisition most pulse oximeters can display a plethysmographic waveform, sometimes useful to distinguish an artifactual from a true signal.

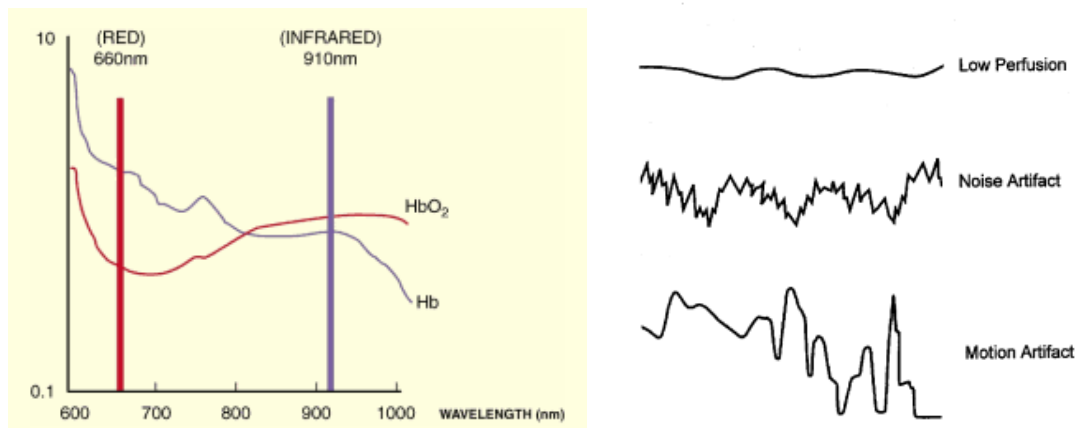


Figure 25 - Typical wavelengths used and common pulsatile signal obtained in a pulse oximeter. [34] [36]

The device chosen to measure this parameter was the Nonin 4100 Digital Pulse Oximeter. This Oximeter allows SpO₂, heart rate and plethysmographic examination, transmitting wirelessly the data to a Bluetooth-enabled device. The Nonin 4100 oximeter uses a class II Bluetooth radio with 2AA batteries which allows a battery life of approximately 120 hours (5 days). [37] [38]

Besides these Nonin 4100 also presents these core features:

- **Oxygen Saturation Range:** 0 to 100%..
- **Pulse Rate Range:** 18 to 300 pulses per minute
- **Measurement Wavelengths:** Red - 560 nm; Infrared - 910 nm
- **Bluetooth Profiles Supported:** Serial Port Profile
- **Dimensions:** 7.6 x 7 x 3.3 mm (without wrist strap).
- **Weight:** 125g (with batteries).



Figure 26 - Nonin 4100 Digital Pulse Oximeter

Nonin 4100 oximeter works as a slave, invisible to other Bluetooth devices and allowing the master device to create a point-to-multipoint piconet where it can be connected to 6 more Bluetooth devices.

6.1.3 - Accelerometer

Falls are a major source of morbidity and mortality in the elderly and post-surgered people but accelerometer sensors have the potential, in the future, to stratify falls risk facilitating early initiation of appropriate therapeutic intervention, thus reducing, further falls.

These tri-axial accelerometers should be able to extract useful information from the acceleration measurements: both static (e.g. gravity) and dynamic (e.g. vibration) acceleration. They consist of a moveable bar suspended on micro-machined springs that provides resistance and against acceleration. Deflection of this bar is then converted into an acceleration reading that can be extended inside a single device onto a three-dimensional axis. [39]

Currently, accelerometers are used primarily in a research setting; however, with the right processing algorithms and monitoring techniques it is possible the incorporation into clinical practice, evaluating gait and balance, assessing falls risk and monitoring mobility in a non-invasive and portable way.

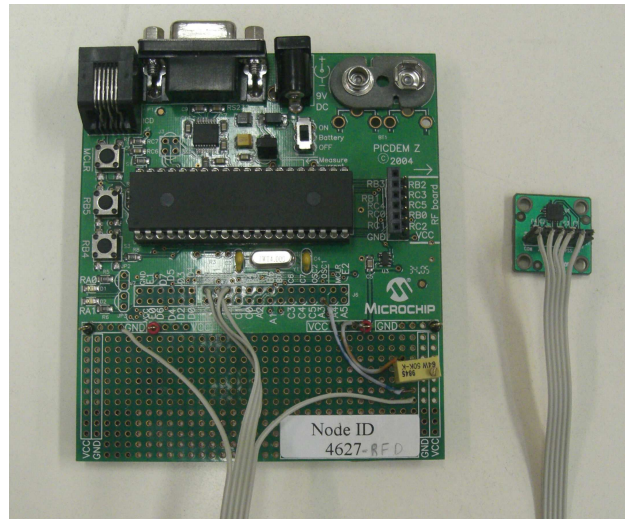


Figure 27 - Accelerometer acquisition system using a microchip demoboard.

A circuit was created to analyse the data acquired with the ADXL330 accelerometer from Analog Devices. This is a 3-axial accelerometer with a range of $\pm 3g$, able to measure static acceleration of gravity and dynamic acceleration resulting from motion, shock or vibration.

This accelerometer was connected to a demoboard, to obtain a valid signal. Some tests were done to acquire this signal and to be certain if this was a suitable option to the system. The results obtained showed the accelerometer provides good accuracy and precision.

However, the work with the accelerometer was not concluded since the priority was the system development to a specific healthcare unit (see chapter 9). More tests should be done in order to develop an algorithm that provides useful clinic information.

6.1.4 - Other sensors

Different vital signs can be added to the system in order to increase the amount of information available for the healthcare professional in their decision-

making. Some of those sensors that are expected to enrich the system in short-term future should give information about the patient's temperature, blood pressure and expiratory flow.

6.2 - Transmission Module

The transmission module works as an intermediary between the sensors and the terminal module - a nursing central from a healthcare unit where data are stored in a database and can be easily consulted by a healthcare professional. Thus, this module is responsible for the reception of the vital signs coming from the acquisition sensors, possible store them if the connection with the terminal module is not available and then re-transmit them to the datacenter. The module should consequently support two different types of communication: short and long-range communication technologies.

In spite of the all the schematics and PCB layout have been completed in the previous academic year, a new approach was taken as underlined before. Besides the substitution of the acquisition module by individual wireless sensors already in the market the transmission module was replaced by an electronic board belonging to another project that was being developed in ISA. This change was done because it is effortless having just one board to test and to prototype for two different projects, saving economical and human resources.

The transmission module general architecture can be seen in the Figure 28.

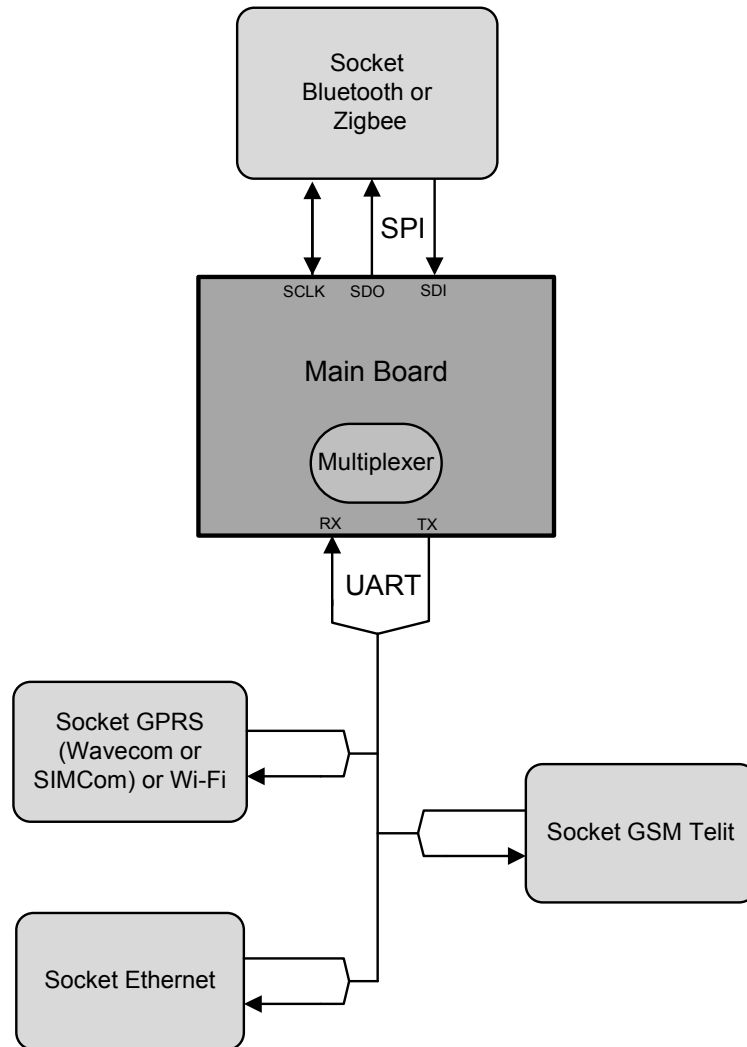


Figure 28 - Transmission module architecture: main board and sockets.

The transmission module operation is enabled by the integration of different modules to communicate with the exterior, through specific sockets.

The first module, where the data is received, should have the same communication technology as the medical sensors. Thus two different sockets were projected: one supporting Bluetooth and other one supporting Zigbee technologies, in a short-range type of communication. Both of these sockets are connected to the same physical place in the main board, thus, allowing just the connection of one of them at the same time. Thereby, these two solutions should act in different applications, depending on the type of technology supported by the medical sensors.

Once the data have been processed in the main board, it must be transmitted once more to become available to healthcare professionals. Three different

technologies are used in the output data sockets: Wi-Fi, GSM/GPRS (three different modules - Wavecom, SIMCom and Telit) and Ethernet. Three different sockets can be connected to the main board, as specified in Figure 28, changing the communication technology module automatically, through a plug-and-play system.

6.2.1 - Main Board

The main board receives the data from the sensors and processes them, allowing a correct visualization of the same, and finally re-transmits to the final destination, the DataCenter.

The board circuit is done all over the microcontroller PIC24HJ128GP306. This is a 16-bit high performance microcontroller, with a 64-pin TQFP packaging and is supplied by a 3.3 ($\pm 10\%$) operating voltage. The microcontroller incorporates a range of serial communication peripherals, including two Enhanced USART, two 3-wire SPI and two I²C Master and Slave modes of operational. Also, this controller offers up to 85 programmable I/O pins.

A block diagram is represented in the next figure, showing the general system architecture of the main board.

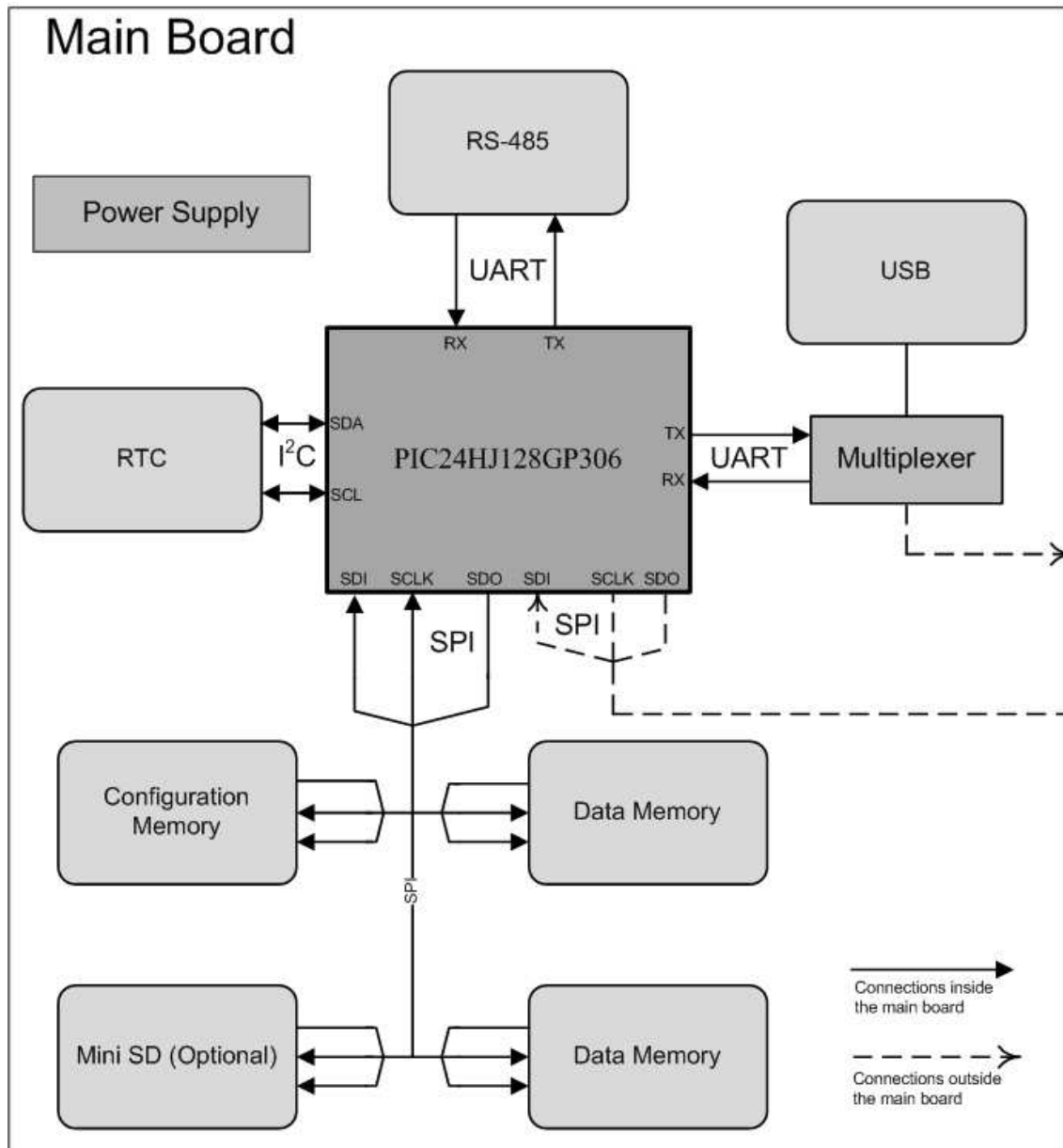


Figure 29 - General architecture of the main board.

Once the data have been integrated into the microcontroller it can be downloaded to the PC through a mini-USB connection (optional). The USB connection is available through a multiplexer that makes the connection between the microcontroller, the long range transceiver and the USB interface. As the transmission module has been designed to continuously sending data via wireless (or wire, in the Ethernet case), the system has been organized in a way that this wireless communication suspension happens only if the establishment of a USB connection is detected.

Using an UART communication module the system also integrates RS-485 communication, available for other purposes that the user may consider relevant, as a connection to a PC, through a RS-485/RS-232 or RS-485/USB interface.

The data can be integrated in the memories available in the board: two serial-interface Flash Memory endowed with 16Mbits of memory capacity each. This is extremely helpful when no net coverage is reached, being the accumulated data sent when a connection is established again. A 128K non-volatile ferroelectric memory is also used for configuration instructions. In addition there is also an interface that allows the connection to a microSD card when extra memory is needed. All these memories are connected to the microcontroller through an 3 -wire SPI connection, as seen in Figure 29.

The power supply to this module can be provided by two different ways: domestic current when the patient is anywhere inside a building or a rechargeable Li-ion battery when the patient needs to move to the exterior. The transmission module automatically recharges the battery when this is connected to the domestic current and the system beneficiates the autonomy the battery confers to it.

6.2.2 - Bluetooth Socket

The Bluetooth socket is one of the available modules to interface the data transmission between the sensors and the transmission module.

An overview of the socket integration is shown in

Figure 30.

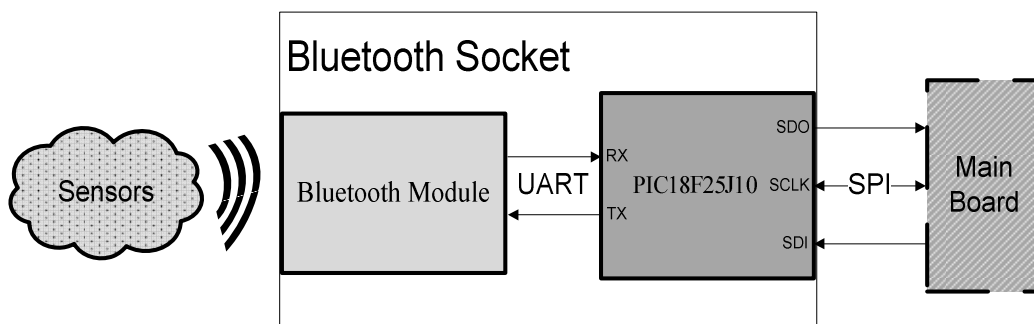


Figure 30 - Socket Bluetooth architecture and input and output connections.

Medical sensors communicate with the Bluetooth module through a wireless communication (up to 7 slave devices can be connected to the Bluetooth module). Inside the socket an UART communication module establish the protocol between the microcontroller and the Bluetooth module. The firmware integrated in the microcontroller establish a wireless UART communication, thereby the connection is done directly between the microcontroller and the sensors and the Bluetooth module does not have any intervention in the communication, besides establishing the connection.

Finally PIC18F25J10 acts as a slave beyond the main microcontroller, connected to this through a 3-wire SPI communication.

6.2.3 - Zigbee Socket

This type of communication was also choose to interface the vital signs equipment acquisition with the transmission module; however any solution has been yet planned and designed since the vital signs transmission is done using only Bluetooth communication.

Despite being the ideal solution in a long-term future, nowadays there is no medical equipment available with this communication interface; thus, the creation of a Zigbee socket does not make sense at this moment, since in few years it could possibly become obsolete. Furthermore, as explained before, Zigbee communication involves the payment of royalties, increasing the overall cost of the system.

6.2.4 - Wi-Fi Socket

A Wi-Fi socket was also created (but not yet prototyped) thinking in a hospital monitoring scenario. Because data transmission via Wi-Fi can only span a limited distance till the quality of the signal degrades, various repeaters should be placed along the corridor to preserve the signal integrity and extend the distance over which data safely travel, till it reaches the terminal module. To integrate this option in the system should be guaranteed the hospital a Wi-Fi network.

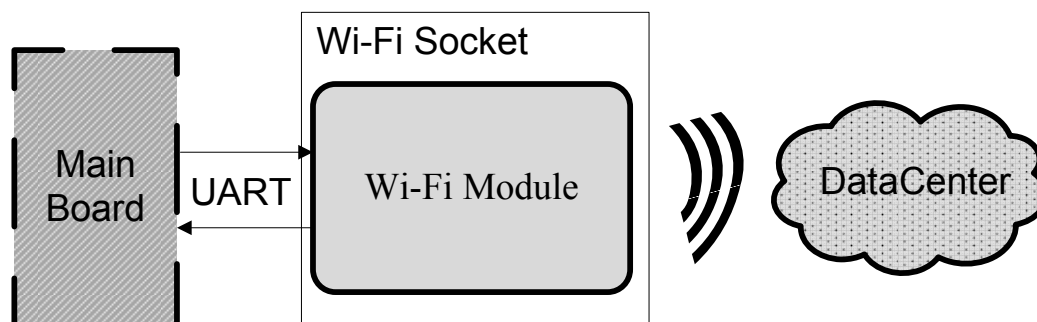


Figure 31 - Wi-Fi Socket architecture and input and output connections.

The architecture is the same for all the long-range sockets: the wireless module (Wi-Fi in this case) acts as a slave to the microcontroller in the main board, over an UART communication, being the data sent wirelessly to the terminal module.

6.2.5 - GSM / GPRS Socket

A wide range wireless technology with large territorial coverage is necessary to the patient's monitoring at his own home. Data must be available in healthcare units that can be located many kilometres wherever the patient is at home or in displacement at his normal daily routine. Three communication technologies - GSM GPRS, GSM EDGE and UMTS - have been initially considered to be implemented in this system, but the choice felt in the GPRS option once this technology supports larger network coverage.

A GSM/GPRS socket was already developed inside the company and it could be exported to our project. The solution allows to choose between 3 different GSM GPRS modules - Telit, WaveCom and SIMCom - as shown in the general overview. The Telit module is integrated in one board and the WaveCom and SIMCom in a different physical socket but all of them have the same architecture as shown in the next figure and with the same communication as explained in the Wi-Fi socket.

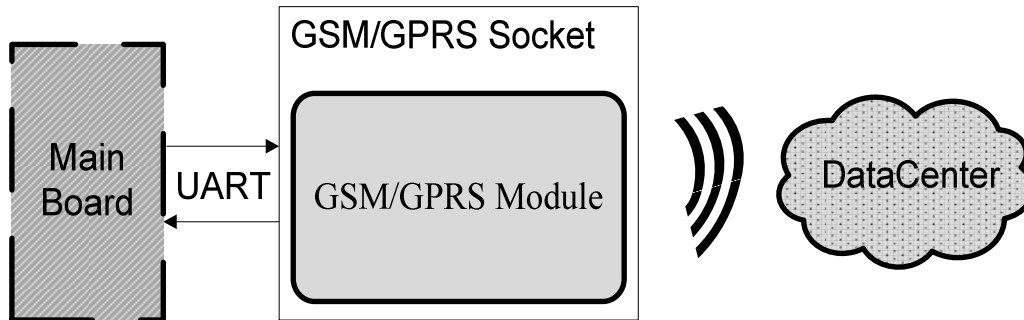


Figure 32 - GSM/GPRS Socket architecture and input and output connections.

6.2.6 - Ethernet Socket

Having a hospital monitoring scenario an Ethernet socket also developed inside the company - as the GSM GPRS sockets - is integrated in the system. This solution was not considered in a first stage to be integrated in our project but since the solution was available and mainly because the requirements to the system development in CCC (see chapter 9) the Ethernet socket is used to establish a connection between the transmission module and the terminal module.

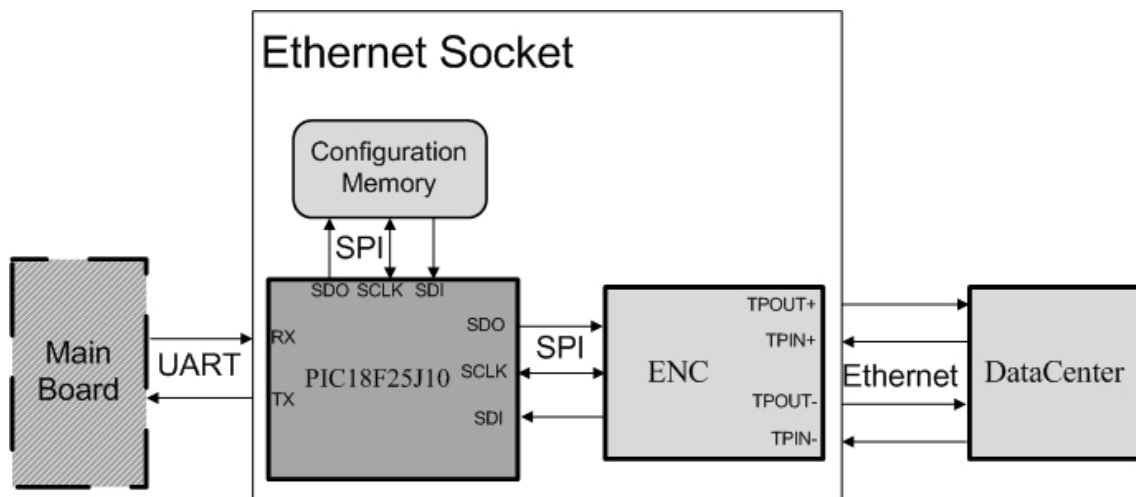


Figure 33 - Ethernet Socket architecture.

As well as Wi-Fi and GSM/GPRS sockets, Ethernet socket is also connected through an UART module to the main board. But, on the other hand there is a microcontroller in the Ethernet socket that manages the data processing inside socket. An SPI interface connects a 1048K non-volatile memory used for configuration

instructions. Another 3-wire SPI connects the microcontroller with the Ethernet controller (ENC), responsible for the creation of an interface network that will direct the data to the datacenter installed in the nursing center. [36]

6.3 - Terminal Module

After the data collection and processing, these parameters arrive to datacenter, where user-friendly software, beyond the data reception by the datacenter, manages the vital signs statistical treatment. The datacenter should provide the information over an internet connection to different types of users: common user (e.g. patient), a doctor (usually in a PDA) and nursing centre. Each type of user has different permissions and priorities in the data visualization and management.

As been told before, the web application should allow a real-time visualization of the vital signs monitoring; alarms management, personalized for each patient or vital sign; monitoring reports session, created automatically by the software and where the healthcare professional can alter any important notes potentially relevant to the patient health analysis and a database historic relative to each patient with graphics and statistics.

The terminal unit is briefly explored and only the basic operations are described in this document once the student had as responsibility the hardware development, regarding only the vital signs acquisition and the transmission module.

7 - HARDWARE DESIGN

This chapter has as main objective to give a general overview about the hardware adopted and to describe the circuit schematics and PCB design for each specific module. As referred before, the project followed a different path relative to the past year. Since the system architecture is based in a main board to process all the data, designed within the company, the student just had to conceive diverse sockets to support the different types of communication technologies not yet created in the original system: Bluetooth and Wi-Fi (Ethernet and GSM/GPRS sockets were already designed).

The chapter is divided in two main sections: at first it is described the construction of the schematics circuit and in the second part the printed circuit board layouts design are clarified.

For the complete schematics and PCB Layout designs, please refer to Appendix A.

7.1 - Schematics Design

As referred in chapter 3 - KNOWLEDGE ACQUISITION - the student used the software Altium Designer 6 to capture both system schematics and PCB layouts.

7.1.1 - Bluetooth Socket

The Bluetooth socket project is organized in two schematic documents: the central processing unit, where beyond the central component - microcontroller - were designed the I/O connectors, the LED's, the buttons and the oscillators; and a second document with the Bluetooth module selected for this system and the corresponding circuit.

Each schematic design document is next described in detail.

Central Processing Unit

The Microchip PIC18F25J10 microcontroller, belonging to the family of Microchip PIC18F45J10 microcontrollers, was selected to be the core of this socket. This family offers the advantages of all PIC18 microcontrollers - namely, high computational performance and power sensitive applications at an economical price.

Inside this family the microcontroller PIC18F25J10 28-Pin SSOP was the best suitable in our project, since the number of pins available were enough to satisfy all our requirements, and the QFN package (4-side) initially chosen was dropped by a SSOP (2- side) case style since the size was not a critical factor in this board and the SSOP microcontrollers are not problematic when sold. Beyond this aspect there are several core features that made us choose this microcontroller: [40]

- NanoWatt Technology - power consumption during operation can be significantly reduced for example using power managed modes such as Alternate Run Modes in which the controller can be clocked by either timer1 enabling power consumption reduction during code execution, Multiple Idle Modes in which peripherals can be maintained active while the CPU core is disabled or also the On-the-Fly Mode Switching for power managed mode evocation by the user code during operation;
- Three different oscillator structures: one crystal mode, using crystals or ceramic resonators; one external clock mode and one internal source. The internal source is available as a clock source or as an internal oscillator block that provides additional features such as Fail-Safe Clock Monitor where the main clock source is constantly monitored against a reference signal provided by the internal oscillator and if a clock failure occurs the controller is switched to the internal oscillator block; or Two-Speed Start-up that allows the internal oscillator to serve as the clock source from Power-on Reset, or wake-up from Sleep mode, until the primary clock source is available.
- Communications: The PIC18F25J10 incorporates a range of serial communication peripherals, including 1 independent Enhanced USART which supports RS-485, RS-232 and LIN 1.2 and 1 Master SSP modules capable of both 3-wire SPI (all 4 modes) and I²C Master and Slave modes of operation. Also, one of the general purpose I/O ports can be reconfigured as an 8-bit Parallel Slave Port for direct processor-to-processor communications.

- 10-bit A/D Converter: This module incorporates programmable acquisition time, allowing for a channel to be selected and a conversion to be initiated without waiting for a sampling period and thus, reduce code overhead.
- Program memory - PIC18F25J10 provides 32 Kbytes of readable, writable and erasable program memory.
- Data memory - 1 Kbyte of Static RAM allowed for data.
- 3 bidirectional ports.
- 10-bit and 10 Analog-to-Digital channels Converter module (A/D) with auto-acquisition capability, conversion available during sleep and self-calibration feature.

A voltage of 3.3V is given by the main board through the headers to supply the Bluetooth socket and consequently the PIC18F25J10, which supports operating voltage ranges from 2.0 to 3.6V. To help filtering the electrical noise given by the power supply - the most critical area in the system submitted to noise- is usually used a pair of filter capacitors - called decoupling capacitors - for each pin of power supply in the microcontroller. Since this microcontroller is supplied just in one pin, 2 capacitors, one of 1 μF and the other of 100 nF, are disposed in parallel to improve noise filtering. This is shown in Figure 34.

