RFID-BASED WIRELESS SENSOR DATA COLLECTION UNIT

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The purpose of this thesis was to research the methods of radio frequency identification based wireless data transfer, battery charging and microcontroller programming as well as to develop the author’s project work and hardware design skills. The goal was to design and implement a working wireless sensor data collection unit prototype by using the learned methods. This unit automatically collects the sensor data in its memory in specified time intervals. The data can be read by a radio frequency identification reader device.

The project was started by searching for the necessary theoretical information for a hardware design. The next step was a selection of the components and after that the schematic design could be done. The antenna design was done in parallel with the schematic design, because the antenna component was designed directly on circuit board as a track loop antenna. The layout design was made after the schematic design was finished. After the circuit board was ready and assembled it needed to get a life so the hardware programming was done in this stage. The rest was testing and further development of the design.

The result of this project was a working wireless sensor data collection unit and one further development design of this prototype. The prototype design, assembly and programming was successful and the further development prospects are good.

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VOCABULARY

ALU	Arithmetic Logic Unit
ASK	Amplitude Shift Keying
CPHA	Clock Phase
CPOL	Clock Polarity
DMA	Direct Memory Access
EPROM	Erasable Programmable Read Only Memory
EEPROM	Electronically Erasable Programmable Read-Only Memory
EPC	Electronic Product Code
ESD	Electrostatic Discharge
FBGA	Field Programmable Gate Array
FSK	Frequency Shift Keying
HF	High Frequency
ISO	The International Organization for Standardization
JTAG	Joint Test Action Group
LED	Light Emitting Diode
LF	Low Frequency
Li-Ion	Lithium-Ion
NFC	Near Field Communication
PSK	Phase Shift Keying
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
RFID	Radio Frequency Identification
RISC	Reduced Instruction Set Computer
ROM	Read Only Memory
SCK	Serial Clock
SPI	Serial Peripheral Interface
TWI	Two Wire serial Interface
UHF	Ultra High Frequency
USART	Universal Synchronous/Asynchronous Receiver-Transmitter

1 INTRODUCTION

The topic of this thesis project was to design and implement a RFID- based wireless sensor data collection unit. This thesis was commissioned by Mr. Veijo Korhonen, Project Manager from Oulu University of Applied Sciences, IT department and the contact person was Mr. Tommi Sallinen, Designer.

The data collection unit collects sensor data in its memory at specified time intervals and memory content can be read over the RFID interface when it is activated with the RFID reader. When the RFID reader starts communication between the devices, the data collection unit wakes up and starts to transmit desired data to the RFID reader. The data collection unit was designed and implemented in this project.

The communication frequency between the RFID reader and the data collection unit is 13,56 MHz. In order for the coupling to be possible and the RFID interface to work between these devices, the data collection unit has to have its own 13,56 MHz tuned antenna. This high frequency antenna was designed in this project and it is placed directly on the circuit board. The designed unit supports only the ISO 15693 RFID standard, so the reader device has to support this standard, too.

The data collection unit is powered by a rechargeable battery and charging is made using induction power, because the final goal is to have a completely sealed sensor for hazardous environments. The charging circuit for the battery was also designed in this project. The induction charger was purchased as a ready product from the market.

2 RFID-TECHNOLOGY

The abbreviation RFID stands for Radio Frequency Identification, which means the wireless identification method where information is transferred using radio waves. The word RFID is a general name for all kinds of technologies that work in radio frequency areas. (16)

2.1 General

During the World War II (1939–1945) the first passive RFID system was invented by the Germans. The radar system was invented earlier in 1935 to notify of incoming aircrafts. The problem was that the radar could not see the difference between an enemy plane and an own plane. The Germans discovered that if pilots rolled their planes when they returned to the base, it would change the radio signal reflected back. This is the first passive RFID system. The first active RFID system was developed by the British and it is called the Identify Friend or Foe system (IFF system). The British put a transmitter in each plane and when it received the radar signal, it began broadcasting the signal back. The RFID works in the same way. (11)

The first active RFID transponder (Tag) with rewritable memory was patented in 1973. That same year the first passive tag was patented. It was used to unlock the door without a key. The first commercial applications were introduced in 1980´s. (12)

The basic idea of the RFID is simple: attach the RFID tag to the desired destination, write the information into a tag or read the information from a tag with the RFID reader. (16)

RFID technology can be compared with barcode technology, but barcode technology doesn’t offer same kinds of possibilities as RFID technology does. Barcode technology needs always a direct visual contact between the reader and the barcode, so that the reading can be done. If the barcode is dirty, or there is some obstacle between the reader and the barcode, reading fails. The RFID reader can communicate with a tag without any physical- or visual contact so it differs from the barcode technology. Reading distances are dependent on the standards that are used and on the frequency range. (4) (16)

RFID has been technically possible for decades and it has already been used for a long time, for example on key cards, travel cards and for recording animals. RFID is also used in industry as a part of production efficiency and quality control, logistics and cargo tracking. The RFID is not a single technology, it is a number of technologies with the same operating principles. (4) (16)

2.2 Components of RFID system

Main components of a RFID system are a transponder, interrogator or reader and application. The tag is attached to the object which you want to be identified. Normally a tag consist of a coupling element which is an antenna and an electronic microchip where information is hold. The main components of a RFID system are shown in the Figure 1. (4)

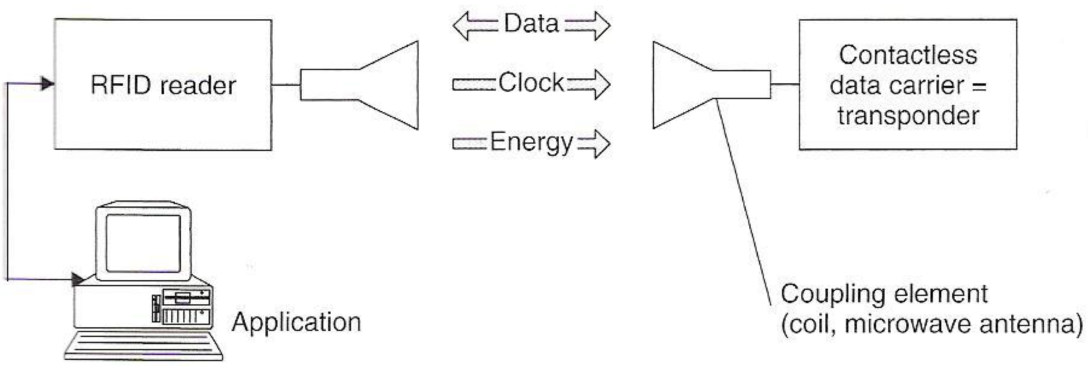


FIGURE 1. Main components of RFID system. (4)

When a tag doesn't have its own power supply and it is not in an interrogation zone of a reader it is totally passive. An active transponder has its own power supply. (4)

A RFID reader has three functions; to stimulate tags, read tags data and transmit data to a host computer with an external connection. Nearly all readers can also write data to the tag's memory. A better term for the reader would be "reader/writer". The reader consists of a radio frequency module, a control unit and a coupling element which is the antenna. There is a sample picture of coupling elements in Figure 2. (3)

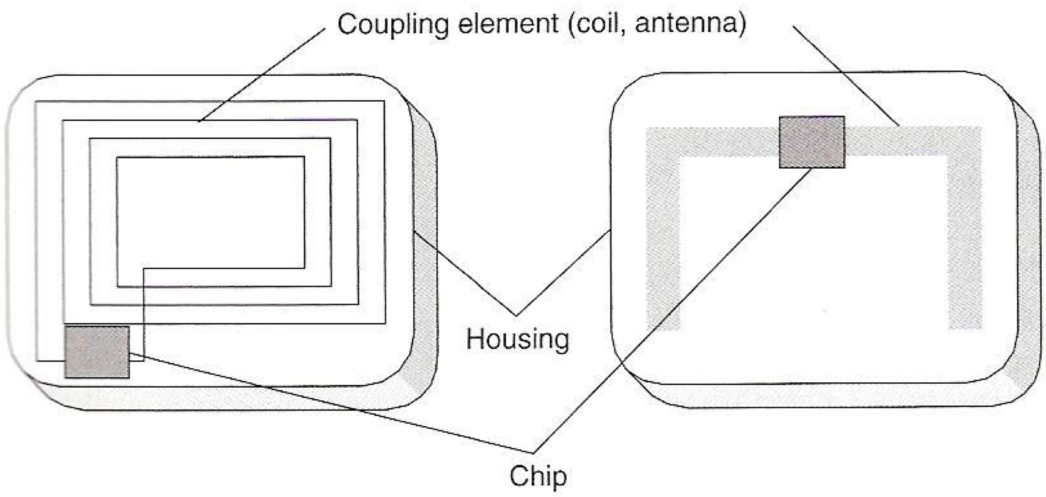


FIGURE 2. Coupling elements. Left, inductively coupled transponder with antenna coil; right, microwave transponder with dipolar antenna. (4)

An application system includes a computer, database, servers, information processing applications and terminal equipments. The application system is used for editing information to suit to the user. (19)

2.3 RFID Transponders

RFID tags can be divided into three categories based on tag properties. An example picture of a RFID tag in the Figure 3. (23)

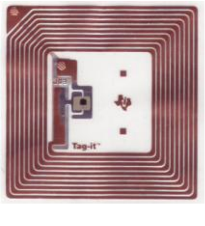


FIGURE 3. RFID tag. (17)

2.3.1 Passive transponder

A passive transponder is a tag that doesn't have its own power supply. It is active only when the RFID reader is near by. The tag takes its energy from the RFID reader by induction power. With this power, the tag can send a reply to the RFID reader. Normally the reply is just the tag's own ID-number. As there is no power supply, the tag can be very small. In year 2007 the smallest tag was 0,05 mm x 0,05 mm. Passive RFID tags are cheaper to produce than active RFID tags. For this reason, most RFID tags currently used are passive tags. (20) (23)

Passive tags are broken down into two categories based on their voltage technology and data writing technology which are near-field technology and far-field technology. Near-field technology is based on electromagnetic induction and far-field technology is based on radio waves. Low frequency (LF) and high frequency (HF) tags use electromagnetic induction, while ultra high frequency (UHF) tags use electric field reflection to data and the operating voltage transfer. (15)

In the LF- and HF-bands a reader and a tag forms an inductive connection like a transformer. Normally there are copper loops in the tag, which form a coil and it works as a tag antenna. There are same kind of loops in the RFID reader. By passing an alternating current in to the loop, the reader generates an oscillating magnetic field, for example a frequency of 13,56 MHz. This magnetic field induces the same alternating current to the tag coil when the tag is in the reader's detection distance. In this case, a microchip in the tag receives the operating voltage from the induced current. When the microchip is powered on, the EEPROM memory content is modulated in the tag coil voltage. The modulated voltage is shown as changes in the reader coil voltage. (15)

In the UHF and microwave frequency bands, communication between tag and reader happens through electromagnetic radiation i.e. using radio waves. The reader sends out radio waves through its antenna, and the tag's dipole antenna receives these radio waves and backscatters them. The tag modulates data from its microchip to a backscattered wave. The tag can send data with a backscattered signal to the reader in many ways, for example like increasing the amplitude of the reflected signal *(Amplitude Shift Keying, ASK)*, shifting of the reflected signal phase *(Phase Shift Keying, PSK)* or converting the frequency of the reflected signal *(Frequency Shift Keying, FSK)*. (15)

2.3.2 Semi-passive transponder

A semi-passive transponder is a tag that has its own power supply, but a transmitter is missing. Since there is no transmitter, the semi-passive tag needs power from the reader to be able to send data. The semi-passive tag has a greater operational range than the passive tag and the semi-passive tag has memory of its own. This feature allows it to storage data in the memory, for example temperature data from a sensor to an EEPROM. (23)

2.3.3 Active transponder

An active transponder is a tag that has its own power supply in the same way as semi-passive tags. Thus the active tags production costs will increase compared to the passive tags. That's why active tags are not as popular as passive tags and active tags are used only for special purposes. Unlike the semi-passive tag, the active tag has also a transmitter which is powered by a battery. The active tag listens all the time to the possible incoming signal from the reader and answers it if necessary. Communication of active tag and the reader is similar to communication between two radios or mobile phones. Active tags enable wireless reading even up to 100 meters. (15) (23)

The previously mentioned IFF-system is based exactly on active tags. An active tag was attached to the airplane and it answered to the radar signal automatically by sending an identification signal back to the radar. That is how the British identified their own planes from the enemy planes.

2.4 RFID frequencies

RFID technology uses a number of different frequency bands all over the world. This section observes only commonly used frequencies used in Europe. In Finland, the Finnish communications regulatory authority (Ficora) controls the usage of the frequency bands, which impose requirements and constraints to the usage of RFID systems. (14)

A LF-band RFID system is working normally at the frequency of 125 kHz and the frequency band is 125–134 kHz. The data transfer interface of these RFID systems is based on inductive coupling and these kinds of systems have slow data transfer rate and the reading distance is usually under half a meter. As an advantage of LF-band systems can be considered excellent readability on the dense non-metallic substances and through water. The LF-band is commonly used for the identification of animals and in some access control applications. Closed systems are very common and highly used in this frequency band, which means that different manufacturers products are not compatible with each other. (4) (14)

13,56 MHz frequency is used in HF-band RFID systems, which is an internationally open frequency, and anyone can make systems for this frequency. A RFID system which operates in this frequency band is also based on inductive coupling in the same way as LF-band systems. The data transfer rate is usually 106 kbit/s which is better than in LF-band systems. The maximum reading distance between the antenna and the chip is one and a half meter in optimum conditions. The reading distance depends on the application and is usually between five centimetres to one meter. The 13,56 MHz RFID systems are commonly used in libraries for books, airports for baggages, factories for pallet tracking and access control, and also in personal identification applications. A high clock frequency enables the usage of microprocessors in the tag and data encryption. Compared to UHF technology, 13,56 MHz technology has better field permeability through substances that contains water such as trees and human beings, better interference resistance in industrial environments, and it poses no problems with reflection. (4) (14)

Modern 13,56 MHz tags are dual interface smart cards which means there are two interfaces in one card. A card has a contactless interface and a contact interface. Both interfaces has access to the internal memory and processing. Contactless smart cards can be used in applications where a safe encryption for the data transfer is required. These kinds of applications are for example an electronic wallet or a public bus card. (4)

In Europe the 868 MHz frequency is used in UHF-band RFID systems. A RFID system which operates in the UHF-band has a faster data transfer rate and a longer reading distance than lower frequency applications. RFID systems which operates in the UHF-band works in a different way compared to RFID systems in the LF- and HF-band. When operating in the UHF-band operation technology is called far-field technology and when operating in LF- or HF-band operation technology is called near-field technology. 868 MHz frequency passive tags can be read about three meters away and active tags reading distance can grow up to a hundred meters. A dipole antenna is usually used in tags. This frequency tags are commonly used in logistics, container tracking and pallets. (4) (14)

Microwave frequencies which are used in Europe are 2,4 GHz and 5,8 GHz. These frequencies enable very fast data transfer rate. Passive tags data transfer rate is 10–50 kbit/s when reading distance is about twelve meters. Active tags can perform 1 Mbit/s data transfer rate when the reading distance is the maximum of thirty meters. These kinds of RFID systems has bad permeability on non-metallic substances because of reflections and attenuations of microwaves. RFID systems which operating in microwave frequency band are usually used in an active mode whose best-know application is an automatic identification of the customs. Frequency of 2,4 GHz is widely used in different applications as Bluetooth, WLAN, Zigbee etc. so this frequency is quite congested. (4) (14) (18)

2.5 RFID standards

There are many established standards for RFID even though it is quite often said that there are no standards in RFID. A great deal of work has been done over the past decade to develop standards for different RFID frequencies and applications. Main standards determine the data transfer protocol and tag's data content. Important standards has been developed in the payment system- and logistic applications, since different operators have to be able to read same kinds of tags with their own devices. The ideal situation would be if with standardization, different manufacturers RFID systems would be able to read each others tags. When someone building a system, it would be easier to ensure equipment availability in the future, if would not have to commit to a single manufacturer's products. Although a standard does not in itself guarantee everything , there are so called open standards which can be utilized by anyone. (10) (13)

There are no open standards in the LF-band. Most LF-band applications like different kinds of access control systems have been implemented as closed systems at the frequency of 125 kHz. The International Organization for Standardization (ISO) has created standards for tracking cattle. The standard that has been defined for the cattle identification is ISO 11784 which describes the tag data content. At the frequency of 134 kHz standard ISO 11785 defines the data transfer protocol. (10) (13)

The HF-band in frequency of 13,56 MHz has agreed standards. The standard ISO 14443 is not independent of the manufacturer, but NXP Mifare technology has achieved a de facto standard status of this frequency band. The reading distance is limited to 3–4 cm and is widely used in various payment applications. The HF-band's other standard is ISO 15693 and it is independent of the manufacturer, Philips I-CODE SLI chip is the most know chip in Finland which follows this standard. (13)

Today the most important UHF-band standard is ISO 18000-6C also known as GEN2. It is a standard developed by EPC (Electronic Product Code), a global organization, and the standard orders data transfer protocols. This standard's contribution to the UHF band has been more secure identification and operation has improved especially in a multi-reader environment. (13)

The Auto-ID Center was set up in 1999 to develop the EPC-standard and related technologies that could be used to identify products and track them through the global supply chain. The starting point for developing was to make a low-cost RFID system, because tags needed to be disposable. When a manufacturer puts tags on products which are shipped to a retailer, the manufacturer is never going to get those tags back to reuse them. The second point was to exploit UHF band's reading distance which was good for logistic applications. Auto-ID Center also wanted its RFID system to be global and to be based on open standards. It needed to be global because the aim was to use it to track goods as they flowed from a manufacturer in one country or region to companies in other regions and eventually to store shelves. Auto-ID Center developed a standard that covers the data transfer protocol and the tag data content protocol. Auto-ID Center also developed a network infrastructure to serve the preservation of information and the transfer between the various actors worldwide. (10) (13)

Unlike the original idea of developing one data transfer protocol, Auto-ID Center developed many EPC tags in accordance with a number of the class division, where the upper classes provide more opportunities for a higher price. The classes changed over time, but there were originally five classes that were proposed. According to the original class division, for example, Class 1 tags are passive and could be only read. Class 5 tags are active and could communicate with other Class 5 tags and/or other devices. In the end however, the Auto-ID Center adopted a Class 0 tag, which was a read-only tag that was programmed at the time the microchip was made. Since the Class 0 tag used a different protocol from the Class 1 tag, end users had to buy multiprotocol readers to read both Class 1 and Class 0 tags. Class 0 and Class 1 EPC tags are the most relevant in logistic application. (10) (13)

In 2003, the Auto-ID Center licensed EPC Class 0 and Class 1 protocols to EPC global organization against the condition that the standard had to be open and freely accessible to everyone. EPC Class 0 and Class 1 are not compatible with ISO standards, and there is a problem using these standards globally, because they do not comply with all the European regulations, for example. (13)

ISO has developed RFID standards for automatic identification and item management. This standard, known as ISO 18000 series (which also includes the previously mentioned Gen2) covers the air interface protocol for systems likely to be used to track goods in a supply chain. They cover major frequencies used in RFID systems around the world. The seven parts are:

- 18000-1: Generic parameters for air interfaces for globally accepted frequencies.
- 18000-2: Air interface for 135 kHz
- 18000-3: Air interface for 13,56 MHz
- 18000-4: Air interface for 2,45 GHz
- 18000-5: Air interface for 5,8 GHz
- 18000-6: Air interface from 860 MHz to 930 MHz
- 18000-7: Air interface for 433,92 MHz

Although some of the standards and technologies are fairly well established, the future reader and software application standards are still some mysterious. Different tag standards are however finally stabilized because of the UHF bands Gen2 standard. (10)

3 SELECTION AND THEORY OF COMPONENTS

The first step on this project was the selection of the components which this device could be built, and the search of the induction charger was started.

