Low-Cost Wireless Sensors

Designer Reference Manual

RS08
Microcontrollers

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Low-Cost Wireless Sensors

Designer Reference Manual

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The following revision history table summarizes changes contained in this document. For your convenience, the page number designators have been linked to the appropriate location.

Revision History

Date	Revision Level	Description	Page Number(s)
06/2007	0	Initial release	146

Contents

Chapter 1
Introduction

1.1 Application Functionality

The Low-Cost Wireless Sensors using a MC9RS08KA2 reference design provides a solution for interfacing different sensor modules, via radio frequency (RF) to a base station which is connected to a computer. The output of the different sensor modules is monitored by a graphical user interface (GUI).

Every module contains a Tango RF transmitter (MC33943) and a RS08 family 8-bit ultra low-cost microcontroller unit (MCU) (6-pin MC9RS08KA2). The pressure and acceleration applications have also an accelerometer sensor (MMA6261Q) and a pressure sensor (MPXM2102G).

This reference design demonstrates that Freescale's cost-effective solution enables to implement a diverse sensor network. A multi-faceted sensor network can be implemented by using only an MCU, sensors, and RF products.

1.2 Low-Cost Wireless Sensors Using a MC9RS08KA2 Reference Design Benefits

The benefits are:

- Only one pin of the MC9RS98KA2 transmits the data, enables transmission and the powering on the accelerometer and the pressure sensor.
- Low cost due to the price of most components.
- Low power consumption by disabling the Tango when not transmitting. Accelerometer and pressure sensors are also disabled during non-transmission times.
- Safeguards information sent by the Tango with encryption.
- Five sensor modules: acceleration, lighting, pressure, temperature, ultrasound and push-button.
- Real time measures presented in an intuitive GUI.
- The push-button module can be used as a remote control.
- The ultrasound module board size is 1.75 in x 1.8 in.
- The rest of the board size is 1.014 in x 1.8 in.
- The range is up to 15 m.

Chapter 2
Quick Start

2.1 Introduction

This section describes how to set up and start the Low-Cost Wireless Sensors (LCWi) demo boards. The reference design shows the basic and advanced functionalities of the LCWi.

2.2 System Requirements

The application software is in the MCUs flash memory, if necessary the original software is located at www.freescale.com.

To interface the Romeo with the computer, a serial cable is needed. And the power supply voltage required is 9 V. Use HyperTerminal or the GUI supplied with this DRM to see the data transmitted by the LCWi boads.

The power supply voltage required by the Tango is 3 V.

The LCWi transmitters can operate on a CR 1/3N 3 V Lithium cell, or be powered by the background debugging mode (BDM) connector.

2.3 Low-Cost Wireless Sensors Setup

The LCWi requires minimal set up. The modules are distributed with the application in flash memory and all jumpers in default position. Table 2-1 describes the jumpers default position.

Table 2-1. Function and Default Positions for Module Jumpers

Jumper	Default position	Function
J2	Not connected	Connected: data/enable circuit closed. Allows transmission of data and enables transmission for the Tango. Not connected: data/enable circuit open. Used for debugging. Can program board without applying voltage to the data pin of the Tango.
J3	Connected	Connected: enables the use of the pushbutton if available on the board. Not connected: disables the pushbutton to avoid shorts to ground during programming. See note.
J4	Soldered	Functions as a permanent connection for the data/enable circuit of the Tango. Can be placed after final debugging, replacing J2.

NOTE

The pressure module does not include a pushbutton and therefore J3 is not in the board.

Table 2-2 describes the positions and functions of the jumpers for the ultrasound module.

Table 2-2. Function and Default Positions for Module Jumpers in Ultrasound Module

Jumper	Default position	Function
J2	Not connected	Connected: data/enable circuit closed. Allows transmission of data and enables transmission for the Tango. Not connected: data/enable circuit open. Used for debugging. Can program board without applying voltage to the data pin of the Tango.
J3	Connected	Functions as a permament connection for the data/enable circuit of the Tango. Can be placed after final debugging, replacing J2.