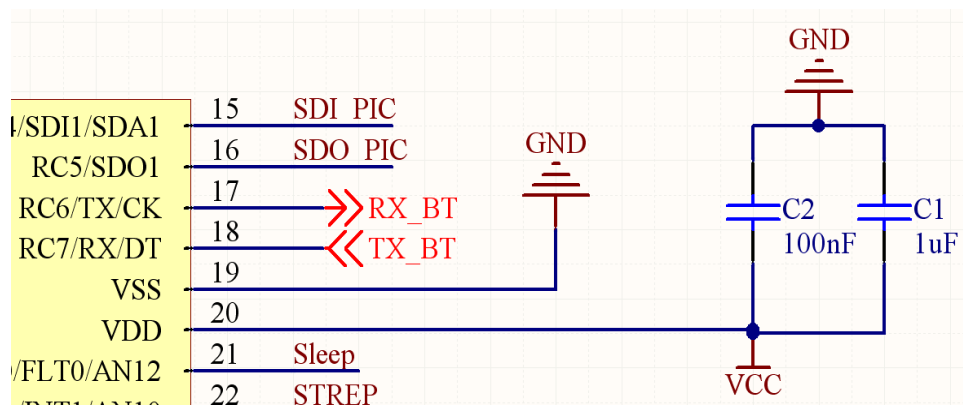


Figure 34- Power Supply pin of the microcontroller and noise filtering - A pair of decoupling capacitors is used to filter electrical noise in VDD pin.

The power supply to the microcontroller is 3.3V, inside the range of 2.0 to 3.6V in which PIC18F25J10 operates. But the core digital logic works with a nominal voltage of 2.5 V. This is allowed by an internal on-chip regulator, with low ESR filter

capacitor of 10uF connected to the VDDcore/Vcap pin to help maintaining the stability of the regulator.

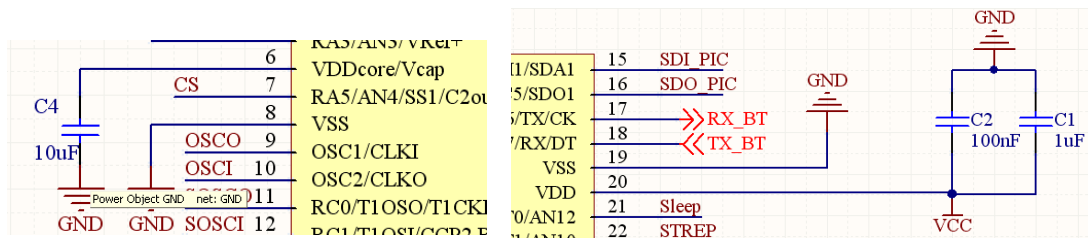


Figure 35 - Connections for the on-chip regulator enabled: power supply and ESR filter.

In this schematic, 2 external oscillators are associated to the microcontroller: primary and secondary oscillator. The 7.3728 MHz crystal is connected to the OSC1 and OSC2 pins (pins 9 and 10), working in High-Speed Oscillator mode, and coupled to two capacitors of 33 pF, as recommended in the datasheet. The other crystal works as a secondary oscillator, connected to the T1OSO and T1OSI pins, filtered by two 18 pF capacitors. This crystal continues operating even after the controller is placed in a power-managed mode, consuming less current.

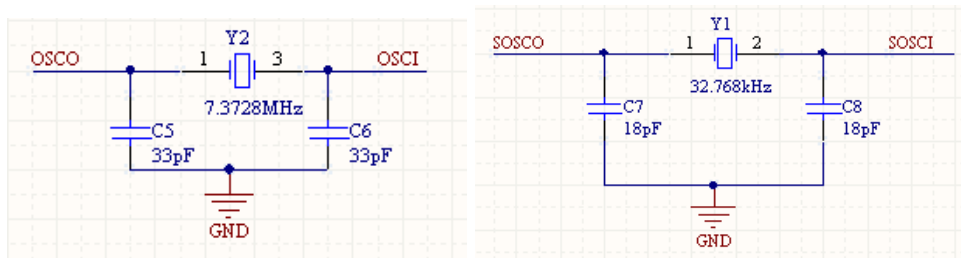


Figure 36 - Primary and Secondary oscillator and respective capacitors.

To guarantee that the microcontroller remains in a reset status when VDD is below a certain value, a pull-down is created in the MCLR pin to hold this pin low, providing a method for triggering a hard external. The following figure shows how the circuit can also be reset by the microcontroller in the main board with an external connection - (RESET_CON).

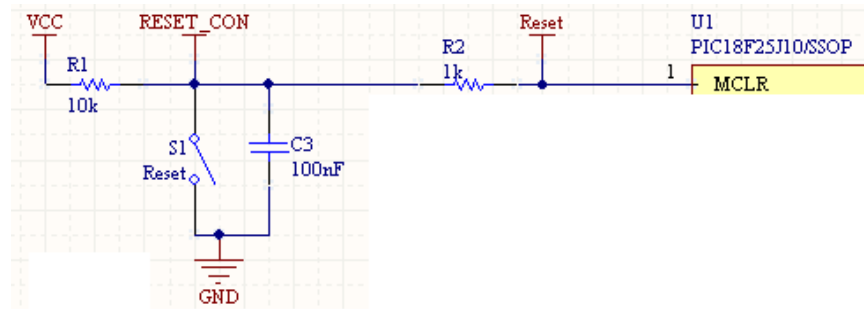


Figure 37 - External Power-On Reset circuit for slow VDD power-up. The circuit is tied to the microcontroller through an 1K Ω resistor that limits any current flowing into MCLR from the 100nF capacitor, in the event of MCLR pin breakdown, due to electrostatic discharge or electrical overstress.

A strep circuit is connected to RB1/INT1/AN10 (pin 22) in the microcontroller. This circuit is activate pressing a button, as shown in Figure 38, and can be used for several applications (see Chapter 9 - SYSTEM DEVELOPMENT TO CCC).

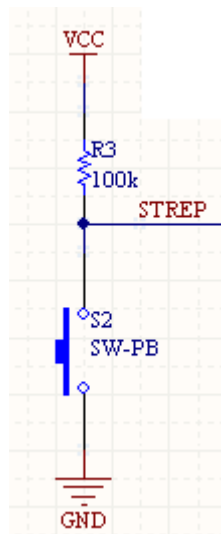


Figure 38 - STREP circuit.

The peripheral parts are also represented in the central processing unit schematic.

First of all two 10-pin connectors do the bridge between the main board and the Bluetooth socket. Even if represented as a single component with 20 pins in the schematic, the respective footprint shows two 10-pin connectors which provide better mechanical stability to the socket supported by them. Through this connector, the socket is power supplied by the main board (pins 11 and 20), other two pins are tied to ground (pins 12 and 19) and it is also possible to make a reset (RESET_CON

attached to reset circuit) or put the system into sleep with an order given by the microcontroller in the main board (pins 9 and 10, respectively). This header also establishes an UART and a SPI interface. The SPI connection is made between the microcontroller from the main board and microcontroller in the socket Bluetooth, where the second one acts as slave and the first one as master. The UART serial module was created thinking in the interoperability of this system, i.e. using this socket applied to a different main board, where the Bluetooth module would be controlled directly by the main board. To make this possible resistances of Ohm are attached to the CTS and RTS pins, allowing to short circuit the system according to the architecture used at the moment. The last 6 pins are 2 analogue and 4 digital input/outputs used for general purposes that the user may require.

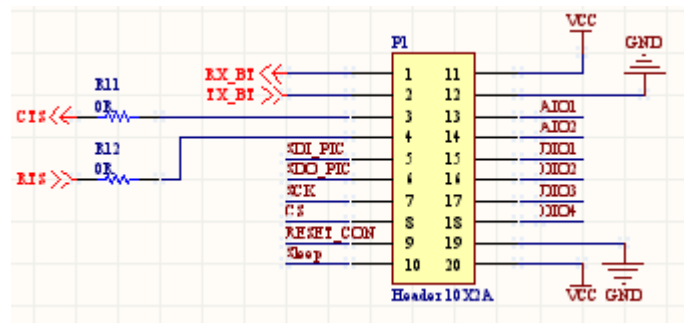


Figure 39 - Input/Output connector to the main board.

There is also a 6-pin connector available by the user to program the microcontroller through PGD and PGC lines - pins 27 (RB6/KB13/PGC) and 28 (RB7/KB14/PGD) of the microcontroller.

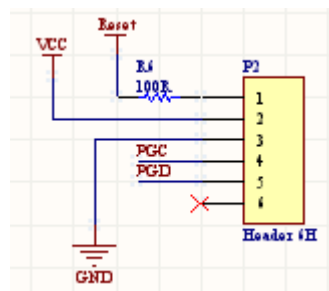


Figure 40 - Programming Connector

Two LEDs are also attached to the digital I/O pins 4 and 5. The red led signals the power status – it is on when the Bluetooth socket has a power supply applied on it. The green led is used to indicate the communication status of the Bluetooth module

with other devices surrounding it (sensors). One resistance of 1k is attached to each LED to regulate current intensity and voltage.

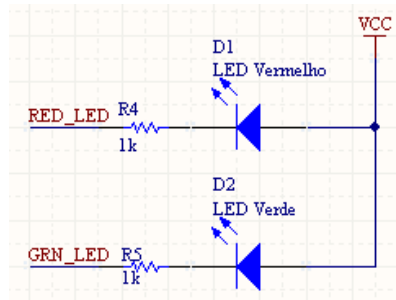


Figure 41- LED's and respective resistors.

The remaining 8 pins connections will be explained in the Bluetooth module section.

Bluetooth Module

Followed by a market analysis the Free2Move solution F2M03GLA has been selected to establish the Bluetooth communication between the sensor(s) and the transmission module.

The F2M03GLA is a low power consumption embedded Bluetooth module with an integrated high output antenna. It integrates UART, USB, SPI (test and debug) and I²C interfaces and offers digital and analogue I/O. With a transmit power of up to +8dBm and receiver sensibility of down to -83dBm confers a range of 350 meters in line of sight. The recommended operating conditions are a supply voltage between 3.1 and 3.6V. In this case the module works in Bluetooth v2.0+EDR specification, allowing a data rate up to 3 Mbit/s. [41]

F2M03GLA can be delivered with diverse firmware versions. Wireless UART firmware implementing the Bluetooth™ Serial Port Profile (SPP) has been chosen to this application due to his key features: robustness, high configurability, high security, low complexity and low power. One of the advantages offered by the module that made it an attractive option for the present application is that using the wireless UART firmware, there is no additional need for drivers or Bluetooth software on the host. The wireless UART offers one asynchronous channel on which all information sent or received is exchanged transparently via Bluetooth with the connected remote device. As soon as a successful connection with the latter has

been established, communication via the asynchronous data channel is enabled without the need of sending any configuration commands. The device running the wireless UART firmware can operate either as the master or slave of the piconet to which it belongs.

The module is certified according to CE and FCC, which give fast and easy Plug-and-Go implementation and short time to market and is usually applied in medical systems.

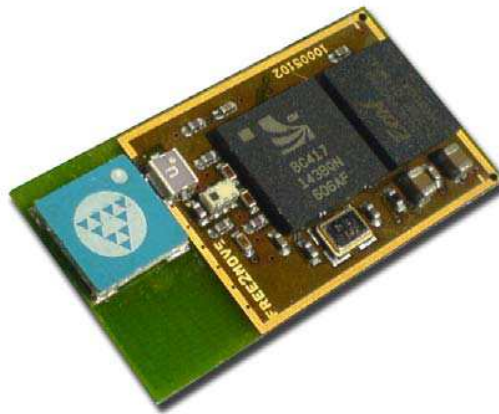


Figure 42- Bluetooth Module: F2M03GLA from Free2Move. [41]

The UART interface establishes the communication between the Bluetooth module and the PIC18F25J10. It uses 4 lines to transfer the signals: TX_BT, RX_BT, CTS and RTS. There are two other lines connecting these two devices: WU_CTRL1 and WU_CTRL2 attached to PIO[2] and PIO[3], respectively, in the Bluetooth module. These lines are required when the Wireless UART Firmware is used and allow the microcontroller to break the connections with remote devices - WU_CTRL1 - and indicate if a successful Bluetooth connection was established - WU_CTRL2.

Three other lines are connected. Using one MOSFET - channel p - integrated in the power supply pin, through the CTRL_BT line attached to the microcontroller is possible to break the supply connection and turning the Bluetooth module off. One decoupling capacitor of 4.7 uF is used to filter electrical noise as recommended in [42].

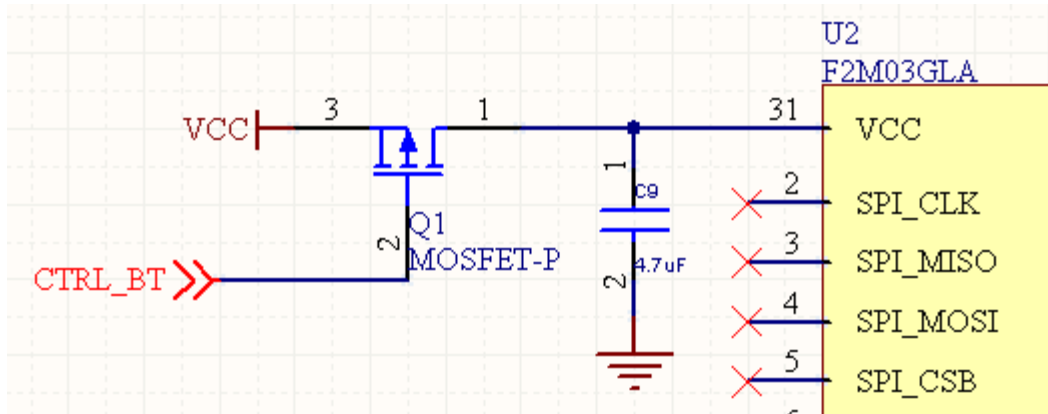


Figure 43- Power Supply Circuit - CTRL_BT line allows to break the supply to the Bluetooth module.

A pull down resistor of $1.8\text{K}\Omega$ is attached to the active low reset [8] and connected to the microcontroller. This guarantees the low state of the reset pin whenever the microcontroller is unstable. A power LED is also connected to the Bluetooth module, indicating its power status. The remaining pins, involved in the pulse code modulation, USB voice, Master Synchronous Serial Ports (SPI and I^2C) and standard I/O programmable pins, are not used.

7.1.2 - Wi-Fi Socket

The Wi-Fi socket project is organized in three schematic documents: the connectors pin out and indicators (Status, Output enable and LED indicator) in one document, a second document with both regulators (low dropout and voltage regulators) and the level shift and finally a third document where the Wi-Fi module was designed.

Each schematic design document is next described in detail.

Connector and Indicators

The first schematic document presents the inputs and outputs from this socket, through the respective connectors and the output enable, LED and Status indicator.

The connection between the Wi-Fi socket and the main board is achieved using two headers: one 12-pin and the other 14-pin, as represented in Figure 44.

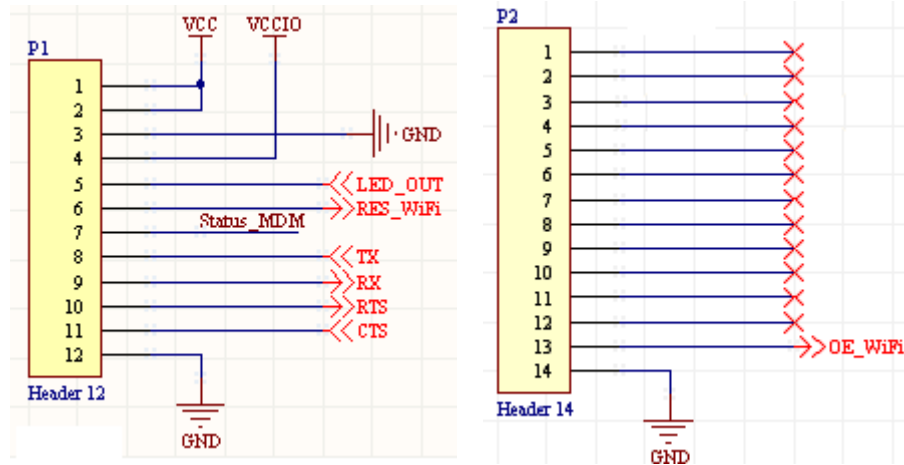


Figure 44 - 12 and 14 pin connectors between the socket module and the main board.

Looking to the figure is possible to visualize two different power supplies given by two different pins: VCC and VCCIO. VCC corresponds to VCC GSM in the main board - approximately 4 V - and it is supposed to power supply the Wi-Fi (or GSM) socket. VCCIO corresponds to the main microcontroller's power supply, 3.3V. Four other pins are needed to establish the UART interface: TX, RX, RTS and CTS. RES_WiFi, coming directly from the main microcontroller is used to reset the Wi-Fi module when necessary. The last 3 connected pins (LED_OUT, Status_MDM and OE-WiFi) are also attached to the main microcontroller to manage the indicators next presented.

As referred above, three indicators were designed to show the state of 3 different parameters.

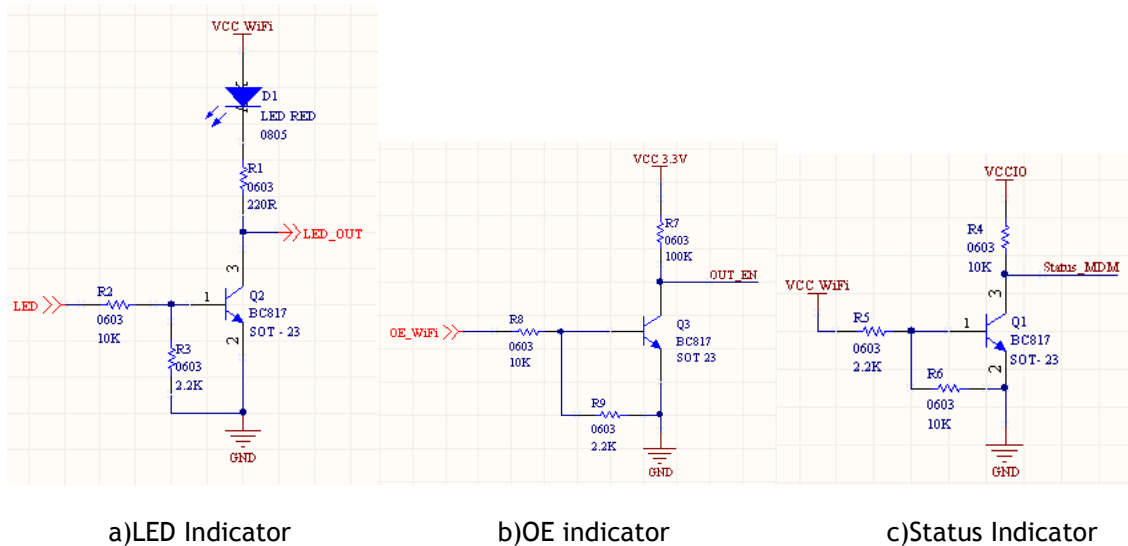


Figure 45- Indicators architecture.

All three indicators use the same architecture: applying a typical voltage, one transistor interfaces the response signal according to the input, using protective resistors on each signal line. The indicator LED turns a red LED on when the Wi-Fi module is connected (pin 58), indicating the power supply status, and informs the main board if the LED is on through the LED_OUT line. The OUT_EN signal is used to activate the level shift (described later) and it is controlled by the OE_WiFi command, coming directly from the main board. The last indicator allows to verify if the Wi-Fi socket is correctly connected, sending a signal in the Status_MDM line to the main board.

Regulators and translator

The second schematics document - Regulators_Translator – describes the design of the two regulators and the level translator.

One regulator and one level shifter are used to guarantee that UART lines are able to communicate, shifting voltage levels of both sides: microcontroller and Wi-Fi module.

The LP5951MG-3.3 regulator was chosen to convert VCCIO voltage (microcontroller operating voltage) to VCC 3.3V (Wi-Fi module operating voltage). This low dropout CMOS voltage regulator has a 5 lead package [43] - SC70-5 - and it is

stabilized using small 1uF ceramic capacitors. Behind the input and output regulated voltages pins, one pin is connected to ground and other unconnected. The last pin is the enable control pin, active when in a high state. Thus, connecting it to input voltage pin, allows to an active shutdown mode through a logic signal at the Enable pin, reducing power consumption to (virtually) zero.

VCC 3.3V, generated in the regulator, will power supply the voltage level translator, together with VCCIO. These are the two functional voltages of UART communication used in this 4-bit bidirectional translator. Furthermore, an output enable pin, controlled by the main board, put all outputs in high impedance state when the pin is low. This pin should be supplied by VCC_3.3V (as shown in the output enable indicator). [44]

In addition, four 0Ω resistors are incorporated in the circuit, connecting the UART lines coming from the microcontroller and the Wi-Fi module, allowing short-circuiting the system if the shifting operation is not needed (microcontroller and Wi-Fi module operating at the same voltage level).

Finally, another regulator is needed to convert the VCC supplied by the main board to the operational voltage of the Wi-Fi module. This conversion is done using TPS63000, a buck boost converter commonly applied to medical portable products.

This device is able to regulate the output voltage properly at all possible input voltage conditions, automatically switching from step down operation to boost operation as required. Therefore, it operates as a step down converter (buck) when the input voltage is higher than the output voltage and as a boost converter when the input voltage is lower than the output voltage.

The circuit was designed having the typical application for adjustable output voltage provided in TPS63000 datasheet as reference.

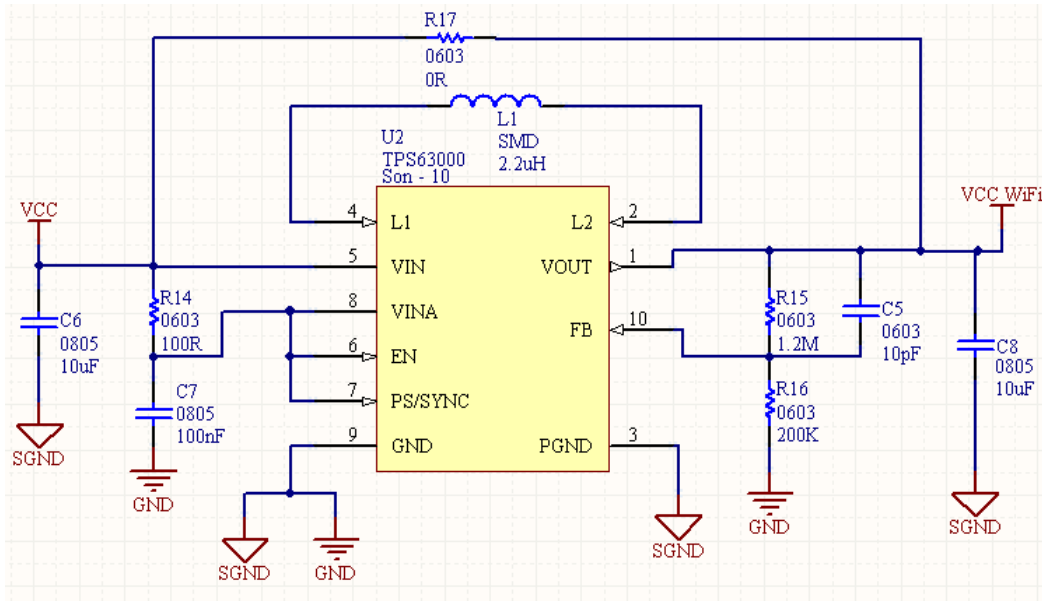


Figure 46 - TPS63000 buck-boost converter circuit diagram and connections.

The inductance value was chosen based on a recommendation in the device datasheet. A suitable inductor to generate 3.3V in the output voltage with an input range between 2.5V and 4.2V should be 2.2uH.

Input and output capacitors, C6 and C8, respectively, have been set to 10 uF. Input capacitor is used to improve transient behaviour of the regulator and the output capacitor is required to maintain control loop stability. The output capacitor value was estimated using Equation 1.

$$C_{out} = 5 \times L \frac{\mu F}{\mu H} \quad (\text{Equation 1})$$

$$C_{out} = 5 \times 2.2 \mu F = 10.4 \mu F \approx 10 \mu F$$

To properly configure the fixed output voltage devices, the FB pin (number 10) is used to sense the output voltage; thus, this means that it must be connected directly to VOUT, as shown in figure .An external resistor divider must be used to adjust the output voltage; this divider is connected between VOUT, FB and GND. When the output voltage is regulated properly - maximum value of 5.5V - the typical value of the voltage at FB pin is 500mV and the current into this pin is 0.01uA.

Based on the datasheet the current through the resistive divider should be about 100 times greater than the current in the FB pin (0.01 uA), thus, around 1 uA and the voltage across the resistor between FB and GND, R16, is typically 500mV. Taking these facts into account and in order to set the divider current at 1 uA or higher is recommended to keep the value for this resistor in the range of 200 KΩ.

Taking this in account, the value of the resistor connected between VOUT and FB, R15, depends on the needed output voltage (VOUT), as show in equation 2:

$$R1 = R2x\left(\frac{Vout}{VFB} - 1\right) \quad (\text{Equation 2})$$

$$R1 = 200 \times \left(\frac{3.3}{0.5} - 1\right) = 1120K\Omega \approx 1.2M\Omega$$

To improve control performance one feedforward capacitor in parallel to R15 is used. The value of this capacitor was calculated using equation 3:

$$C_{ff} = \frac{2.2us}{R15} \quad (\text{Equation 3})$$

$$C_{ff} = \frac{2.2us}{1.2M\Omega} = 183pF$$

The PS/SYNC pin (pin 7) can be used to select different operation modes. To enable power save, PS/SYNC must be set low. Thus, the converter stops operating just when VCC is below the limit.

On the other hand the device is put into operation when EN (pin 6) is high. Thus, this pin is connected to VCC, changing to shutdown mode just when VCC is below the limit.

Finally, when the Wi-Fi module voltage supply doesn't need to be regulated and the buck boost converter has no effect, one 0Ω resistor is added to the circuit, R 17, connecting VIN and VOUT.

Wi-Fi Module

Secure Socket iWiFi has been the selected module to create the wireless connection between the transmission and the terminal module.

This module is a secure serial-to-wireless LAN device server module that also acts as a bridge to connect serial devices to 802.11b/g wireless LANs. It includes the iChip™ CO2128 IP Communication Controller™ chip and Marvell 88W8686 WiFi chipset. The device appeared to be an attractive solution: ideal size to the socket board (64.5x27.4x6.6mm); possibility of Power Save mode; reducing the power consumption to 8 mA; external antenna receiving at 2.4 GHz, making easier the insertion of the antenna in the box; host data rate up to 3Mbps in serial mode; eliminates the need to add Wi-Fi drivers supporting several Internet Protocols (up to 10 simultaneous TCP/_UDP sockets, a web server with SMTP and POP3 clients, FTP and Telnet clients and serialNET mode for serial-to-IP bridging) and security protocols (SSL3/TLS1 protocol for secure sockets, HTTPS and FTPS, WEP, WPA and WPA2 Wi-Fi encryption), configuration can be done remotely and firmware updated over the internet.

Secure Socket iWiFi also presents the following characteristics:

- 32-bit RISC ARM7 TDMI core CPU, running at 48 MHz
- 3.0 to 3.6V operating voltage
- typical power consumption: transmitting - 260 mA; receiving - 190 mA
- Up to 10 simultaneous TCP/UDP sockets and two listening sockets
- Twelve months warranty
- Operates within the 2.412-2.472 GHz ISM frequency band
- Supports IEEE 802.11 b/g standards

A module overview can be seen in Figure 47.

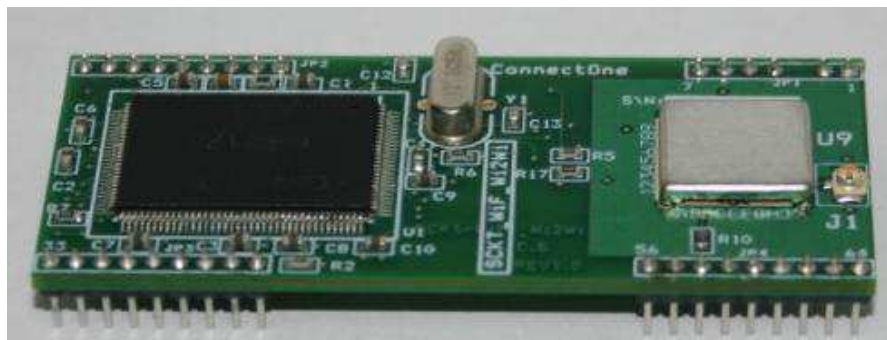


Figure 47 - Secure Socket iWiFi. [46]

The module is power supplied in just one pin, as recommended in the module datasheet, and has 4 pins connected to ground. It integrates UART interface communication, using the typical 4 pins involved in serial interface: RX, TX, RTS and CTS. It also has a LED pin - explained in the Connectors and Indicators schematic document - and a RESET pin. Using a MOSFET - channel n - controlled by RES-WiFi pin connected to the microcontroller in the main board, is possible to reset this socket holding this pin low, as show in Figure 48.

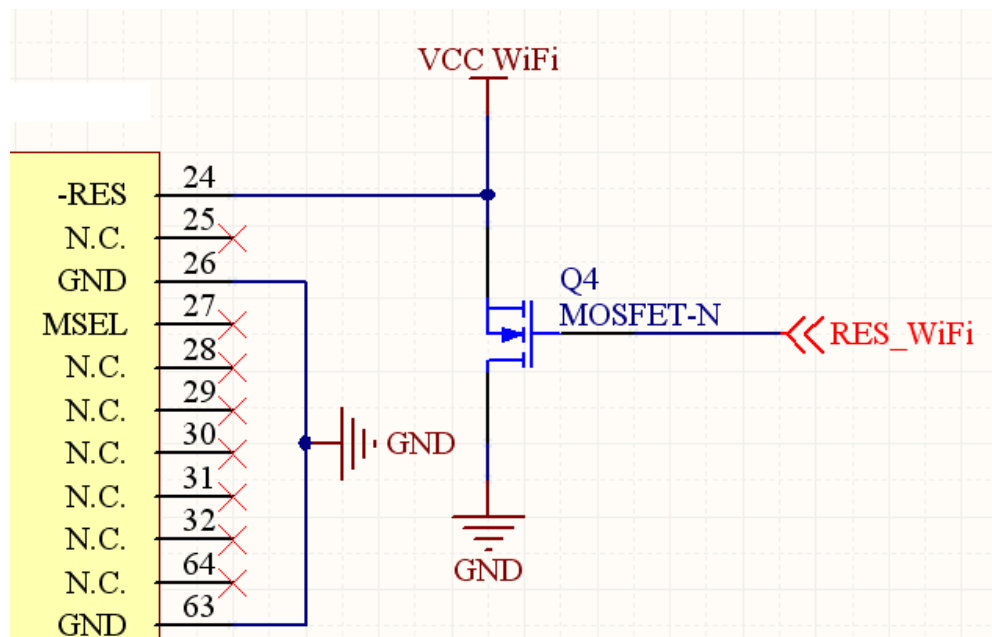


Figure 48 - Reset low circuit allows the device to terminate its present activity and clear its internal logic.