The design was started by the charging circuit design. At first, it was decided what operating voltage this device should have and that the capacity of the battery should be high enough. The result was 3,6 V, because it was decided that the battery should be a Lithium-Ion (Li-ion) battery and the cell voltage of these kinds of batteries is 3,6 V. The battery that was chosen was LR1865AH and it has a 3,6 V nominal voltage, a 2150 mAh nominal capacity, a 4,65 V maximum charge voltage and the maximum charge current of 2200 mA. When charging the Li-Ion battery it is important that the charging circuit is correct or otherwise the battery may explode when charging. (9)

The next step was to look the battery charger controller. Analog Devices manufactures a 1,5 A linear charger for a single cell Li-Ion batteries, ADP2291, and it was just right for the selected battery. So the charger circuit was designed around ADP2291 battery charger controller. The controller has an adjustable charging current up to 1,5 A, an output overshoot protection, a programmable termination timer, a 4,2 V output voltage with +/- 1% accuracy over the line and the temperature and 1 µA shutdown supply current. (1)

MLX90129 was chosen to make a RFID communication and the sensor data collection possible. MLX90129 combines a precise acquisition chain for external resistive sensors, with a wide range of interface possibilities, it can be accessed and controlled through its ISO 15693 RFID front end or via its SPI port. Adding a battery will enable the use of the standalone data logging mode. The sensor data can be stored in the internal 3,5 kbits EEPROM user memory or an external EEPROM. In this project the chip is controlled by a microcontroller via SPI port. (7)

It was decided that a microcontroller will be used in this device. Microcontroller allows to insert more sensors, more memory space and accessories into device. Microcontroller also allows debugging source code. When it was decided that MLX90129 would be controlled with microcontroller, it was time to decide what microcontroller would be suitable to do this job. In the result of a long consideration it was decided to use ATmega32A, a newer version of ATmega32 which has been very popular among developers. Main reasons for why this microcontroller was chosen was its easy availability, a lot of user experience available, low power consumption in idle mode as well as active mode, low operating voltage, 32 kbytes of in-system self-programmable flash program memory, master/slave SPI serial interface, 1024 bytes EEPROM and JTAG (Joint Test Action Group) interface for programming. (2)

3.1 Battery charger controller

ADP2291 is a linear battery charger controller which is used in this project. It is designed for a single-cell Li-Ion battery for a supply voltage range of 4,5 V to 12 V. This charge controller adjusts the base current of an external PNP transistor to optimise current and voltage applied to the battery during charging. A low value resistor placed in series with the battery charging current provides current measurement for ADP2291. The charging circuit which is designed in this project is shown in the Figure 4. (1)

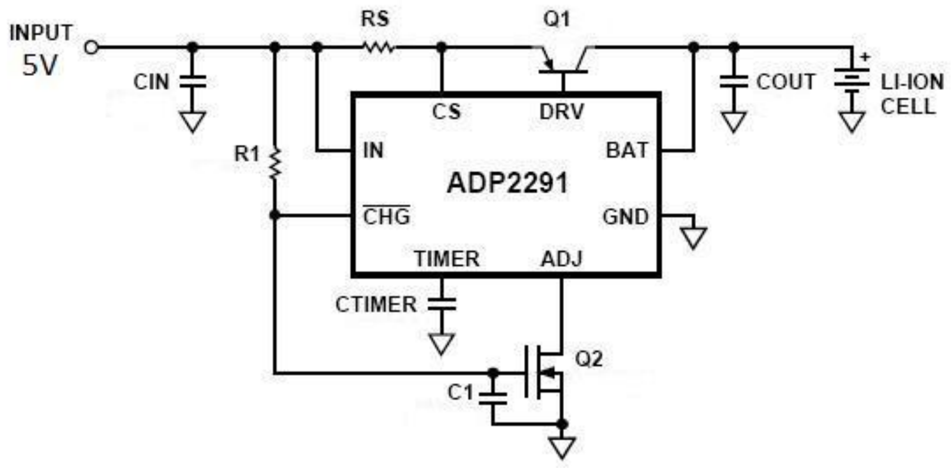


FIGURE 4. Charging circuit. (1)

3.1.1 Charge modes

There are three charge modes in ADP2291 which are a precharge mode, an end of charge mode and a shutdown mode. ADP2291 charges the battery by step by step cycle, which ensures safety and a long battery lifetime. The first thing that the controller does when the charge cycle begins is to determine the charge level, which is done by measuring the battery voltage. When the battery is deeply discharged, the controller goes to the low current precharge mode and once the precharge is ready, the normal fast charge at the maximum current starts. The maximum current can be adjusted. The charging current is reduced when the battery starts approaching its full capacity and it continues until the end of charge condition is reached. If the battery is not deeply discharged the controller starts right away the fast charging. (1)

When the battery voltage is below 2,8 V the precharge mode starts the charging cycle, because of deeply discharged cell. The charging current is reduced in the precharge mode and it is one tenth of the maximum charging current when the adjust pin voltage is 3 V and one fifth when the adjust pin voltage is 1,5 V. The precharge time is typically 30 minutes and if the battery voltage does not increase over 2,8 V before that time, the controller assumes that the battery is defective and it shuts down. The controller does not restart the charging before the input voltage is switched OFF and then back ON again. (1)

The controller goes in the end of charge mode as soon as the voltage loop reduces the charge current to one tenth of its nominal value i.e. the maximum current. The controller detects the end of charge state, and the charge status indicator goes in to the high impedance state. The low level charging continues as long as the timer ends it, typically in 30 minutes. (1)

The controller goes to the shutdown mode after the adjust input pin voltage is pulled below 0,4 V. When the controller is in this mode, the charger is disabled and the power consumption of the controller is less than 1 µA and the current drawn from the source falls to 0,7 mA. (1)

3.1.2 Functions

ADP2291 controller has a charge restart function. Once the charging is completed (the end of charge mode or the timer has expired), the controller continuously monitors the cell voltage and the charging current. As the time goes by and the cell voltage drops by 100 mV, the controller initiates another charge cycle to keep the cell fully charged. The controller also initiates another cycle of charging when the charge current increases beyond the end of charge hysteresis. (1)

The controller has a programmable timer. The on-chip timer is controlled by an external capacitor CTIMER, different values of this capacitor gives different timeout intervals of the various charger modes. For example, if CTIMER value is 0,1 µF then the precharge timeout interval is 30 minutes, the fast charge timeout is 3 hours and the end of charge timeout is 30 minutes. The ratio between the precharge and the end of charge to the fast charge timeout is always one sixth. If the timer pin is connected directly to the ground, the timer is not enabled. (1)

There is a charge status output CHG in ADP2291 controller that sinks current when charging is ON. There are two options to connect this pin. When connecting this pin to a LED (Light Emitting Diode), you get visual signal when charging is ON or it can be used to generate a logic-level charge status signal by connecting a resistor between the CHG pin and logic high. (1)

An automatic reverse isolation function of the controller is designed so that, when the voltage on the BAT pin (battery voltage sense input) is higher than the IN pin (voltage on input pin), the controller automatically connects the base of the pass device to BAT. Because of this function there is no need to use an external diode between the pass device and the battery. The component count is reduced and charger's footprint in the layout is smaller. (1)

The overshoot protection circuit in the controller is activated when the battery voltage rises up to 5 V and sinks the current up to 1,5 A to protect the external components. The voltage can rise if the battery is removed while charging, because the battery sense input maybe disturbed. (1)

The power supply check function, checks the absolute voltage level of the input supply and the supply voltage relative to the battery. If the source voltage is below 3,8 V, the controller is internally powered down and does not respond to an external control. Charging will only happen when the supply voltage is more than 165 mV above the battery voltage, ensuring that charging occurs only if the supply voltage is sufficient. VIN_GOOD comparator halts operation if the supply voltage is too low (Figure 5). (1)

The thermal shutdown occurs if controller's junction temperature rises above 135°C. ADP2291 does not start operating during the thermal shutdown until the on-chip temperature drops below 100°C. There is a block diagram of functions in the Figure 5. (1)

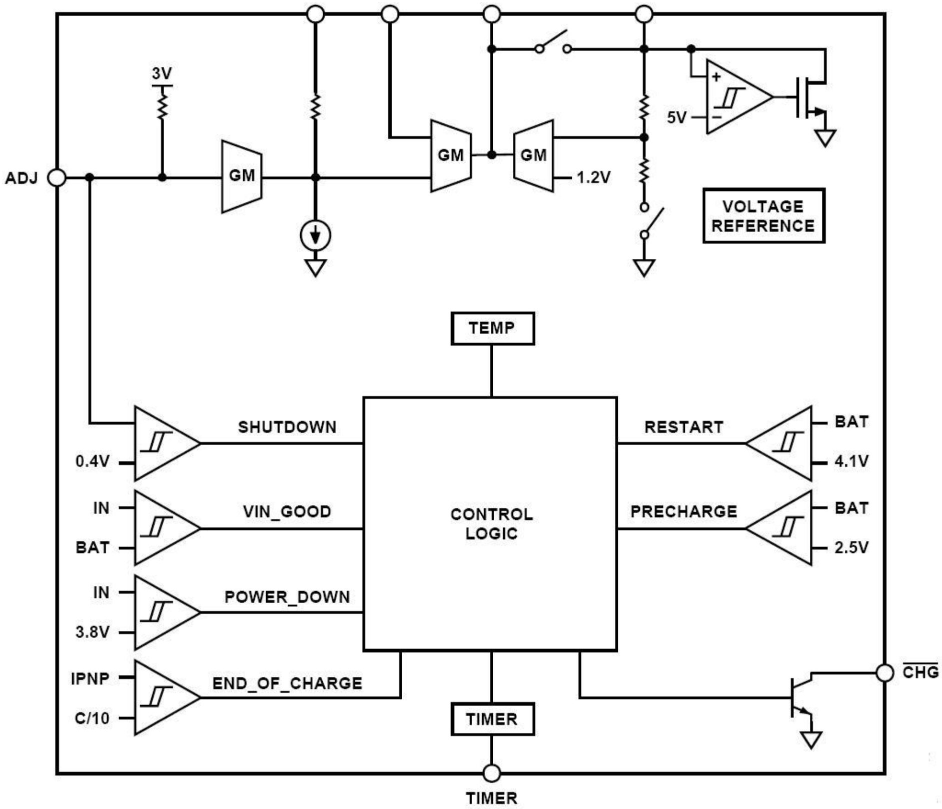


FIGURE 5. Functional block diagram of ADP2291 charger controller. (1)

3.1.3 Settings

The maximum charge current is set by choosing the proper current sense resistor, R_S, and the voltage on the ADJ input (Figure 4). The charger nominally regulates its output current at the point where the voltage across the current sense resistor $V_{RS} = V_{IN} – V_{CS}$ = 150 mV. The maximum charge current rate I_{MAX} is calculated based on Formula 1. (1)

$$I_{\max} = \frac{V_{RS}(mV)}{R_S(m\Omega)} \qquad \text{FORMULA 1}$$

where 50 mV ≤ V_{RS} ≤ 150 mV.

After determining suitable values for V_{RS} and R_S, the value of V_{ADJ} and R_{ADJ} are calculated as shown in Formulas 2 and 3. (1)

$$V_{ADJ} = \frac{V_{RS}(mV) + 50mV}{66{,}7} \qquad \text{FORMULA 2}$$

$$R_{ADJ} = 100k\Omega \times \frac{V_{ADJ}}{3V - V_{ADJ}} \qquad \text{FORMULA 3}$$

The charging circuit which was designed in this project has capability to maximum charge current of 750 mA. Resistors and voltages were selected in accordance with the bottom row of Table 1.

TABLE 1. Few examples of R_S and R_{ADJ} selection. (1)

I_{MAX} [mA]	R_S [mΩ]	V_{RS} [mV]	V_{ADJ} [V]	R_{ADJ} [kΩ]
1500	100	150	3	Open
1000	100	100	2,25	300
750	100	75	1,87	167
500	100	50	1,5	100
750	200	150	3	Open

The maximum charge time of the charging circuit is set by an external capacitor CTIMER as described in Chapter 3.1.2. The maximum charge time is good to be set for the safety reasons. The maximum charge time is intended as a safety mechanism to prevent the charger from trickle charging the cell indefinitely. If there is a failure to reach in the end of charge mode charging is terminated, but otherwise charging lasts as long as it set by CTIMER in normal charging condition. A typical Lithium-Ion cell is charged in about 1,5 hours of course depending on the cell type, temperature and manufacturer. Usually, a three hour time limit is good enough and the normal charge cycle reaches to end, before the charge timer ends charging. (1)

The value of the capacitor CTIMER is calculated using the Formula 4.

$$CTIMER = \frac{t_{chg}(\min) \times 1\mu F}{1800 \min} \qquad \textit{FORMULA 4}$$

As was said earlier the precharge and the end of charge periods are one sixth duration of the fast charge time limit. If the timer is disabled, the fault and the timeout states are never reached, so the timer should only be disabled if charging is monitored and controlled externally. (1)

The external PNP transistor Q1 must be chosen based on the given operating conditions and power handling capabilities. Also taking into account what is the input and the output voltage and the maximum charging current. (1)

Providing a charge current of I_{MAX} with a minimum base drive of 40 mA, minimum beta value for PNP transistor is calculated based on formula 5. (1)

$$\beta_{\min} = \frac{I_{MAX}}{I_B} = \frac{I_{MAX}(mA)}{40mA}$$ *FORMULA 5*

The beta of a transistor drops off with collector current. Because of that, the beta at I_{MAX} have to meet the minimum requirement. (1)

When the input voltage is low, the saturation voltage must be taken into account. The input voltage is low when it is under 5,5 V (in this project, the input voltage to charger is about 5 V). The saturation voltage can be calculated by using the Formula 6. (1)

$$V_{CE(SAT)} = V_{ADAPTER(MIN)} - V_{RS} - V_{BAT}$$ *FORMULA 6*

The power handling capability of the PNP transistor is also an important parameter that had to be taken into account. The maximum power dissipation (P_{DISS}) of the PNP transistor can be estimated and calculated by using the Formula 7. (1)

$$P_{DISS}(W) = I_{MAX} \times (V_{ADAPTER(MAX)} - V_{RS} - V_{BAT})$$ *FORMULA 7*

where V_{RS} = 150 mV at V_{ADJ} = 3,0 V and V_{BAT} is the lowest cell voltage where the fast charge can occur which is 2,8V. (1)

Based on these calculations the PNP pass transistor was selected. The results of the calculations were:

- β_{min} = 18,75

- $V_{CE(SAT)}$ = 0,65 V

- P_{DISS} = 1,5 W

FZT549 PNP transistor meet these requirements. FZT549 transistor values are:

- β = 130

- $V_{CE(SAT)}$ = 0,25 V

- $P_{DISS(MAX)}$ = 2 W

3.2 Atmel AVR-microcontroller

AVR is a microcontroller family which was developed by semiconductor manufacturer Atmel in 1996. AVR was one of the first microcontroller family which uses on-chip flash memory for program storage, as opposed to single programmable ROM (Read Only Memory), EPROM (Erasable Programmable Read Only Memory) or EEPROM (Electronically Erasable Programmable Read-Only Memory) used by other microcontrollers at the time. A flash memory is a semiconductor memory, which can be electronically erased and reprogrammed. (22)

The basic architecture that is used in the AVR-microcontrollers, were developed by two Norwegian students Alf-Egil Bogen and Vegard Wollan. They sold the architecture to Atmel and continued its development there. AVR name is believed to came words Alf and Vegard RISC (Reduced Instruction Set Computer). RISC is a computer processor architecture design philosophy, in which machine language instructions have been kept simple and quickly performed a standard time. (22)

The AVR family has now over 50 different microcontrollers. All models have the same processor and memory structure. The main differences between the models are the memory capacity and the number of the I/O ports. AVRs are generally classified into five broad groups which are tinyAVR, megaAVR, XMEGA, application specific AVR (as megaAVRs with special features not found on the other members of the AVR family, such as a LCD controller, a USB controller, an advanced PWM, CAN etc.) and FPSLIC (AVR with FPGA). FPGA (Field Programmable Gate Array) is an integrated circuit designed to be configured by the customer or the designer after manufacturing – hence "field-programmable". Table 2 shows the comparison of the characteristics of three main groups. (22)