Figure 2-1 through Figure 2-5 show the pictures of the LCWi boards that showcase the most important parts of the modules.

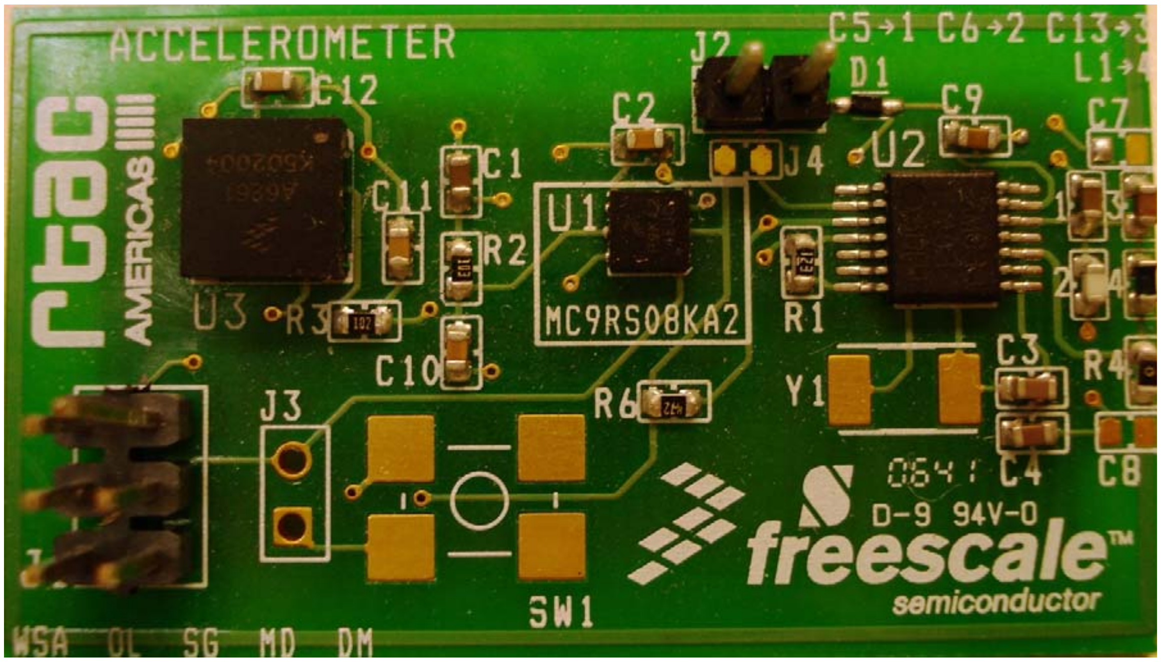


Figure 2-1. Low-cost Wireless Sensors Using a MC9RS08KA2 Board Acceleration Module (Front)