7.2 - Design Simulation

When the schematics circuits are completed, project parameters should be specified to validate the functional correctness of the design.

Thereby the design schematic is analyzed through simulation generating error reports and violations according to the rules set up by the user. If the design does not meet the required specification a panel displays the errors that should be verified and the project should be re-compiled until all the errors are solved.

In addition, the bill of material should be created. This is a list representing all the components that make part of the circuit and their technical and sales characteristics: codes, manufacturer, distributor, footprints, prices, quantities, etc. According to the market research, some of the components can be modified, compelling to changes in the design schematics.

7.3 - PCB Layout Design

The Altium Designer software has also been used to create the PCB layout design. In this section are firstly presented a set of basic rules that were taken in account for PCB layout creation and later explained the specific characteristics of each PCB board.

According to the bill of materials created, the footprints were assigned to each corresponding part of the schematic. Most of the footprints could be found easily in the libraries included with Altium Designer having simply recourse to the library search panels available on the program but sometimes they had to be created. The creation consists in arranging a set of pads - surface mounted or through-hole - respecting the package rules and sizes and creating a correspondence between each pad to a pin number. After the pads disposition, the component enclosure should be done, to define the components outline.

Following the footprints assignment a new PCB file is ready to be created. The first step is define the PCB board features - board dimensions, power planes, signal layers, clearances, vias size, tracks size, etc. Finally the netlist containing all the device names of the components used in the board and a list of the interconnections between the pins of those parts can be imported and started to be placed and routed.

7.3.1 - Parts placement

The PCB will be populated with several components. The component location on the PCB is critical for efficient routing, good electrical function, thermal dissipation and ergonomic considerations where a user may need to access part of the PCB to control components (e.g. switches) or for test and evaluation process.

Each designer has his own methods of placing components and no one does the same circuit. So there is not any unfailling way to place the components but there are quite a few basic rules to give your design best electrical performances. Here are some of them:[18]

- Measurement units: use imperial inches (thou) for tracks, pads, spacing and grids and metric millimetres (mm) for mechanical and manufacturing requirements like hole sizes and board dimensions
- Grid: the board layout should be done on a fixed grid to keep components neat and symmetrical, making future editing, dragging, movement and alignment of the tracks easier.
- Decoupling capacitors: these capacitors are used between the ground and the power of the device to ensure low ac impedance, to reduce noise and to store energy. They should be as close as possible to the V_{IN} pin of the IC to minimize the inductive influence of the trace and is especially important for small capacitor values.

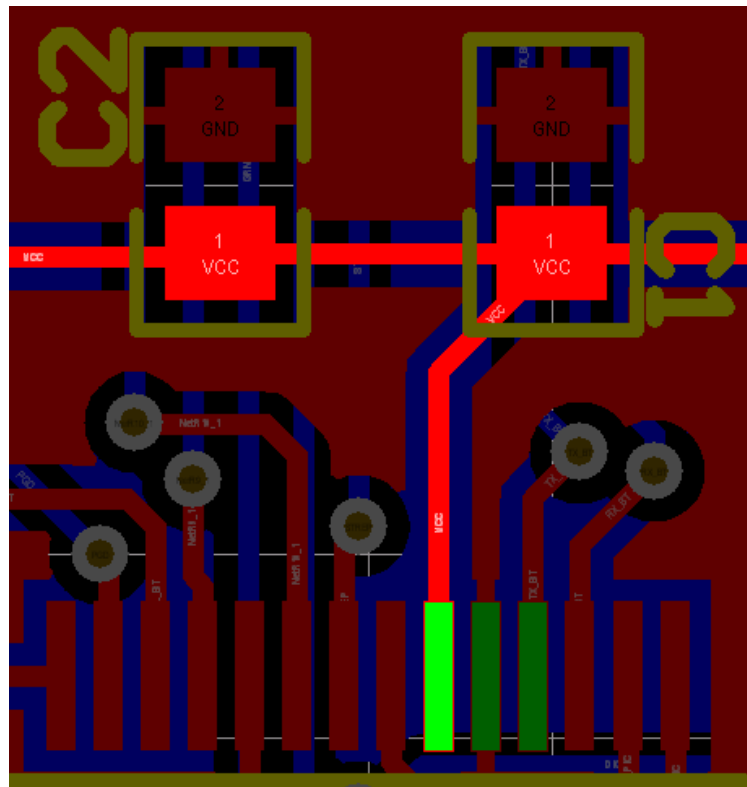


Figure 49- Bypass Capacitors Placement: as indicated in the component placement rules the decoupling capacitors are directly tied to the power supply pin of the IC - PIC18F25J10 here - as close as possible to the device.

- Crystals: should be placed as close as possible to the integrated circuit to which they are associated and the tracks should have the same size to avoid signal delays related to different track sizes.
- Pads: through hole components should have a ratio of the pad size to the hole size of at least 1.8 or 0.5 mm larger, for alignment tolerances on the drill and artwork on top and bottom layers. Pin 1 is symbolized as a rectangular pad. All the pads should be larger than the theoretical values for soldering facilities.
- Building blocks: try to “break” the design into blocks with the same function. They are usually visible by the IC in the core of the block, surrounded by the supporting parts - like resistors and capacitors - placed like suggested in schematics design.
- Orientations: components placement should be done just with vertical or horizontal orientation to aid component soldering.

7.3.2 - Board Routing

Once the components are conveniently placed routing should be done. This is the process of laying tracks and vias on the board and connect the components.

- **Clearance:** distance between two objects inside the board. Clearance should be as large as possible to route all the components because too tight clearances between tracks and pads may lead to “hairline” shorts or other etching problems during manufacturing [48]. A minimum clearance of 0.05mm in the intern of the board and 0.1 mm to the external enclosure is defined by IPC to circuits with a power supply between 0 and 15 volts (like in our case). The boards developed were routed using 0.3mm of internal clearance and 0.8mm of external clearance.
- **Tracks type:**
 - Signal tracks: provide the necessary electrical connections for signals to flow between components. Unless the signals require high current levels or the track carrying the signal is very low resistance, the signal track widths are normally small to allow many signal tracks to be patterned on the PCB

- **Power tracks:** provide the required voltage and current to the components. They should be wider than the signal tracks to provide low-resistance paths. As they must be wide and supply all the devices on the board, they are considered the critical parameter to route and consequently should be the first.

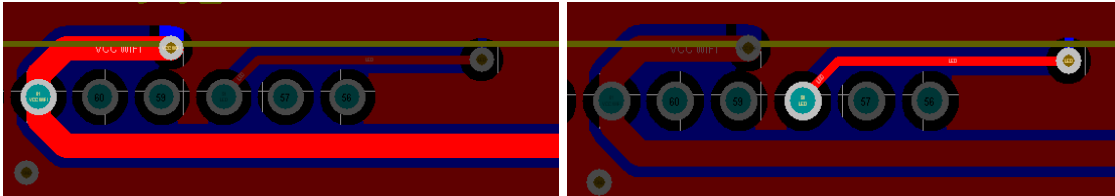


Figure 50 - Power track vs. Signal track: on the left a power track with 0.8mm of width while on the right a signal track with 0.3mm, as recommended before.

- **Nets:** should be kept as short as possible because the longer the total track length, the greater is the resistance, capacitance and inductance.
- **Angles:** right angles should be avoided and under no circumstances angles greater than 90 degrees should be used. The capacitance increases in these corner regions, causing more radiation.
- **Overlap:** tracks should not be routed above, below or in the middle of the crystals, avoiding interference in the clock signals.
- **Connection point:** the track must be always taken to the centre of the pad because the program may not recognize it as an electrical connection.
- **Vias:** are used to connect both layers and allow the vertical/horizontal strategy: Traces in different layers should have opposite orientations to avoid coupling. Vias are essential in routing but should be applied just when required as they bring noise to the circuit. Multiple vias are also used in power planes, to reduce track impedance and improve reliability.

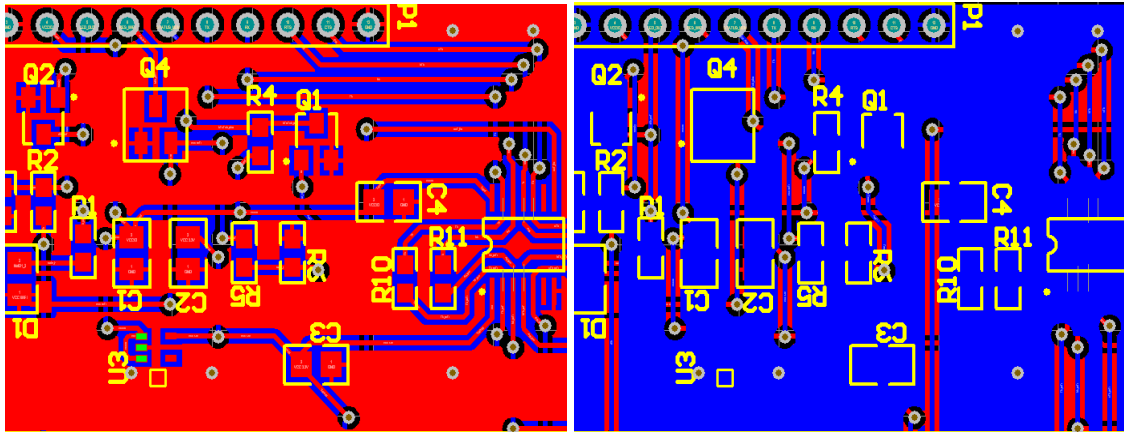


Figure 51 - Horizontal/Vertical tracing. Top layer (on the left) with horizontal routing organization while bottom layer (on the right) tracks use vertical routing. Both images belong to the same region of the Wi-Fi PCB board.

- **Ground and Power Planes:** these are large areas of metal that provide a large area for current flow, creating a low-resistance path for the current and allowing for substantially more current than would be possible in a thin track, besides enabling heat dissipation. The power plane is normally used in a single layer, referred as a single plane. On other hand ground planes are separated into different layers, stitched using vias in what is called a split plane

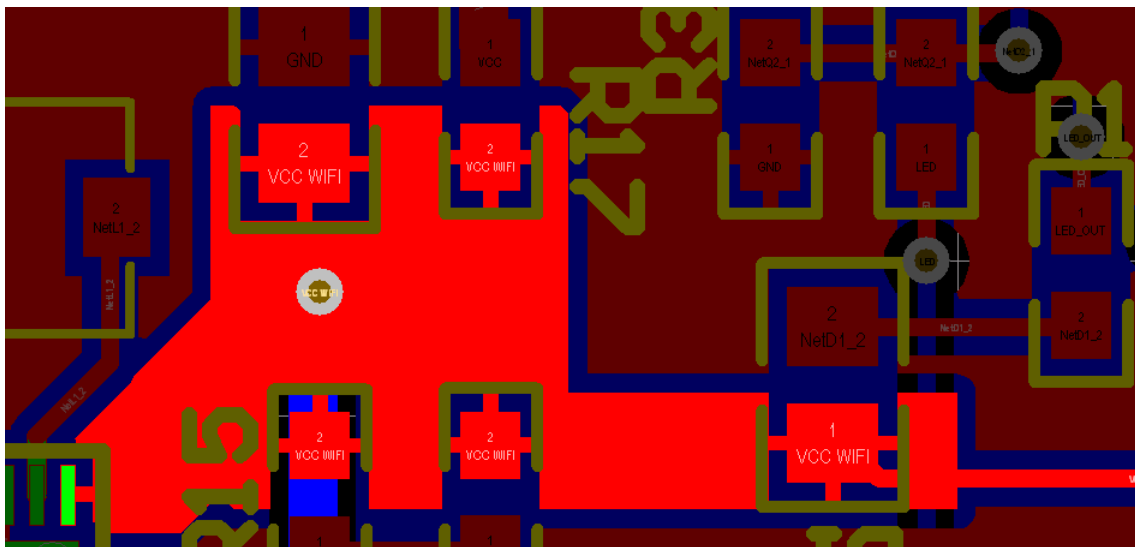


Figure 52 - Power Plane: polygon connecting all the pads powered with VCC WIFI, belonging to the Wi-Fi Socket board.

- **Second opinion:** it can sound a bureaucratic process but it is a vital step. Another point of view and a different mindset will pick up problems you will never perceive.

Some basic rules for PCB layout design were presented in this section but they are not mandatory. In some situations in the circuit board creation these rules were not strictly respected depending on the part of circuit being treated or in particular recommendations of the components manufacturers.

7.3.3 - Bluetooth Socket

The Bluetooth Socket board size took in account, in first place, the position of the two 10-pin connectors that should notch in the main board. These were the only components with a defined position that could not be changed. This board has 29.59mm (L) x 51.05 mm (W) extension and it has an external area of 15.11mm (L) x 6.98mm (W), which corresponds to the Bluetooth module integrated antenna that cannot be positioned over a power or ground plane.

The Bluetooth module is notch using surface mount technology, so the pads should be larger than the theoretical size because it should be solder with hot air in the top layer and the components

As referred before the rules presented to design PCB board cannot or should not be respected. When routing the crystals in Bluetooth socket the track size was impossible to be equal as shown in Figure 53.

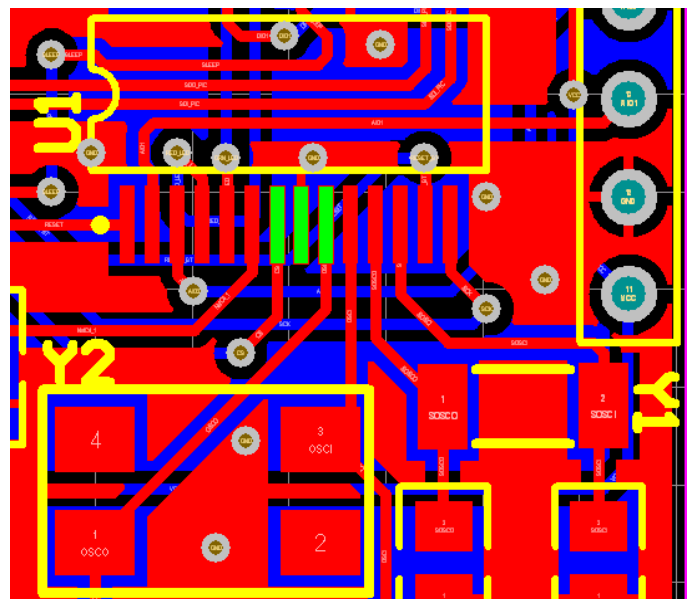


Figure 53- Crystal Placement. In the figure is shown two crystals (Y1 and Y2) connected to the microcontroller (U1) where, due to crystal sizes and the crystal pins disposition on the IC was impossible to respect the same track sizes in each crystal.

7.3.4 - Wi-Fi Socket

Wi-Fi Socket is larger than Bluetooth Socket and, as the first one, should respect the connectors' position, reaching a size of 67.56mm (L) x 60.32mm (W).

It respects all the rules followed for parts placement and board routing, thus, any specific violations is showed in this topic.

At the end a Design Rule Checking (DRC) has been run to automatically check manufacturing errors. The parameters should be given by the user and it usually checks if every track on the board matches the connectivity in the schematic, if the clearance between tracks, pads and components is respected as well as min/max hole sizes, track widths, via widths and short circuits.

This DRC is not compulsory done just when the PCB is finished since some packages have the ability to do it in real time, emending possible errors much easier.

8 - QUALITY CONTROL

8.1 - Experimental Tests

Following the boards design, the main board and the Bluetooth and Ethernet sockets were prototyped. To guarantee the correctness of the hardware design and the electrical verification and functional validation were tested. The design implementation analysis was done in collaboration with Nuno Varelas, particularly in the firmware operation tests.

All the test results can be consulted in attachment to appendix B.

8.1.1 - Electrical Verification

Verifications seek to examine the precision in the operation of the electronic circuits, achieving a mathematical answer that can be correct even if not exactly as expected. These verifications were focused on the voltage supplies of the main components and on the oscillation frequencies of the crystals. Voltage supplies analysis was carried out both in static and dynamic domain, evaluating not only the DC voltage but also the load transient response and RMS and peak-to-peak noise.

The board was supplied with a domestic current, using an adaptor with 12 V of output voltage. Tests using battery were not performed since the main regulator integrated in the circuit, TPS63000 buck-boost converter, has been originating some problems, heating exaggeratedly and increasing current power consumption; problems which have not been solved yet. Thus, this regulator is not mounted and the circuit architecture is mainly designed to work supplied by domestic current.

Referring to the main board, it was divided into 8 functional blocks: Power Supply, Power Control, Microcontroller, Memories and RTC, RS-485 + RS-232, Modem GSM + SIM Holder, RF + Ethernet and finally USB. The division considers the circuit schematic sheets of the main board, available in the appendix B.

Some of the power voltages verified present differences between 10 and 30 mV lower than the expected value; however this fact does not constrict the system operation.

All the oscillator frequencies were verified with the oscilloscope and the results were the expected in theory.

A particular attention was given to the power voltages that supply the main board - VCC 3.3V - and each one of the sockets - VCC ETH to Ethernet socket, VCC GSM and VCC 2.8 to GSM or Wi-Fi socket and VCC RF to Bluetooth socket. Any of these power supplies presents constant restrictions. The load transient time never exceeds 1ms and the noise applied to the system only is relevant in the Ethernet socket supply voltage, but it does not affect its operational functions.

8.1.2 - Functional Validation

Validations seek to examine the correctness in the operation of the electronic circuit by examining its behaviour, through simulation. There are only two possible results: valid or not valid.

The parameters tested were focused on the buttons and LED's response, transistors performance and communications establishment - RS-485, I²C, SPI and USB - using firmware codes implemented by Nuno Varelas to assure the tests accomplishment.

8.2 - Power Consumption

Following the certification of the correctness of the circuits the theoretical consumption values boards were calculated and the real components consumption currents were measured.

The following table presents the comparison between the theoretical and the real current consumptions of the more power consuming components integrated in the main board. Excepting the microcontroller, which consumption was calculated for two functional situations, the other components were in an active status.

Table 4 - Main board components power consumption.

Component	Typical		Maximum	
	Theoretical	Real	Theoretical	Real
PIC (sleep state)	293 μ A	312,785 μ A	988 μ A	627,9 μ A
PIC (40 MIPS)	84 mA	59,712 mA	88 mA	59,674 mA
Flash Memory	12 mA	5,79 mA	17 mA	5,87 mA
EEPROM	3 mA	2,87 mA	3 mA	2,92 mA
RTC	40 μ A	267 μ A	120 μ A	325 μ A
RS-485	0,6 mA	5,5 mA	1 mA	6,0 mA

It is important to point out that current measures were made interrupting the circuit after the power management electronic block, which includes the current regulators. This was done to avoid the consumption of the voltage regulators which changes according to the current supplied at the entrance.

The table analysis illustrates that the microcontroller, the flash memories - the consumption presented is for just one but there are two in the board - and the EEPROM show power consumptions lower than expected, both in typical and maximum situations. On the other hand RTC and RS-485 consumption reveals that the real values are slightly higher than the values described in the datasheets. However, these deviations are considered normal and, the most important, do not compromise the system performance.

Both Bluetooth and Ethernet sockets power consumptions were also measured even if the real consumption of each component had not been calculated.

Bluetooth socket consumptions were measured for three different types of activity: in configuration, pairing and paired. Even if the consumption calculus in a configuration status was carried this can be ignored, once this situation just happens when the module is activated, only for 4 seconds.

Pairing and paired consumption modes are presented in the following tables.

Table 5 - Bluetooth Module power consumption in pairing mode.

Components	Theoretical		Real	
	Typical	Maximum	Typical	Maximum
PIC18	11,5 mA	23 mA	50 mA	51 mA
Bluetooth Module	53 mA	53 mA		
LED D1	0	1,6 mA		
Total	64,5 mA	77,6 mA		

Table 6 - Bluetooth Module power Consumption in paired mode.

Components	Theoretical		Real	
	Typical	Maximum	Typical	Maximum
PIC18	11,5 mA	23 mA	8 mA	17 mA
Bluetooth Module	5,6 mA (not transmitting)	24,6 mA (transmitting)		
LED D1	0	1,6 mA		
LED D2	0	1,6 mA		
Total	17,1 mA	50,8 mA		

From the table analysis it is possible to observe how consumptions are lower than expected in both situations. As will be seen later, there is a first approach here to the consumption differences, when the Bluetooth Module is still pairing to the case in which it is already paired. The differences are mainly focused in the Bluetooth Module that is in the core of the process when it is pairing, when it is trying to find out other devices. When the connection is already established the Bluetooth Module works just as a bridge between the microcontroller and the slave device, decreasing significantly the consumption level, mainly yet when no data is being transferred from the medical sensor to the transmission module.

In Table 7 is possible to examine Ethernet Socket power consumption. It is impossible to conclude anything related with the typical consumes, since any value to the ENC power consumption is given in the datasheet. On the other hand, the maximum value is lower than the theoretical sum of the values, which can be considered normal. It is also important to point out the differential consumptions from the Bluetooth socket to the Ethernet Socket. The last one power consumption

can reach 26 times the Bluetooth power consumption. This fact is not considered critical since using Ethernet the transmission module is not projected to be used as a portable device so often. When the integration of Wi-Fi and mainly the GSM/GPRS socket will be done should be taken in account this fact, since the consumption system must be as optimized as possible.

Table 7 - Ethernet Socket Power Consumption

Components	Theoretical		Real	
	Typical	Maximum	Typical	Maximum
ENC	--	250 mA	210 mA	215 mA
PIC24	84 mA	84 mA		
Rj-45	residual	residual		
LED D1	0	5 mA		
Total	Not applied	339 mA		

The last consumption test was executed to observe how consumptions vary with different voltages applied to the system.

A range between 8 and 30 volts was used and a graph was constructed as can be seen in Figure 54.

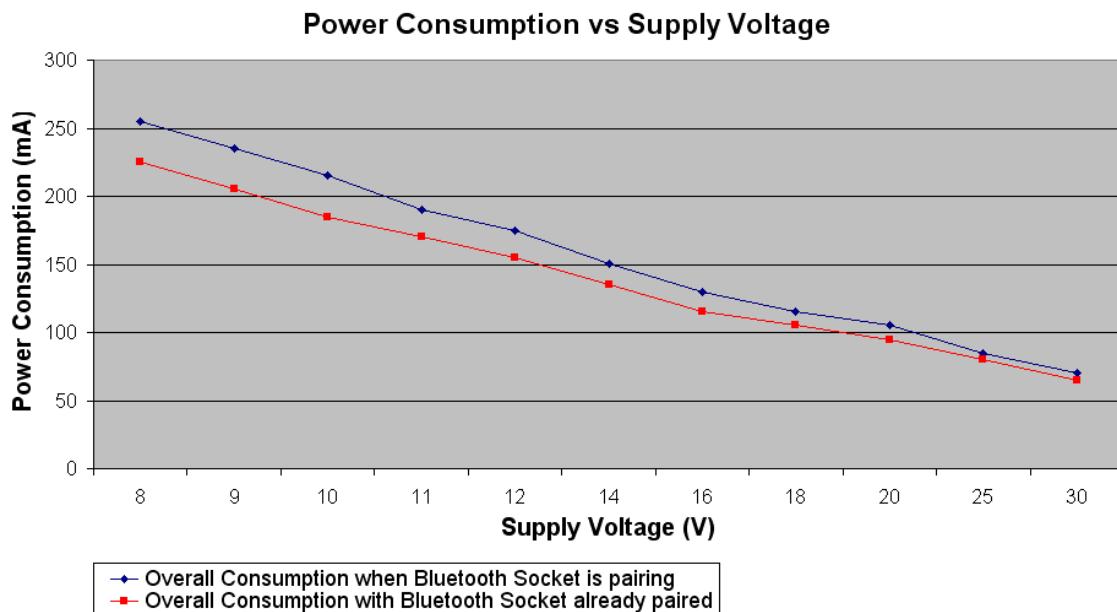


Figure 54 - Power Consumption vs Supply Voltage.

The first thing to conclude - and already expected - is the decreasing power consumption with an increasing in power supply. The lower voltage applied necessary to make the system work is 8 volts. Increasing slowly the voltage supply, until 16V, the consumption decline considerably; after this value it continues decreasing but smoothly, reaching a consumption of just 70mA to the maximum voltage, 30 volts.

It is also important to compare the different consumption of the entire system when the Bluetooth socket is in paring mode or when is already paired. As seen before in the Bluetooth consumption tables, there is a higher consumption in pairing mode, that is, when the module is searching for a device for the first time or when the module loses the connection with the medical sensor(s) and try to re-establish a connection; the overall consumption of the module when the Bluetooth socket is already paired is approximately 30mA lower than in the other mode. These discrepancies slow down with the increasing voltage as the regulators become more efficient with higher voltages. In the extreme situation, with 30V supplied to the system, the differences between the two modes are almost impossible to detect.

Tables with the consumptions used to construct the graph can be consulted in the attachments.

8.3 - System Features

The system characteristics are applied to the architecture used in the development to CCC (see chapter 9). This architecture is represented by an oximeter, as medical sensor, and the transmission module, using the Bluetooth socket as short- range communication and the Ethernet socket as long-range communication.

8.3.1 - Bluetooth Communication

Delays

Some tests were run to measure the delay times of Bluetooth communication. The pairing delay, that is, the time it takes to establish a connection between the Bluetooth module and the slave device was 4 seconds. This is considered a good delay. The unpairing delay, that is, the time it elapses since the loss of signal until

the real Bluetooth disconnection was 20 seconds. This is not considered a good delay but, unfortunately, this is an intrinsic characteristic of the communication and cannot be changed.

Bluetooth ranges

The Bluetooth communication range was also tested, via connection between the oximeter and the Bluetooth socket. The oximeter, Nonin 4100, operates in class 2, allowing a theoretical range of 10 meters; the Bluetooth module is settled to operate in all the classes but the configuration used turns it accessible in class 1, with up to 100 meters of range communication.

Table 8 presents the Bluetooth test ranges in line of sight and with obstacles between the devices.

Table 8 - Bluetooth communication ranges.

Barrier	Maximum Range
Line of sight	80 m
1 wall	50 m
2 walls	22 m
3 walls	15 m
4 walls	Not applicable

The results obtained exceed the expectations since diverse problems use to origin by the interposal of obstacles in Bluetooth communication.

Bluetooth ranges established by modules operating with different classes are closer to the range of the higher module, here the F2M03GLA Bluetooth module. The high sensibility of this module allows to receive data from a class 2 device, even with distances superior to 10 meters. Even if the signal gets weaker with higher distances, the Bluetooth module is able to detect it without losing any data. This is shown by the range obtained in line of sight, 80 meters, closer to the theoretical range of the Bluetooth master module but inferior than this, prejudiced by the class 2 oximeter.

The communications present very good performances, regarding the interposal of obstacles. Bluetooth communication usually origin several problems when trying to cross walls but our experiences demonstrate the opposite. Data was able to be send

across a maximum of 3 walls, always with good ranges. The interposal of a 4th wall degrades exponentially the signal, with constant loss of communication between the devices. However, the performances exceed our expectations and reveal this type of communication is adequate to the system architecture since in a normal house the distance between the user and the transmission module is hardly higher than 15 meters and scarcely cross more than 3 walls.

Memory

The transmission module saves data received from the medical sensors even if this data is being re-send to the datacenter. The data is then stored over the older information, being deleted. In the particular case of the oximetry signal, which is stored with 11 bytes per sample and with a frequency of 1 save per second, it guarantees the store of 54,6 hours of data in one 16 Mbit flash memory. This feature is useful when the connection between the transmission module and the datacenter is lost, mainly in the case of transmission with wires (Ethernet), since if the user need to move should disconnect the module and when re-connected the stored data is finally transferred.

8.3.2 - Battery

Experiments were also prepared to determine the battery duration. These tests were done with Nonin 4100 Bluetooth oximeter and data transmission over Ethernet cable. The average duration of the battery was 2 hours and 10 minutes. Despite being an acceptable value, this is not well founded, once the more potent regulator in the integrated system - the buck-boost -, which optimizes the system's consumption has been showing some problems and it has not been mounted. When these situations will be solved, the battery duration is expected to be greater.

The system had not registered main concerns regarding the tests carried, however mechanical and thermal tests should be performed.

8.4 - Certifications

Once the system is completed and all the tests have been passed the following task is register the product.

For electronic circuits and systems to be available for commercial sale, they must meet the requirements of specific legislation. If electronic products meet the requirements, they will have a verifying marking on the outside, usually either CE (in Europe) or FCC (in USA).

The CE marking is a declaration by a product manufacturer that the product meets all of the appropriate provisions of the relevant legislation required to implement specific European Directives. It is meant to be a mark of product quality.