TABLE 2. Main AVR groups.

	tinyAVR	megaAVR	XMEGA
Program memory (kbyte)	1-8	4-256	16-384
Housing size (pins)	8-32	28-100	44-100
Features	Limited peripherals/ interfaces	Extended instruction set, extensive peripherals/ interfaces	Enhanced performance features, extensive peripherals/ interfaces includes D/A-converters

3.2.1 AVR architecture

Flash, EEPROM and SRAM memories are all integrated onto a single chip, removing the need for an external memory in most applications. To maximize the performance, AVR uses a Harvard architecture. It has a separate memory and buses for command and data. Some devices have a parallel external bus option to allow adding an additional data memory or memory-mapped devices. The program memory commands are performed in a pipeline. The pipeline means that while one command is carried out, at the same time the next command is accessed from program memory. This allows commands to be executed with every clock cycle. Almost all devices (except the smallest tinyAVR chips) have serial interfaces, which can be used to connect larger serial EEPROMs or flash chips. In the Figure 6 there is a block diagram of the AVR MCU architecture. (2)

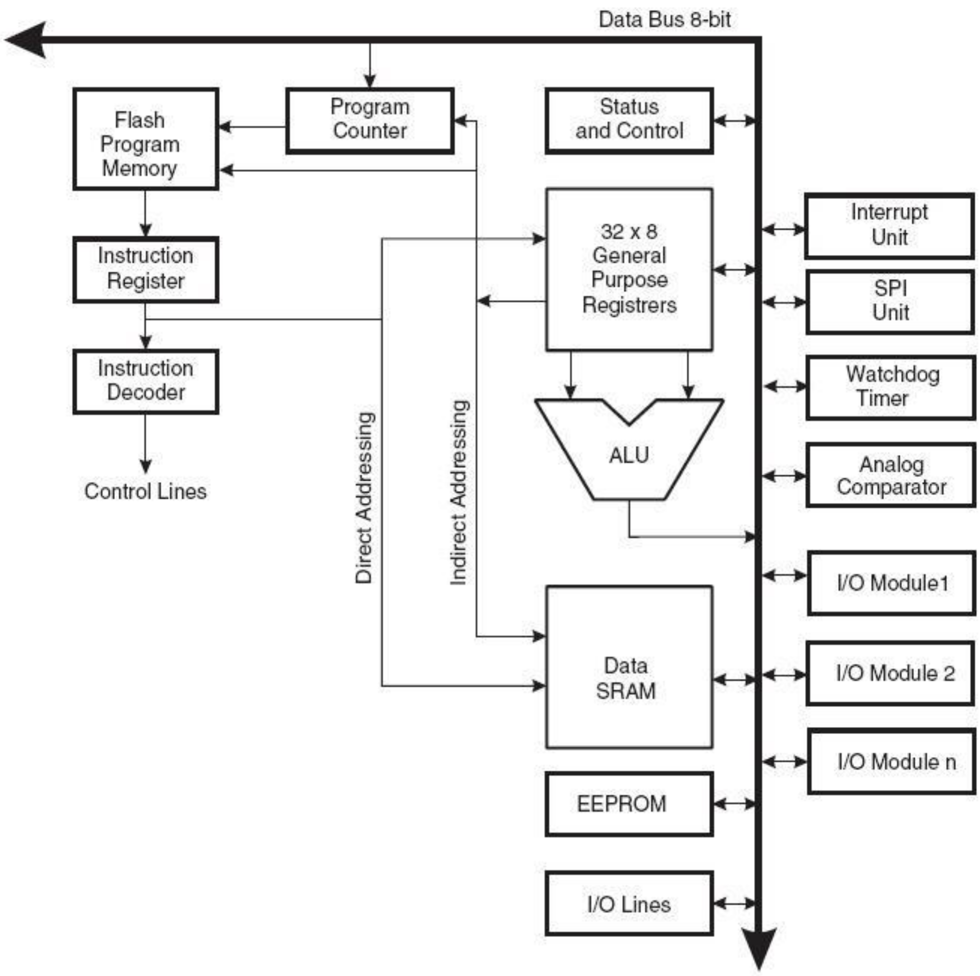


FIGURE 6. Block diagram of the AVR MCU architecture. (2)

The AVR ALU (Arithmetic Logic Unit) operates in a direct contact with all 32 general purpose work registers. The ALU is a digital circuit that performs arithmetic and logical operations. The ALU supports arithmetic and logic operations between of two registers or between a register and a constant. A single register operations can also be carried out in the ALU. The ALU operations can be divided into three main categories which are: arithmetic-, logical- and bit-function operations. In a typical ALU operation, two operands will be fetched in register file, execute the operation and save the result into register file. All this happens during one clock cycle. (2)

The status register always contains the latest information of the arithmetic operation. This information can be used to change the program process, which allows conditional execution of operations. Since the status register is automatically updated after each arithmetic operation, the code is faster and more compact. (2)

Fast to use registry file consists of 32 8-bit general purpose registers, and it is optimised for the AVR’s enhanced RISC instruction set. The access time of these registers is one clock cycle, which allows one cyclic operation. In order to achieve the required performance and flexibility, the following input/output schemes are supported by the register file, which are presented in Table 3. (2)

TABLE 3. Register file transfer methods.

Output	Input
One 8-bit operand	One 8-bit result
Two 8-bit operands	One 8-bit result
Two 8-bit operands	One 16-bit result
One 16-bit operand	One 16-bit result

Six of 32 general purpose registers can be combined into three 16-bits pointers, which are named as X-, Y- and Z-register. These are used as an indirect pointers of the data space, enabling effective address calculations. One of these pointers can also be used in the flash program memory as a lookup table pointer. X-, Y- and Z-registers have functions in different pointer areas as an automatic adding and reduction and in the solid transition. The AVR CPU general purpose working registers are shown in the Figure 7. (2)

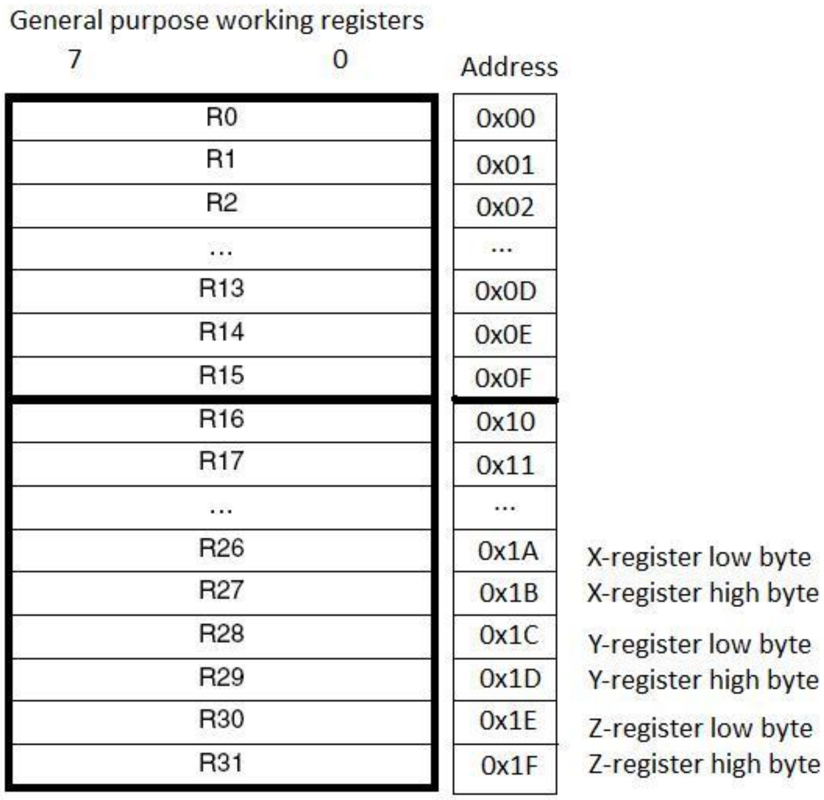


FIGURE 7. AVR CPU general purpose working registers. (2)

3.2.2 AVR Memories

The AVR microcontrollers has three kinds of memories. Main memory areas are SRAM data memory and flash program memory spaces. In addition, there is EEPROM memory for data storage. All three memory spaces are linear and regular. (2)

The ATmega series microcontrollers has 4 – 256 kbytes on-chip in-system reprogrammable flash memory for the program storage. The memory is divided into 2 – 128 k x 16-bit parts, because all AVR commands are 16 or 32 bits wide. The flash program memory is divided into two different parts which are the boot program section and the application program section, this allocation is made for software security. The Flash memory has an endurance of at least 10,000 write/erase cycles. (2)

SRAM data memory includes the register file, the I/O-memory and the internal data SRAM. The first 32 locations address the register file and the next 64 location address the I/O memory, and the next 2048 locations address the internal data SRAM. (2)

The ATmega series microcontrollers has 256 – 1024 bytes EEPROM memory. EEPROM memory is slower than SRAM memory and is frequently used to store program settings etc. for long term data storage. The memory is located in a separate memory area, which can be both read and write individual bytes through registers that are there for this purpose. These registers are the EEPROM Address Registers, the EEPROM Data Register, and the EEPROM Control Register. The EEPROM has an endurance of at least 100,000 write/erase cycles. (2)

3.2.3 AVR peripherals

The AVR microcontrollers have a wide range of integrated peripherals. For example, the following peripherals can be found in ATmega32A which is going to be used in this project:

- three counters (two 8-bit and one 16-bit)
- four PWM (Pulse Width Modulation) channels
- eight channel 10-bit A/D-converter
- on-chip analog comparator

For data transfer there is a byte-oriented two-wire serial interface (TWI) which is compatible with I2C, programmable serial USART (Universal Synchronous/Asynchronous Receiver-Transmitter) and master/slave SPI serial interface. (2)

3.3 Communication

The Melexis sensor tag IC (MLX90129) can be accessed and controlled through its SPI port or using its ISO 15693 RFID front end.

In this project the microcontroller (µC, ATmega32A) will be attached through SPI port to the sensor tag IC. The µC controls functions of the sensor tag IC and a RFID reader can access to it to retrieve the sensor data.

In Chapters 3.3.1 and 3.3.2 are explained how these two data transfer methods work with the components that are used in this project.

3.3.1 Serial peripheral interface

Telecommunication company Motorola has developed the synchronous serial bus, the Serial Peripheral Interface Bus, SPI. The bus operates in full duplex mode which means, that data can be transferred in both directions simultaneously. Devices communicate in a master/slave mode and only the master can start the data transfer. The Figure 8 shows the SPI bus in simplest form. (24)

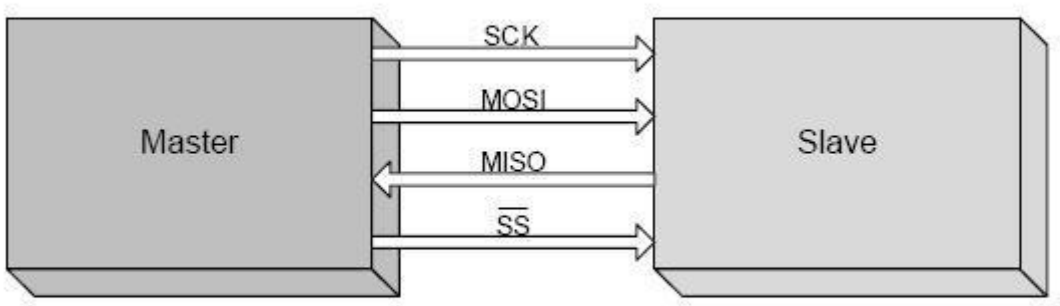


FIGURE 8. Single master and single slave SPI. (24)

In this project there are only two devices in SPI bus as described in the Figure 8. The µC is in a master mode and the sensor tag IC is in a slave mode. Table 4 shows line names and their descriptions and also the pin configuration for both of these devices.

TABLE 4. SPI description. (8)

Name	Description	Pin Tag IC	Pin µC
SS	Slave Select	12	5
SCK	Serial Clock	11	8
MOSI	Master data Output, Slave data Input	10	6
MISO	Master data Input, Slave data Output	9	7

There is no specific standard for SPI and that's why different manufacturers have slightly different solutions. Serial clock frequency (SCK), clock polarity (CPOL) and clock phase (CPHA) vary between devices. Some devices can only receive information, while some other devices can only send information. The message length can be 8-, 12- or 16-bit. The µCs has settings that allows SPI bus to be compatible with a variety of different devices. (24)

The sensor tag IC can be in the slave or the master mode. When it's in the slave mode, the SPI master (µC) controls the serial clock signal, the slave select signal and transmits the data to the slave via the Master-Out-Slave-In (MOSI) signal. As a slave, the sensor tag IC answers with the Master-In-Slave-Out (MISO) signal, synchronized on a serial clock signal. When the sensor tag IC is configured as in the master, it's SPI can select an external slave, for example an external serial EEPROM for data logging. It is possible to control the sensor tag IC as a master by using a custom RFID commands used over the RFID front end. (7)

To enable the communication between the master and the slave device, the master must set SPI bus clock to the maximum frequency or a smaller value than slave device supports. The clock polarity and phase must be set in the same way as the slave device. (24)

To enable a SPI communication with the sensor tag IC, the following settings must be set by the master:

- CPOL=0 which means that the serial clock is active when high and when the serial clock is low the bus is in the idle mode.

- CPHA=0 which means that the data sampling occurs on rising edges of the serial clock. The toggling of the data occurs on falling edges.

- DORD=0 (Data order) which leads to that the most significant bit is set to transmitted first on MISO/MOSI lines and the maximum baud-rate of the sensor tag IC's SPI bus is 1 MHz. (7)

Before starting the data transfer, the master puts a byte on the shift register which will be sent to the slave. Next, the master selects a slave device by pulling the SS line of the slave device down, after that the master starts creating a clock pulse. One bit is transferred from the master to the slave and from the slave to the master on every clock cycle. The information is always transferred in both directions even while the other device does not have any useful information being sent. For the data transfer a typical hardware configuration has been carried out by using two shift registers to form an inter-chip circular buffer as shown in the Figure 9. (24)

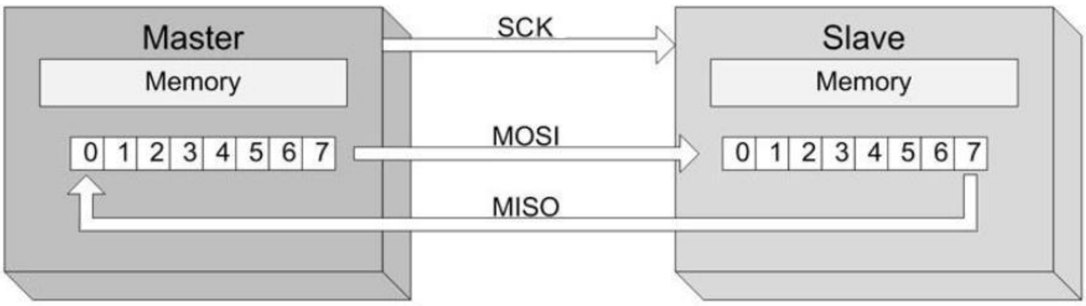


FIGURE 9. SPI bus shift registers. (24)

Information is usually shifted out with the most significant bit first, while shifting a new least significant bit in to the same register. After that register has been shifted out, the master and the slave have exchanged register values. Then the master pulls the SS line back to high and devices do what they are programmed to do with that information, e.g. write the byte into EEPROM. If more information needs to be moved, the new values will be loaded in shift registers and the process starts again. There are no hardware flow control or hardware slave acknowledgment in SPI bus. These things have to be taken into account when designing software which is using SPI bus. (24)

To ensure safe SPI communication between the master and the slave, the master needs to respect some basic timing, as described in timing diagram in the Figure 10. Table 5 shows timing specifications for the sensor tag IC. (8)

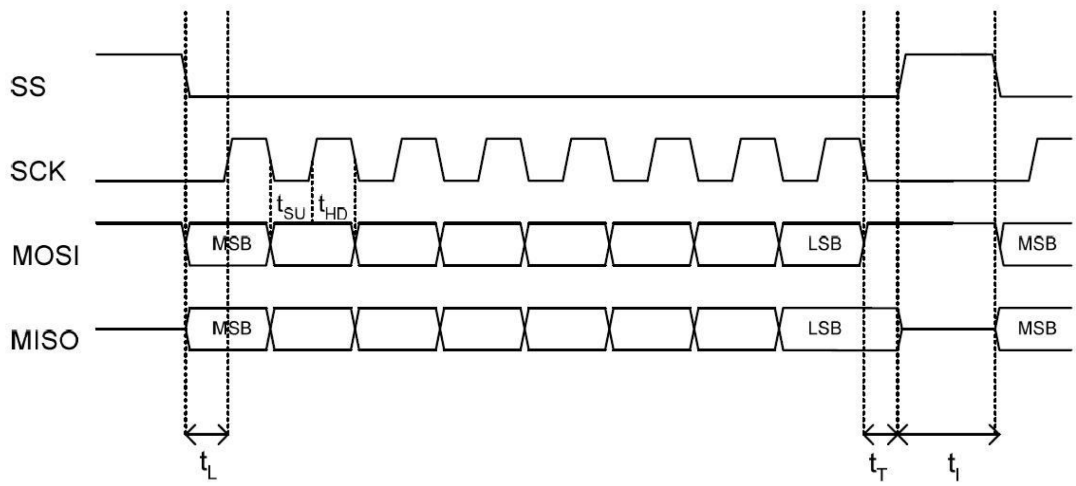


FIGURE 10. Timing diagram. (8)

TABLE 5. Timing specifications for sensor tag IC . (8)