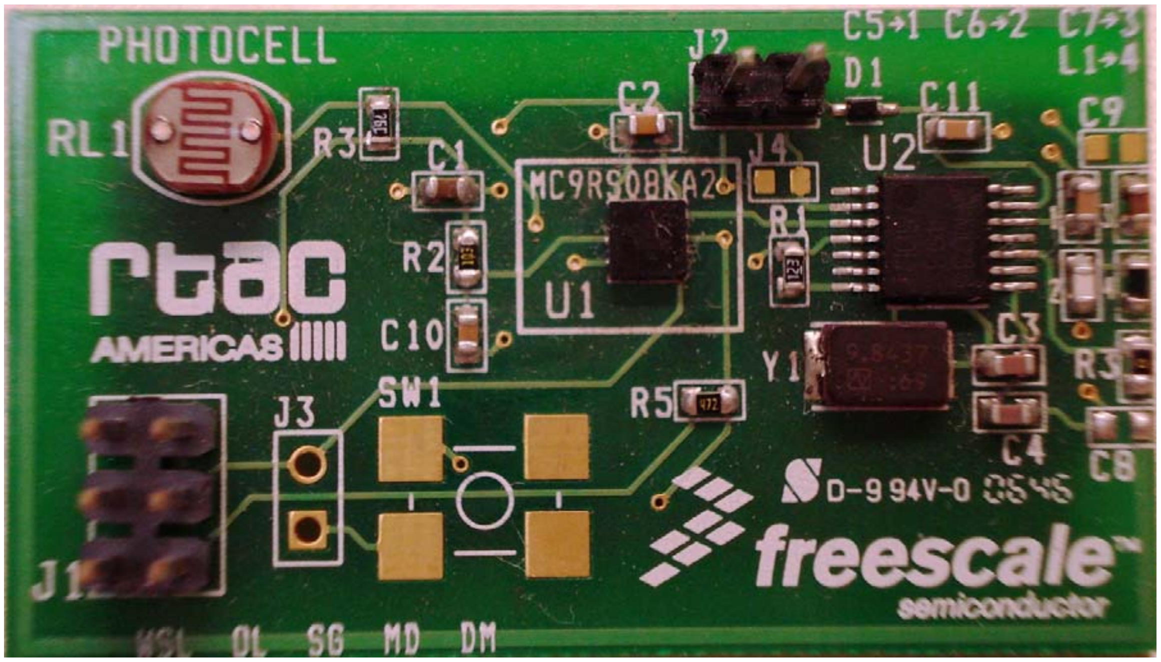


Figure 2-2. Low-cost Wireless Sensors Using a MC9RS08KA2 Board Lighting Module (Front)

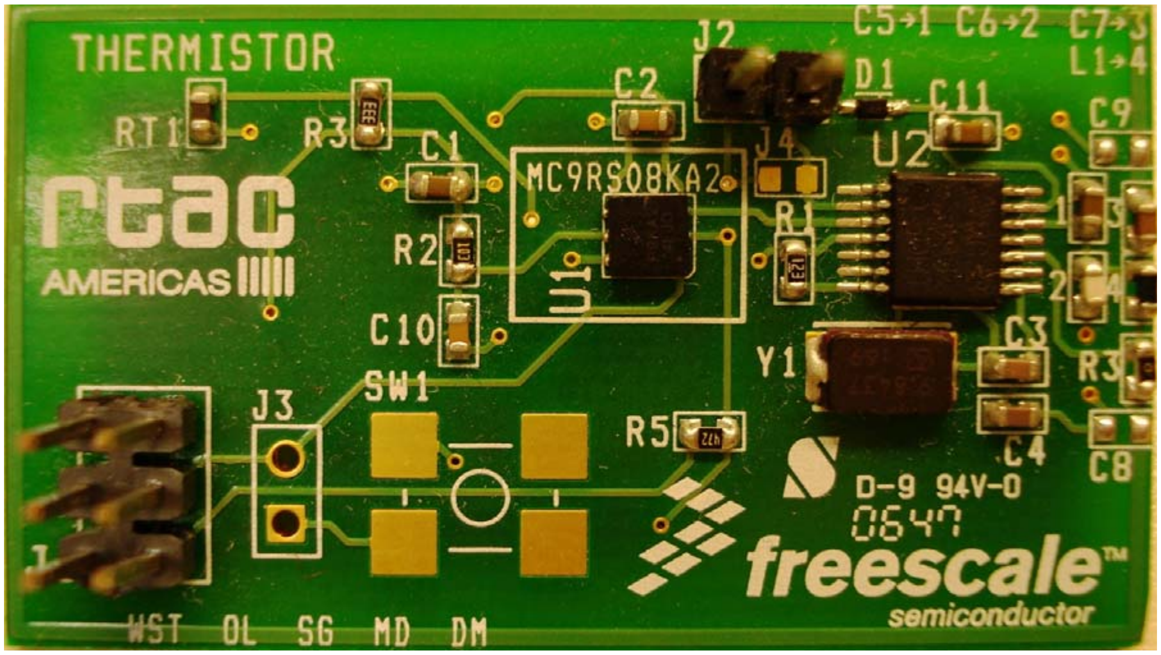


Figure 2-3. Low-cost Wireless Sensors Using a MC9RS08KA2 Board Temperature Module (Front)