Focusing in our system, it should respect 4 different directives: [49]

- Low Voltage Equipment Directive 2006/95/EC.
- Electromagnetic Compatibility Directive 2004/108/EC.
- Medical Devices Directive 2007/47/EC.
- Radiocommunications and Telecommunications Terminal Equipment 1999/05/EC.

The entity which regulates the certification of medical devices inside the Portuguese territory is INFARMED - Portuguese regulatory authority that evaluates, authorises, regulates and controls medical devices.

Before initiating the product certification and marking a technical report should be compiled, comprising the system specifications, a technical exam to the system, the construction techniques employed and a technical description. [50]

9 - SYSTEM DEVELOPMENT TO CCC

Centro Cirúrgico de Coimbra (CCC), a well-know private healthcare provider in the region of Coimbra, showed their interest in our system, compelling to the development of a different application to this specific case. The main functionality of the system should be the emission of an alarm, remotely sent to a healthcare professional, when any vital sign parameter shows abnormal behaviour. Thus, just one vital sign is acquired in real-time - pulse oximetry - being the transmission module responsible for the remote transmission of this data, plus the recognition of an alarm fired by a vital signs monitor already in use in the clinic, as shown in Figure 55 . Thereby, the user application installed in the nursing central should allow the visualization of data in real time and emit alarms when anything is out of normal. When this occurs a pager message is sent to the healthcare responsible, provided with a pager receptor. This professional should verify the patient status and confirm that the message was received. If this confirmation is not given the system will continue sending messages to other addresses, following a hierarchy incorporated in the application.

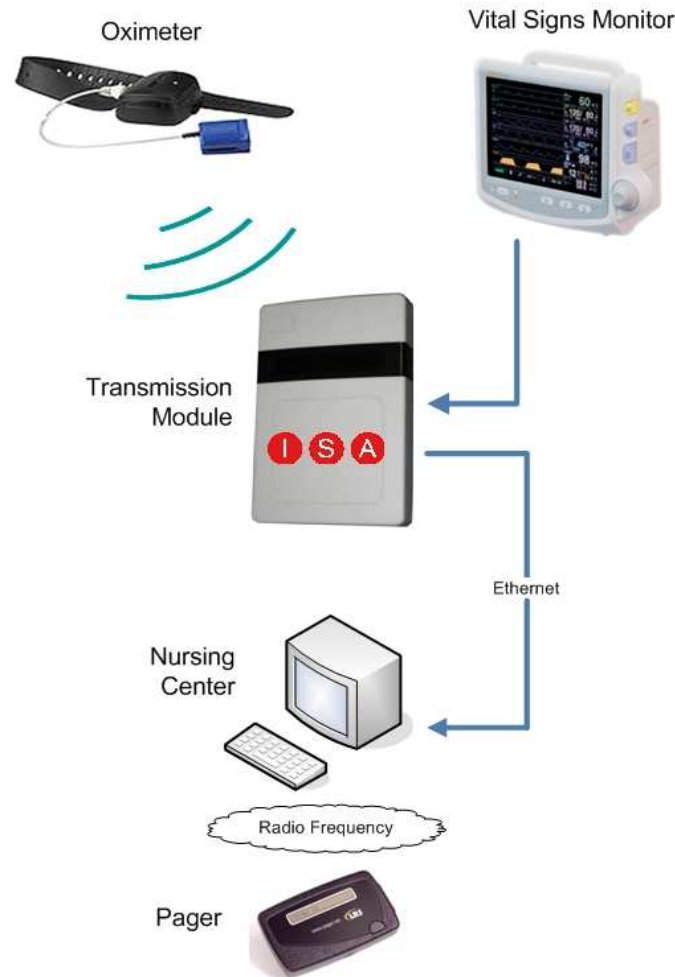


Figure 55 - CCC application: general architecture.

9.1 - Acquisition Module

As required in the project specifications the acquisition parameter consists in an oximetry signal, provided by the pulse oximeter described in 6.1.1 -. As said before, this oximetry uses Bluetooth communication to send the data to the transmission module, being the only vital sign acquired in real-time in this specific application of the project - with the respective cardiac frequency obtained with the same device, as also explained in chapter 6.1.1.

Beyond the oximetry signal, a monitor (in use in the clinic) where several vital signals (ECG, arterial pressure and temperature) are acquired is connected through a wire to the transmission module, giving information to the system when an alarm is emitted. It is important to point out that the only information acquired and remotely

transmitted regarding this monitor is the alarm generation, and any vital signs data is available in the nursing centre.

9.2 - Transmission Module

The transmission module designed to the application in CCC is composed for three modules (described in detail in chapter 6.2): a Bluetooth and an Ethernet socket enclosed in the main board.



Figure 56 - Transmission Module Board Overview.

The data is received over the Bluetooth socket - oximetry data - and a switch on the main board is connected to the vital signs monitor - indicating the generation of an alarm in the monitor, by closing the switch. This data is then processed over the instructions of the microcontroller in the main board and, through the Ethernet socket, sent to the clinic's network, having the nursing centre as final destination.

Some technical measures were made to the transmission module. Thus, the module size is 168mm (L) x 107mm (W) x 35mm (H) and its weight is approximately 300g.

9.3 - Terminal Module

As explained before the terminal module installed in the nursing centre receives the data through an Ethernet interface, realizing the operations described in chapter 6.3. When an alarm is emitted the software should generate automatically a SMS pager that is connected to the pager transmitter as explained in the following section.

9.4 - Paging System

The main objective of this application is that the healthcare professional can be reached, wherever he is, inside the clinic facilities, when the patient status is outside the normal parameters. Thus, after the recognition of an alarm in the nursing centre, it is needed a way to communicate with the healthcare professional.

The first option considered was the delivery of a SMS using GSM/GPRS communication technology, but this choice was dropped since this communication could interfere with the medical devices used in the clinic.

Thus, an old and for some obsolete technology was considered: a pager (or beeper). In spite of the limitations of this technology, it is even more suitable than GSM/GPRS communication to this specific application. Pager communication emits little radiation power and guarantees the electromagnetic compatibility of the medical devices and beyond this fact, the transmitter pager is confirmed when the message is received by the receptor, being this type of communication faster and

less disruptive when compared with GSM. For these reasons paging messages still survive nowadays, used in niche markets as emergency service and medical personnel. In addition pager communication avoids the payment of royalties, unlike GSM communication technology.

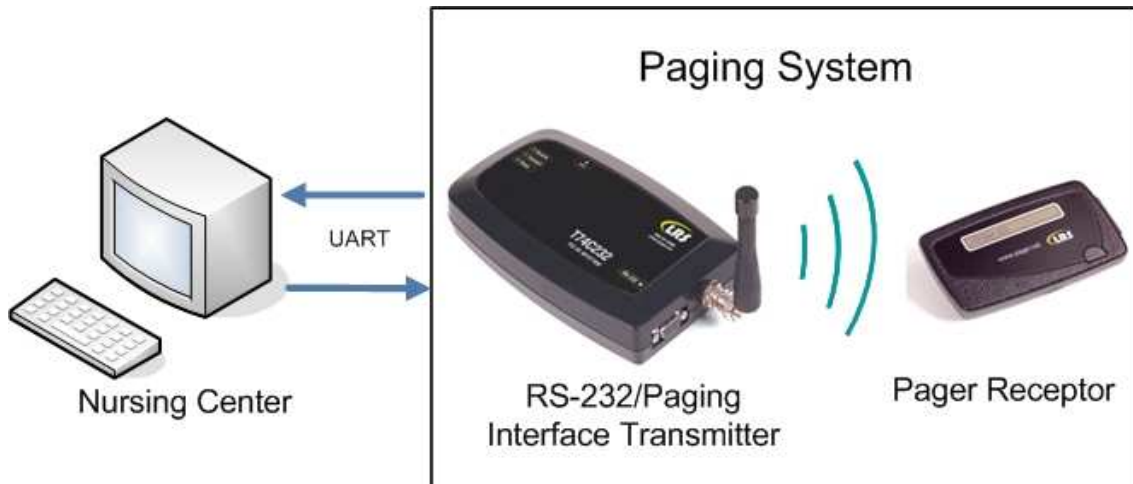


Figure 57 - Paging System Communication.

A messaging software platform to integrate in the nursing center was searched in the market but, unfortunately, any solution was found with the possibility of sending messages automatically as well as creating a hierarchy of receptors. Thereby, the solution consists in creating our own software, able to sending messages automatically when an alarm is generated and continue re-sending them to different operators if any confirmation is introduced in the nursing centre, authenticating the surveillance of the patient status. This software is interfaced by a pager transmitter connected to a RS-232 port.

After a market research and further contact with the distributors the T74C232 Interface Transmitter, from the american company LRS - Long Range Systems -, was selected to establish the communication between the messaging platform and the pager receptor. This transmitter allows the creation of our own application to operate with any LRS pager and interfaces with any computer using a LRS, WaveWare or JTECH communication protocol. It operates with a 220V supply, using UHF band (420 - 470 MHz). It supports over 1000 pagers and up to 76 precanned messages. Three LEDs are present in the device: the first shows the power status and the other two the messages transmission and reception. The transmitter offers a range of approximately 3000 meters in an unobtrusively environment, adequate to this

specific application and also appropriated even when applied to a large scale hospital. [51] [52]

The final destination of our system is the receptor pager. Our choice was the SP5 rechargeable pager, an alphanumeric pager operating with 1 AAA battery that lasts approximately 3 months. The SP5 supports up to 99 messages and holds up to 200 character each message.

10 - CONCLUSION

The Remote Vital Signs Monitoring system has been described in the present thesis as a project carried throughout the past academic year. The architectural projection and technical design of a system able to remotely acquire and process physiological data accurately and in real-time was the main goal of the project and the central theme of this thesis. Following, the project status is described and analysed, preceding the presentation of some ideas and suggestions to improve the system's features and finally and personal appreciation of the overall project is done from two points of view, on one hand the general society benefits and on the other and the student personal and professional grow.

10.1 - Project Status

This is a continuance project that started to be developed in the previous academic year; nevertheless the system was highly changed and this fracture compelled a renewal of many requisites and system architectures. These modifications comprise both acquisition and transmission modules. The development of the system's sensors and connection through wires with an acquisition module carried by the user was dropped in benefit of the purchase of wireless sensors already certified. This fact speeds the system's implementation once all the certification and marking process of medical products is extremely lengthy. Transmission module also suffered modifications, where the old design was replaced by a new system already developed by the company and which provides an increased modularity, allowing the incorporation of add-ons that manage the exterior communications. Beyond this improvement, the utilization of the same system to two different projects saves economical and human resources, both in development, prototyping and testing phases. Finally, when compared with the last architecture this system also integrates the possibility of wired communication (Ethernet), useful when the healthcare provider does not have any available wireless network.

Nevertheless, the proposed plan was not entirely reached. Once the creation of a specific system has been proposed, the integration of other sensors, beyond the pulse oximetry had decreased their priority and has not been accomplished. The long-

range communications are not yet completely implemented in the system, however they are in an advanced state. Ethernet and GSM/GPRS communication modules were created outside the project team but inside the company and, from a physical point of view, are completely developed, missing just the prototyping and test of the GSM/GPRS socket. The Wi-Fi module had been already designed by the student however it is in the same situation as GSM/GPRS socket. This delay is due to many unforeseen problems: the lack of experience in circuit design and the knowledge acquisition in CAD software was lengthy; the student was involved in other project during the first semester, slowing down the main project progress and the re-definition of methodologies delayed the system's prototyping.

However a valid solution, that integrates only one vital sign (pulse oximetry) and both wireless Bluetooth and wire Ethernet communications, has been accomplished. Regarding the quality control, electrical tests and functional validation of the system were successfully achieved, and system features reach performance requirements. Only the battery duration must be improved, to increase portability, but the poor performance is mainly due to the problem verified with the integration of the main regulator, which should be reviewed shortly.

10.2 - Future Work

In this section some ideas are suggested to continue the project improvement, which can be used as an initial orientation for future developers.

In a short term, long-range transmission solutions should be completed. GSM/GPRS and Wi-Fi sockets should be prototyped and tested, allowing to embed the needed firmware in order to achieve accurate communication with the datacenter.

Some long-term objectives can also be suggested, despite the system requirements are not completely defined, making harder the proposition of improvements. Long-term approaches are mainly connected with the physiological data acquisition. The first step passes through the integration of new medical sensors. Secondly, the communication technology should be re-thought, as Zigbee proportion increased portability due to power save consumption. The collection of all the data in a single wireless acquisition module is a double-edged sword. On one hand it saves power and economical resources, once the system just need to be supplied with one

wireless module. On the other hand, a data acquisition module, to which all the sensors are connected, decreases patient freedom of movements, as wires should be attached to this module; and increase complexity in the integration of new sensors, once the acquisition module should support interfaces for all the vital signs acquired.

10.3 - Final appreciation

The final appreciation of this document regards both the project status and the developed work throughout the academic year.

From a clinical point of view the system provides real-time monitoring and alarms emission, essential to prevent patients in distress; and storing and statistical treatment of data allows studies' analysis to early diagnose future health troubles in the patient's condition.

Regarding the technical characteristics, it comprises a set of communication technologies, allowing various personalized solutions, depending on the users (or clients) demands.

The personal final appreciation of this work is very positive. Technically speaking the student acquired some primarily experience in the electronics field and particularly in PCB design and circuit construction. The acquisition of a different view to high-tech devices used in the daily routine was also earned with the realization of this project, trying to understand not just how to work with it but also how it works. Considering the work environment, the integration in a company provided a first perspective of how an enterprise daily routine is and how professional life will be. As this is a group project the student acquired a good work team spirit, distributing tasks and conciliating different perspectives into a single and final result.

The overall project development allowed a mature, global and practical use of the knowledge acquired though the academic pathway in such a way that the student hopes to be able to apply his professional and personal skills to improve general society life quality.

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ATTACHMENTS

A. Schematic Documents and PCB Layout

A.1. Main Board

1

2

3

4

U_1 - POWER SUPPLY
1 - POWER SUPPLY.SchDoc



U_2 - CTRL POWER
2 - CTRL POWER.SchDoc



U_3 - MICROCONTROLLER
3 - MICROCONTROLLER.SchDoc



U_4 - Mem + RTC
4 - Mem + RTC.SchDoc



U_5 - RS485 + Rele
5 - RS485 + Rele.SchDoc



U_6 - GSM
6 - GSM.SchDoc



U_7 - RF + Ethernet
7 - RF + Ethernet.SchDoc



U_8 - USB
8 - USB.SchDoc



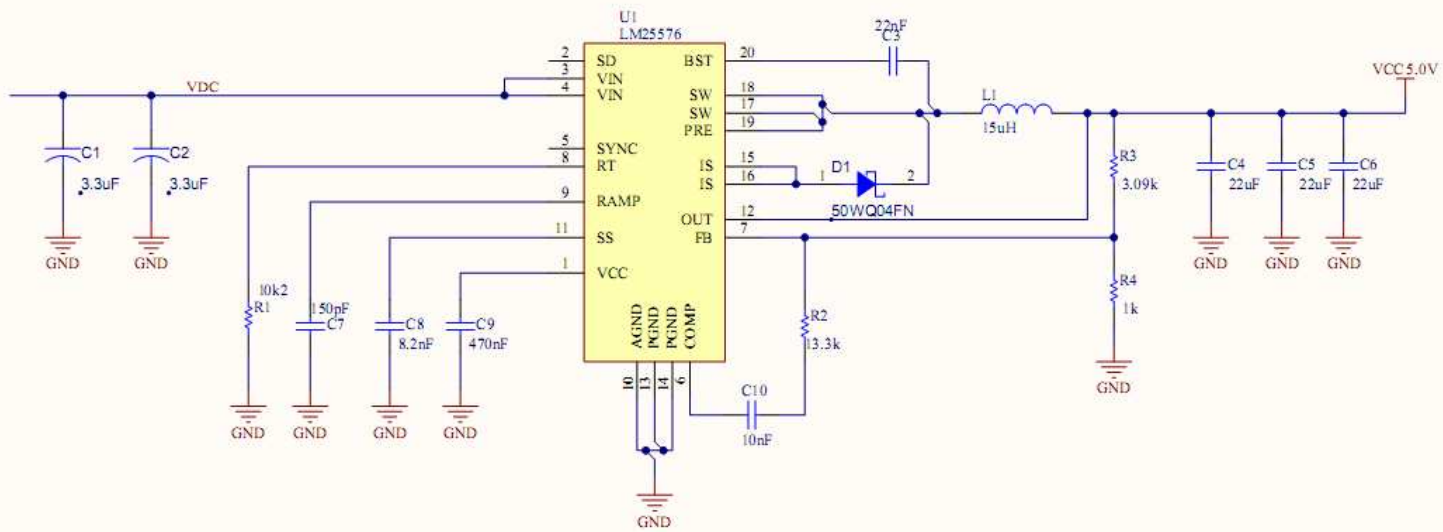
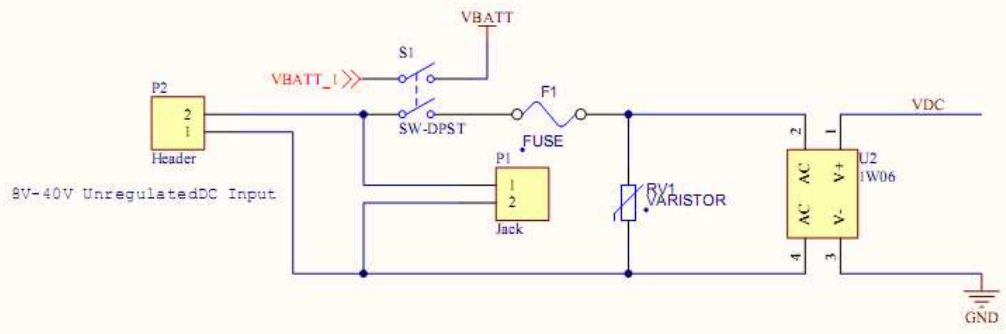
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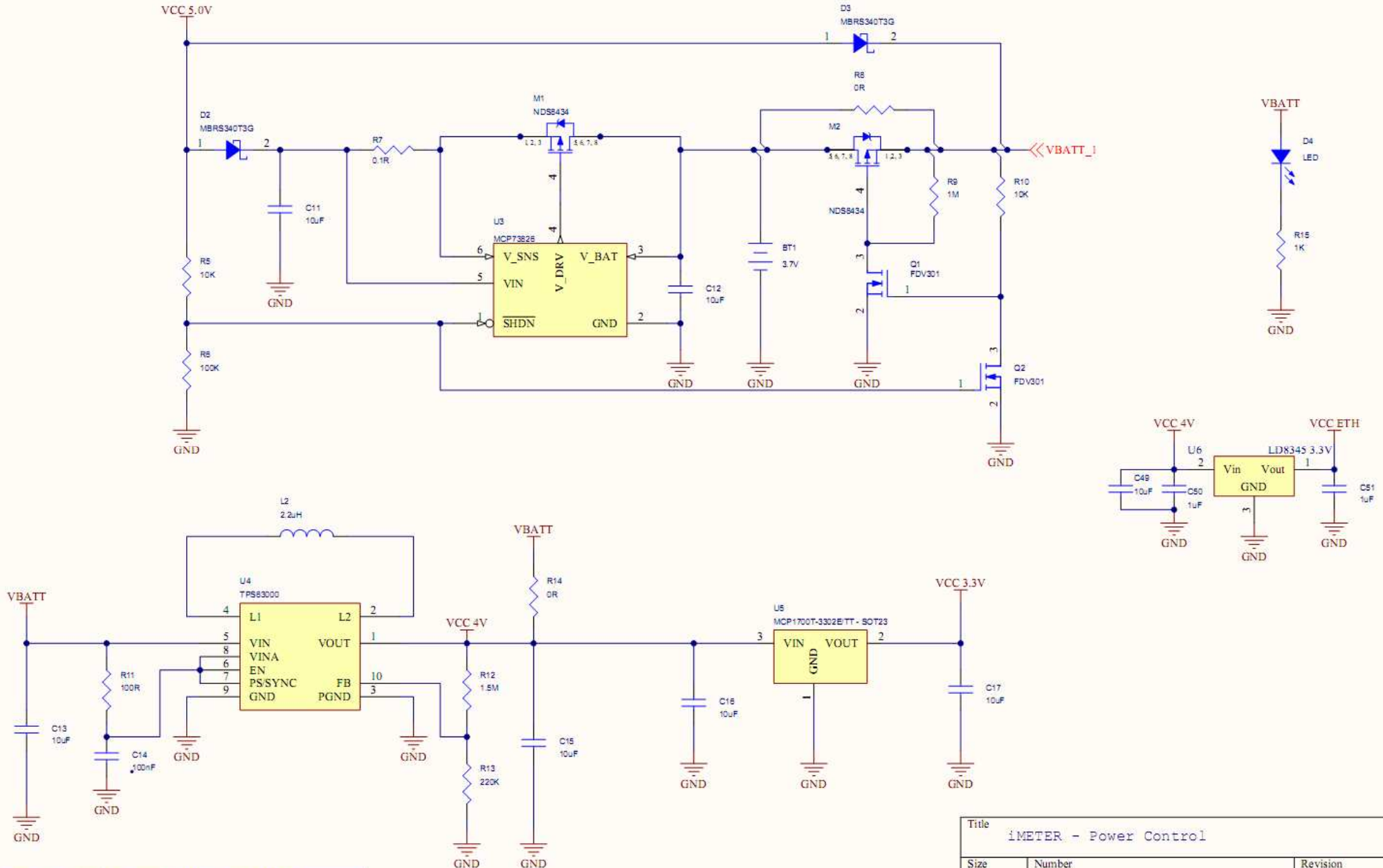
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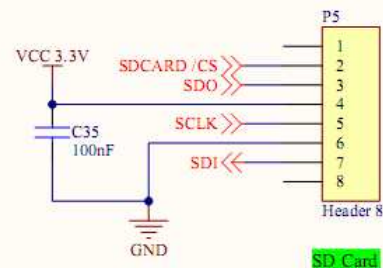
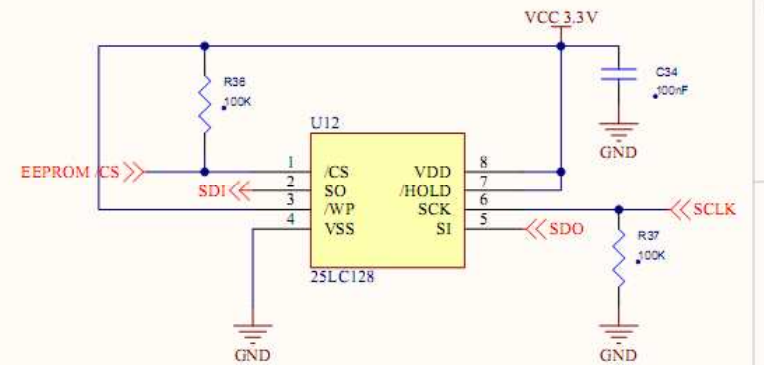
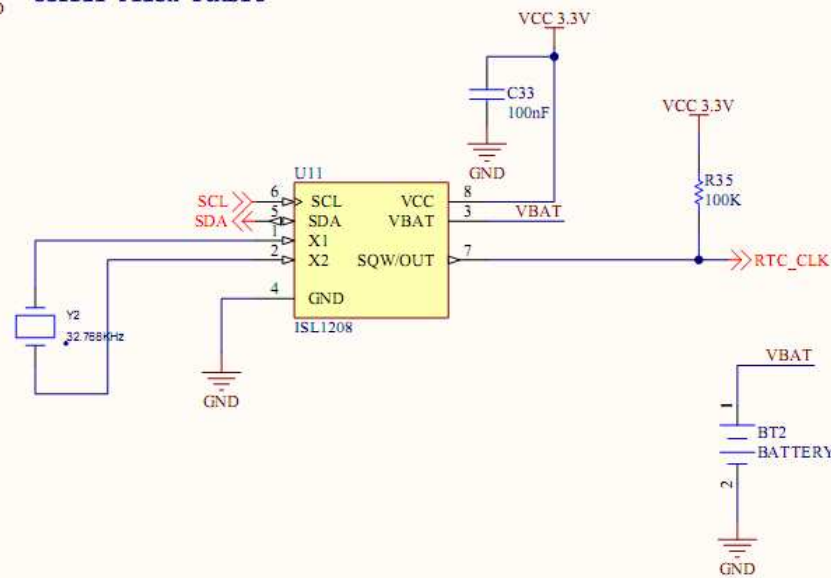
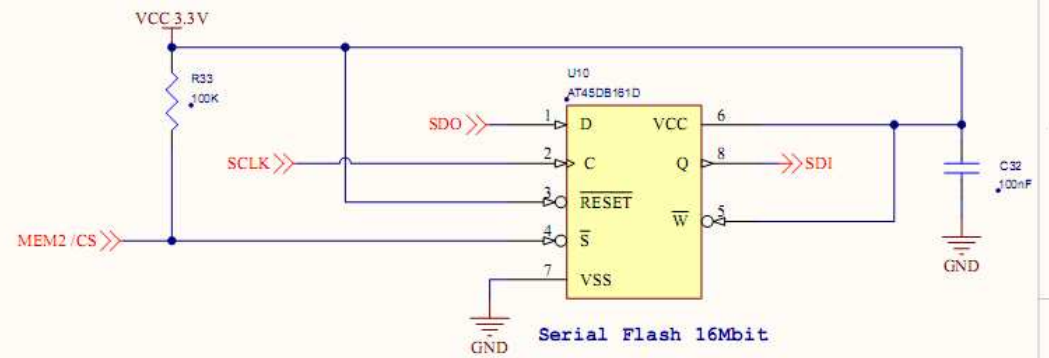
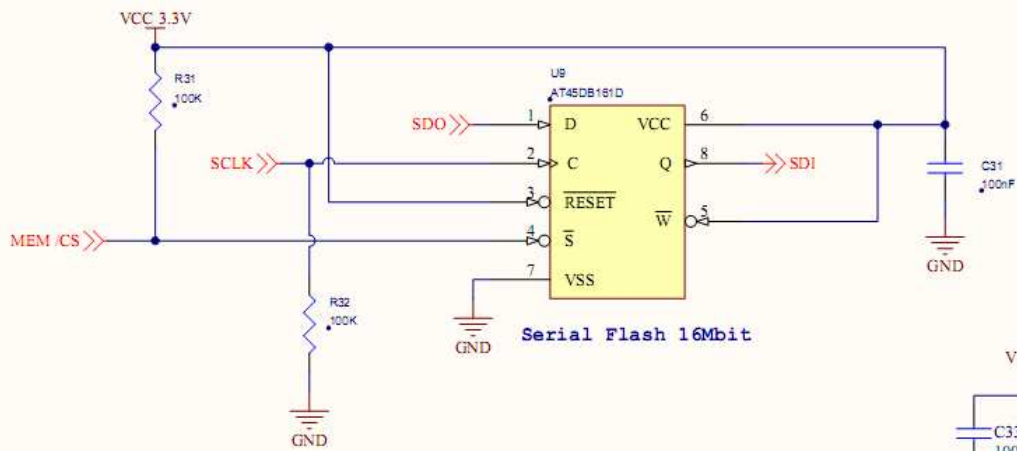


Title		
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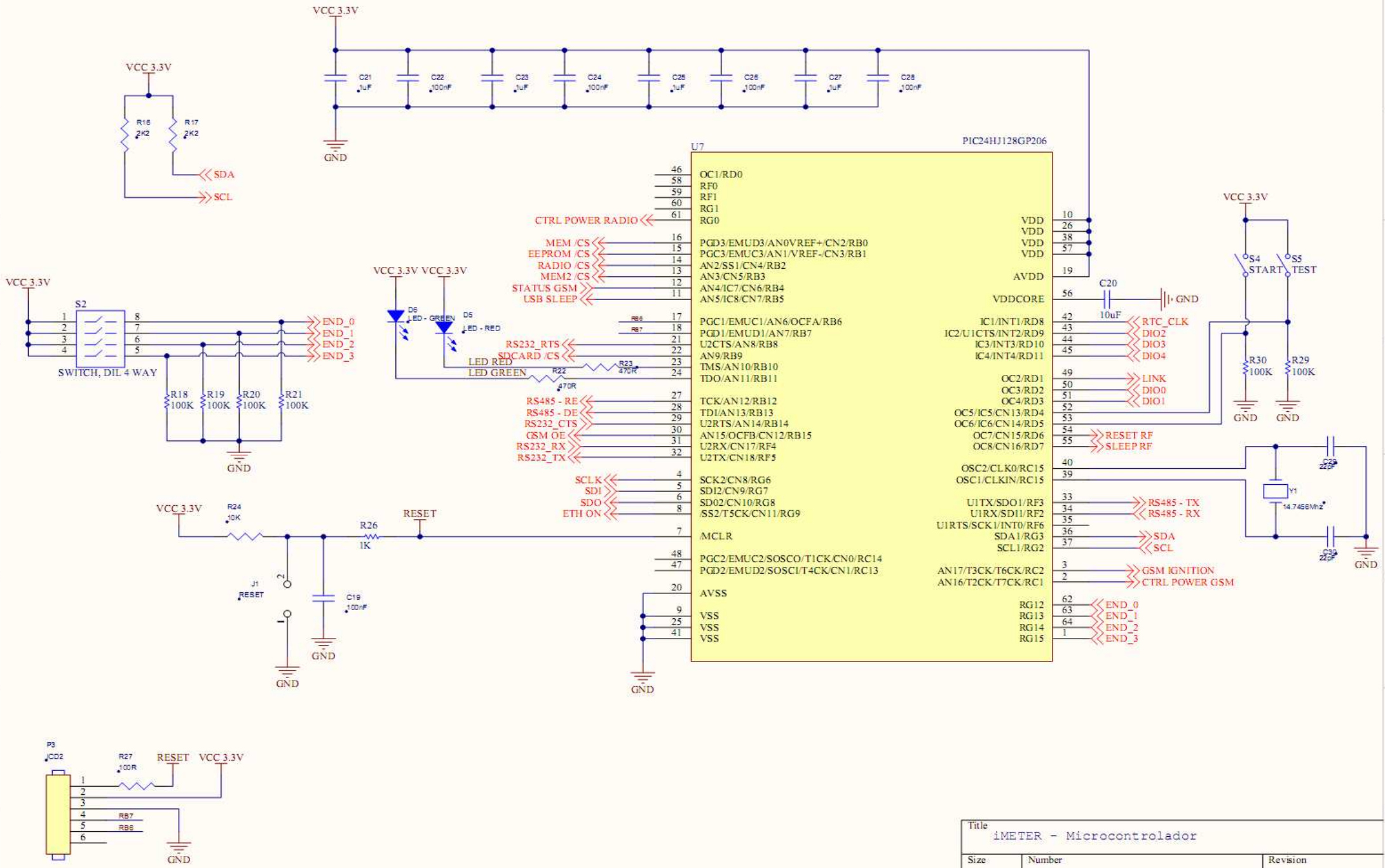