Parameter	Description	Slave side Min Max	Units
tch	SCK high time	500 -	ns
tcl	SCK low time	500 -	ns
tSU	Setup time of data, after a falling edge of SCK	100 -	ns
tHD	Hold time of data, after a rising edge of SCK	500 -	ns
tL	Leading time before the first SCK edge - when the MLX90129 is not in sleep mode - when the MLX90129 is in sleep mode	 600 - 1,5 -	 ns ms
tT	Trailing time after the last SCK edge	500 -	ns
tI	Idling time between transfers (SS=1 time)	500 -	ns

3.3.2 RFID analog front end

The sensor tag IC's (MLX90129) RFID interface complies with the ISO 15693 requirements. For example, some of the supported features according to ISO 15693 are: reader to tag modulation index of 10% and 100%, reader to tag coding pulse position modulation 1 out of 4 is supported, tag to reader modulation supports single and dual sub carrier, tag to reader supported sub carrier frequencies are 423 kHz / 484 kHz, tag to reader coding supports the Manchester code, and tag to reader data rate supports high data rate which is 26 kBit/s. (7)

A RFID reader access in the sensor tag IC with a modulated 13,56 MHz carrier frequency over the RFID interface. The data is recovered from the amplitude modulated signal (ASK, Amplitude Shift Keying 10% or 100%). The Data transfer rate is 26 kBit/s using the 1/4 pulse coding mode. (7)

The outgoing data is generated by an antenna load variation, using the Manchester coding, and using one or two sub carrier frequencies at 423 kHz and 484 kHz. From the incoming field, the RFID interface recovers the clock and makes its own power supply. The rectified voltage may also be used to supply the whole device in the batteryless applications, but in this project a power supply is used. There is a block diagram of the sensor tag IC RFID analog front end in the Figure 11. (7)

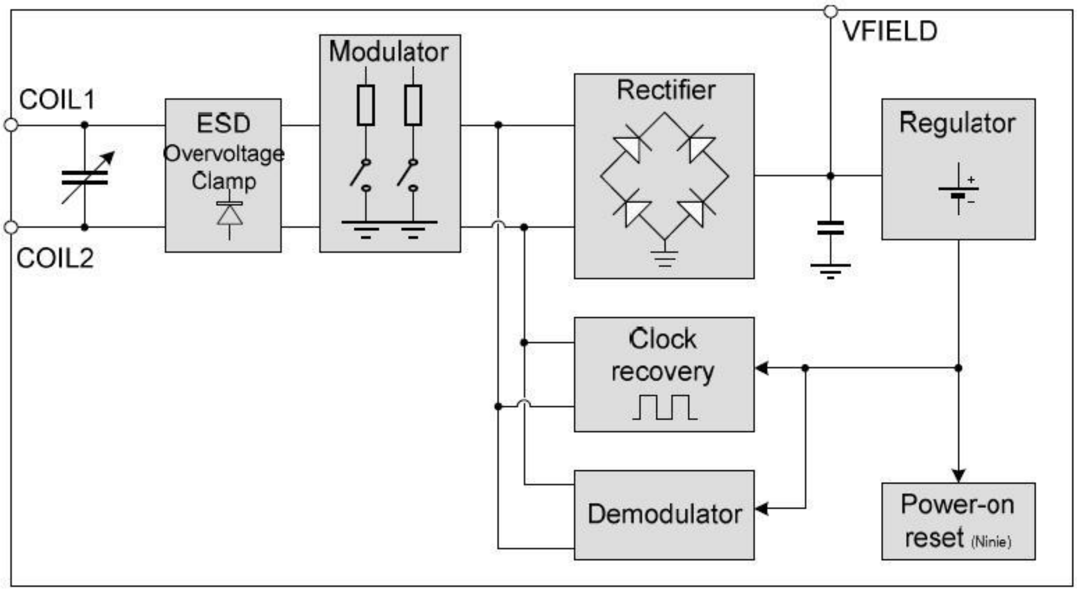


FIGURE 11. Block diagram of RFID analog front end. (7)

The antenna coil is connected to the internal tuning capacitor. This connection forms a resonance circuit. The capacitor is connected to the protection diode, which protects the internal circuit from ESD (Electrostatic discharge) and over voltage spikes.

3.4 Inductive charging

Battery of the sensor data collection unit is charged with an induction charger. As said in Chapter 1 an induction charger was purchased as a ready product from the market and was not designed in this project.

Two suitable charger products were found after a little searching. The first product was Powermat wireless charging mat, but the company did not transport products to Finland directly and dealers could not be found. The second product was Powerkiss demonstration kit which was selected.

Induction charger overview is shown in the Appendix 3.

An inductive charging is a short distance wireless energy transfer method and it uses the electromagnetic field to transfer energy between two objects. A charging platform and a receiver form inductive coupling. Energy is transferred through this coupling to an electronic device, and when the receiver is connected to that device it stores the energy to the battery. (25)

The charging platform creates an alternating electromagnetic field by using an induction coil. The induction coil is inside the charging platform, and the second induction coil is in the receiver. The receiver takes power from the electromagnetic field and converts it back into electrical current to charge the battery. (25)

An advantage of this charging method is low risk of electric shock, because there are no exposed conductors. Also the ability to fully enclose the charging connection makes the approach attractive where water impermeability is required or the casing is sealed. (25)

4 HARDWARE DESIGN AND ASSEMBLY

The goal was to design a completely sealed sensor data collection unit which can be read over the RFID air interface at a reader device. The battery charging is made by induction power, because the unit's case has to be completely sealed for hazardous environments.

The first step was to choose the RFID transmission chip which would be used in this project. Basically there were two choices: the first choice was PN511 transmission module from NXP semiconductors and the second choice was MLX90129 13,56 MHz sensor tag/data logger IC from Melexis. PN511 chip would have been preferred, because it supports NFC technology and the reader device could have been a Nokia 6212 classic phone. However after a little research, it was found out that the MLX90129 has a internal temperature sensor and two external sensor connection in the chip itself, so MLX90129 chip was chosen.

The MLX90129 chips were also much easier and cheaper to obtain than PN511 chips. And there were also many useful application and example notes for the MLX90129 chip in Melexis website that could be helpful.

To make the RFID interface possible the 13,56 MHz antenna design had to be done. Melexis website has a good antenna design document, which gave some guidelines to design an antenna for the RFID interface of the HF enabled sensor tag IC (MLX90129). The document explained antenna parameter calculations, prototyping tips and also, two antenna reference designs.

4.1 Antenna design

The antenna was designed directly on the circuit board, so it was drawn as a component footprint. The antenna was designed and drawn with a printed circuit board design software.

The antenna is attached to the sensor tag IC and this allows energy transfer and data exchange between the reader device and the sensor tag IC. (6)

In ISO 15693 standard carrier frequency is 13,56 MHz, so the system antenna should be tuned to resonate at 13,56 MHz. In this project the antenna is designed as a simple LC resonant circuit. The antenna inductance is L and C corresponds to the parallel tuning capacitor. Theoretical value of the resonance frequency is calculated by the Formula 8. (6)

$$f_{resonance} = \frac{1}{2\pi\sqrt{C \times L}}$$ *FORMULA 8*

There is an internal tuning capacitor in the sensor tag IC, so there is no need for an external capacitor. It saves space from the circuit board. The internal tuning capacitor's typical value is 75 pF. This value cannot be changed after it is trimmed in the production. There is an example of the configuration in the Figure 12. (6)

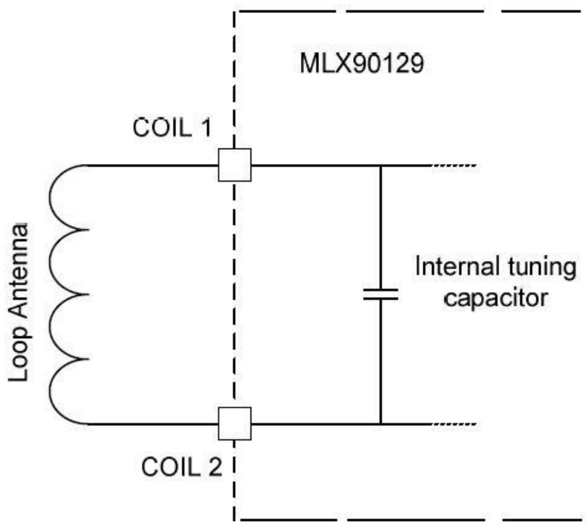


FIGURE 12. Basic configuration. (6)

When the internal tuning capacitor value is 75 pF, the value of the loop antenna inductance should be 1,837 µH, in accordance with the Formula 8. (6)

$$L = \frac{1}{(13{,}56 \times 10^{6}\,Hz \times 2\pi)^{2} \times 75 \times 10^{-12}\,F} = 1{,}837\,\mu H$$

If the inductance of the antenna is not 1,837 µH, it can be adjusted by adding an external capacitor as shown in the Figure 13. (6)

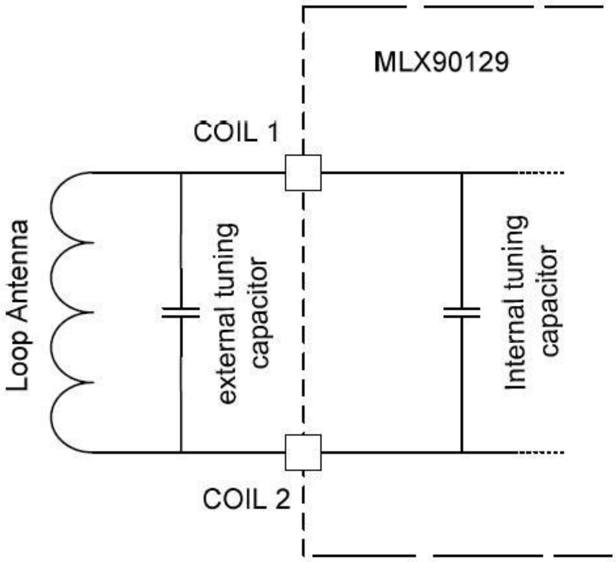


FIGURE 13. Configuration with the external tuning capacitor. (6)

The value of the external capacitor can be calculated by applying the Formula 8. For example, if the inductance of the loop antenna is 0,963 µH, the external tuning capacitor value has to be 68 pF, so that the resonance frequency of the loop antenna is 13,56 MHz. (6)

$$C_{external} = \frac{1}{(13{,}56 \times 10^{6}\,Hz \times 2\pi)^{2} \times 0{,}963 \times 10^{-6}\,H} = 68\,pF$$

There were two antenna reference designs in the Melexis document, the rectangular loop antenna and the circular loop antenna. It was decided to use the first one, the rectangular loop antenna design. The following parameters were given in the Melexis document which allows reproducing this antenna for custom designs as in our device. Parameters are shown in the Figure 14 where the wire width is 0,76 mm and the distance between wires is 0,38 mm. (6)

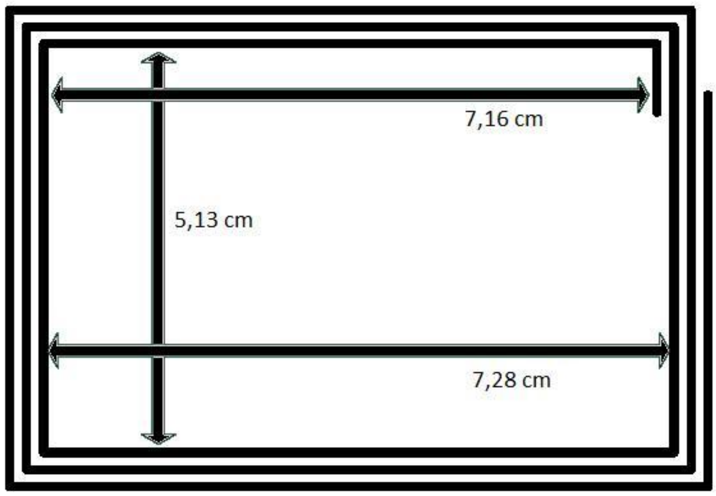


FIGURE 14. Rectangular antenna parameters. (6)

The inductance of the N turn planar rectangular antenna coil is expressed by the following formula (Formula 9). (6)

$$L_{T1} = \frac{N^2 \mu_0}{\pi} \times \left[-2(w+h) + 2\sqrt{h^2 + w^2} - h \ln\left(\frac{h + \sqrt{h^2 + w^2}}{w}\right) - w \ln\left(\frac{w + \sqrt{h^2 + w^2}}{h}\right) + h \ln\left(\frac{2h}{a}\right) + w \ln\left(\frac{2w}{a}\right) \right] \mu H$$

FORMULA 9

where *N* is the number of turns, *w* is the width of the rectangle in meters, *h* is the height of the rectangle in meters and *a* is the wire width in meters. (6)

Concerning the antenna used in this project, the parameters are: *N* = 3, *w* = 78,88 x 10^{-3} m, *h* = 57,38 x 10^{-3} m and *a* = 0,76 x 10^{-3} m. (6)

It also has to be assumed that the antenna is composed of 12 segments of planar rectangular inductors shared in 3 turns. The total inductance of the coil is the sum of the self inductances of these segments and the mutual inductances between the segments. (6)

The rectangle width w and height h will be measured as shown in the Figure 15.

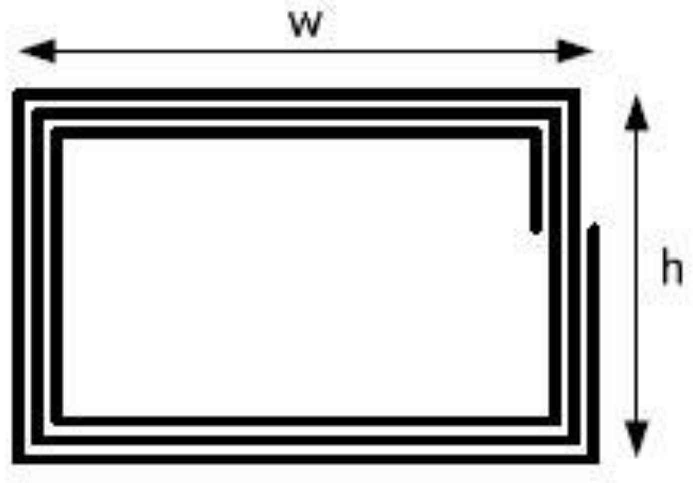


FIGURE 15. Rectangular antenna width and height. (6)

When designing the PCB layout it is important that the sensor tag IC's pins, COIL 1 and COIL 2 are as close as possible to the antenna connection. The long connection wire could impact the antenna tuning, because the inductance can change. The second thing which is good to do is to remove a ground plan inside or behind the antenna to avoid reflections. (6)

4.2 PCB design

The Printed Circuit Board (PCB) design consist of the wiring schematic, the layout design as well as the correct choice of the components. The design had to be done carefully, because mistakes made at this stage cost the most time.

The PCB design software that was used was Eagle version 5.9.0. The software is free of charge so it has some limitations as the usable board area is limited to 100 x 80 mm, only two signal layers can be used (Top and Bottom) and the schematic editor can only create one sheet. But in this project these limitations were not a problem and the design could be done with this software.

At this point components were selected and it was time to start the schematic design. The charger operating circuit was designed first, around the ADP2291 battery charger controller.

The charging circuit consist of the charger controller chip and external components which are: a micro USB connector, four capacitors, three resistors and two transistors. The battery charging circuit schematic is shown in the Figure 16.

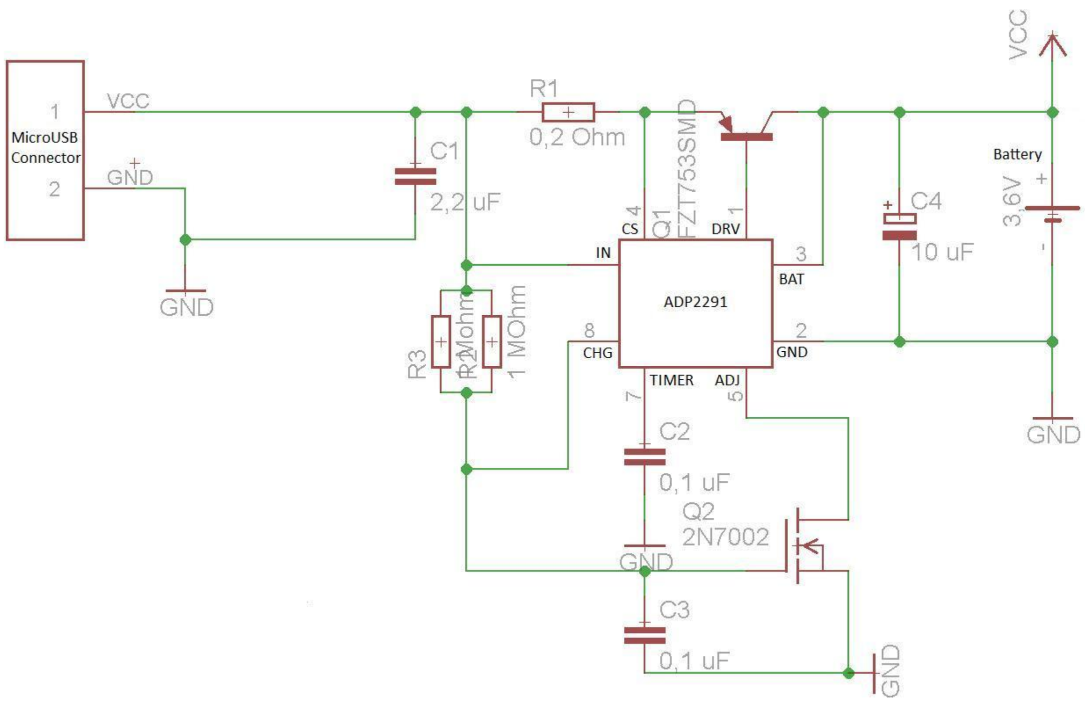


FIGURE 16. Battery charging circuit schematic.

Table 6 shows pin numbers, abbreviations and these descriptions.