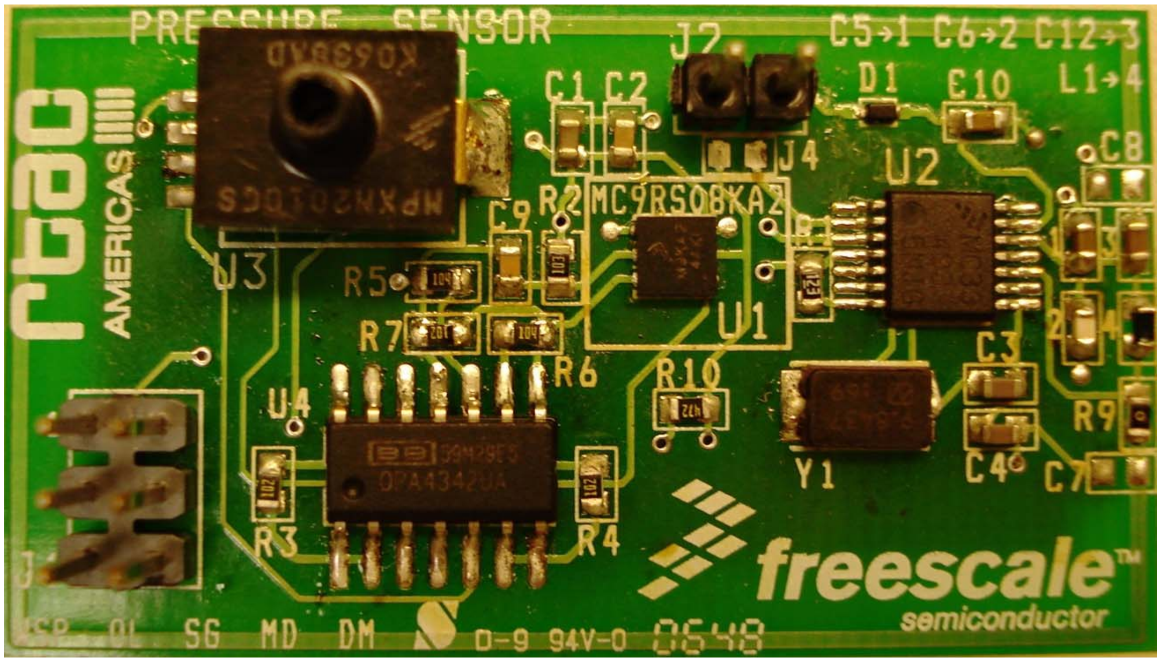


Figure 2-4. Low-cost Wireless Sensors Using a MC9RS08KA2 Board Pressure Module (Front)