* Componentes opcionais, não montados na versão normal da placa

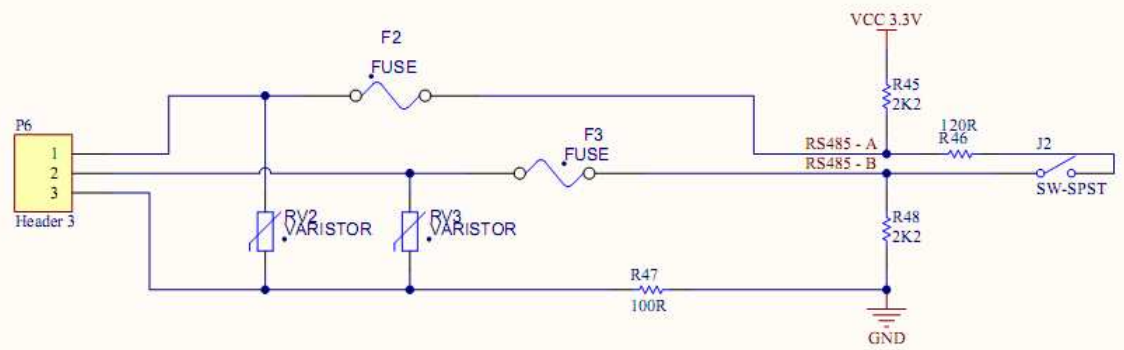
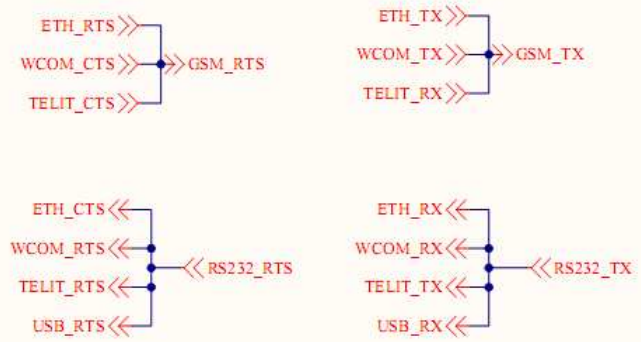
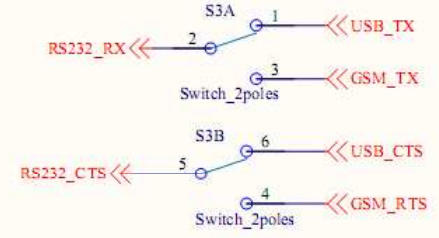
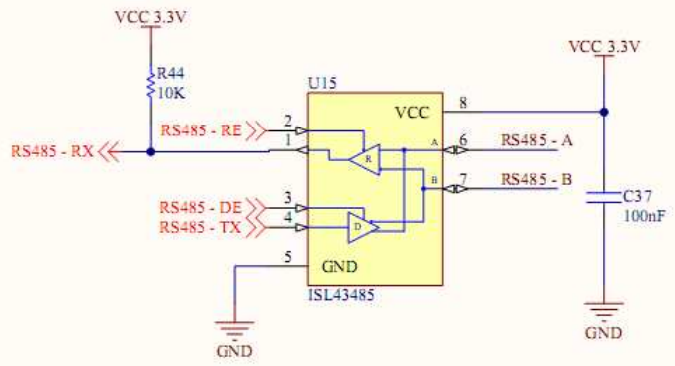
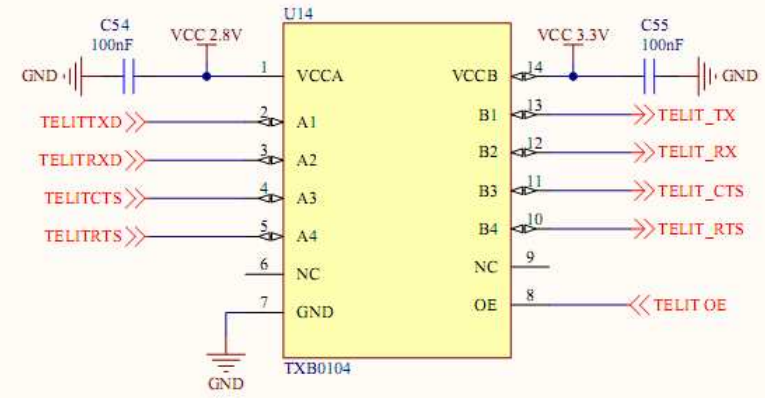
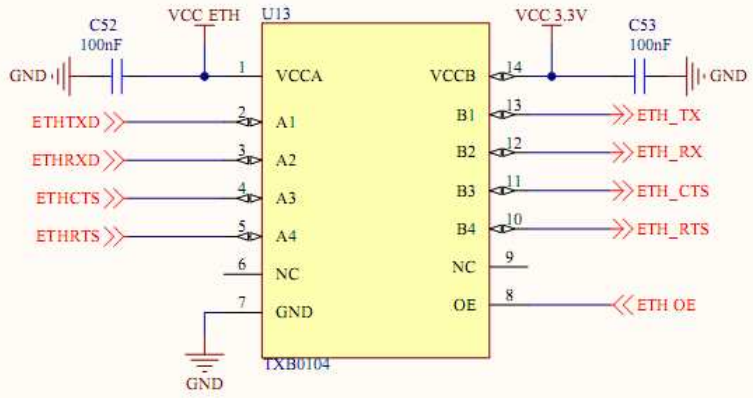
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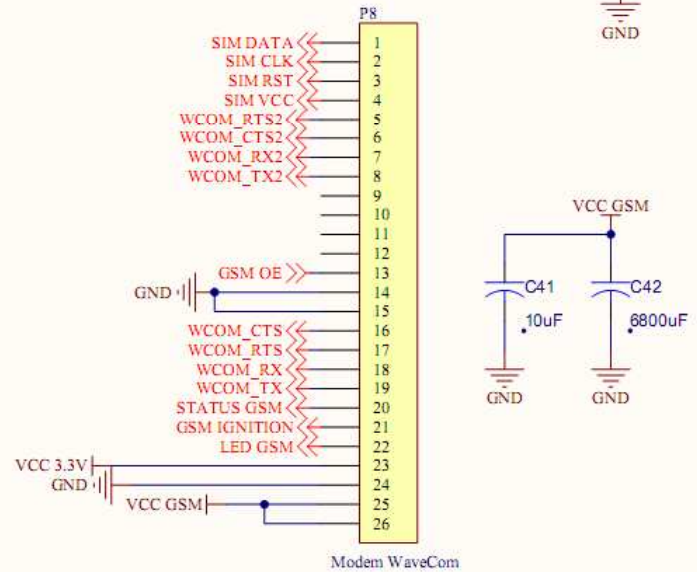
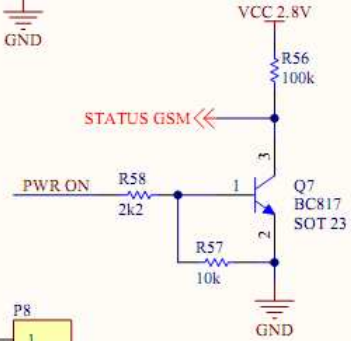
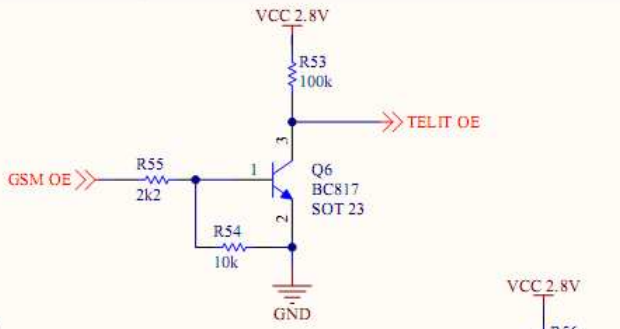
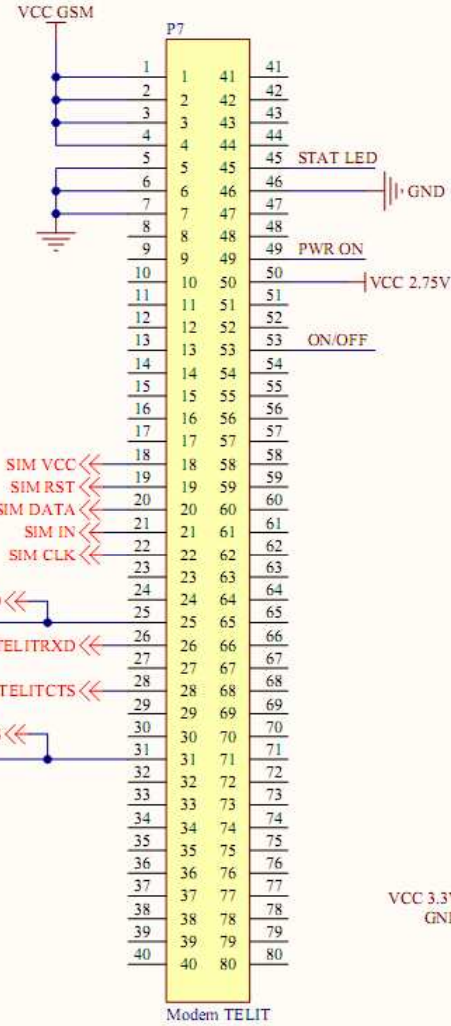
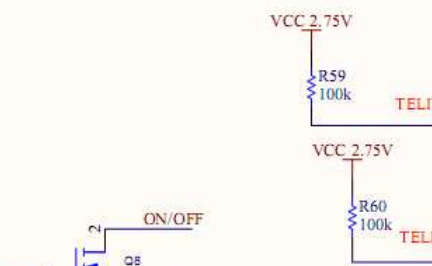
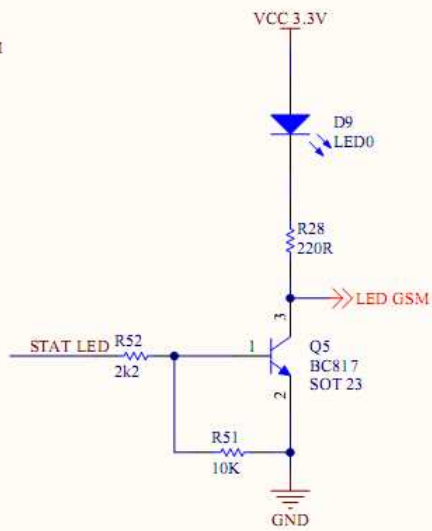
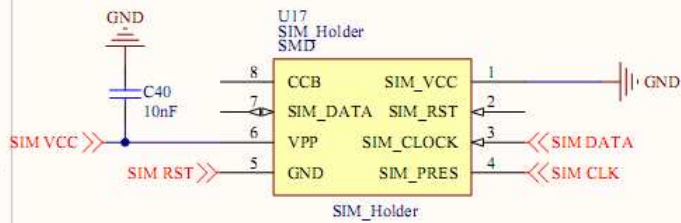
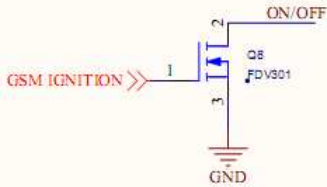
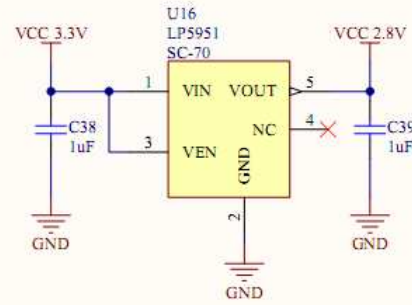
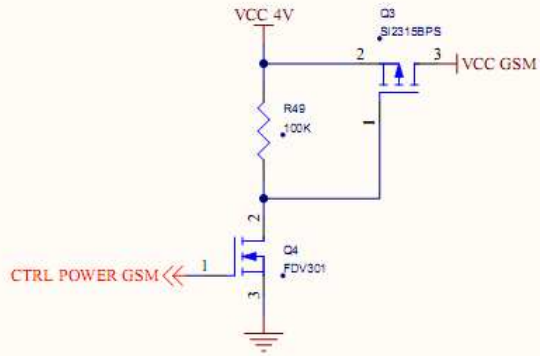
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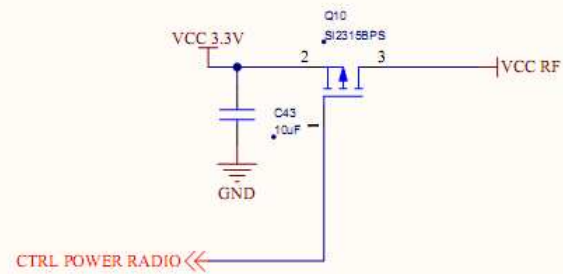
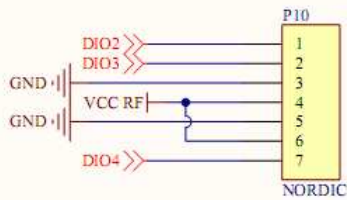
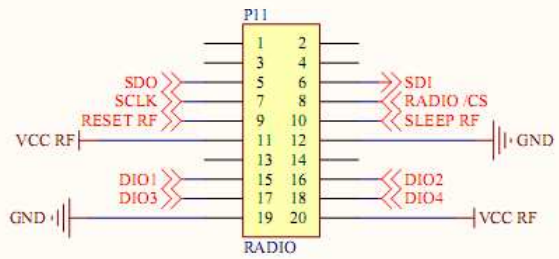
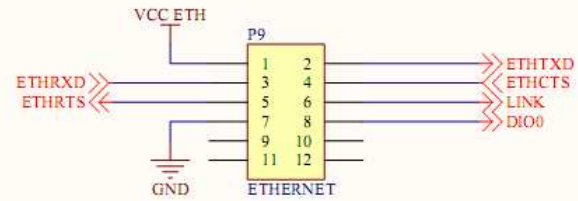
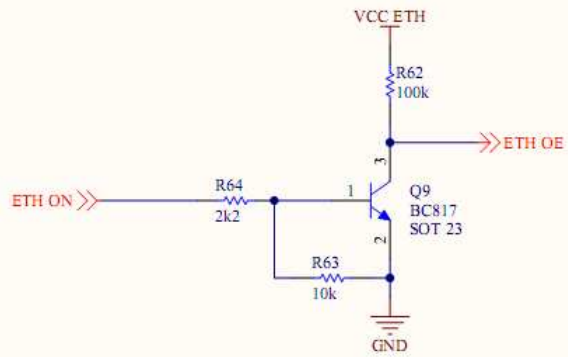
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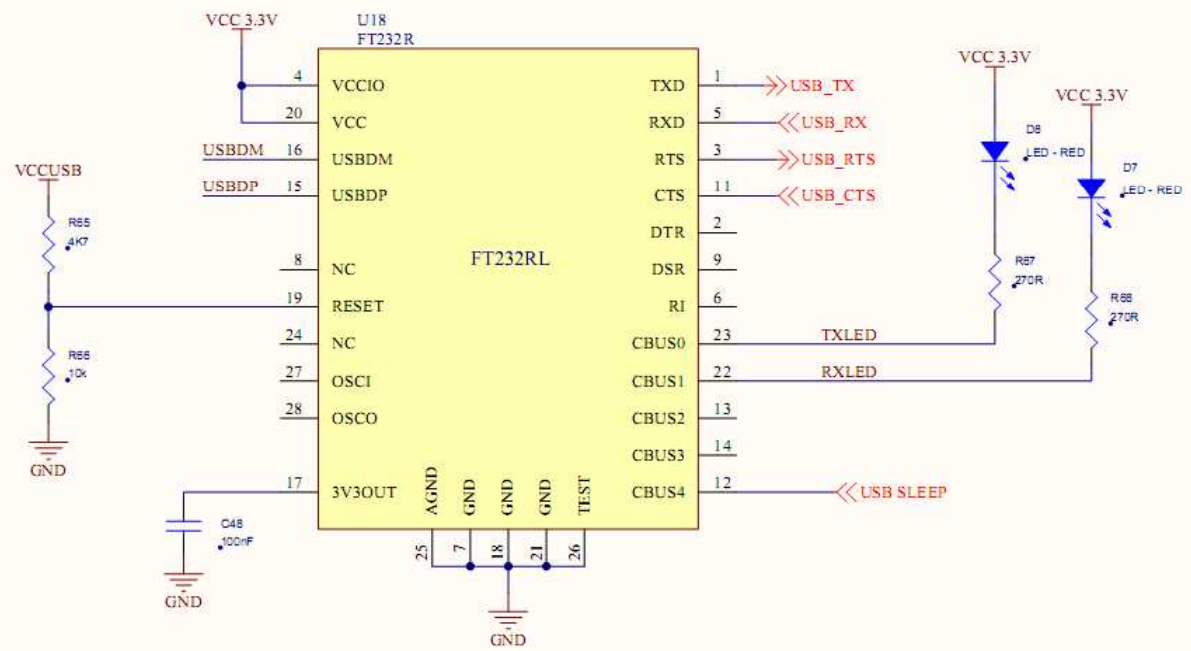
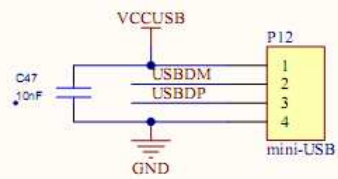
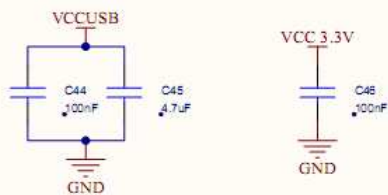
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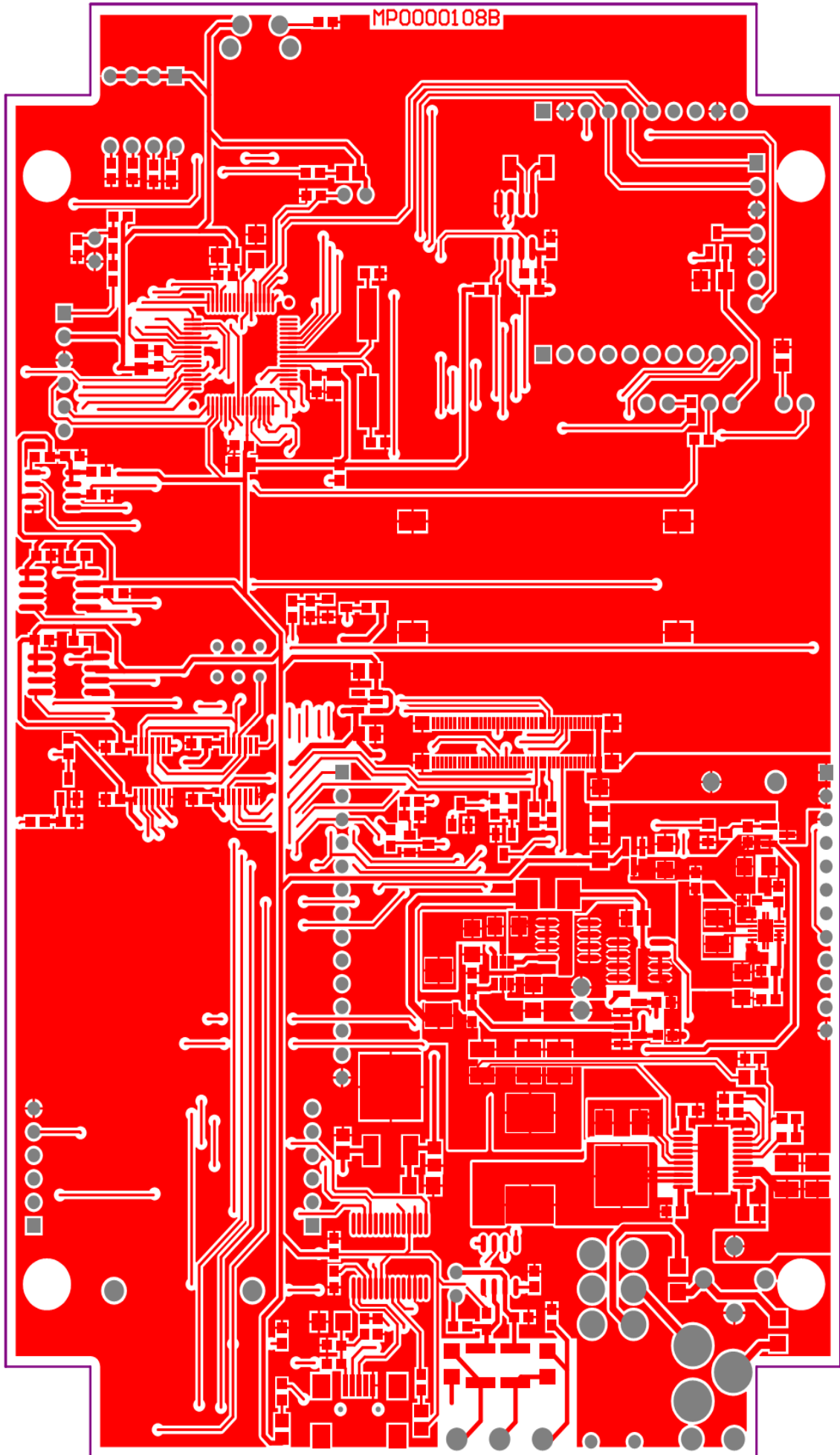
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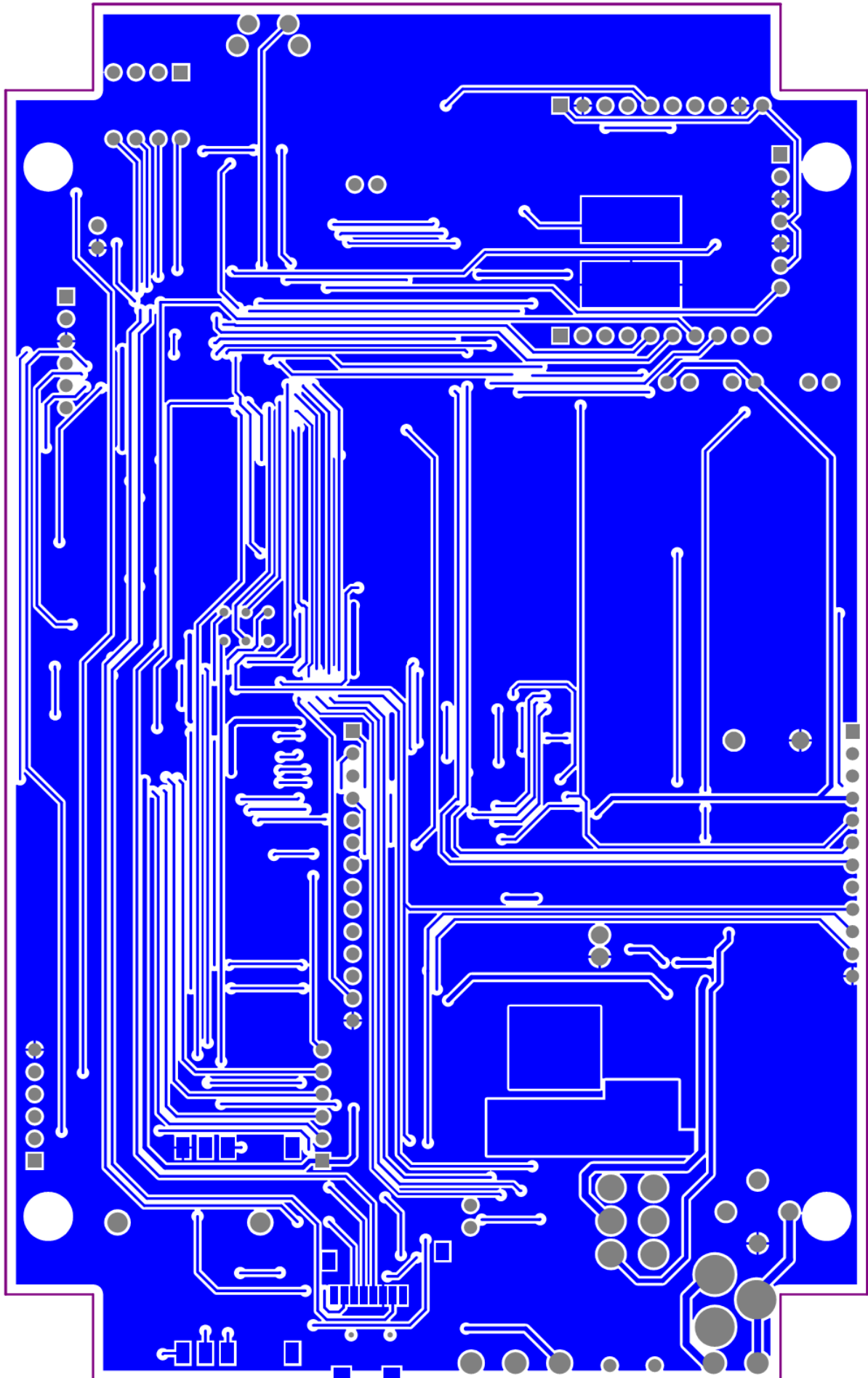