TABLE 6. Pin function descriptions for the ADP2291. (1)

Pin No.	Abbr.	Description
1	DRV	Base Driver output. Controls the base of an external PNP pass transistor.
2	GND	Ground.
3	BAT	Battery voltage sense input.
4	CS	Current sense resistor negative input.
5	ADJ	Charging current adjust and charger shutdown input.
6	IN	Power input and current sense resistor positive input.
7	TIMER	Timer programming input/disable.
8	CHG	Charge status indicator. Open-collector output.

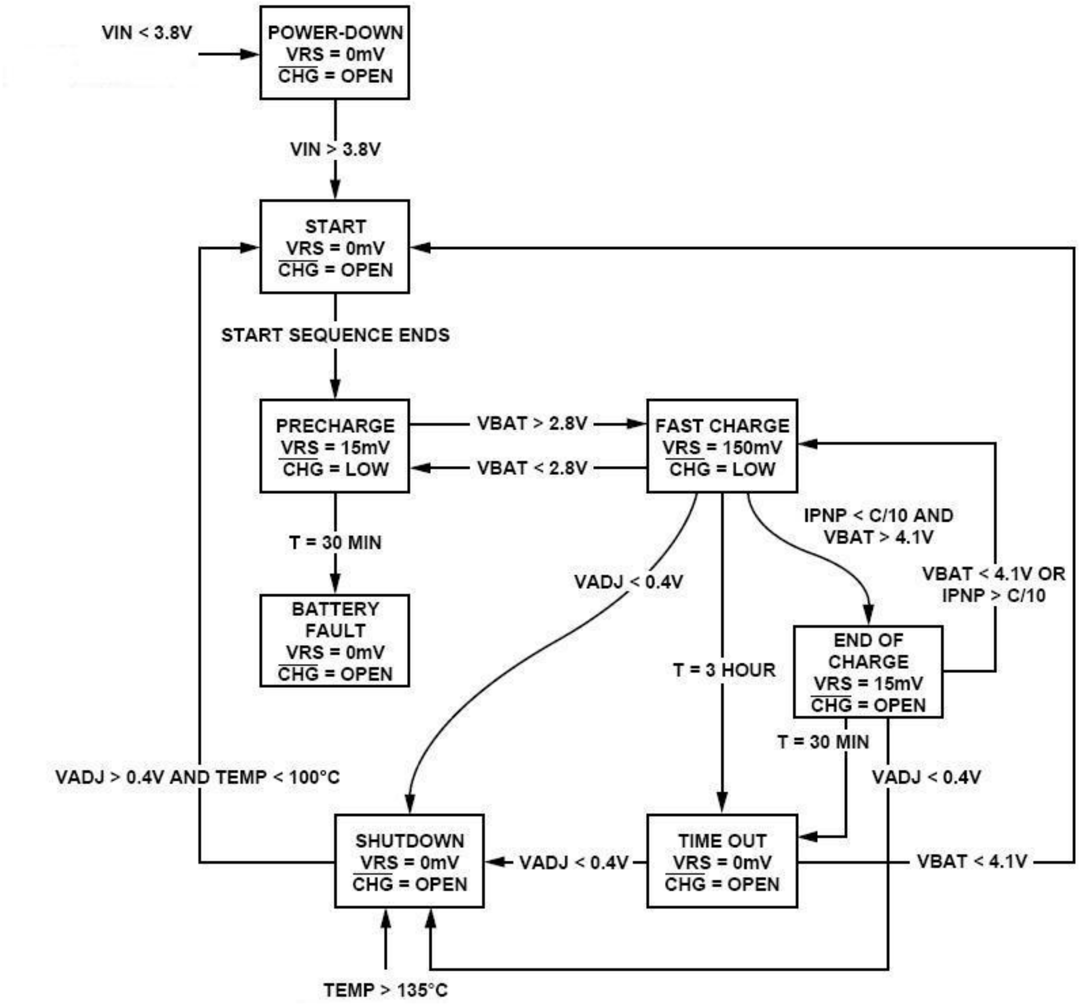


FIGURE 17. State diagram for the ADP2291. (1)

The charging circuit operation is described in the block diagram above. The capacitor CTIMER value is 0,1 µF as shown in charger circuit schematic in the Figure 16. For notice, in the schematic CTIMER is marked as C2.

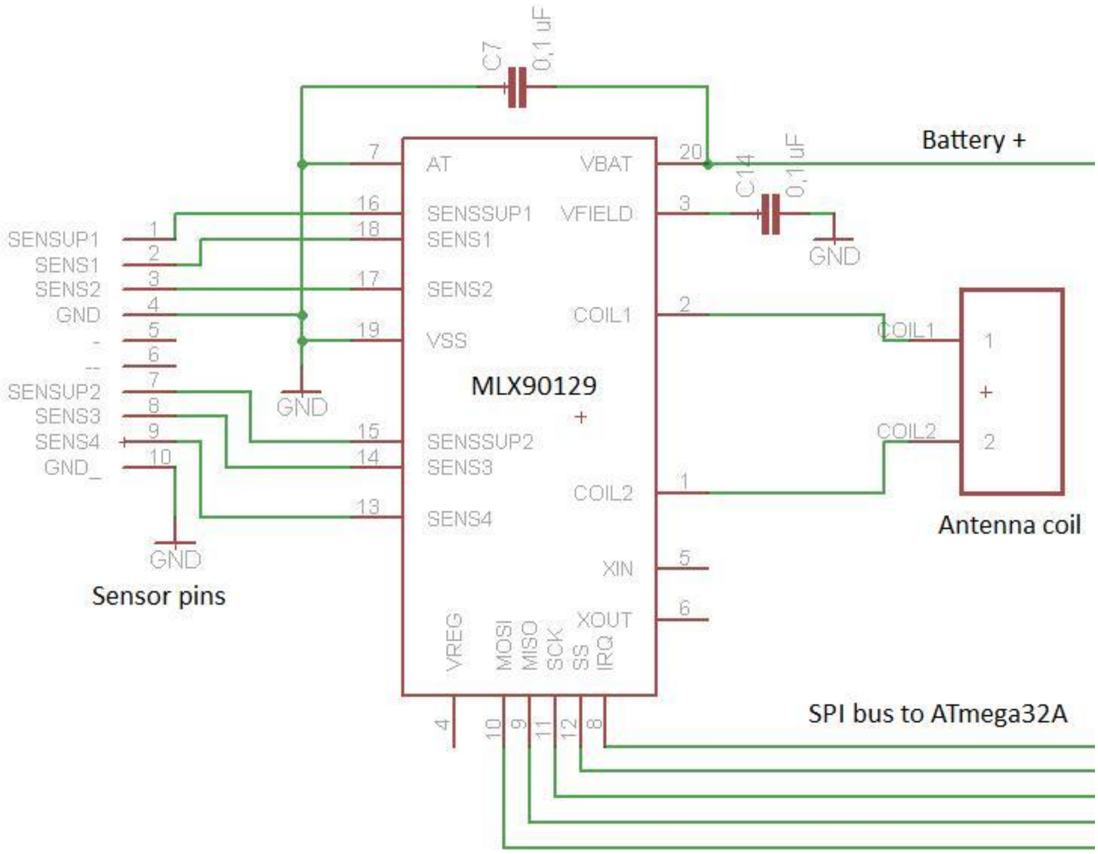


FIGURE 18. MLX90129 schematic.

After the charger circuit schematic was designed it was time to add the sensor tag IC (MLX90129) and other components to the design. The Figure 18 shows the schematic of the MLX90129 connections. There are only few external components which are: two capacitors, a 10 pin header connector for external sensor connections and an antenna coil.

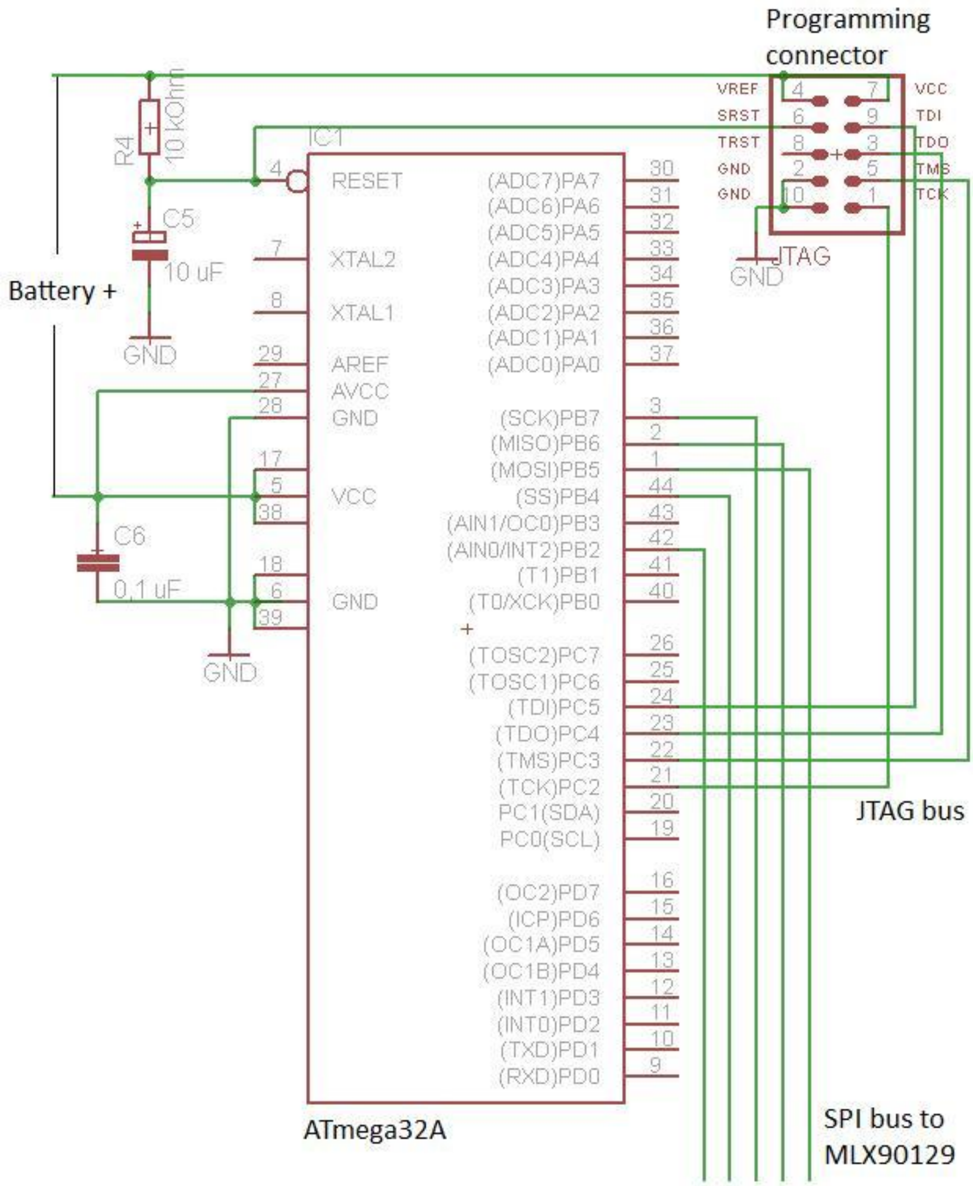


FIGURE 19. ATmega32A schematic.

The Figure 19 shows schematic of the ATmega32A connection. There are also few external components in this design. There is an external reset connection which consists of one resistor and one capacitor. One small capacitor is placed close to power connection. The 10 pin header connector for programming is attached to the µC over its JTAG interface, a programming device is used over this interface for programming and debugging the µC.

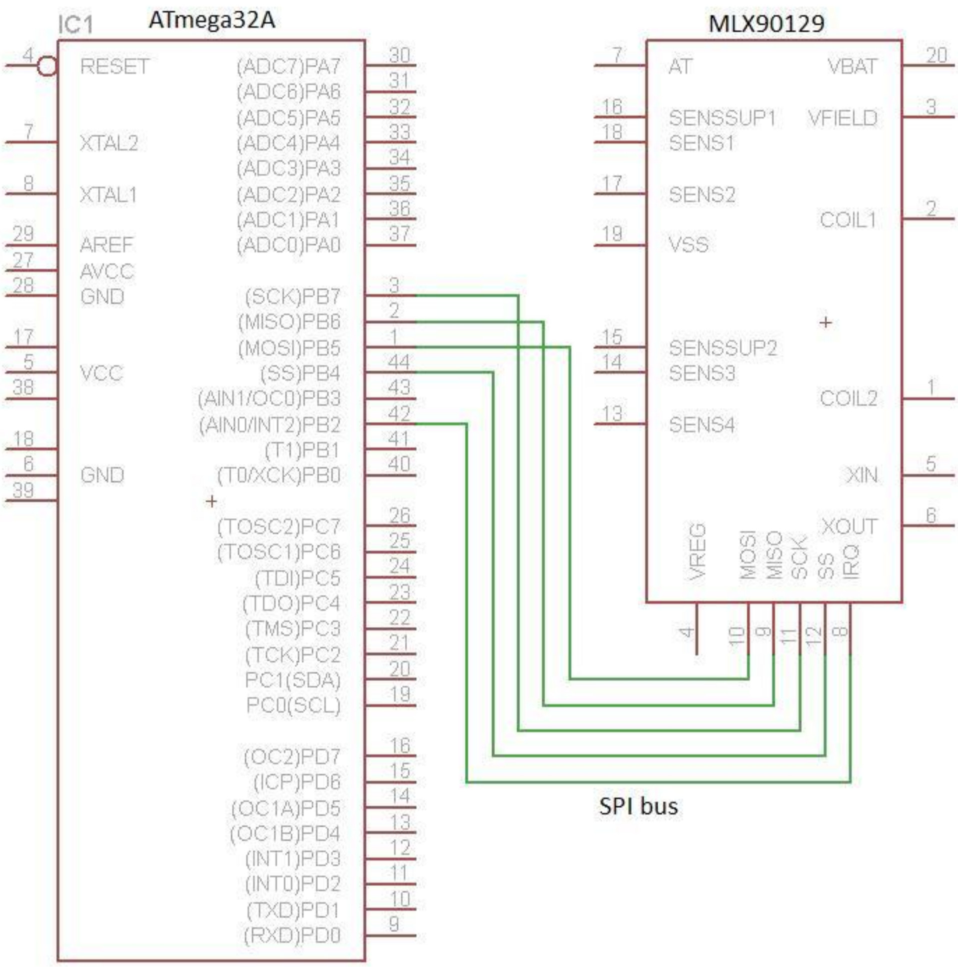


FIGURE 20. SPI bus schematic.

Communication between the µC and the sensor tag IC is happening over the serial peripheral interface, as explained in the Chapter 3.3.1 earlier. The Figure 20 shows connection between these components.

Full schematic is given in the Appendix 1.

At this point schematic was designed and the layout design could start. The maximum board dimensions that Eagle software supports is 100 mm x 80 mm and these dimensions were used on this circuit board. The layout of the sensor data collection unit is presented in the Figure 21.

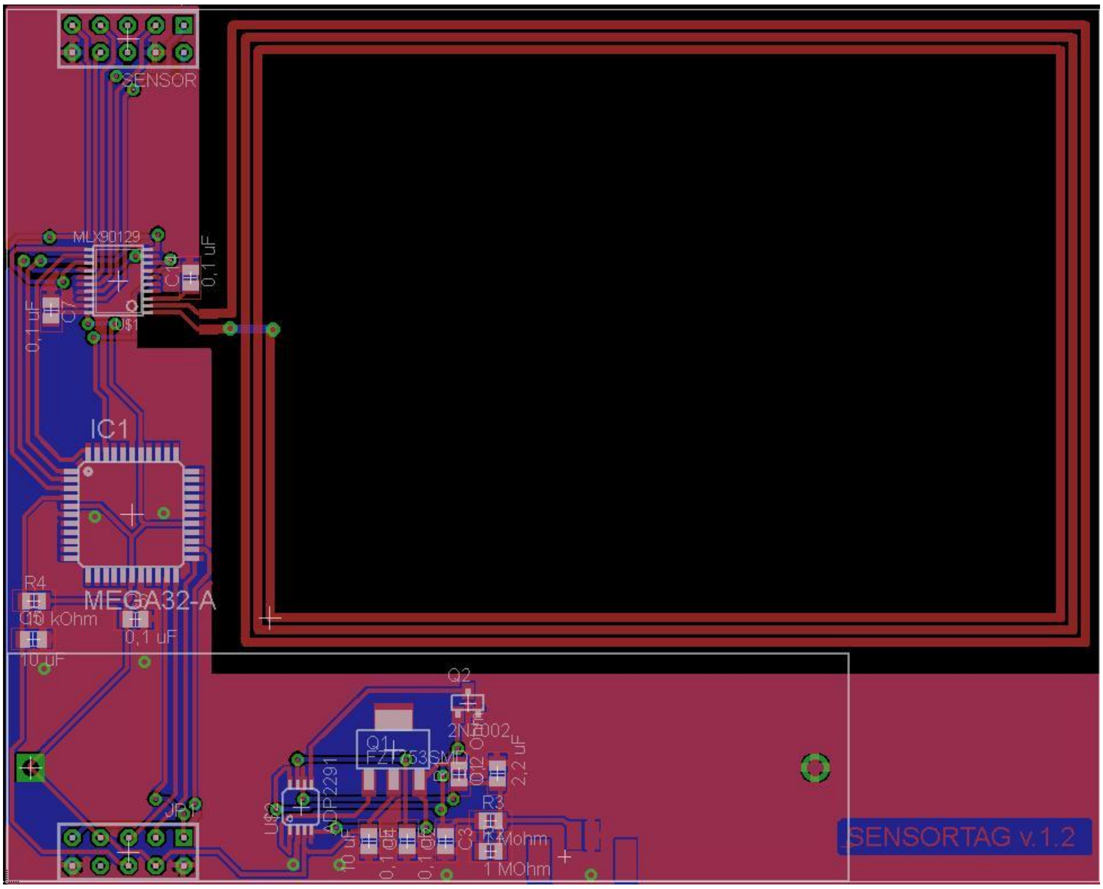


FIGURE 21. Layout of the sensor data collection unit.