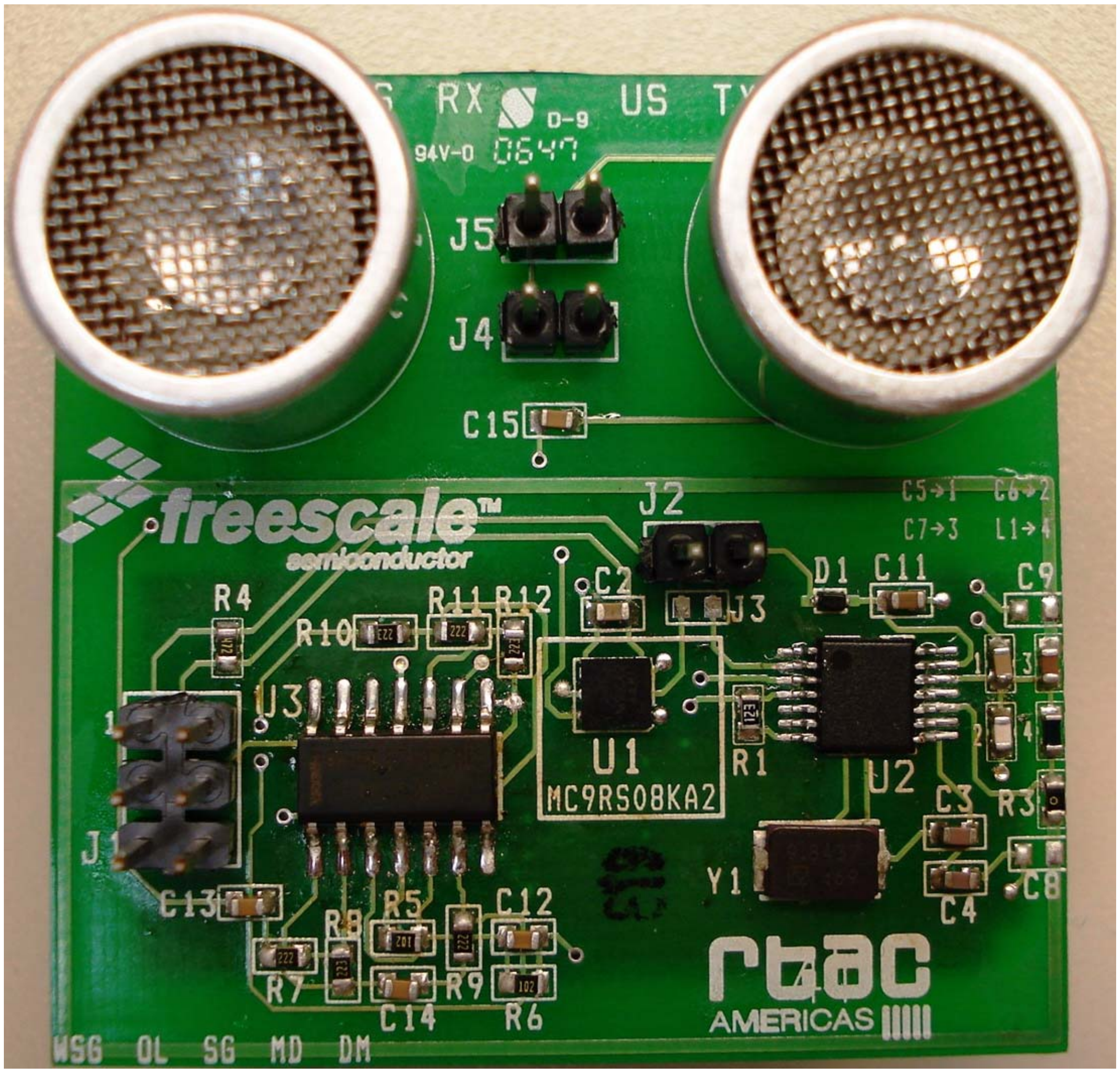


Figure 2-5. Low-cost Wireless Sensors Using a MC9RS08KA2 Board Ultrasonic Module (Front)

The following steps are required to run the LCWi demo:

1. Connect the whip antenna to the Romeo board.
2. Connect the Romeo board to the AP64 demo board.
3. Plug the serial cable into the computer and to the AP64 board.
4. Ensure all module jumpers are in default position as described in Table 2-1 and Table 2-2.
5. Insert the CR 1/3N 3 V battery into its holder.

Chapter 3 Hardware Description

3.1 Introduction

This section describes the module electrical design, its features, and the advantages of using modular architecture.