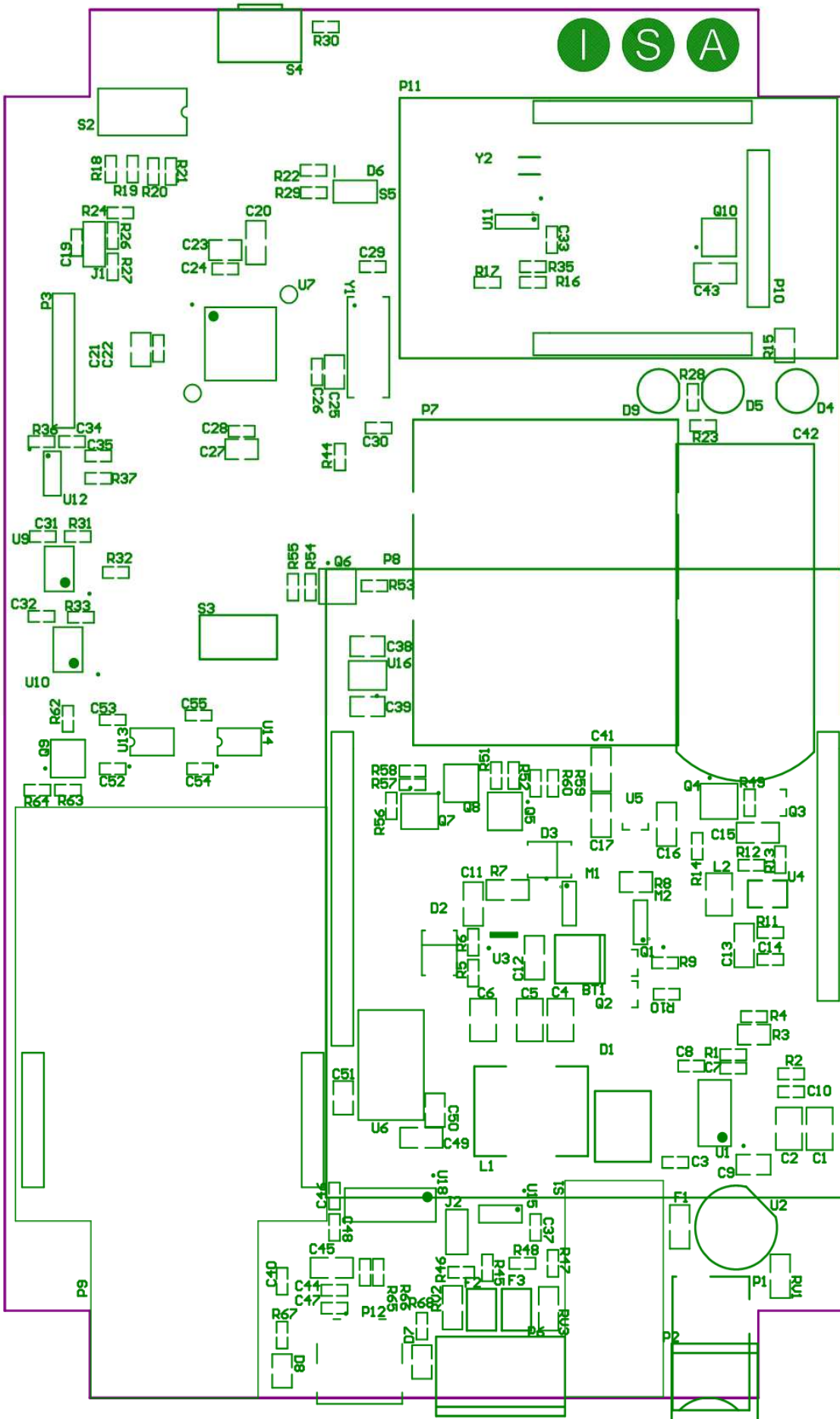
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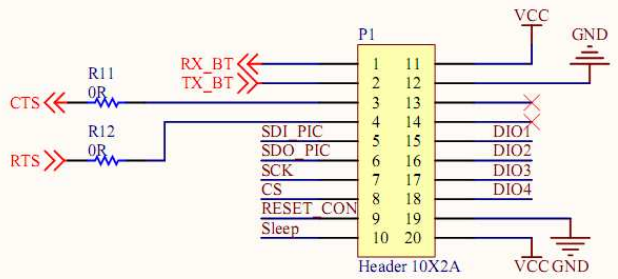
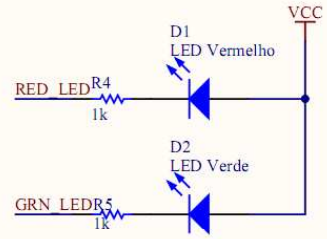
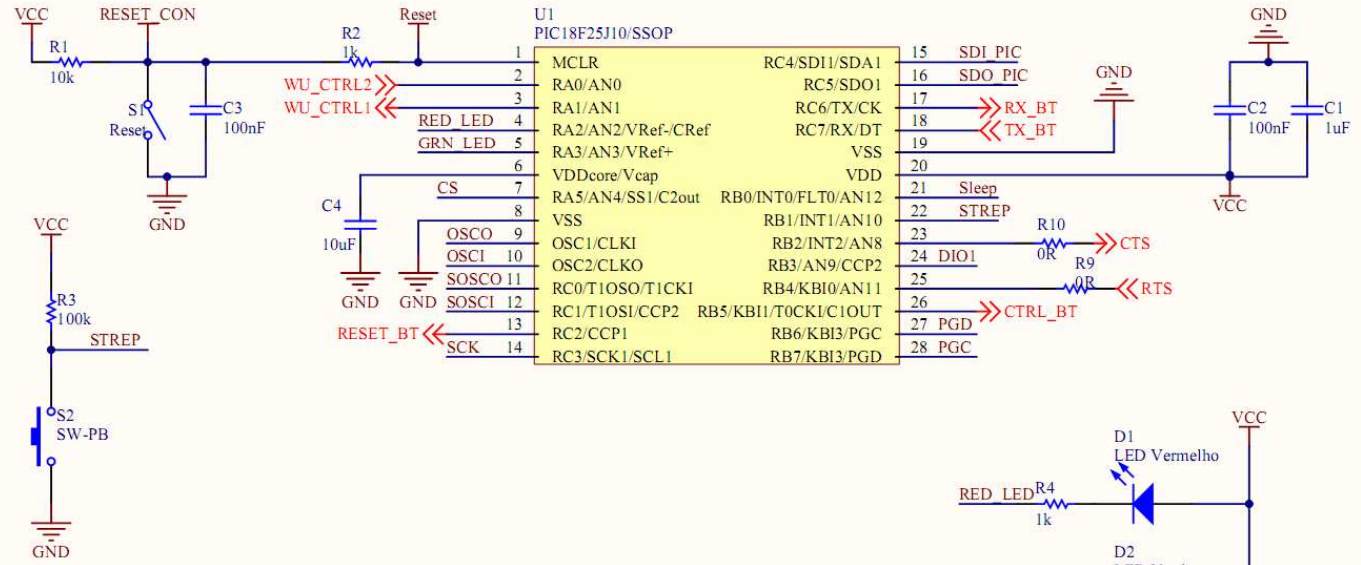
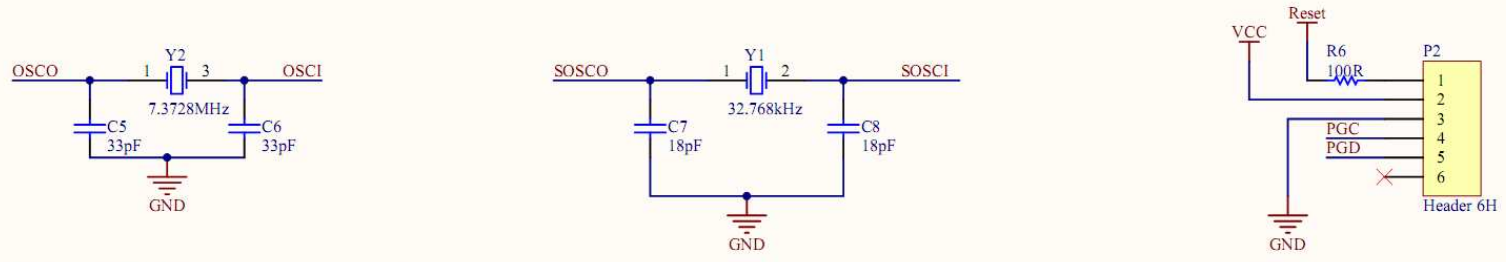
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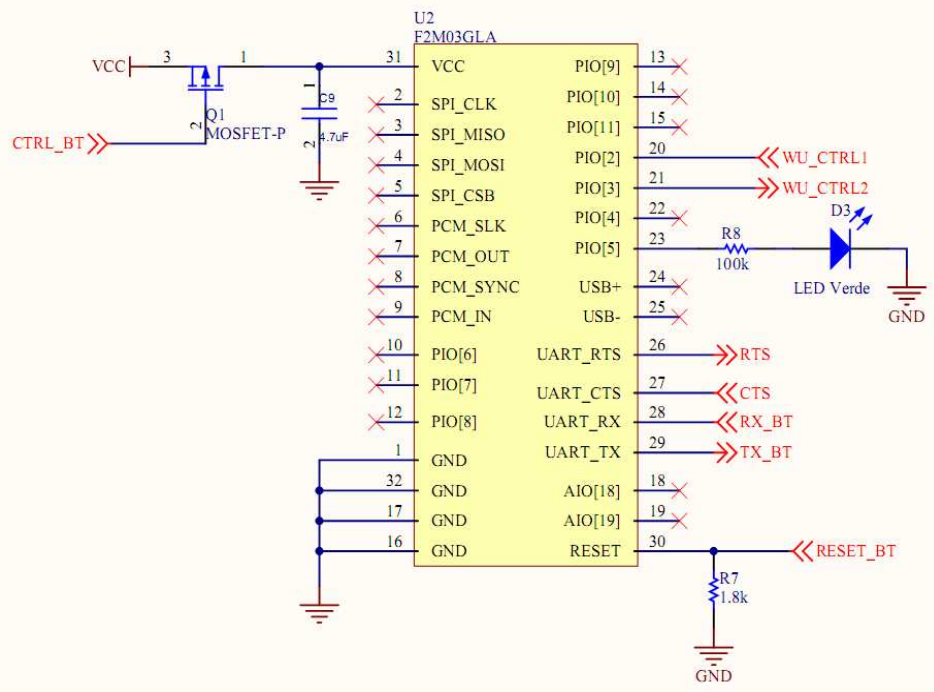




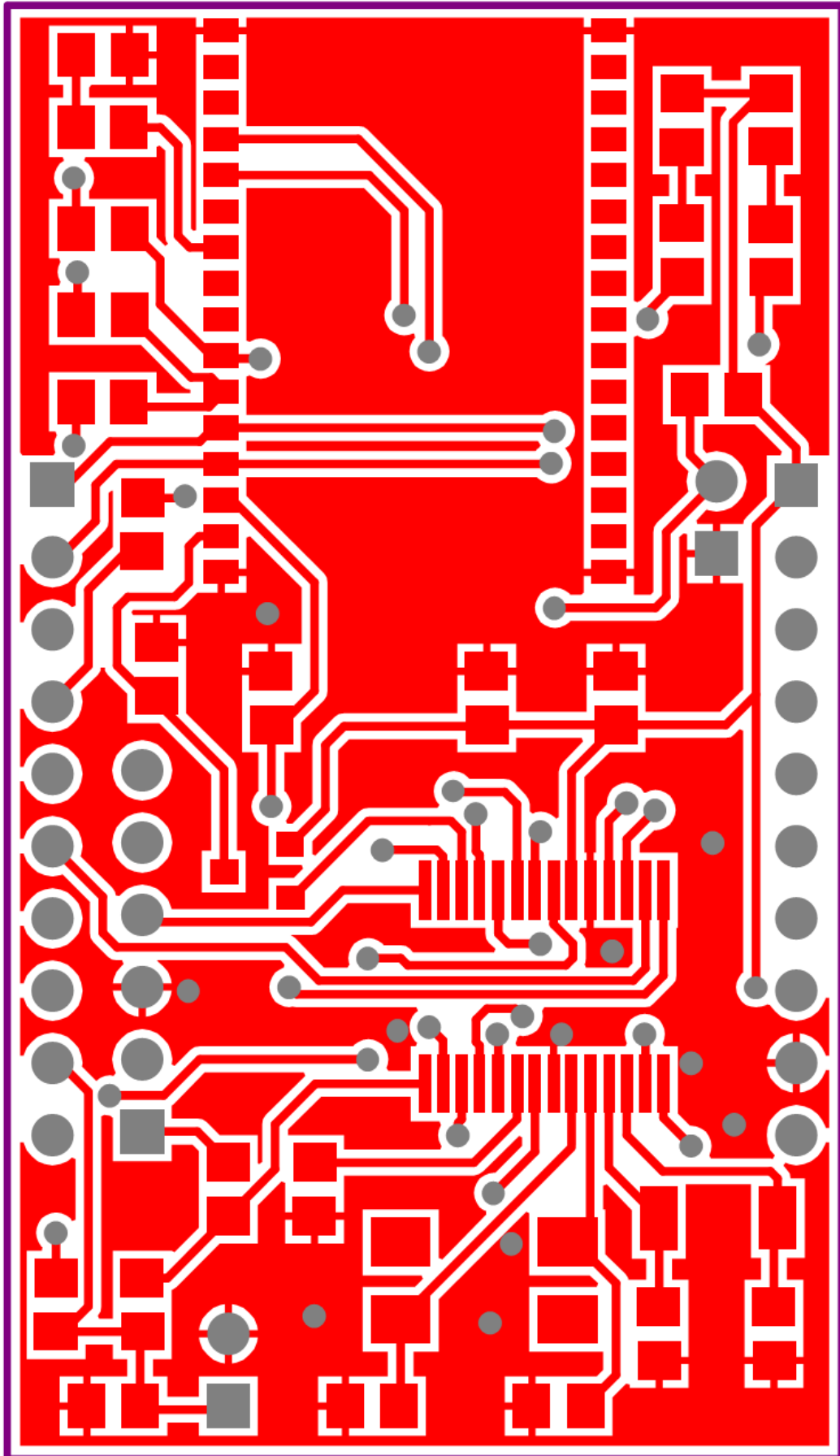
A.2. Bluetooth Socket

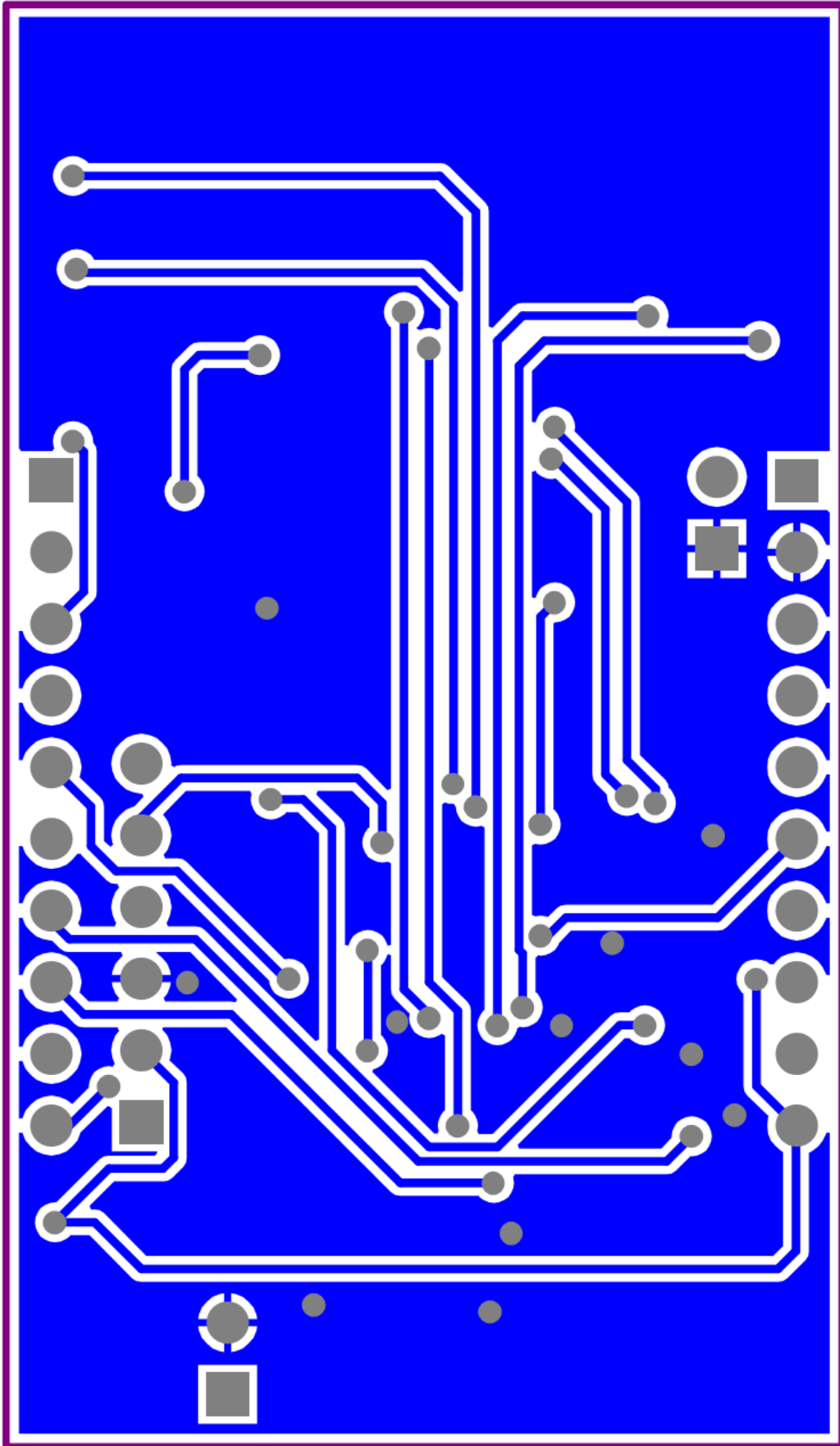


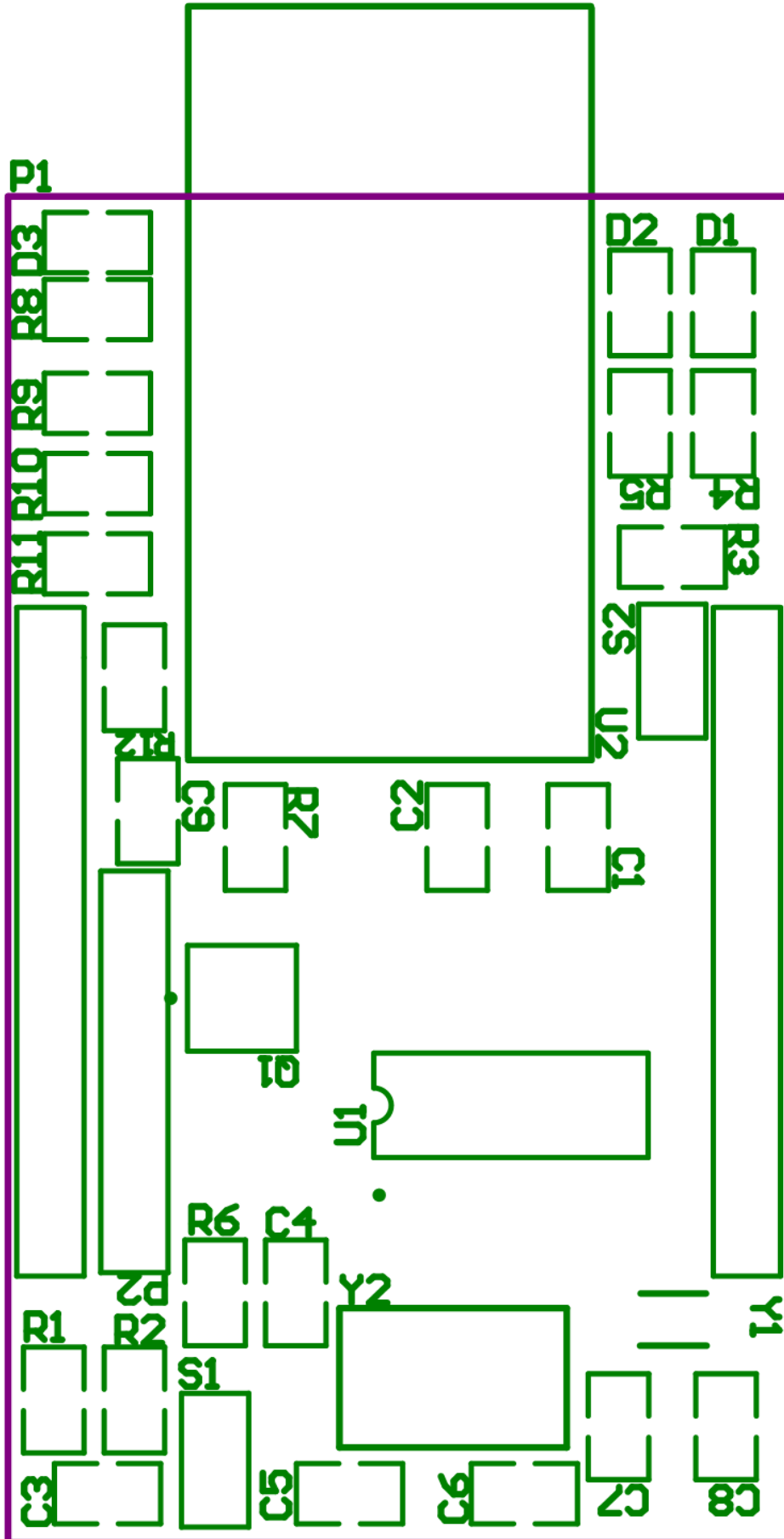
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Size	Number	Revision
A4	Text	Text
Date:	02-09-2008	Sheet of Microcontrolador
File:	D:\Universidade\...Microcontrolador.SchDoc\Drawn By: Text	



Title		
Bluetooth		
Size	Number	Revision
A4		
Date:	02-09-2008	Sheet of Chip BT
File:	D:\Universidade\...Chip Bluetooth.SchDoc Drawn By:	







A.3. Wi-Fi Socket

1

2

3

4

A

A

U_Headers_Indicators
Headers_Indicators.SchDoc



U_Regulators_Translators
Regulators_Translators.SchDoc



U_WiFi Module
WiFiModule.SchDoc



B

B

C

C

D

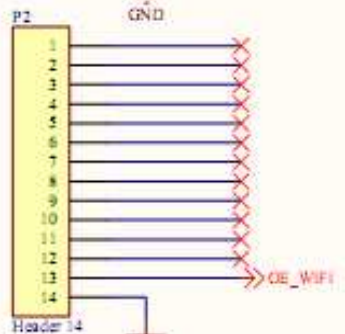
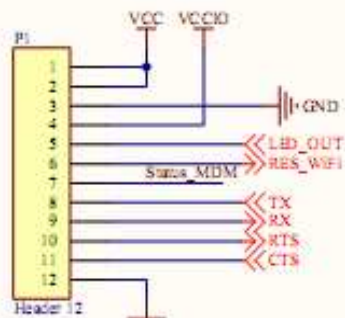
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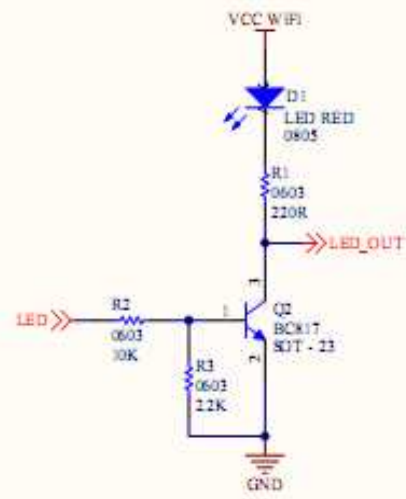
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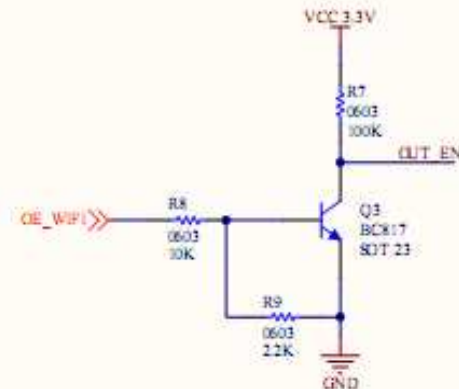
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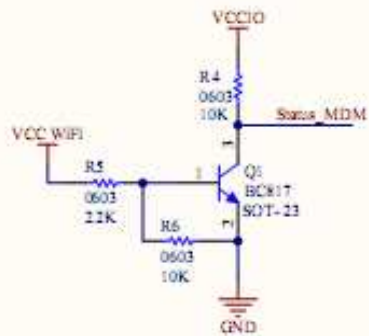
Headers



LED Indicator



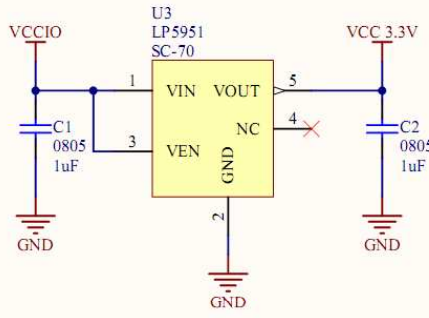
Output Enable Indicator



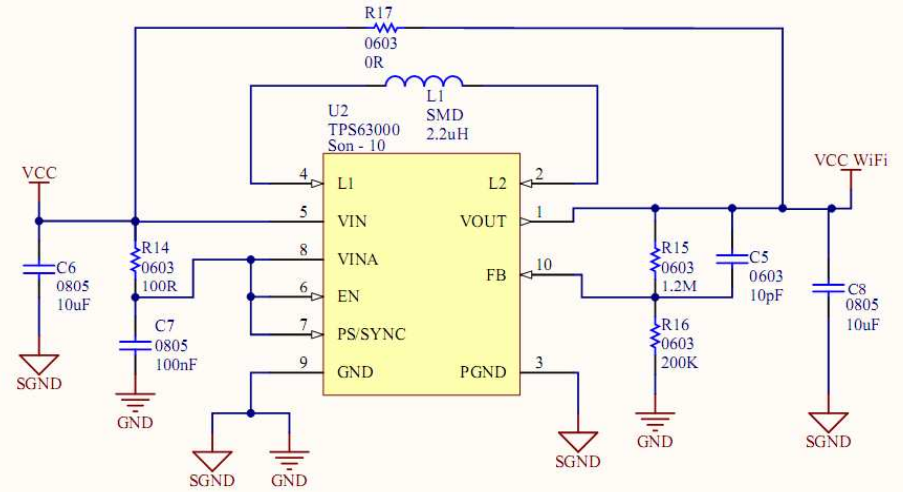
Status Indicator

Projeto: Socket WiFi			
Módulo: Headers and Indicators			
Número: *		Desenhado por: *	
Data: *	Revisão: *	Substituído: *	Sheet: 1 of 3