A ground plan is left out from inside and behind the antenna, because of reasons given in Chapter 4.1. The signal wires are pulled directly and the same length to avoid interference. There are basically three different electronics areas in this layout which are:

- charger circuit connections

- MLX90129 connections

- ATmega32A connections

The assembled PCB's top layer is shown in the Figure 22 and the bottom layer in the Figure 23.

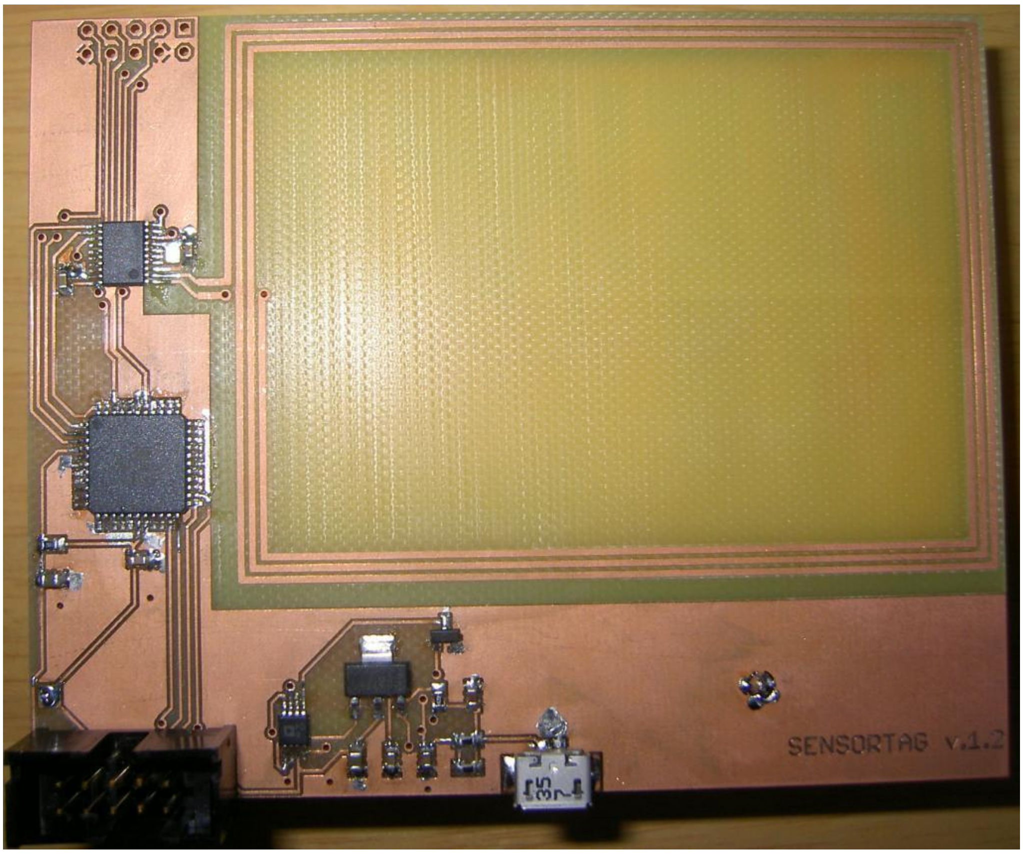


FIGURE 22. Top layer of the sensor data collection unit.

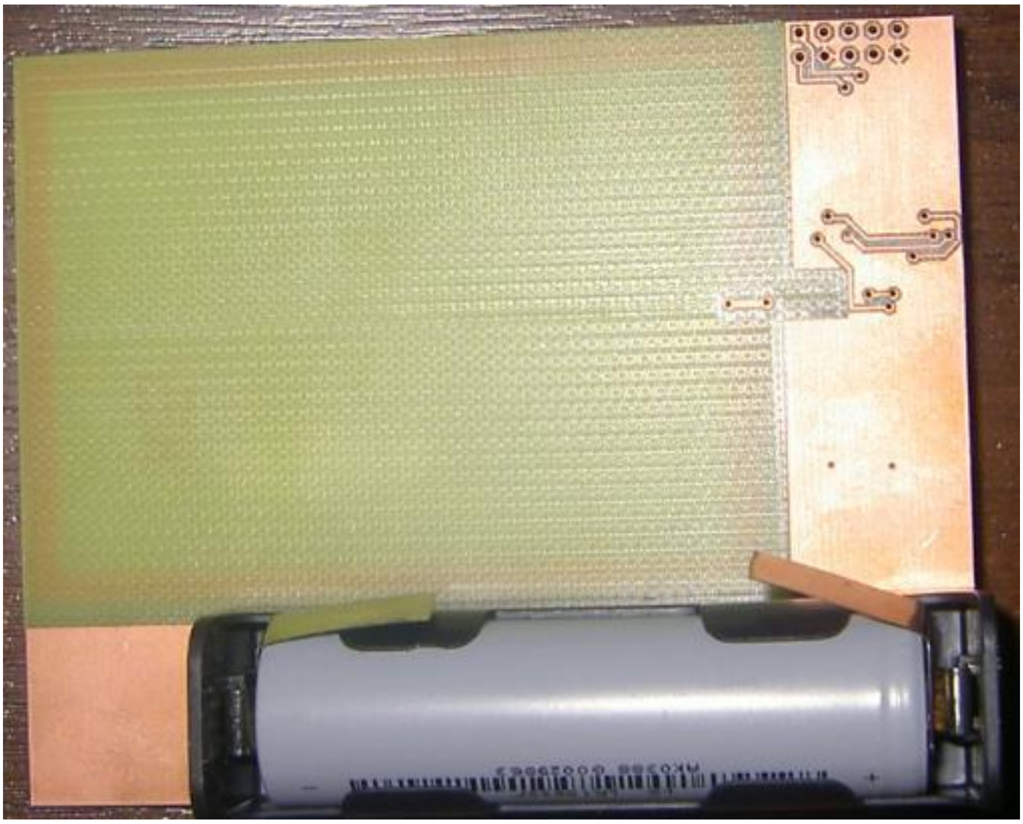


FIGURE 23. Bottom layer of the sensor data collection unit.

5 PROGRAMMING

At this point the sensor data collection unit was assembled and it was time to start the µC programming. Earlier in this project it was decided to use the AVR Studio 4 v.4.18 software with the C compiler Win AVR to write, assemble, compile and link source code in to the µC. This set forms integrated development environment for programming the AVR devices. The AVR studio is a freely distributed software from Atmel and it can be downloaded from Atmel’s web page. (21)

The source code was written in C language. C language is one of the most commonly used programming languages in embedded system programming, because it is portable between different µCs. (21)

The communication between MLX90129 and ATmega32A is over SPI, so the first thing was to ensure that this connection works. The code was written to write hex decimal value ABCD to the MLX90129 internal EEPROM address 0x11. A small piece of code example for a write routine:

```
void SPI_MLX90129_write(void)
{
  char write_command;
  char address;
  char data_MSB;
  char data_LSB;
// Write EEPROM at address 0x11 with data 0xABCD
  write_command=0x0E;
  address=0x11;
  data_MSB=0xAB;
  data_LSB=0xCD;
SS_L; // SS low selects the slave for the communication
  _delay_us(1500); // delay when tag IC is in sleep mode
  SPI_MasterTransmit(write_command);
  SPI_MasterTransmit(address);
  SPI_MasterTransmit(data_MSB);
  SPI_MasterTransmit(data_LSB);

  SS_H; //SS high deselects the slave

  _delay_ms(17); // delay to write EEPROM
}
```

Characters are described first in this code and then next character values are described in hex decimal. Then the write routine calls SPI_masterTransmit routine which sends data to the correct address. This code tells µC to write EEPROM at address 0x11 with data 0xABCD.

Once the code has been written and compiled, it must be transferred from PC's memory to the µC's program memory. Therefore, the programming device is needed. In this project the programming device that was used was Olimex AVR-USB-JTAG dongle for programming and debugging. The dongle was connected to the PC with a USB cable and other end of the dongle was connected to the device to be programmed with a JTAG connector. Connections is shown in the Figure 24.

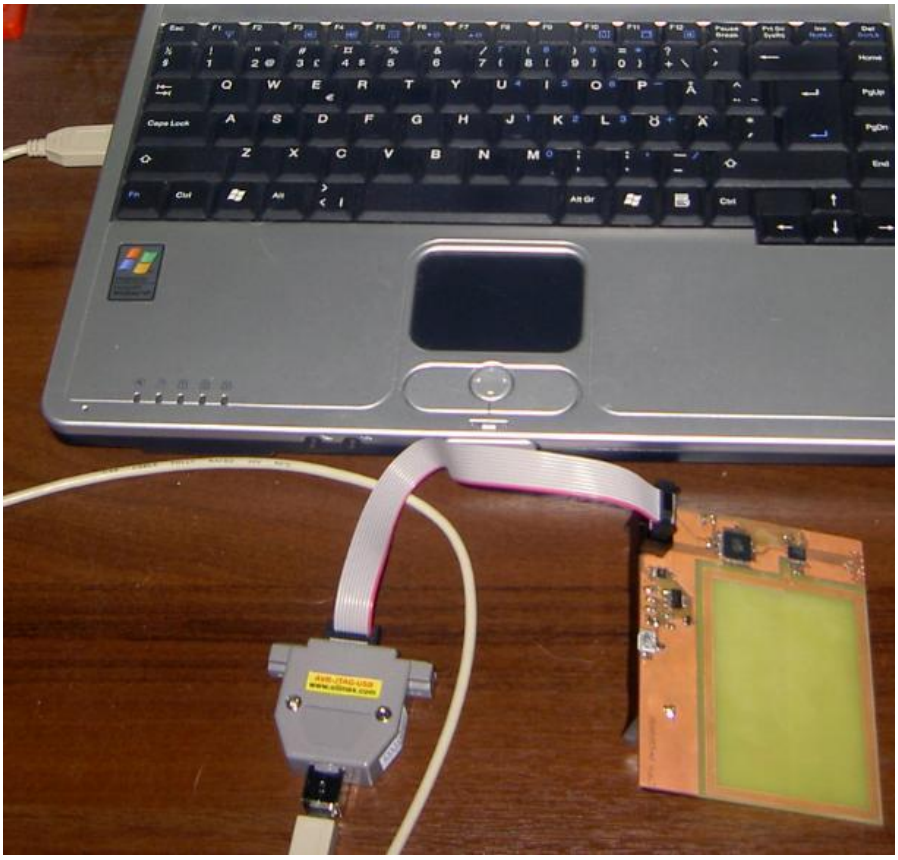


FIGURE 24. Programming/debugging connections.

In debugging mode the sensor tag IC's internal EEPROM memory can be read. In this way it can be ensured, that data 0xABCD went to address 0x11.

Code example for a read routine:

```
void SPI_MLX90129_read(void)
{
  char read_command;
  char address;
  char data_MSB;
  char data_LSB;

// Read Register at address 0x11
  read_command=0x0F;
  address=0x11;
  data_MSB=0xFF;
  data_LSB=0xFF;

  SS_L; // SS low selects the slave for the communication
  _delay_us(1500); // delay when MLXchip is in sleep mode

// send read command and targeted address
  SPI_MasterTransmit(read_command);
  SPI_MasterTransmit(address);
  _delay_us(50); // delay to read EEPROM

// send 0x00 (or other random data) to generate SPI clock
and get the slave answer
  data_MSB=SPI_MasterTransmit(0x00);
  data_LSB=SPI_MasterTransmit(0x00);

  SS_H; // SS high deselects the slave and end the commu-
  nication

}
```

Data transferred unconverted to the correct address. It was time to start MLX90129 configuration.

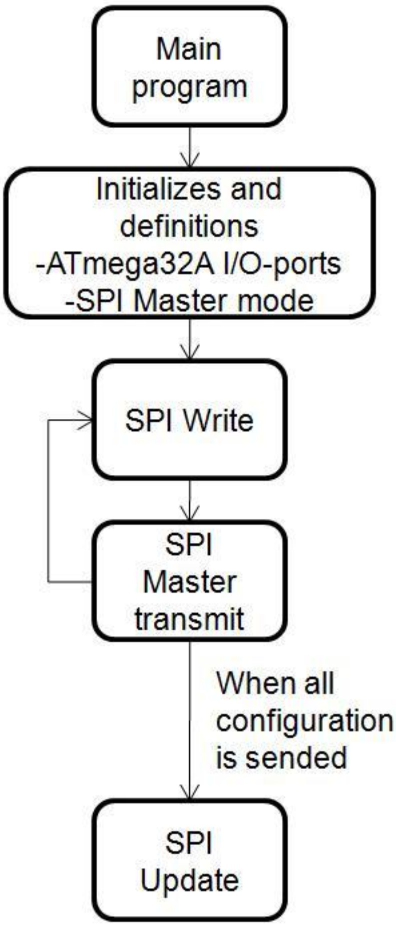


FIGURE 25. Block diagram of the source code.

SPI write routine contains all the sensor tag IC (MLX90129) EEPROM configurations. Configurations are written in internal EEPROM of the MLX90129 addresses 0x00 to 0x26. Some configurations are already done by the manufacturer so these addresses do not need to be touched. These addresses are 0x00 to 0x06 which contains identification and security options of the MLX90129. 0x12 and 0x14 contains sensor power configuration and sensor trimming which are set already as well.

The MLX90129 internal EEPROM addresses 0x09 to 0x0C is used to set DMA (Direct Memory Access) configurations. The DMA is a digital unit which manages datalogging. In this project the following configurations are set: sensor 0 which is internal temperature sensor is set to sensing sequence of the DMA, destination for collected sensor data is internal EEPROM of the

MLX90129. Sensor ADC buffer is source from which the data are collected in to EEPROM. The sensor values are stored to the internal EEPROM addresses 0x29 to 0xD7.

0x0D and 0x0E are SPI external memory configuration spaces. Bits are set to 0, because in this project the external EEPROM is not used.

The timer configurations space is on addresses 0x0F and 0x10. Bits are set so that the automatic logging mode is on. MLX90129 is in sleep mode and wakes up once in every hour when the internal sensor measures temperature, data goes in the ADC buffer where data is transferred to the EEPROM. After data is collected, MLX90129 goes back in the sleep mode.

Addresses 0x15 to 0x1A are space for the internal temperature sensor configuration. The sensor initialization time is set to 150 µs and the ADC mode to the slow mode, because it is the most accurate. The data collection interval is long, so the most accurate mode can be used and also data samples can be controlled. It can be adjusted so that the sensor data value is mean of 2, 8 or 32 samples or just single sample is taken. In this project single sample was set.

The SPI master transmit is a routine which sends data to the slave device. In a write routine the SPI master transmit routine will be called to make data transfer possible.

The SPI update routine updates EEPROM register files. All just sent configurations are set and saved.

The source code with comments can be found in the Appendix 2.

Figure 26 shows the entire sensor data collection unit operation. With the configuration explained earlier, 216 measurements can be saved to the internal EEPROM. The memory lasts 9 days with these settings, after that a DMA starts writing over the oldest measurement.

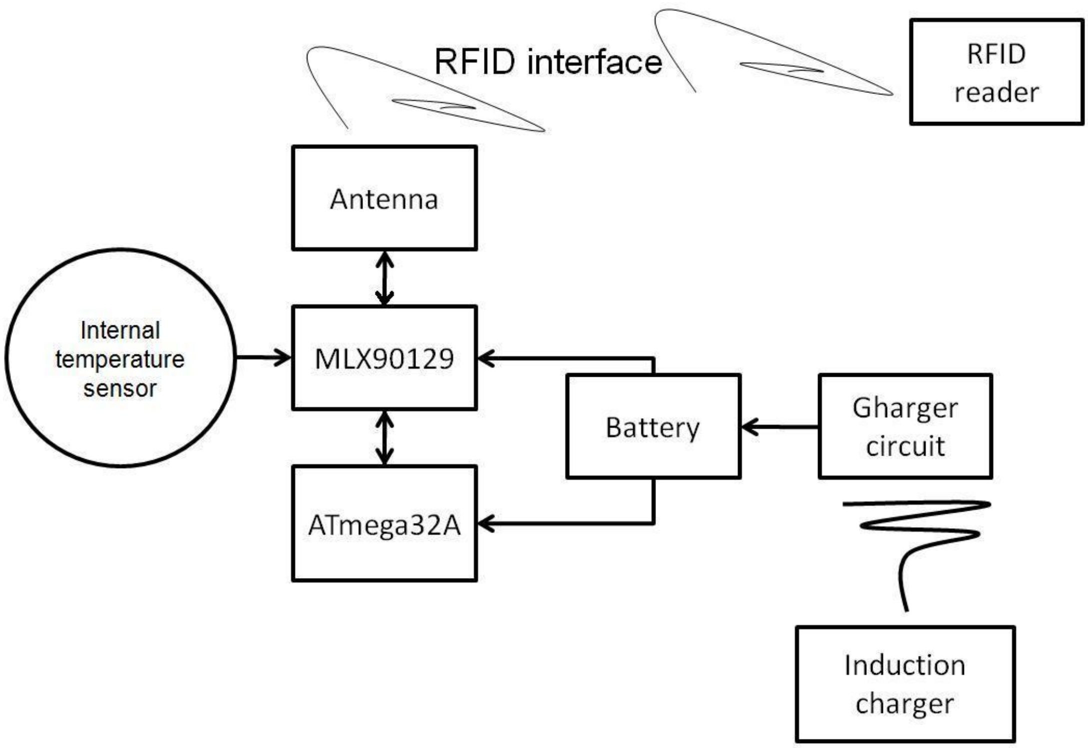


FIGURE 26. Operation of the sensor data collection unit.

The induction charger tag is connected to the board charger circuit with a micro USB connector. Power is induced to the tag from the induction charger board and induced power charges the Li-Ion battery.

The 3,6 V battery gives power to the ATmega32A µC and the MLX90129 sensor tag IC so that the system can operate. MLX90129 collects data from its own internal temperature sensor and sends collected data to the internal EEPROM.