Figure 3-1 through Figure 3-5 show the basic block diagrams of each module of the reference design. The main block is based on the MC33493 transmitter and the MC9RS08KA2 MCU.

Each module contains the required circuitry to support its application. Two modules use freescale analog products: the acceleration module (MMA6260Q) and the pressure module (MPXM2010GS).

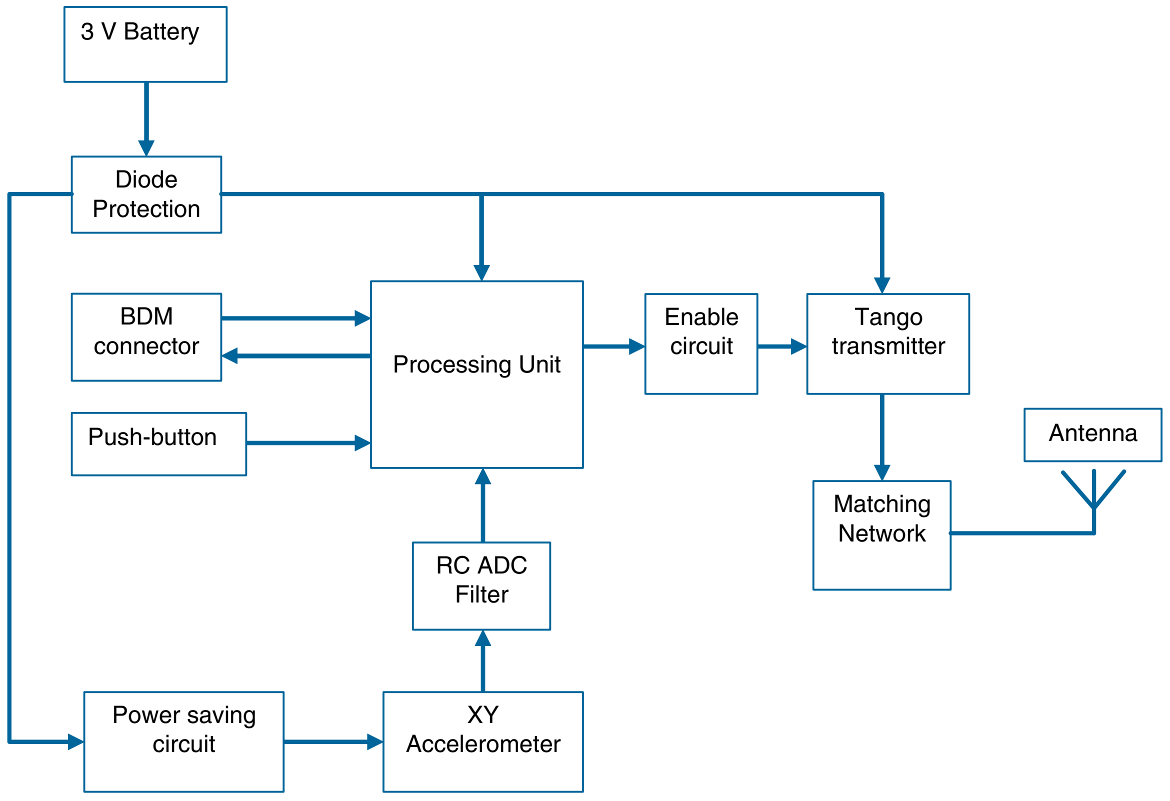


Figure 3-1. Acceleration Module Building Block

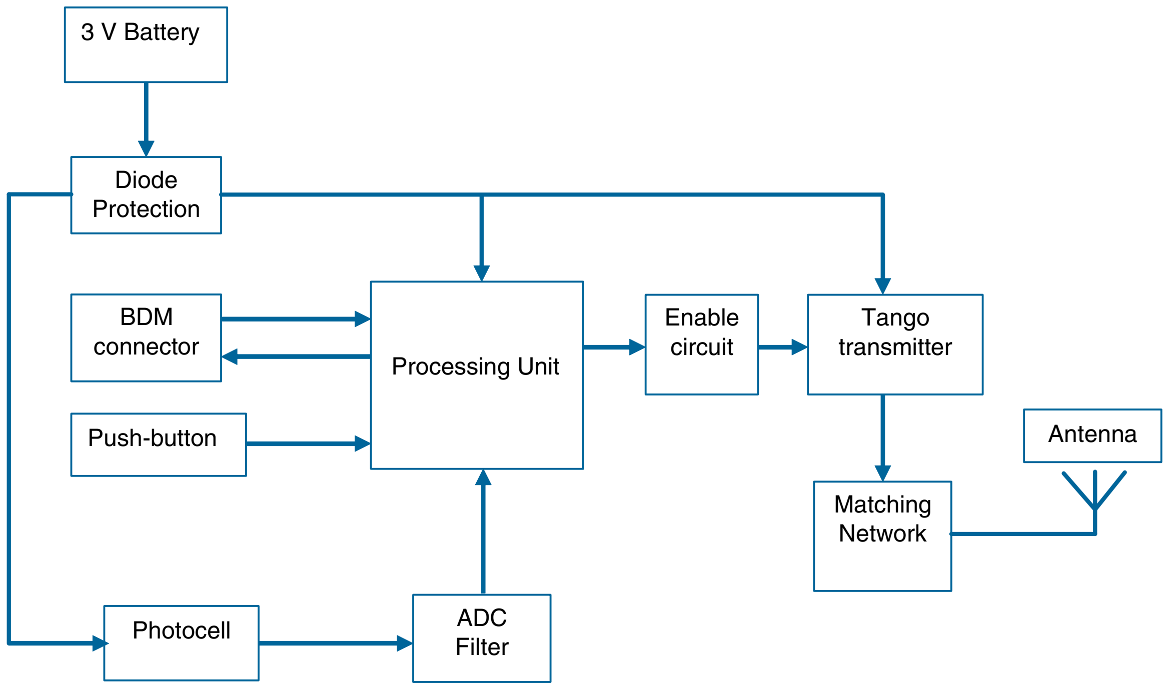