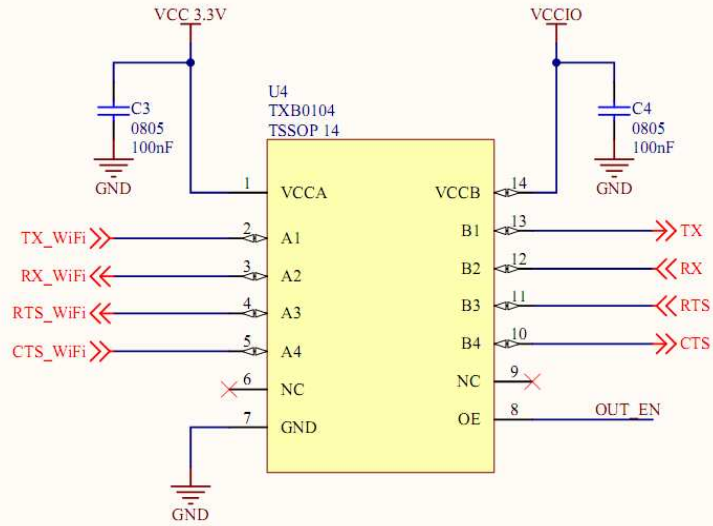




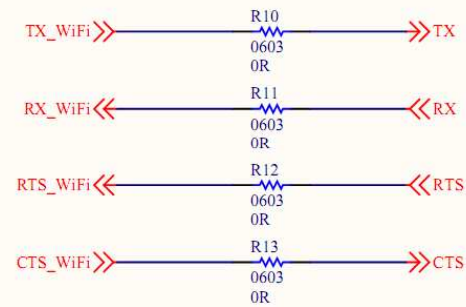
Low Dropout Regulator




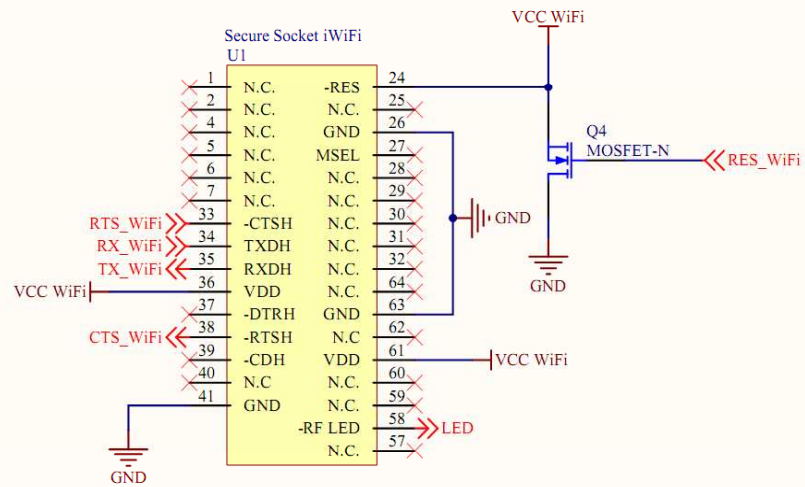
Voltage Regulator

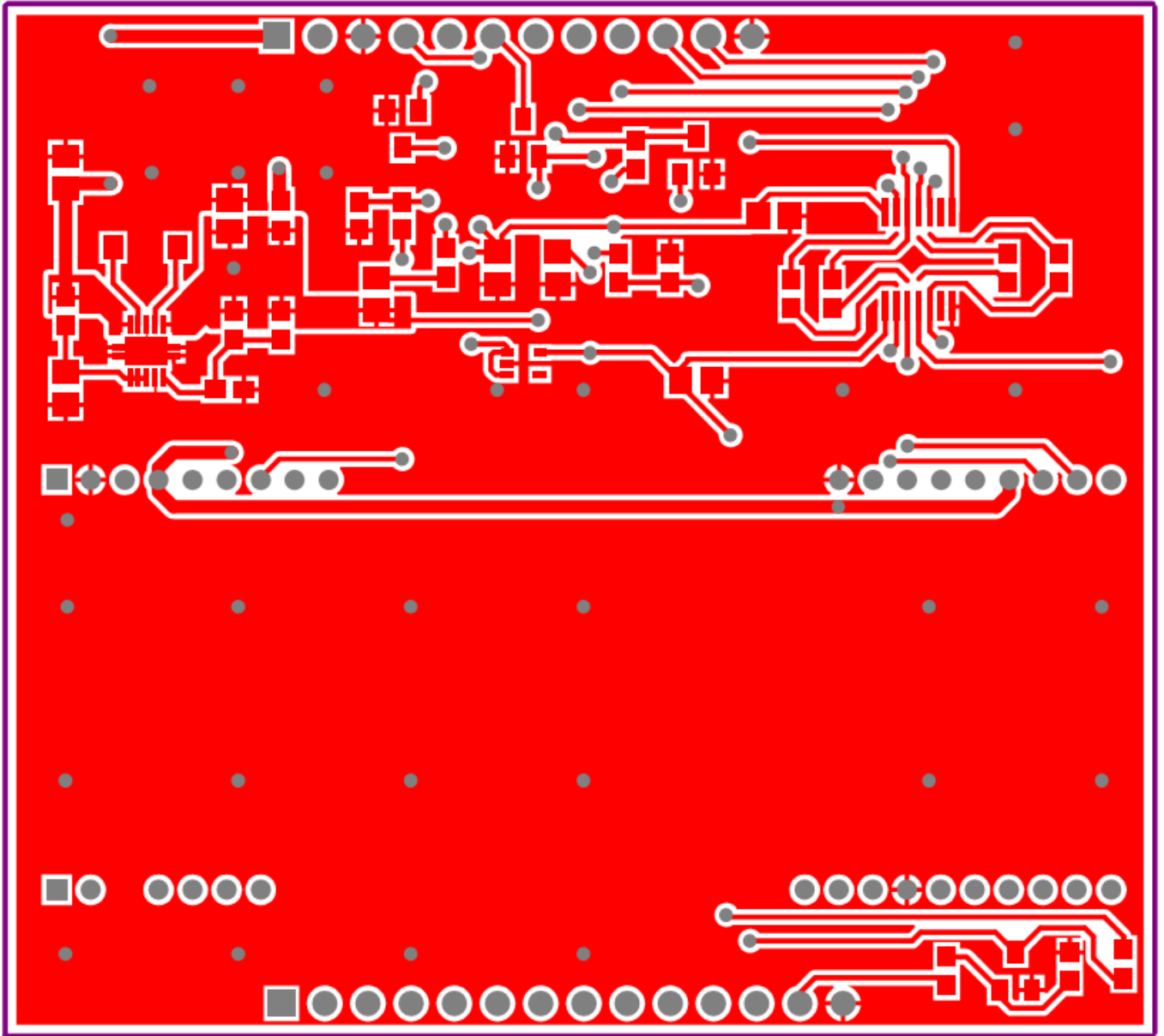


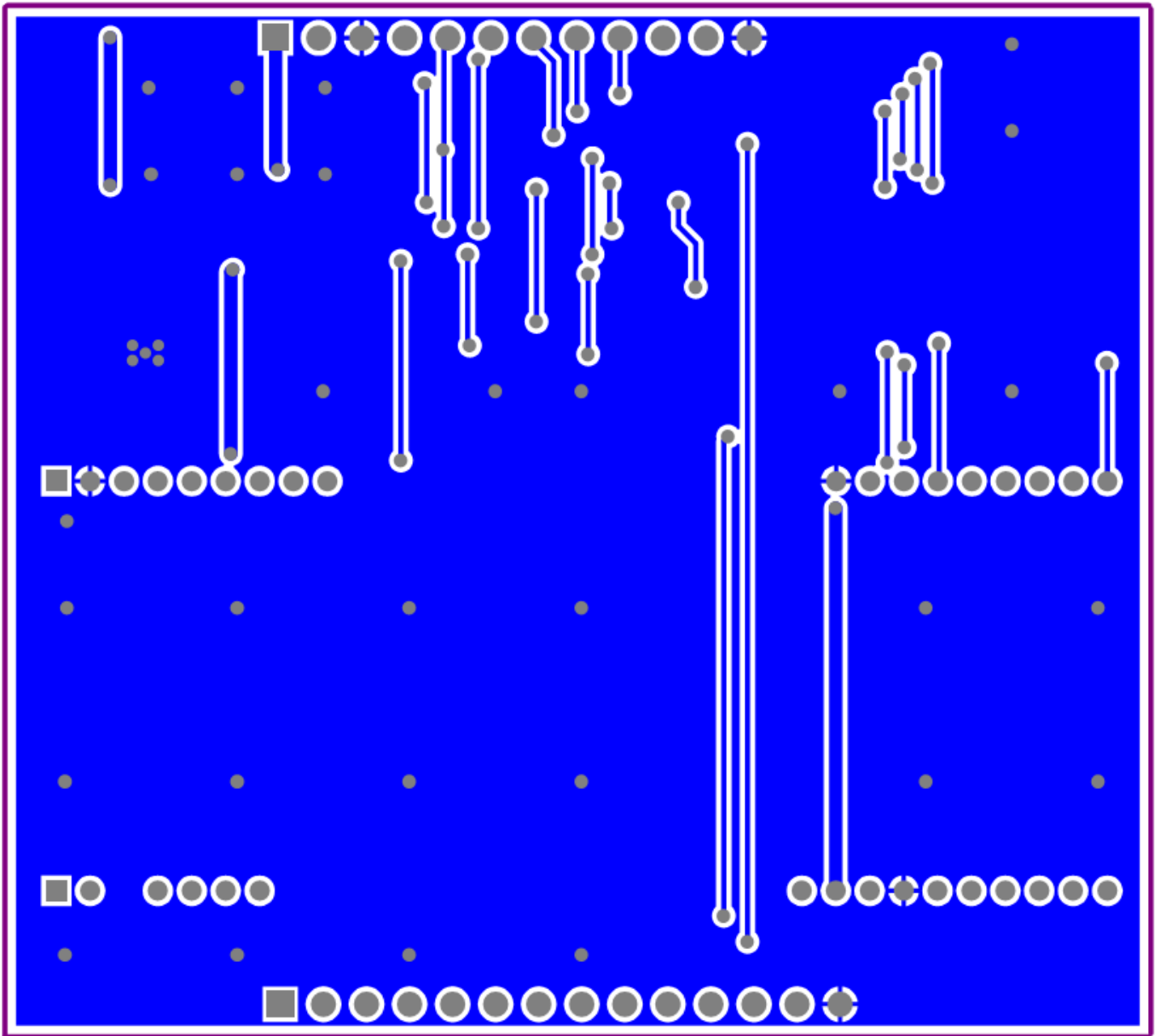
Level Shift



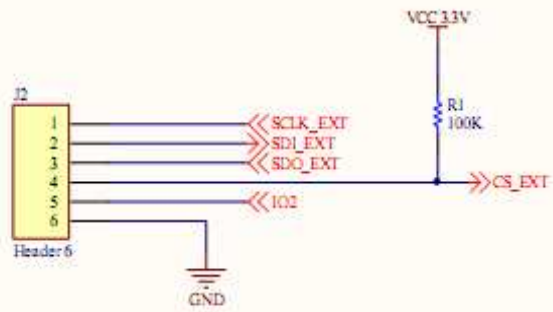
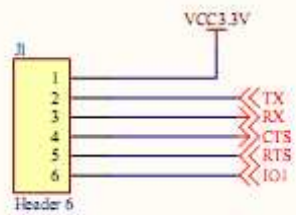
Projecto: Socket WiFi				 Intelligent Sensing Anywhere
Módulo: Regulators and Translators				
Número: *		Desenhado por: *		
Data: *	Revisão: *	Substituiu: *	Sheet: 2 of: 3	



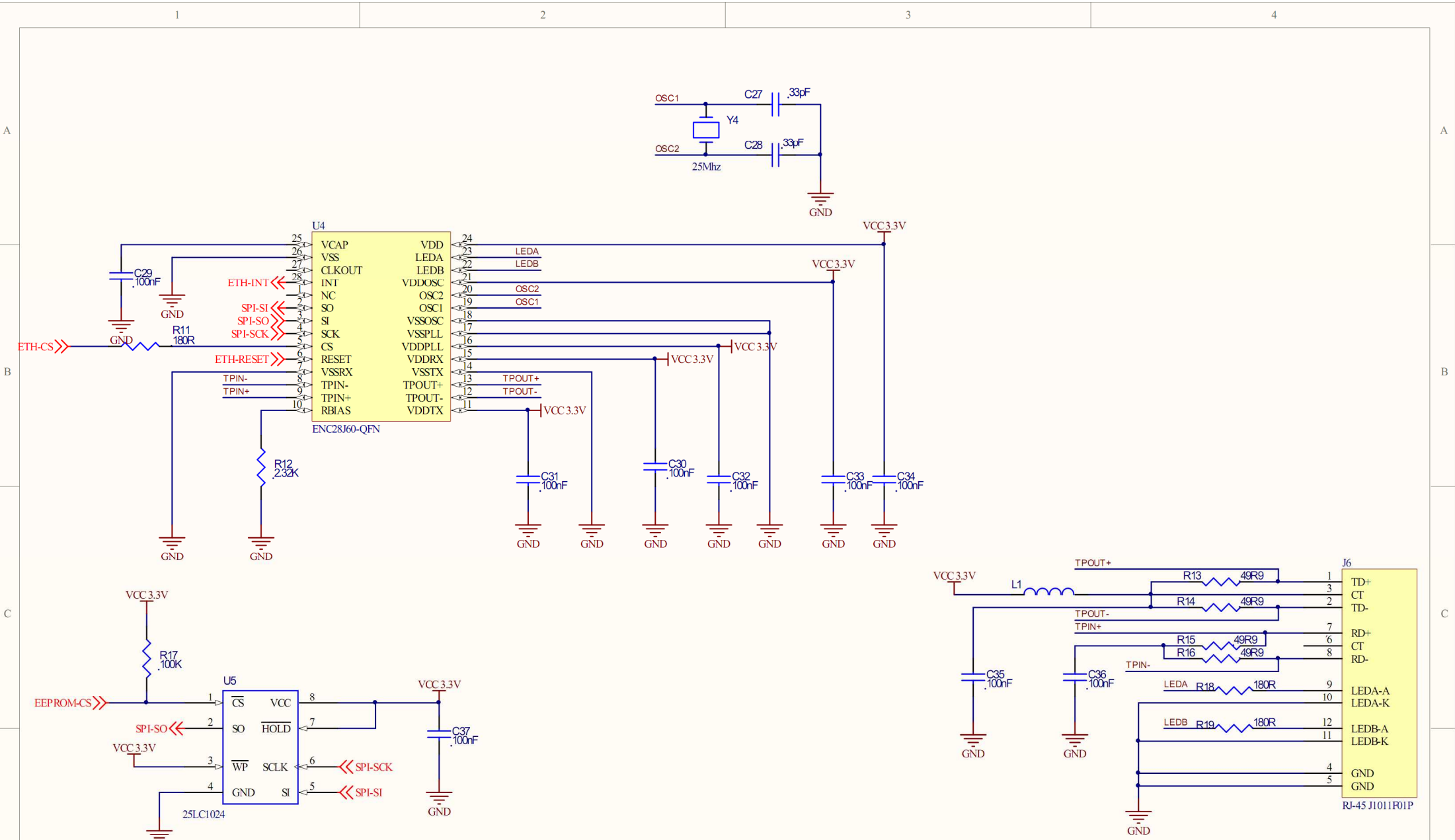




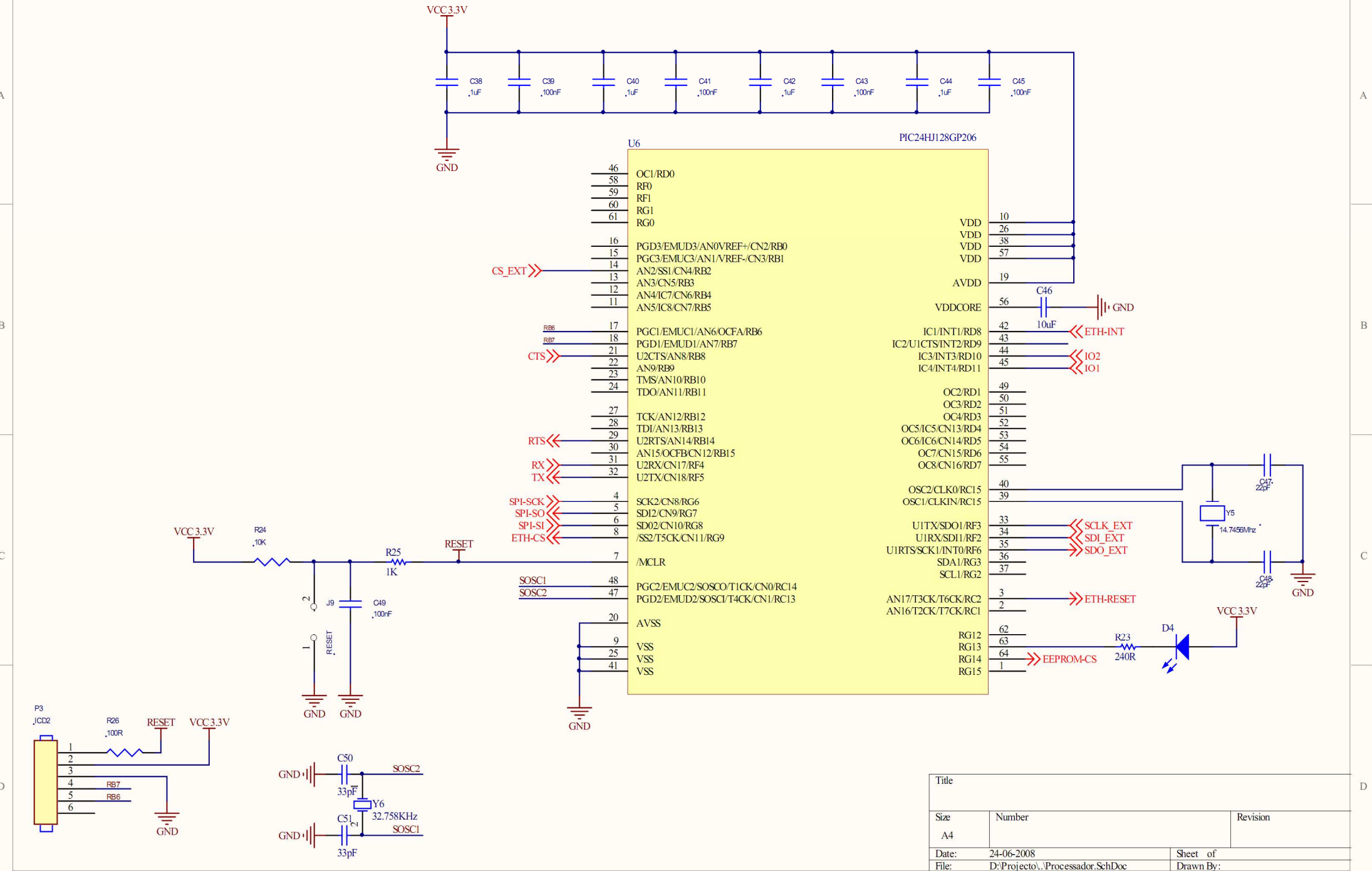
A.4. Ethernet Socket



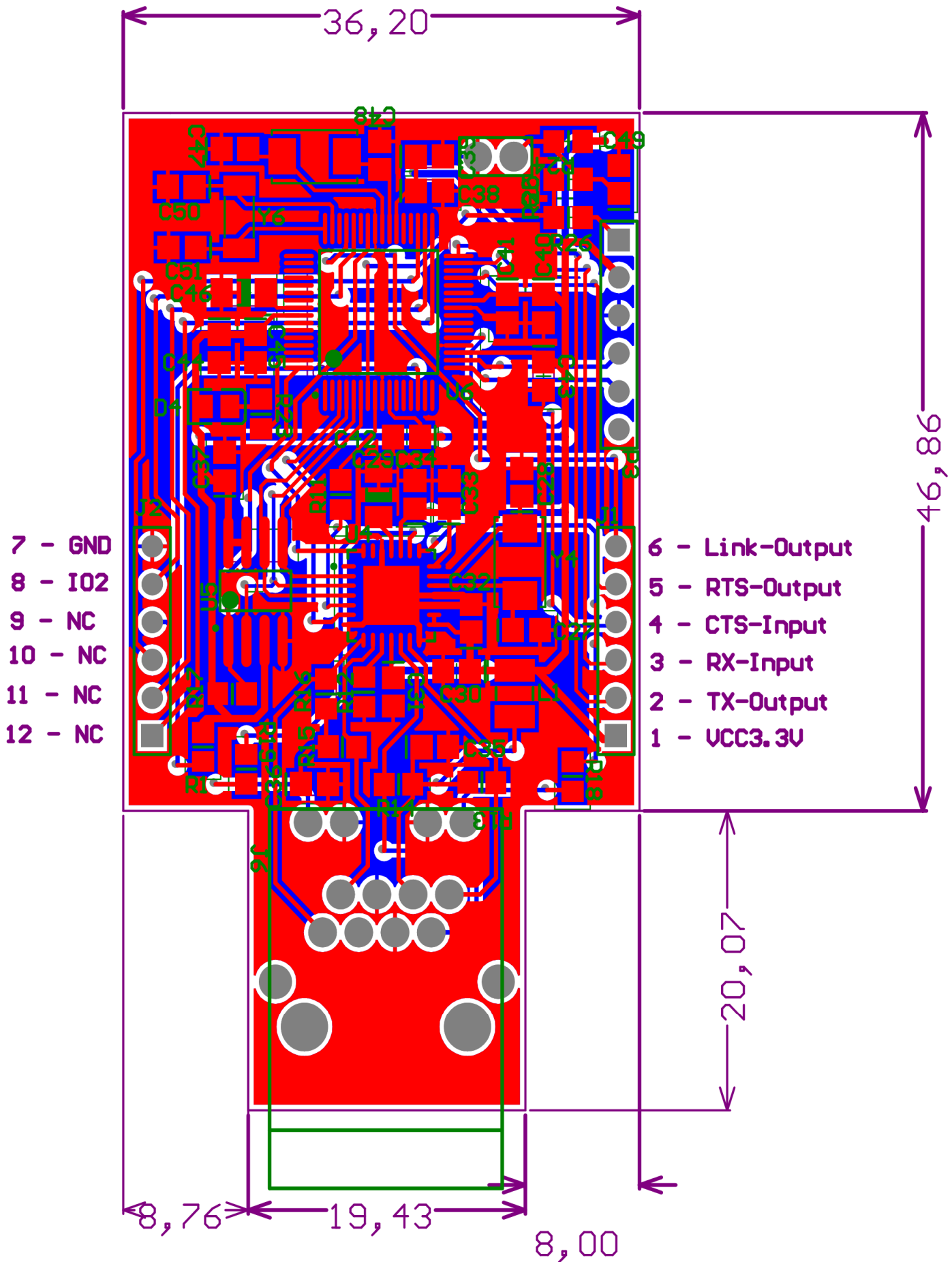
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Date:	24-06-2008	Sheet of	
File:	D:\Project\Goscor.SchDoc	Drawn By:	



Title		
Size	Number	Revision
A4		
Date:	24-06-2008	Sheet of
File:	D:\Projecto\ENC28J60.SchDoc	Drawn By:



Title		
Size	Number	Revision
A4		
Date:	24-06-2008	Sheet of
File:	D:\Projecto\...\Processor.SchDoc	Drawn By:



B. Experimental Tests

B.1. Electrical Verification and Functional Validation

- Testes estáticos

Nota: alimentação - rede doméstica (adaptador 12V DC)

Main board

Power supply

Parâmetro	Valor esperado	Resultado	Validação
Corrente de entrada (Ic) com LED 4 ON	--	53 mA	-
VDC	--	7.77V (alimentado a 9.78V)	-
VCC	5V	5V	OK

Power Control

Parâmetro	Valor esperado	Resultado	Validação
VBATT	--	4.73V	OK
VCC 4V	4.73V (R14 ligado)	4.73V	OK
VCC 3.3V	3.3V	3.3V	OK
VCC ETH	3.3V	3.3V	OK
V BT1	4.1/4.2	Bateria não montada	-

PIC

Parâmetro	Valor esperado	Resultado	Validação
VCC 3.3V	3.3V	3.288V	OK

VDD	0V	0V	OK
MCLR	0V	0V	OK
Y1	14.756 MHz	14.756 MHz	OK
FCY (velocidade máxima do PIC)	$FOSC = (14.756/4)*43/2$ FCY=FOSC/2	FCY=39.6288 MHz	OK

Memoria e RTC

Parâmetro	Valor esperado	Resultado	Validação
VCC U9	3.3V	3.289V	OK
VCC U10	3.3V	3.289V	OK
VCC U11	3.3V	3.288V	OK
VCC U12	3.3V	3.289V	OK
VCC P5	3.3V	3.32V	OK
Y2	32.768 KHz	32.768KHZ	OK
VBAT (RTC)	--	3.088V	OK

RS485+RS232

Parâmetro	Valor esperado	Resultado	Validação
VCC ETH	3.3V	3.28V	OK
VCC 3.3V	3.3V	3.26V	OK
VCC 2.8	2.6V	2.79V	OK

Model GSM+ SIM Holder

Parâmetro	Valor esperado	Resultado	Validação
VCC GSM	4.73V	4.73V	OK
VCC (2.8V)	2.8V	2.79	OK

RF e Ethernet

Parâmetro	Valor esperado	Resultado	Validação
VCC RF	3.3V	3.3V	OK

USB

Parâmetro	Resultado	Validação
VCC USB (cabo ligado ao PC)	5V	--

Nota: testes com a bateria ainda não foram realizados devido aos problemas verificados com o regulador buck-boost.

o Testes dinâmicos

Parâmetro	Resultado	Validação
VCC 3.3V (à saída de U5):		
Tempo de estabilização	$T_s = 1\text{ms}$	OK
Ruído rms	$\text{rms} = 4\text{ mV}$	
Ruído p-p	$\text{p-p} \approx 24\text{ mV}$	
VCC ETH		
Tempo de estabilização	$T_s = 1\text{ms}$	OK
Ruído rms	$\text{p-p} \approx 180\text{mV}$	
Ruído p-p	$\text{rms} \approx 20\text{mV}$	
VCC GSM		
Tempo de estabilização	$T_s \leq 1\text{ms}$	OK
Ruído rms	$\text{p-p} \approx 10\text{mV}$	
Ruído p-p	$\text{rms} \approx 1\text{mV}$	
VCC 2.8 (à saída de U16):		
Tempo de estabilização	$T_s = 500\text{us}$	OK
Ruído rms	$\text{rms} \approx 2\text{mV}$	
Ruído p-p	$\text{p-p} \approx 8\text{mV}$	
VCC RF		
Tempo de estabilização	$T_s \leq 840\text{us}$	OK
Ruído rms	$\text{rms} \approx 2\text{mV}$	
Ruído p-p	$\text{p-p} \approx 8\text{mV}$	

- Validação dos componentes (necessário firmware específico para testes)

Parâmetro	Validação
LED D5	OK
LED D6	OK
LED D7	OK
LED D8	OK
LED D9 (os sockets devem estar montados para teste)	--
Q3 e Q4 (coordenar CTRL Power GSM com VCC GSM)	
Q5 (coordenar LED GSM com STAT LED) (os sockets devem estar montados para teste)	--
Q6 (coordenar GSM OE com TELIT OE)	OK
Q7 (coordenar PWR ON com STATUS GSM) (são necessários os sockets)	--
Q9 (coordenar ETH ON com ETH OE)	OK
Q10 (coordenar CTRL Power Radio com VCC RF)	OK
Botões S4 e S5	OK
RS-485 (conversor rs-232)	OK
SPI (EPROM's)	OK
SPI (Flashes)	OK
I2C (RTC)	OK
USB	OK
Level Shift - U13	OK
Level Shift - U14 (necessário os sockets GSM para testar comunicação)	--

Nota: o teste em que os sockets GSM ou Wi-Fi estão envolvidos não foram realizados pois nenhum protótipo foi realizado até ao momento.

Socket Bluetooth

○ Testes estáticos

Parâmetro	Valor esperado	Resultado	Validação
VCC	3,3V	3,19V-3,23V	OK
VDD	0V	0V	OK
Y1	32,768 KHz	32,68 MHz	OK
Y2	7,3728 MHz	7,372 MHz	OK

Nota: VCC alterna entre os 2 valores referidos visto que em modo de emparelhamento consome mais corrente do que quando já emparelhado e, conseqüentemente, a tensão baixa.

○ Testes dinâmicos

Parâmetro	Resultado	Validação
VCC ():		
Tempo de estabilização	Ts = 160us	OK
Ruído rms	Rms ≈ 40 mV	
Ruído p-p	p-p ≈ 120 mV	

○ Validação dos componentes (necessário firmware específico para testes)

Parâmetro	Validação
LED D1	OK
LED D2	OK
Q1 (coordenar VCC com CTRL_BT)	OK
SPI (PIC com PIC)	OK

Socket Ethernet

○ Testes estáticos

Parâmetro	Valor esperado	Resultado	Validação
VCC3.3V	3.3V	3.27V	OK
VDD	0V	0V	OK
Y4	25 MHz	25 MHz	OK
Y5	14.7456 MHz	14.71 MHz	OK
Y6	32.758 KHz	32.76 MHz	OK

○ Testes dinâmicos

Parâmetro	Resultado	Validação
VCC (à entrada do PIC): Tempo de estabilização Ruído rms Ruído p-p	T _s ≈260 us Rms = 25 mV p-p ≈ 120mV	OK

Nota: na verificação do ruído pico-a-pico observa-se um pico de queda de tensão, não periódico com uma duração inferior a 500 ns, atingindo um valor máximo de 800 mV.

○ Validação dos componentes (efectuado com a stack da microchip programada)

Parâmetro	Validação
LED D4	OK
Q1 (coordenar VCC com CTRL_BT)	OK
SPI (EEPROM)	OK
SPI (ENC)	OK

B.2. Power Consumption

- Cálculo teórico para a corrente de entrada para determinadas condições e confirmação dos valores reais através da subtracção entre a corrente real total e as correntes teóricas dos componentes não utilizados em cada cálculo

Main board

Circuito base (a funcionar em sleep PIC e restantes componentes a nível basal)

Elementos	Teórico		Real	
	Típico	Máximo	Típico	Máximo
PIC	293 μ A	988 μ A	450 μ A	853 μ A
Flash Memory	2 * 25 = 50 μ A	2 * 50 = 100 μ A		
EEPROM	1 μ A	1 μ A		
RTC	1,2 μ A	4 μ A		
USB	70 μ A	100 μ A		
RS485	15 nA	100 nA		
Level Shifters	2 * 10 μ A = 20 μ A	2*10 = 20 μ A		
Total	435,215 μ A	1213,1 μ A		

Elemento	Típico		Máximo	
	Teórico	Real	Teórico	Real
PIC	293 μ A	312.785 μ A	988 μ A	627,9 μ A

Circuito base + PIC a funcionar a 40 MIPS

Elementos	Teórico		Real	
	Típico	Máximo	Típico	Máximo
PIC	84 mA	88 mA	59,8 mA	59,8 mA
Flash Memory	$2 * 25 = 50 \text{ uA}$	$2 * 50 = 100 \text{ uA}$		
EEPROM	1 uA	1 uA		
RTC	1,2 uA	4 uA		
USB	70 uA	100 uA		
RS485	15 nA	100 nA		
Level Shifters	$2 * 10 \text{ uA} = 20 \text{ uA}$	$2*10 = 20 \text{ uA}$		
Total	84,13 mA	88,23 mA		

Elemento	Típico		Máximo	
	Teórico	Real	Teórico	Real
PIC	84 mA	59,712 mA	88 mA	59,674 mA

Nota: O PIC na realidade funciona a 39,6288 MHz, enquanto que os consumos teóricos apresentados correspondem a um funcionamento de 40 MHz

Circuito base + PIC a funcionar a 40 MIPS + Flash Memory

Elementos	Teórico		Real	
	Típico	Máximo	Típico	Máximo
PIC	84 mA	88 mA	65,6 mA	65,7 mA
Flash Memory	$25 \text{ uA} + 12 \text{ mA} = 12,025 \text{ mA}$	$50 \text{ uA} + 17 \text{ mA} = 17,05 \text{ mA}$		
EEPROM	1 uA	1 uA		
RTC	1,2 uA	4 uA		
USB	70 uA	100 uA		
RS485	15 nA	100 nA		
Level Shifters	$2 * 10 \text{ uA} = 20 \text{ uA}$	$2*10 = 20 \text{ uA}$		
Total	96,10 mA	105,18 mA		

Elemento	Típico		Máximo	
	Teórico	Real	Teórico	Real
Flash Memory	12 mA	5,79 mA	17 mA	5,87 mA

Circuito base + PIC a funcionar a 40 MIPS + EEPROM

Elementos	Teórico		Real	
	Típico	Máximo	Típico	Máximo
PIC	84 mA	88 mA	62,7 mA	62,8 mA
Flash Memory	$2 * 25 = 50 \text{ uA}$	$2 * 50 = 100 \text{ uA}$		
EEPROM	3 mA	3 mA		
RTC	1,2 uA	4 uA		
USB	70 uA	100 uA		
RS485	15 nA	100 nA		
Level Shifters	$2 * 10 \text{ uA} = 20 \text{ uA}$	$2*10 = 20 \text{ uA}$		
Total	84,14 mA	91,22 mA		

Elemento	Típico		Máximo	
	Teórico	Real	Teórico	Real
EEPROM	3 mA	2,87 mA	3 mA	2,92 mA

Circuito base + PIC a funcionar a 40 MIPS + RTC

Elementos	Teórico		Real	
	Típico	Máximo	Típico	Máximo
PIC	84 mA	88 mA	60,1 mA	60,2 mA
Flash Memory	$2 * 25 = 50 \text{ uA}$	$2 * 50 = 100 \text{ uA}$		
EEPROM	1 uA	1 uA		
RTC	40 uA	120 uA		
USB	70 uA	100 uA		
RS485	15 nA	100 nA		
Level Shifters	$2 * 10 \text{ uA} = 20 \text{ uA}$	$2*10 = 20 \text{ uA}$		
Total	84,18 mA	88,34 mA		

Elemento	Típico		Máximo	
	Teórico	Real	Teórico	Real
RTC	40 uA	267 uA	120 uA	325 uA

Circuito base + PIC a funcionar a 40 MIPS + USB

Elementos	Teórico		Real	
	Típico	Máximo	Típico	Máximo
PIC	84 mA	88 mA	66,6 mA	66,7 mA
Flash Memory	2 * 25 = 50 uA	2 * 50 = 100 uA		
EEPROM	1 uA	1 uA		
RTC	1,2 uA	4 uA		
USB	15 mA	15 mA		
RS485	15 nA	100 nA		
Level Shifters	2 * 10 uA = 20 uA	2*10 = 20 uA		
Total	99,07 mA	103,13 mA		

Elemento	Típico		Máximo	
	Teórico	Real	Teórico	Real
USB	15 mA	6,8 mA	15 mA	6,9 mA

Circuito base + PIC a funcionar a 40 MIPS + RS-485

Elementos	Teórico		Real	
	Típico	Máximo	Típico	Máximo
PIC	84 mA	88 mA	65,4 mA	65,9 mA
Flash Memory	2 * 25 = 50 uA	2 * 50 = 100 uA		
EEPROM	1 uA	1 uA		
RTC	1,2 uA	4 uA		
USB	70 uA	100 uA		
RS485	0,6 mA	1 mA		
Level Shifters	2 * 10 uA = 20 uA	2*10 = 20 uA		
Total	84,74 mA	89,23 mA		

Elemento	Típico		Máximo	
	Teórico	Real	Teórico	Real
RS-485	0,6 mA	5,5 mA	1 mA	6,0 mA

Socket Bluetooth (em configuração)

Elementos	Teórico		Real	
	Típico	Máximo	Típico	Máximo
PIC18	11,5 mA	23 mA	15 mA	27 mA
Modulo Bluetooth	-	-		
LED D2	1,6 mA	1,6 mA		
Total	Não aplicável	Não aplicável		

Nota: o valor teórico para o PIC é para 40 MHz mas na prática ele está a trabalhar a 29,5 MHz.