Power from the RFID reader device induces electromagnetic induction between the board antenna coil and the reader antenna. ISO 15693 standard commands are used to read desired data from the sensor data collection unit board.

6 TESTING

Immediately after the board was assembled the charging circuit operation could be tested. 5 V supply voltage was fed in the charging circuit connector from the PSU (Power Supply) and the battery voltage was monitored with a DMM (Digital MultiMeter) from the battery terminal. Measurement connections is shown in the Figure 27.

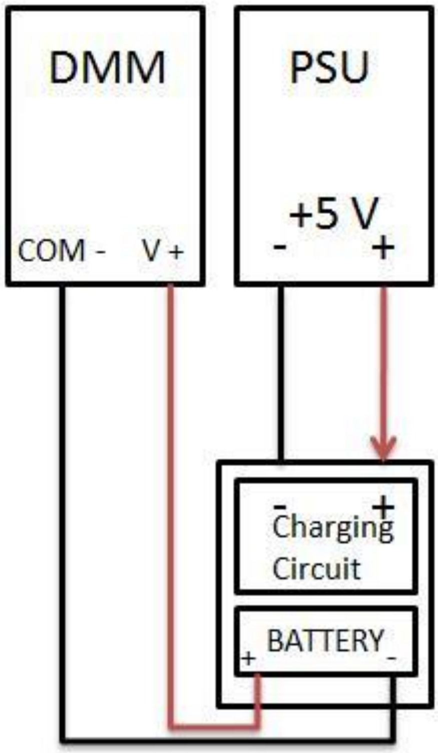
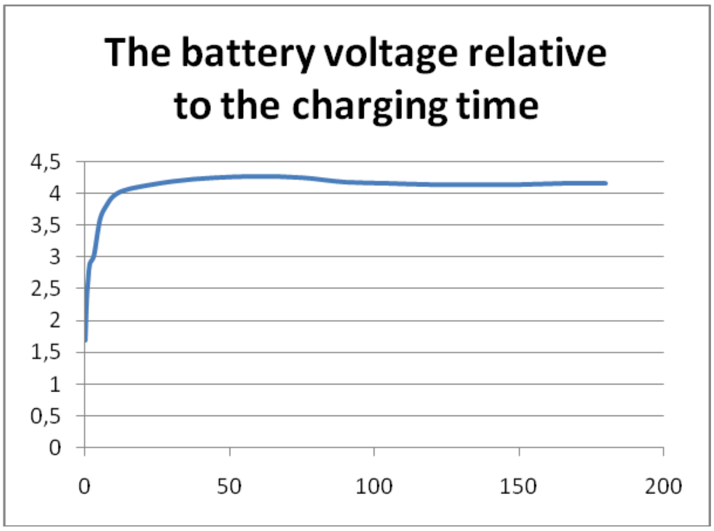


FIGURE 27. Measurement connections.

Cell voltage of the battery was 1,68 V when the charging was started. The battery was charged for 3 hours and 15 minutes and the battery voltage was monitored at specified time intervals. The voltage behaviour was as it should be so the charging circuit was working correctly. Table 7 shows the results of the measurements in different time intervals. After the battery was charged for 3 hours and 15 minutes the cell voltage of the battery was 4,1 V.

TABLE 7. Results of the battery voltage measurements.

Time (min)	Voltage (V)
0	1,68
0,5	2,34
1	2,65
1,5	2,88
3	3,02
5	3,57
7	3,78
10	3,96
15	4,06
30	4,18
45	4,24
60	4,26
75	4,24
90	4,17
105	4,15
120	4,13
135	4,13
150	4,13
165	4,15
180	4,15
195	4,1



Since in this project the AVR µC was used for programming the MLX90129 sensor tag IC, it was easy to examine the MLX90129 internal registers and configurations. Thereby ensuring that all bits are in the position where they supposed to be. The AVR studio software with a programming device also helped to understand the operation of the AVR µCs. Operational testing was performed in debugging mode by reading the EEPROM contents of the sensor tag IC. Debugging connections is shown in Chapter 5 (Figure 24).

All EEPROM addresses of the sensor tag IC were read in debugging mode after the configuration was done in the same way as presented in Chapter 5. Before the sensor tag IC was configured, all EEPROM register values which weren't configured by the manufacturer were 0xAAAA, so it was easy to follow when a new temperature value was come into the EEPROM register. Table 8 shows how to temperature value is read from the EEPROM register of the sensor tag IC in debugging mode by watching µCs general purpose register R24 from the AVR studio window.

TABLE 8. Changes in general purpose register R24.

0x00	Starting point, register is empty
0x10 0xB0 0x50	SPI configurations
0x01	SS_low selects the slave for the communication
0x0F	Read command for sensor tag IC
0xFF	Acknowledgement
0x29	Address to be read
0xFF	Acknowledgement
0x98 0xC3	Measured temperature value
0x10	SS_high deselects the slave and end the communication
0x00	Register is cleared

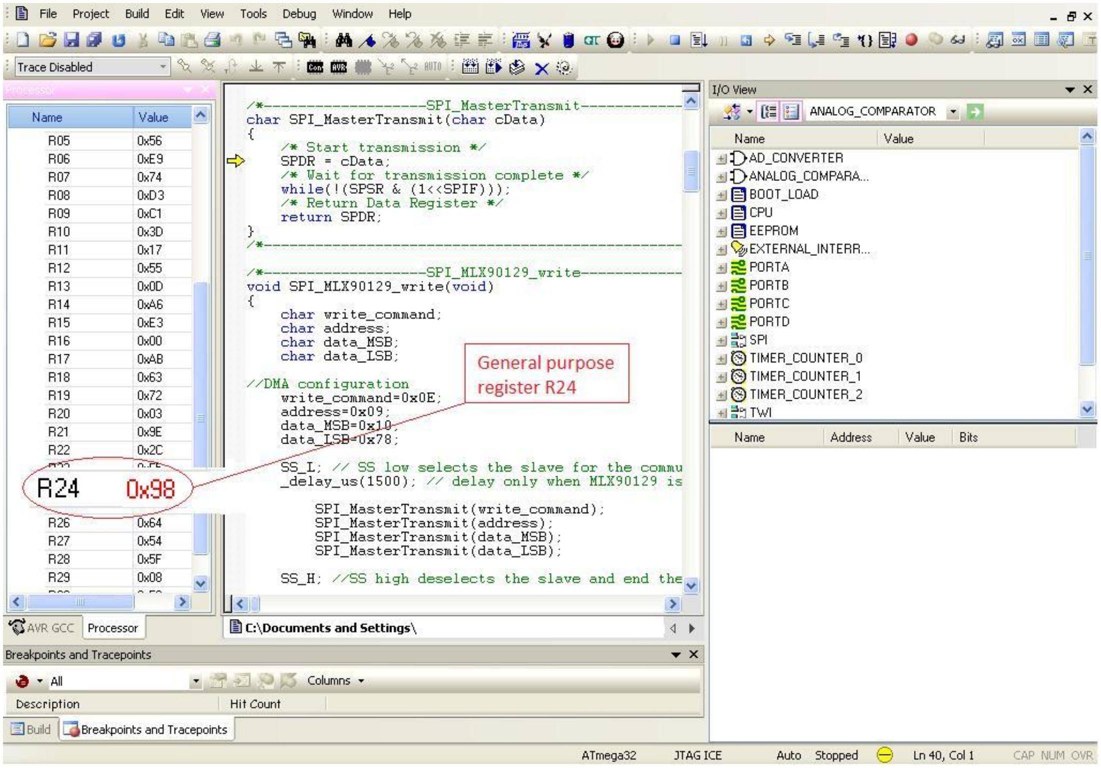


FIGURE 28. AVR Studio window in debugging mode.

In Figure 28 there is a print screen picture which shows where to watch the register changes and verify connection and the EEPROM contents. Programming of the sensor data collection unit was successful and the system worked as required.

The antenna was designed in the PCB using the Melexis AN3 MLX90129 antenna design document. The rectangular antenna design was used in the first version of the PCB. The rectangular antenna takes a lot of space from the PCB so it was decided to reduce the antenna size in the next version of the PCB. It was also decided to increase the memory space of the system by adding an external EEPROM, so if in the future more sensors would be added, there would be enough memory space. For example humidity and acceleration sensors might be added.

The final test was to ensure the functionality of the RFID interface. Testing was performed using the RFID reader. Data was successfully written in the sensor data collection unit and read from the sensor data collection unit. Test of RFID interface is shown in the Figure 29.

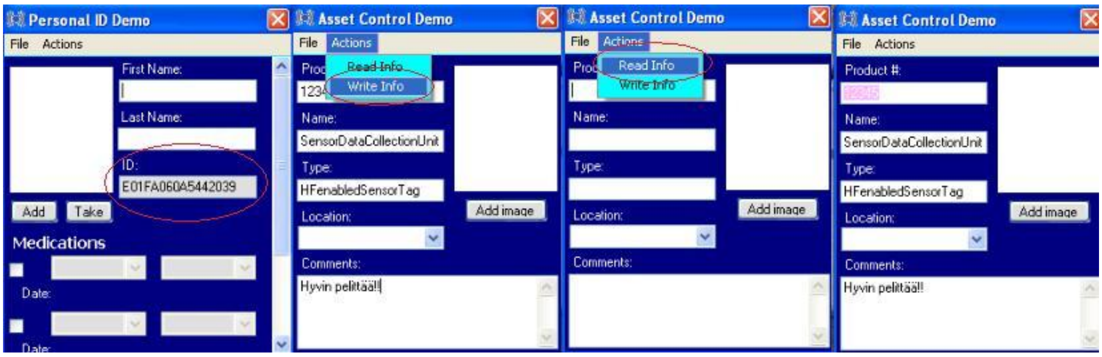


FIGURE 29. Test of RFID interface.

7 CONCLUSIONS AND DISCUSSION

The main objective of this project was to develop a working sensor data collection unit prototype using reasonably priced components. The physical size of the device was not a matter of importance as long as the device works. All sections were worked out as desired, so the main target that was set in the beginning was reached. Testing is explained in Chapter 6.

A few problems occurred as the project progressed: the first version of the PCB was rejected, because the antenna design went wrong. This was repaired by designing the antenna again, but some time was wasted while waiting for the new PCB to arrive. Another problem was the purchase of the induction product, because the company did not deliver the induction product to Finland. Fortunately, another similar product was found in Finland.

There are many opportunities for the further development of this device and one design was made in this project, but time was running out and the design was not implemented. This design is presented in this Chapter.

It was thought that if the temperature sensor and two external sensors would be enough, the µC could be left out of the design and configurations could be made through a RFID interface with the RFID reader using ISO 15693 RFID commands. On the other hand the µC offers many flexible applications. The µC manages the sensor data IC to sense, store or send data via RFID, but it may also control a RF transceiver and an external non-volatile memory or a LCD.

In this further development design the ATmega32A µC is replaced with AT25128B serial SPI EEPROM which is also developed by Atmel. AT25128B has 128 kbyte memory capacity and as many as 8192 data acquisitions can be stored from sensors. The rectangular antenna is replaced with a circular antenna. The circular antenna takes up less space from the PCB than the rectangular antenna.

The PCB dimensions was 100 mm x 80 mm and after changes the PCB surface area decreases significantly to dimensions of 77 mm x 22 mm. Schematic improvements are shown in the Figure 30 and the new layout design is shown in Figure 31.

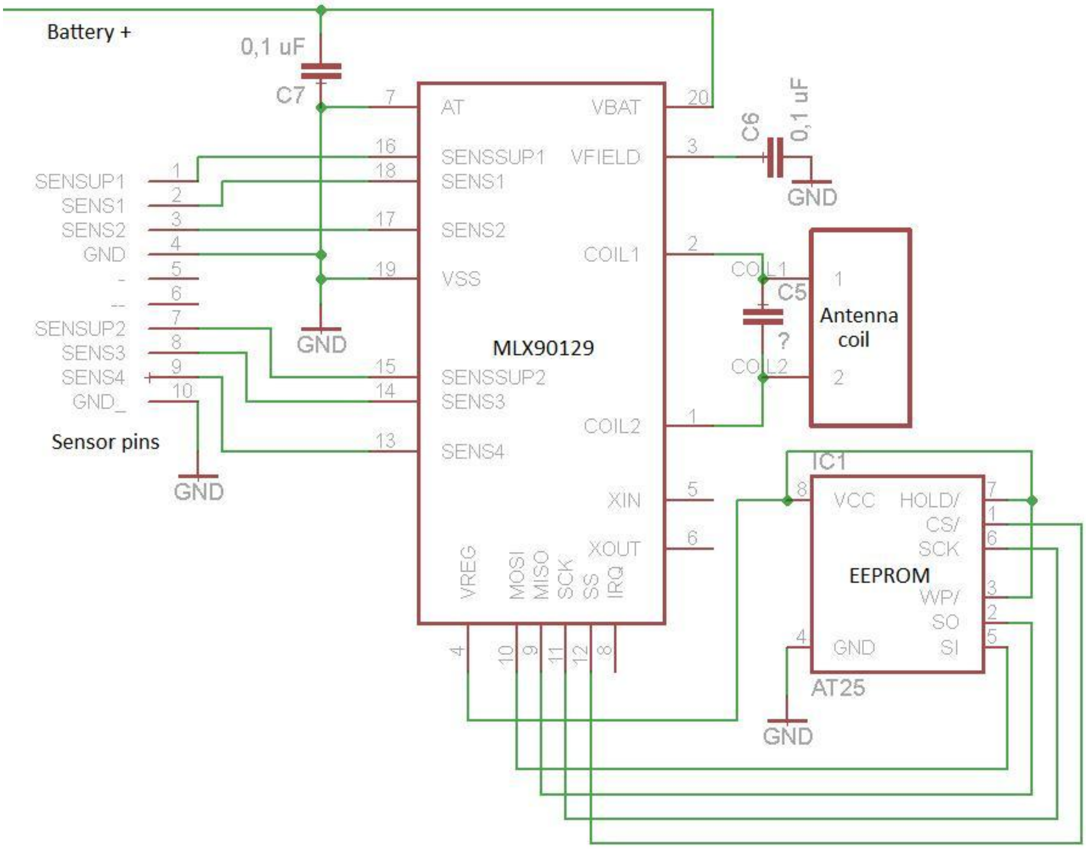


FIGURE 30. Further development of schematic design.

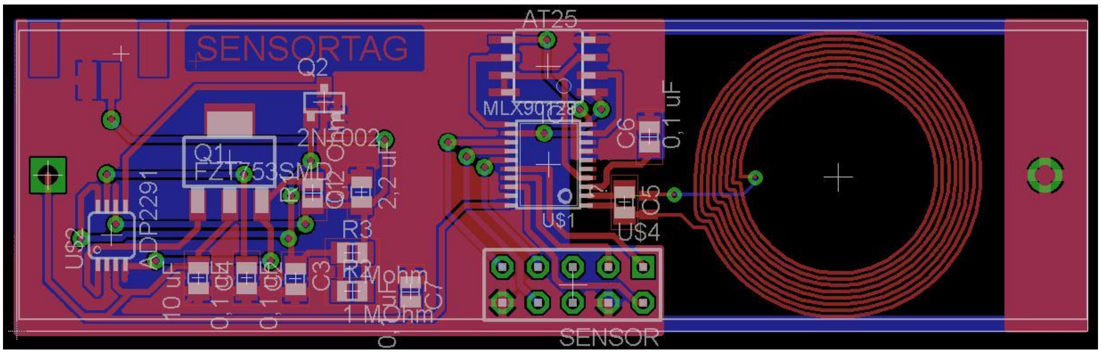


FIGURE 31. Further development of layout design.

This thesis project consisted of many different areas of design such as electronics design, PCB design and antenna design. Some testing and µC programming were also performed. Contents of the project was comprehensive enough and different design stages made working more interesting.

I am oriented in electronics design and testing, so this topic for a thesis was a good practise and it supported my studies well.

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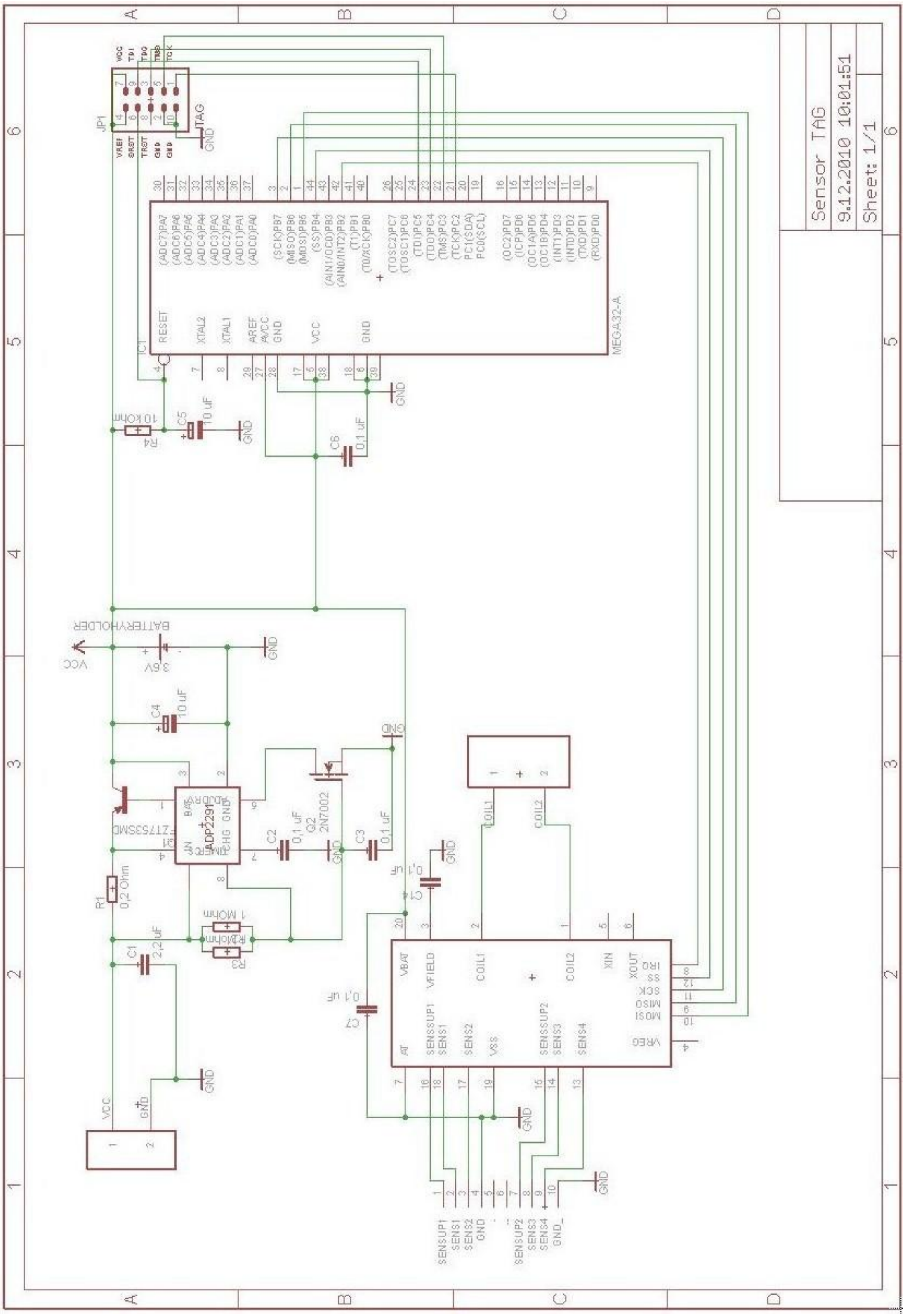
APPENDICES

Appendix 1. Schematic

Appendix 2. Source code

Appendix 3. Induction charger

SCHEMATIC APPENDIX 1



```
#include <avr/io.h>
#include <util/delay.h>

/*-------- SPI -------------
SS => PB4 => OUTPUT
MOSI => PB5 => OUTPUT
MISO => PB6 => INPUT
SCK => PB7 => OUTPUT
---------------------------- */
#define PORTSPI PORTB
#define SS PB4
#define MOSI PB5
#define MISO PB6
#define SCK PB7

#define SS_H PORTB=(1<<SS) // SS line with high level output
#define SS_L PORTB=(0<<SS) // SS line with low level output

#define DDR_SPI DDRB // set the pins of PORTB as Input or Output
#define DD_SS DDB4 // set the pin PB4 as Input or Output
#define DD_MOSI DDB5 // set the pin PB5 as Input or Output
#define DD_MISO DDB6 // set the pin PB6 as Input or Output
#define DD_SCK DDB7 // set the pin PB7 as Input or Output

/*--------------------SPI_MasterInit---------------------*/
void SPI_MasterInit(void)
{
		/* Set SS, MOSI and SCK output, MISO input */
		DDR_SPI = (1<<DD_MOSI)|(1<<DD_SCK)|(1<<DD_SS);
		/* Enable SPI, Master, set clock rate fck/2 = 0,5MHz */
		SPCR = (1<<SPE)|(1<<MSTR);
		SPSR = (1<<SPI2X);
}
/*-----------------------------------------------------*/

/*-------------------SPI_MasterTransmit------------------*/
char SPI_MasterTransmit(char cData)
{
		/* Start transmission */
		SPDR = cData;
		/* Wait for transmission complete */
		while(!(SPSR & (1<<SPIF)));
		/* Return Data Register */
 return SPDR;
}
/*-----------------------------------------------------*/
```

```
/*-------------------SPI_MLX90129_write------------------*/
void SPI_MLX90129_write(void)
{
		char write_command;
		char address;
		char data_MSB;
		char data_LSB;

//DMA configuration
		write_command=0x0E;
		address=0x09;
		data_MSB=0x10;
		data_LSB=0x70;

		SS_L; // SS low selects the slave for the communication
		_delay_us(1500); // delay only when MLX90129 is in sleep mode

			SPI_MasterTransmit(write_command);
			SPI_MasterTransmit(address);
			SPI_MasterTransmit(data_MSB);
			SPI_MasterTransmit(data_LSB);

		SS_H; //SS high deselects the slave and end the communication

		_delay_ms(17); // delay to write EEPROM


//DMA source start address
		write_command=0x0E;
		address=0x0A;
		data_MSB=0x00;
		data_LSB=0x00;

		SS_L; // SS low selects the slave for the communication
		_delay_us(1500); // delay only when MLX90129 is in sleep mode

			SPI_MasterTransmit(write_command);
			SPI_MasterTransmit(address);
			SPI_MasterTransmit(data_MSB);
			SPI_MasterTransmit(data_LSB);

		SS_H; //SS high deselects the slave and end the communication

		_delay_ms(17); // delay to write EEPROM
```

```
//DMA destination start address
          write_command=0x0E;
          address=0x0B;
          data_MSB=0x00;
          data_LSB=0x29;

          SS_L; // SS low selects the slave for the communication
          _delay_us(1500); // delay only when MLX90129 is in sleep mode

                    SPI_MasterTransmit(write_command);
                    SPI_MasterTransmit(address);
                    SPI_MasterTransmit(data_MSB);
                    SPI_MasterTransmit(data_LSB);

          SS_H; //SS high deselects the slave and end the communication

          _delay_ms(17); // delay to write EEPROM

//DMA processing lenght
          write_command=0x0E;
          address=0x0C;
          data_MSB=0x00;
          data_LSB=0xD7;

          SS_L; // SS low selects the slave for the communication
          _delay_us(1500); // delay only when MLX90129 is in sleep mode

                    SPI_MasterTransmit(write_command);
                    SPI_MasterTransmit(address);
                    SPI_MasterTransmit(data_MSB);
                    SPI_MasterTransmit(data_LSB);

          SS_H; //SS high deselects the slave and end the communication

          _delay_ms(17); // delay to write EEPROM
```

```
//SPI-master configuration
          write_command=0x0E;
          address=0x0D;
          data_MSB=0x00;
          data_LSB=0x00;


          SS_L; // SS low selects the slave for the communication
          _delay_us(1500); // delay only when MLX90129 is in sleep mode

                    SPI_MasterTransmit(write_command);
                    SPI_MasterTransmit(address);
                    SPI_MasterTransmit(data_MSB);
                    SPI_MasterTransmit(data_LSB);

          SS_H; //SS high deselects the slave and end the communication

          _delay_ms(17); // delay to write EEPROM

//SPI-master commands codes
          write_command=0x0E;
          address=0x0E;
          data_MSB=0x00;
          data_LSB=0x00;


          SS_L; // SS low selects the slave for the communication
          _delay_us(1500); // delay only when MLX90129 is in sleep mode

                    SPI_MasterTransmit(write_command);
                    SPI_MasterTransmit(address);
                    SPI_MasterTransmit(data_MSB);
                    SPI_MasterTransmit(data_LSB);

          SS_H; //SS high deselects the slave and end the communication

          _delay_ms(17); // delay to write EEPROM

//Timer period
          write_command=0x0E;
          address=0x0F;
          data_MSB=0x00;
          data_LSB=0x01;

          SS_L; // SS low selects the slave for the communication
          _delay_us(1500); // delay only when MLX90129 is in sleep mode
```

```
            SPI_MasterTransmit(write_command);
            SPI_MasterTransmit(address);
            SPI_MasterTransmit(data_MSB);
            SPI_MasterTransmit(data_LSB);

        SS_H; //SS high deselects the slave and end the communication

        _delay_ms(17); // delay to write EEPROM

//Timer configuration
        write_command=0x0E;
        address=0x10;
        data_MSB=0x00;
        data_LSB=0x3C;

        SS_L; // SS low selects the slave for the communication
        _delay_us(1500); // delay only when MLX90129 is in sleep mode

            SPI_MasterTransmit(write_command);
            SPI_MasterTransmit(address);
            SPI_MasterTransmit(data_MSB);
            SPI_MasterTransmit(data_LSB);

        SS_H; //SS high deselects the slave and end the communication

        _delay_ms(17); // delay to write EEPROM

//Sensor trimming
        write_command=0x0E;
        address=0x14;
        data_MSB=0x00;
        data_LSB=0x01;

        SS_L; // SS low selects the slave for the communication
        _delay_us(1500); // delay only when MLX90129 is in sleep mode

            SPI_MasterTransmit(write_command);
            SPI_MasterTransmit(address);
            SPI_MasterTransmit(data_MSB);
            SPI_MasterTransmit(data_LSB);

        SS_H; //SS high deselects the slave and end the communication

        _delay_ms(17); // delay to write EEPROM
```

```
//Sensor 0 control word
        write_command=0x0E;
        address=0x15;
        data_MSB=0xC0;
        data_LSB=0x70;

        SS_L; // SS low selects the slave for the communication
        _delay_us(1500); // delay only when MLX90129 is in sleep mode

                SPI_MasterTransmit(write_command);
                SPI_MasterTransmit(address);
                SPI_MasterTransmit(data_MSB);
                SPI_MasterTransmit(data_LSB);

        SS_H; //SS high deselects the slave and end the communication

        _delay_ms(17); // delay to write EEPROM

//Sensor 0 low treshold
        write_command=0x0E;
        address=0x16;
        data_MSB=0x00;
        data_LSB=0x00;

        SS_L; // SS low selects the slave for the communication
        _delay_us(1500); // delay only when MLX90129 is in sleep mode

                SPI_MasterTransmit(write_command);
                SPI_MasterTransmit(address);
                SPI_MasterTransmit(data_MSB);
                SPI_MasterTransmit(data_LSB);

        SS_H; //SS high deselects the slave and end the communication

        _delay_ms(17); // delay to write EEPROM

//Sensor 0 high treshold
        write_command=0x0E;
        address=0x17;
        data_MSB=0x00;
        data_LSB=0x00;

        SS_L; // SS low selects the slave for the communication
        _delay_us(1500); // delay only when MLX90129 is in sleep mode

                SPI_MasterTransmit(write_command);
```

```
                SPI_MasterTransmit(address);
                SPI_MasterTransmit(data_MSB);
                SPI_MasterTransmit(data_LSB);

        SS_H; //SS high deselects the slave and end the communication

        _delay_ms(17); // delay to write EEPROM

//Sensor 0 conditionner config
        write_command=0x0E;
        address=0x18;
        data_MSB=0x00;
        data_LSB=0x00;

        SS_L; // SS low selects the slave for the communication
        _delay_us(1500); // delay only when MLX90129 is in sleep mode

                SPI_MasterTransmit(write_command);
                SPI_MasterTransmit(address);
                SPI_MasterTransmit(data_MSB);
                SPI_MasterTransmit(data_LSB);

        SS_H; //SS high deselects the slave and end the communication

        _delay_ms(17); // delay to write EEPROM
//Sensor 0 connection configuration
        write_command=0x0E;
        address=0x19;
        data_MSB=0x02;
        data_LSB=0x10;

        SS_L; // SS low selects the slave for the communication
        _delay_us(1500); // delay only when MLX90129 is in sleep mode

                SPI_MasterTransmit(write_command);
                SPI_MasterTransmit(address);
                SPI_MasterTransmit(data_MSB);
                SPI_MasterTransmit(data_LSB);

        SS_H; //SS high deselects the slave and end the communication

        _delay_ms(17); // delay to write EEPROM
```

```
//Sensor 0 resistance network
        write_command=0x0E;
        address=0x1A;
        data_MSB=0x80;
        data_LSB=0x00;

        SS_L; // SS low selects the slave for the communication
        _delay_us(1500); // delay only when MLX90129 is in sleep mode

                SPI_MasterTransmit(write_command);
                SPI_MasterTransmit(address);
                SPI_MasterTransmit(data_MSB);
                SPI_MasterTransmit(data_LSB);

        SS_H; //SS high deselects the slave and end the communication

        _delay_ms(17); // delay to write EEPROM

}


/*-------------------SPI_MLX90129_read-------------------*/
void SPI_MLX90129_read(void)
{
        char read_command;
        char address;
        char data_MSB;
        char data_LSB;

        // Read Register at address
        read_command=0x0F;
        address=0x29;
        data_MSB=0xFF;
        data_LSB=0xFF;

        SS_L; // SS low selects the slave for the communication
        _delay_us(1500); // delay only when MLX90129 is in sleep mode
                // send read command and targeted address
                SPI_MasterTransmit(read_command);
                SPI_MasterTransmit(address);

                _delay_us(50); // delay to read EEPROM

                //send 0x00 (or other random data) to generate SPI
                clock
                // and get the slave answer
```

```
			data_MSB=SPI_MasterTransmit(0x00);
			data_LSB=SPI_MasterTransmit(0x00);

		SS_H; // SS high deselects the slave and end the communication


}

/*------------------SPI_MLX90129_update------------------*/
void SPI_MLX90129_update(void)
{
		char update_command;

		// Update command =0x1C
		update_command=0x1C;

		SS_L; // SS low selects the slave for the communication

		// send the update command
		SPI_MasterTransmit(update_command);

		SS_H; // SS high deselects the slave and end the communication

		_delay_us(1500); // delay for the update of the registers

}

/*---------------------Main program---------------------*/

int main ( void )
{
		SS_H;
		SPI_MasterInit();

			SPI_MLX90129_write();  // write MLX90129 config
			SPI_MLX90129_update(); // update register file
			/*SPI_MLX90129_read();   // read register values*/

return(0);
```

PowerKiss

Wire-free charging for today's mobile customers!

PowerKiss – Why

In airports, hotels, restaurants, cafes, lobbies and many other public places people are on the move. While on the move they are quickly running down the batteries on their portable devices. When they run out, that device stops being a convenience and becomes just another thing to carry. Finding a place to recharge that device becomes paramount and a challenge.

PowerKiss – What

This is where PowerKiss comes in. PowerKiss provides and integrated wire-free charging solution that can be installed in a wide variety of tables, desks, and stands. This wireless charging solution allows customers to charge their portable devices without the their battery charger or a near by power socket.

PowerKiss – How

To turn a surface into a wire-free charging platform it first needs to be given a Heart. Like most, this Heart is also hidden except for a small LED light to indicate that it is ready to charge a mobile device wearing a Ring.

Simply plug a Ring receiver into the device and place it on the marked spot and it begins charging. No need for cables or hunting for an available power socket.

PowerKiss – Where

PowerKiss wire-free charging platforms are valuable in any place where people are taking a pause in their busy schedules to recharge themselves and their mobile devices.

PowerKiss – Facts

- PowerKiss Hearts can be integrated into both new and existing furniture
- PowerKiss suits most surface types
- PowerKiss works with both furniture manufacturers and service providers
- PowerKiss Hearts are intelligent. No charging will occur until it senses the ring
- PowerKiss supports many mobile types
- PowerKiss conforms to European safety standards

Specifications:

The Heart	
Dimensions (LxWxH)	163mm x 132mm 24mm
Max power consumption	12W charging, 240 mW standby
Charging spot	diameter 6 cm
Number of rings supported	2 rings per Heart

The PowerKiss Heart

The Ring	
Dimensions (LxWxH)	45mm x 34mm x 7.5mm
Colour	black, white, custom
Connections	Nokia 2.0mm, microUSB, iPhone*

**available Q3 2010*

Nokia 2.0 mm receiver

How to charge your phone with PowerKiss:

Step 1: Plug the Ring into your mobile phone

Step 2: Place your phone on a PowerKiss charging hotspot

Step 3: Sit back and let PowerKiss charge your device

PowerKiss- Who

PowerKiss was established in 2008 and is located in Espoo, Finland. PowerKiss stands for wire-free charging technology and is a leader in charging through inductive coupling for mobile devices.

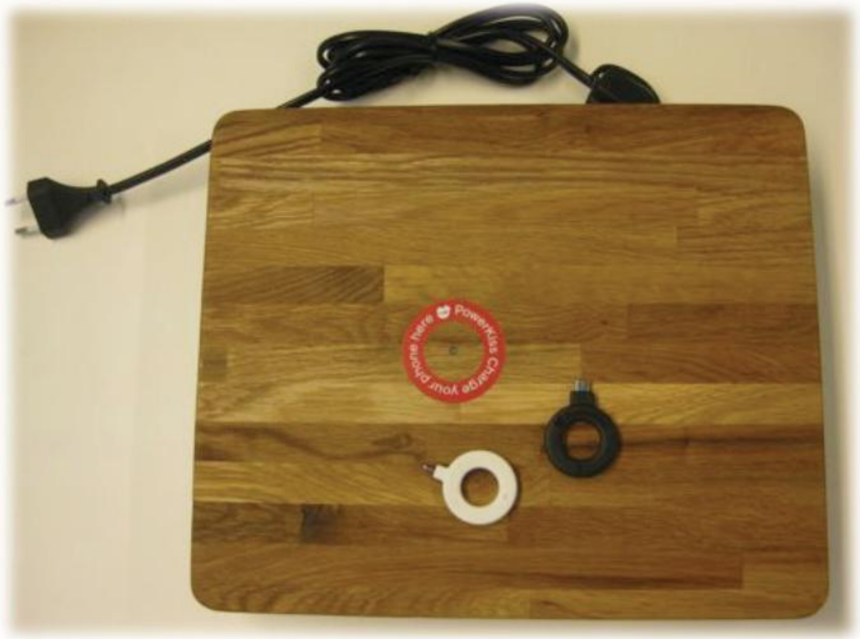
MicroUSB receiver

www.powerkiss.com

Betonimiehenkuja 5, 02150 Espoo. FINLAND

PowerKiss

Demonstration kit
Price: **EUR 400***



Contents:

1 Heart	Attached to mini-table	Power cable included
3 Rings	2 microUSB	
	1 Nokia 2.0mm	

How to demo:

1) Plug in table and wait for light to turn white
2) Plug the Ring into the handset needed to be charged
3) Place the phone and Ring on the spot marked on the table
4) When the light turns red the phone is charging
5) Remove phone and wait for light to turn white again
6) When light turns white the Heart is ready to charge another device

*Price of 1 demo kit can be discounted from first order of 20 Hearts

www.powerkiss.com