Socket Bluetooth (a emparelhar)

Elementos	Teórico		Real	
	Típico	Máximo	Típico	Máximo
PIC18	11,5 mA	23 mA	50 mA	51 mA
Modulo Bluetooth	53 mA	53 mA		
LED D1	0	1,6 mA		
Total	64,5 mA	77,6 mA		

Socket Bluetooth (emparelhado)

Elementos	Teórico		Real	
	Típico	Máximo	Típico	Máximo
PIC18	11,5 mA	23 mA	8 mA	17 mA
Módulo Bluetooth	5,6 mA (não transmite)	24,6 mA (transmite)		
LED D1	0	1,6 mA		
LED D2	0	1,6 mA		
Total	17,1 mA	50,8 mA		

Socket Ethernet

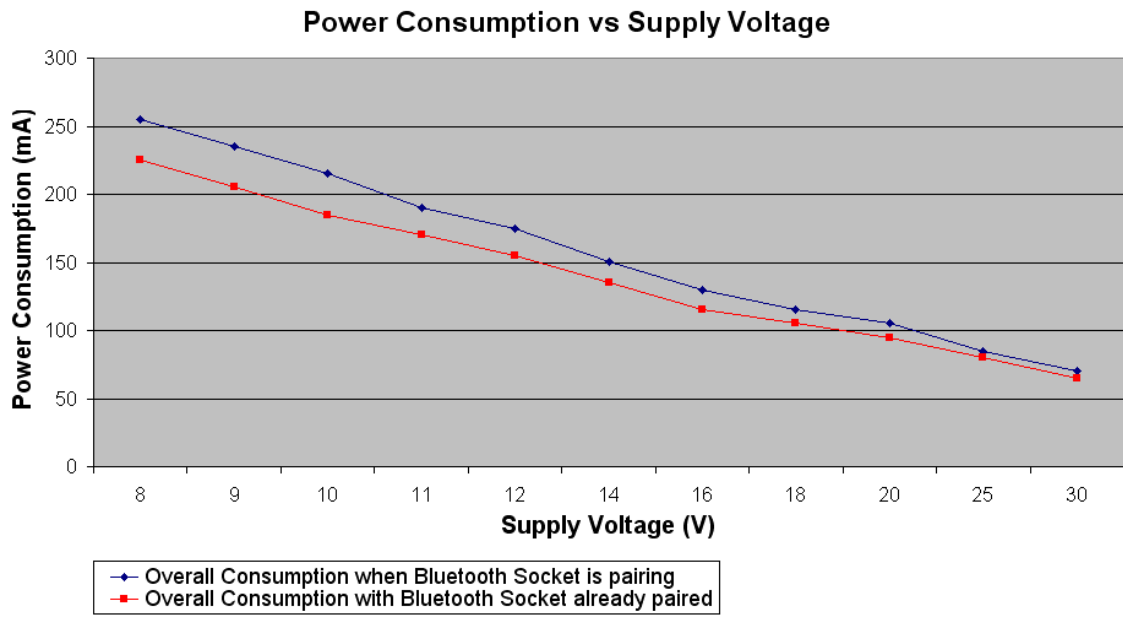
Elementos	Teórico		Real	
	Típico	Máximo	Típico	Máximo
ENC	--	250 mA	210 mA	215 mA
PIC24	84 mA	84 mA		
Rj-45	residual	residual		
LED D1	0	5 mA		
Total	Não aplicável	339 mA		

Nota 1: O PIC na realidade funciona a 39,6288 MHz, enquanto que os consumos teóricos apresentados correspondem a um funcionamento de 40 MHz

Nota 2: não há valores de consumos típicos para o enc e o valor máximo corresponde a uma entrada de 3,45V (a nossa 3,3V) e um oscilador 10 MHz (o nosso 25 MHz)

- Consumos do sistema à entrada (placa principal e sockets bluetooth e ethernet) para diferentes tensões de entrada

Tensão (V)	Corrente (I) com Socket Bluetooth em emparelhamento	Corrente (I) com Socket Bluetooth já emparelhado
8V	250 - 260 mA	220 - 230 mA
9V	230 - 240 mA	200 - 210 mA
10V	210 - 220 mA	180 - 190 mA
11V	190 mA	170 mA
12V	170 - 180 mA	150 - 160 mA
14V	150 mA	130 - 140 mA
16V	130 mA	110 - 120 mA
18V	110 - 120 mA	100 - 110 mA
20V	100 - 110 mA	90 - 100 mA
25V	80 - 90 mA	80 mA
30V	70 mA	60 - 70 mA



B.3. System Features

Communication Bluetooth tests

Atrasos

Tempo de desemparelhamento do socket bluetooth desde que a comunicação com o sensor é perdida: 20 segundos

Tempo de emparelhamento: 4segundos

Alcances

Barrier	Maximum Range
Line of sight	80 m
1 wall	50 m
2 walls	22 m
3 walls	

Memória

Dispondo apenas de uma das memórias Flash, com 16Mbit, o módulo concentrador permite armazenar os dados enviados pelo oxímetro por cerca de 54,6 horas. Após este tempo os dados são regravados por cima dos mais antigos.

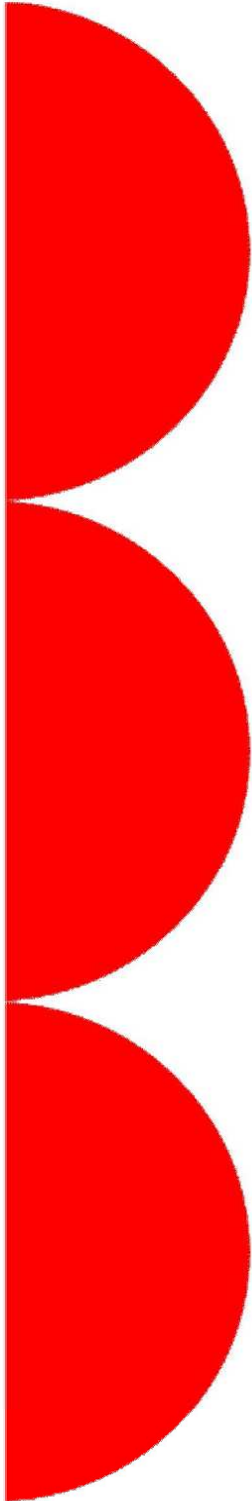
Nota: a comunicação testada é realizada entre o socket bluetooth do módulo concentrador e o oxímetro Nonin 4100.

Battery

Duração: 2 horas e 10 minutos.

Nota: a duração da bateria não pode ser considerada vinculativa uma vez que o regulador mais potente que integra o circuito tem originado alguns problemas e não está montado.

C. Look4MyHealth Specifications



ESPECIFICAÇÃO LOOK4MYHEALTH

SISTEMA DE RASTREIO DE DOENÇAS CRÓNICAS

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1. Introdução

A pressão arterial dos portugueses é demasiado alta. O Inquérito Nacional da Saúde 2005/06 mostra que a doença é comum a 20% da nossa população e, que só no último ano, 1,3% dos portugueses descobriram que são hipertensos, tornando-a a doença crónica com maior prevalência em Portugal.

Os especialistas em hipertensão consideram, porém, que os dados deste inquérito estão subestimados. Portugal é mesmo o país onde mais se morre e sofre por causa de acidentes vasculares cerebrais e, no entanto, dos dois milhões de portugueses que sabem que têm a pressão arterial descontrolada, estima-se que outros tantos tenham este problema e desconheçam o facto, segundo a Sociedade Portuguesa de Hipertensão.

O diagnóstico é feito através da medição da pressão arterial e pela verificação de que os seus níveis estão acima do limite normal. Contudo, um valor elevado isolado não é sinónimo de doença. Só é considerado hipertenso um indivíduo que tenha valores elevados em, pelo menos, três avaliações seriadas.

Um importante facto é ser possível prevenir a ocorrência de aproximadamente 40% dos acidentes vasculares cerebrais (AVC) e 25% dos enfartes do miocárdio caso a hipertensão arterial seja diagnosticada e controlada na devida altura.

A obesidade constitui também um dos maiores problemas de saúde nas sociedades ocidentais e é associada a problemas vasculares, hipertensão e diabetes. Quase 15% da população do nosso país é obesa e o excesso de peso afecta já 44,1% dos homens e 31,9% das mulheres portuguesas.

Para além do excesso de peso, a localização da gordura no corpo humano é um risco potencial para a saúde. Quando a gordura se encontra localizada principalmente na região abdominal ao redor da cintura, a propensão para desenvolver problemas de saúde, nomeadamente cardiovasculares, é maior do que quando a maior parte da gordura se situa na zona das coxas e dos quadris, ainda que o peso da pessoa seja considerado normal.

Com este projecto pretende-se construir um aparelho, que permita realizar uma medição medicamente fiável dos parâmetros anteriormente referidos, permitindo assim o tratamento numa fase precoce de uma condição de Hipertensão Arterial.

1.1. Objectivos

O objectivo do documento é definir as especificações para a criação do sistema Look4MyHealth. Com vista a esse objectivo será feita a descrição da arquitectura do sistema de forma a produzir linhas de orientação para o desenvolvimento deste. Para além disso, examinaremos os requisitos funcionais do sistema de modo a podermos contemplar toda a estrutura operante do mesmo.

1.2. Audiência

O documento destina-se às equipas dos departamentos de Engenharia de Software e de Sistemas Embutidos da ISA e a quaisquer serviços externos que sejam contratados para a realização do projecto.

1.3. Visão

O sistema Look4MyHealth destina-se às unidades clínicas e farmácias permitindo ao utilizador, para além da medição da tensão arterial, peso, medida da cintura abdominal, a sua identificação através de um sistema RFID. A informação medida será posteriormente armazenada, criando assim um histórico clínico do utilizador, podendo ser acedido posteriormente.

2. Arquitectura do Sistema

Globalmente, o Sistema Look4MyHealth será constituído por três domínios distintos:

- **Estação de Medição:** Será responsável pela medição dos parâmetros e pelo envio destes para a base de dados remota. Funcionará em farmácias e Unidades de Saúde Familiar. Esta estação comunica com a base de dados Remota via UMTS.
- **Base de Dados Remota:** Neste local ficarão armazenados todos os históricos dos utentes do serviço, que compreendem os dados dos parâmetros biológicos medidos e outras informações relativas ao utente. A base de dados concentrará as comunicações de todas as Estações de Medição e os acessos de cada Aplicação Web, disponibilizando a informação tanto às estações de medição (necessários quando efectuam um conjunto de medições a determinado utente) como aos utilizadores que acedem via Aplicação Web.
- **Aplicação Web:** Um portal Web permitirá acesso à informação de cada utilizador a partir de qualquer local com acesso à Internet. A aplicação possuirá duas funções distintas. A visualização do histórico das medições por parte do utente e a inserção de dados pessoais tais como o e-mail e número de telefone. A autenticação do utente na aplicação web é efectuada através de um User ID e de um PIN que são fornecidos aquando da primeira utilização.

2.1. Arquitectura Geral

A Arquitectura Geral explica globalmente o funcionamento do Sistema Look4MyHealth. Este permitirá a um utente efectuar medições dos três parâmetros biológicos referidos anteriormente (Pressão Arterial, Peso e Medida

da Cintura) e ter a possibilidade de estes serem armazenados remotamente para posterior acesso através da Aplicação Web.

O esquema seguinte mostra a arquitectura geral do sistema descrito.

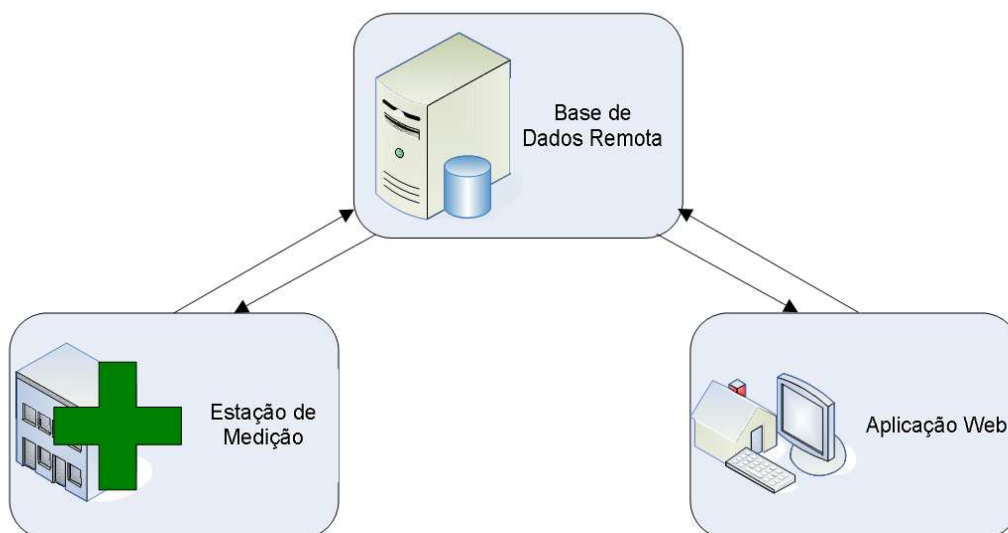


Figura 1 – Domínios do Sistema Look4MyHealth.

2.2. Arquitectura Física:

O esquema seguinte descreve a Arquitectura Física do Sistema Look4MyHealth:

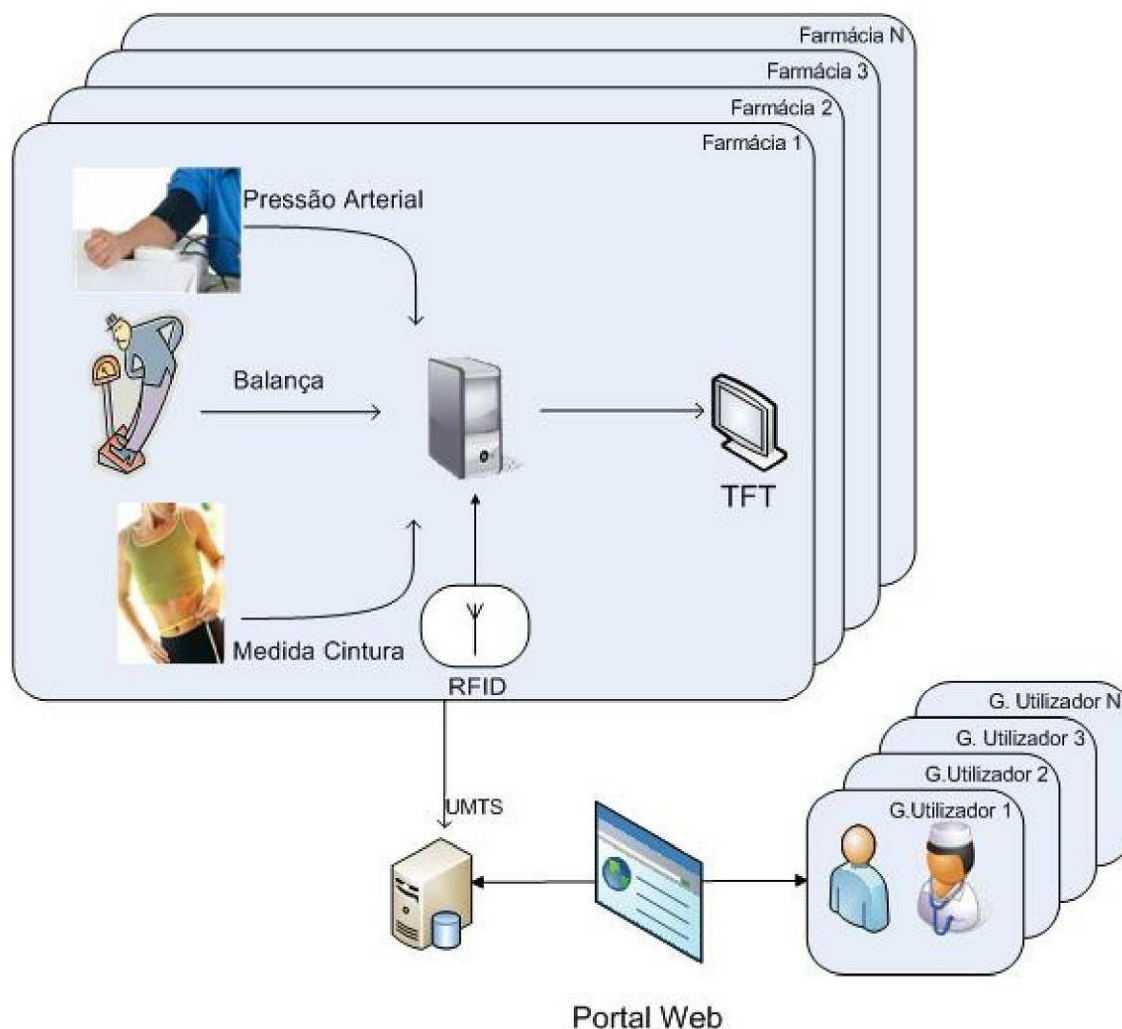


Figura 2 – Arquitectura Física do Sistema Look4MyHealth.

2.2.1. PC

O PC constitui a base de suporte para todos os outros componentes da Estação de Medição. Possui interfaces de ligação USB e série que providenciam ligação aos vários componentes da Estação (tanto os de medição como os de comunicação e de apresentação), bem como uma saída VGA para o display.

Decidiu-se pela utilização da *EdgeBox* da Critical Software, sendo que o sistema Operativo deste pacote é o Linux.

Este componente da Estação de Medição serve de suporte à aplicação de software que gere todos os componentes a ele ligados.

2.2.2. Medidor de Pressão Arterial

Este componente vai ser controlado por um módulo de software (ver Arquitectura Lógica) e os dados resultantes da medição serão transmitidos para o PC via interface RS-232.

O método de medição será o método oscilométrico (o mais indicado para os medidores de Pressão Arterial automáticos) que devolve a Pressão Sistólica, Pressão Diastólica e Pressão Média, para além da Taxa de Batimentos.

O medidor deverá estar ligado a uma braçadeira montada de forma a se poder alternar facilmente entre o braço esquerdo e direito. Esta arquitectura será necessária visto que para uma medição mais precisa é necessário saber em que braço a pressão tem valores mais elevados.

2.2.3. Balança

Este componente é também controlado por um módulo de software, sendo que os dados são transmitidos para o PC por USB/RS-232 no final de cada medição.

2.2.4. Fita de Medição de Cintura

Visto que não existe no mercado uma solução que vai de encontro a todos os requerimentos será necessário construir um sistema que faça o que é pretendido. O sistema basear-se-á numa fita ou num fio em torno de um carreto com um imane que, a cada volta, gera um impulso eléctrico induzido, para que a electrónica conte o número de impulsos. Existe ainda a possibilidade de conceber o sistema com conectividade wireless, o que aumentaria o conforto de utilização.

2.2.5. Apresentação dos Dados

2.2.5.1. Display

Este componente de apresentação tem a função de apresentar imagens e mensagens elucidativas ao utilizador de forma a guia-lo no processo que compreende a medição dos três parâmetros. Serve ainda para apresentar ao utilizador questionários. Este componente da Estação de Medição é controlado por software de forma a ser possível apresentar as mensagens de forma sincronizada com o processo de medição. Possui ainda uma interface de utilização táctil o que possibilita a interacção entre a estação de medição e o utilizador, o que torna o processo *user-friendly*.

2.2.6. Módulo RFID

Na altura da medição cada utente vai ter que possuir uma Tag RFID que torna possível a sua identificação perante a base de dados. O módulo RFID vai permitir a leitura desta Tag e comunica-la ao PC para que o software possa identificar o utente junto da Base de Dados Remota.

2.2.7. Módulo UMTS

O módulo UMTS vai permitir o estabelecimento de uma ligação entre a Estação de Medição e a Base de Dados Remota. Esta ligação será feita através da Internet. Depois de estabelecida a ligação torna-se possível tanto o envio dos dados relativos ao processo de medição como a consulta, tanto dos dados de um utente, necessários à realização deste processo como de outras informações presentes no servidor remoto. A identificação do utente junto da Base de Dados é feita através da sua Tag RFID.

2.3. Arquitectura Lógica:

A figura seguinte ilustra os módulos existentes no Sistema de Medição, bem como as relações entre estes. As setas a azul representam uma interface de ligação física (USB, RS-232 e VGA), enquanto a seta a cinzento representa a relação entre os módulos de software apoiados no Computador e que constituem a Aplicação.

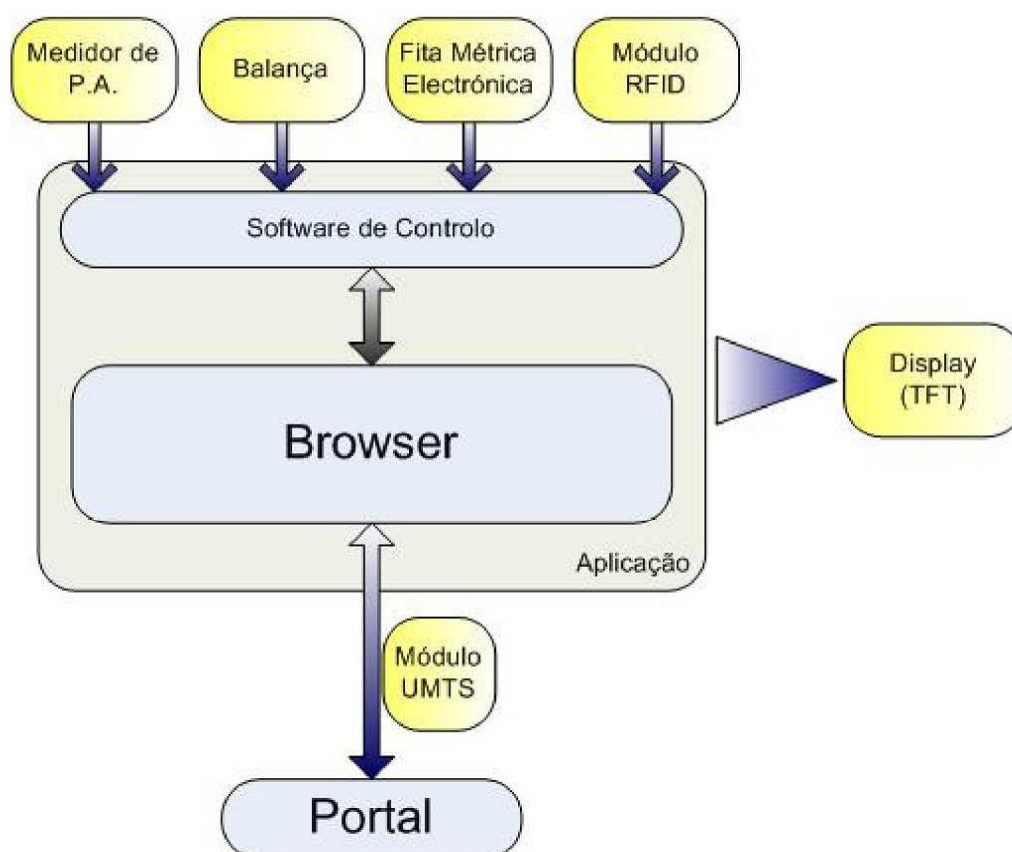


Figura 3 – Arquitectura Lógica da Estação de Medição

2.3.1. Software de Controlo:

Este módulo de software vai permitir comunicar com os diversos dispositivos de medição (medidor de P.A., Balança e Fita Métrica Electrónica), bem como com o módulo de RFID, com rotinas que os permitam controlar e que, após finda a comunicação, permitam receber adequadamente os dados. Este módulo de software deverá ter a capacidade de controlar o fluxo das medições que vão sendo efectuadas ao longo do processo, ou seja o utilizador

poderá dirigir-se por qualquer ordem aos aparelhos de medição visto que a aplicação detecta a sua presença. Deste modo é ainda possível repetir medições.

2.3.2. Browser

Este módulo da Aplicação é o responsável por mostrar informações provenientes do Servidor Remoto. Estas informações compreendem os questionários ao utente.

2.3.3. Aplicação

A aplicação será um módulo de software local que estará instalado no PC da estação de medição e suportará os outros módulos de software. Será a Aplicação a responsável pelo controlo a alto nível do processo.

3. Utilizadores

Existem diversos tipos de utilizadores que se agrupam pelo grau de permissão que possuem ao sistema. Os diversos grupos são:

- Administrador (A)
- Farmacêutico (F)
- Utente (U)

3.1. Permissões

Tendo em conta a Aplicação Web, o papel de cada grupo de Utilizadores é o seguinte:

Tabela 1 – Permissões concedidas a cada um dos tipos de Utilizadores

Funcionalidades	A	U
Adicionar/Eliminar Equipamentos	✓	
Criar/Alterar/Eliminar Contas de F	✓	
Criar/Alterar/Eliminar Contas de U	✓	
Aceder Historial Clínico		✓
Aceder/Alterar Dados Pessoais		✓

Legenda: **A** – Administrador; **F** – Farmacêutico; **U** – Utente

3.2. Hierarquia

Desta forma poderemos definir a hierarquia do sistema, no que diz respeito à Aplicação Web:

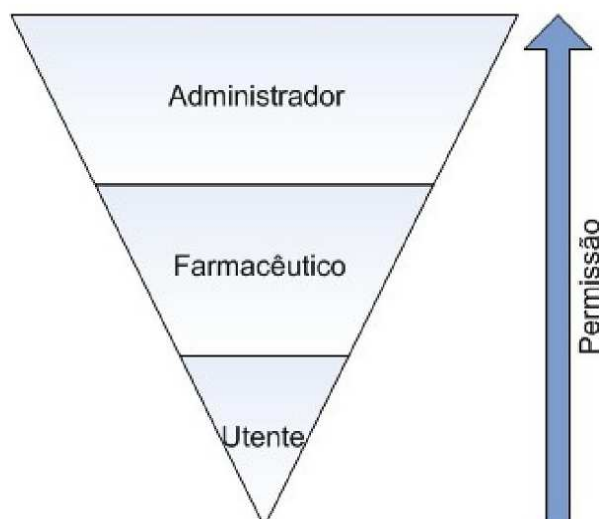


Figura 4 – Hierarquia dos utilizadores

4. Fluxo de Utilização

4.1. Autenticação

São entregues vários pacotes à farmácia que contêm um cartão RFID para identificação junto da Estação de Medição, bem como um User ID e um PIN, para aceder à Aplicação Web. Antes da primeira utilização, cada utente deverá possuir um desses pacotes que deverá usar para autenticação. No caso da Estação de Medição a autenticação será feita apenas por aproximação do cartão RFID à zona de detecção. No caso da Aplicação Web, existirá uma página de login onde serão introduzidos os dados identificativos desse utente.

4.2. Medição dos parâmetros

O fluxo de processo de medição dos parâmetros é aleatório, ou seja, após autenticação o utente pode efectuar qualquer medição, podendo até repetir medições. O sistema detectará quando o utente se encontra a utilizar um determinado módulo de medição.

4.2.1. Medição do peso

Logo que o Sistema detecte uma alteração no valor do peso dado pela balança assumirá que o utente irá efectuar esta medida. Assim que o valor esteja estabilizado durante poucos segundos o Sistema fixa esse valor, grava-o e mostra-o no display.

4.2.2. Medição da Cintura

Tal como na medição do peso, assim que haja uma alteração no valor dado pela fita de electrónica de medição o sistema assumirá que o utente irá efectuar esta medida. O final da medição será detectado

quando o circuito da fita for fechado. Finda a medição, o valor será gravado e mostrado no display.

4.2.3. Medição da Pressão Arterial

O módulo de pressão arterial tornar-se-á activo quando o paciente se sentar na cadeira, devido ao sensor de movimento que esta incorpora. De modo a que o resultado da medição possa ser considerado medicamente aceitável o utente necessita de estar 10 minutos em repouso completo. Porém, esse tempo de espera não é obrigatório, sendo da opção do utente decidir se espera ou não. Durante esse período de tempo irão ser mostradas algumas imagens no display, com carácter de entretenimento, cujo conteúdo depende se a pessoa utiliza o aparelho pela primeira vez ou não.

4.2.3.1. Primeira Utilização

Quando o utente utiliza o aparelho pela primeira vez é lhe pedido que insira alguns dados pessoais. Para além disso, elucida-se o paciente que se irá medir a pressão nos dois braços, para saber qual das pressões é a mais elevada.

4.2.3.2. Não é a Primeira Utilização

Se o utente já tiver utilizado o aparelho, serão mostrados, ao longo dos 10 minutos, alguns inquéritos ou vídeos. O preenchimento dos inquéritos é de carácter facultativo.