Figure 3-2. Lighting Module Building Block

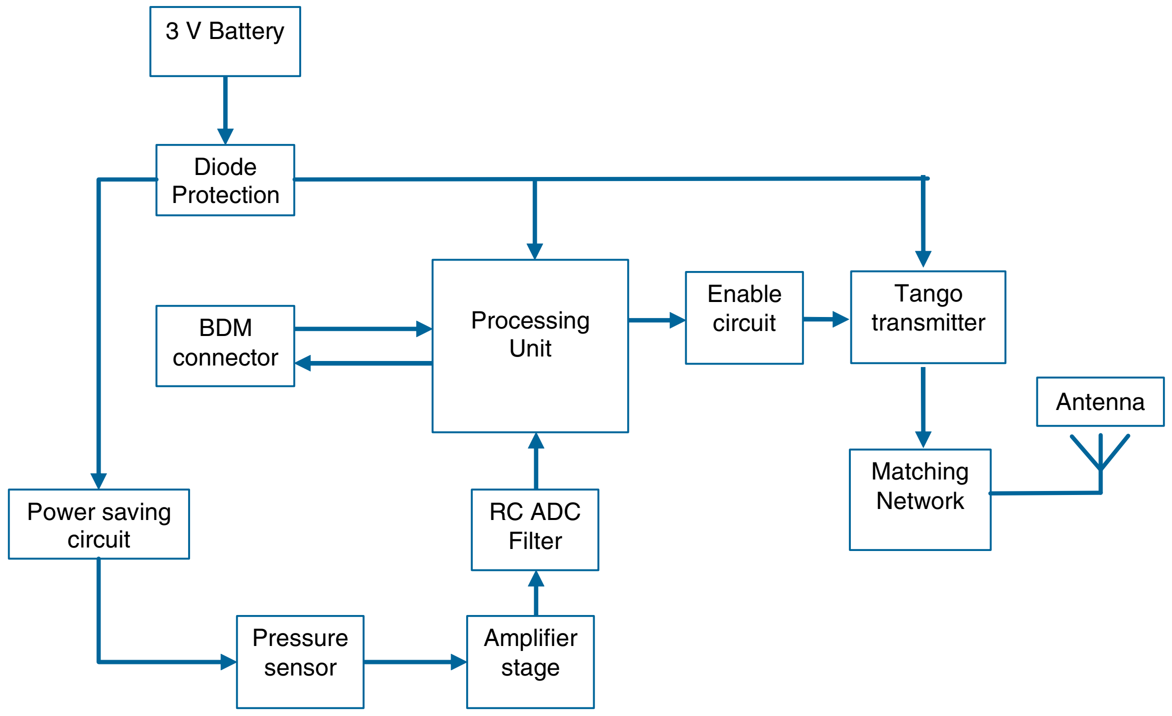


Figure 3-3. Pressure Module Building Block

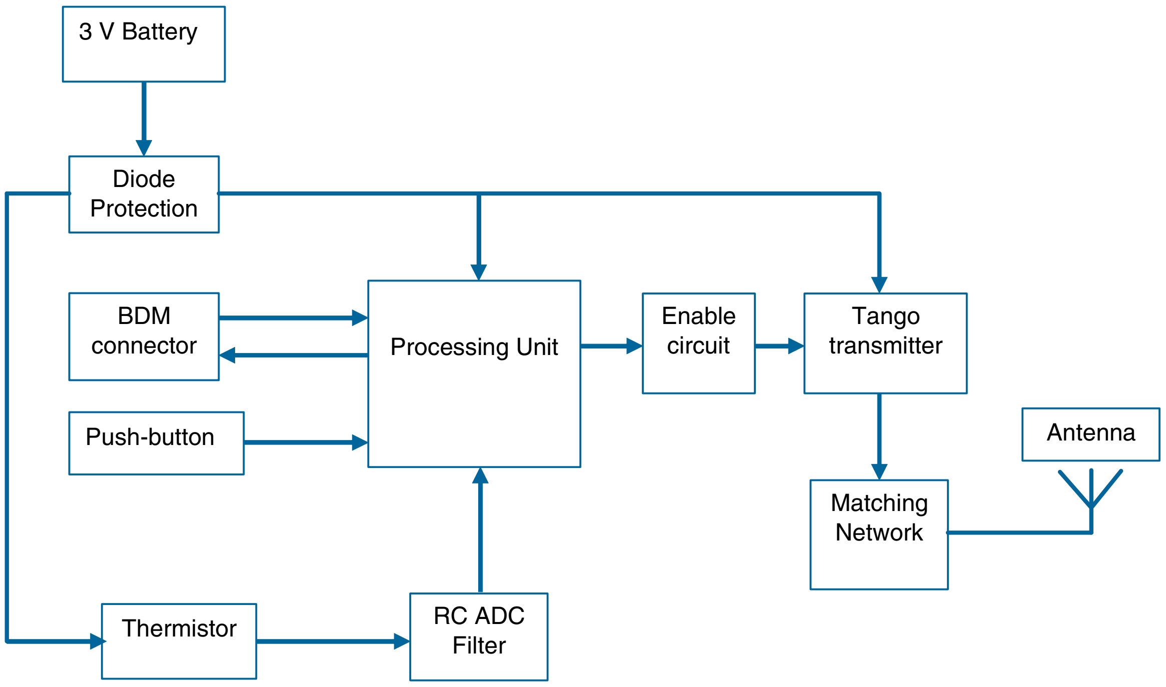


Figure 3-4. Temperature Module Building Block

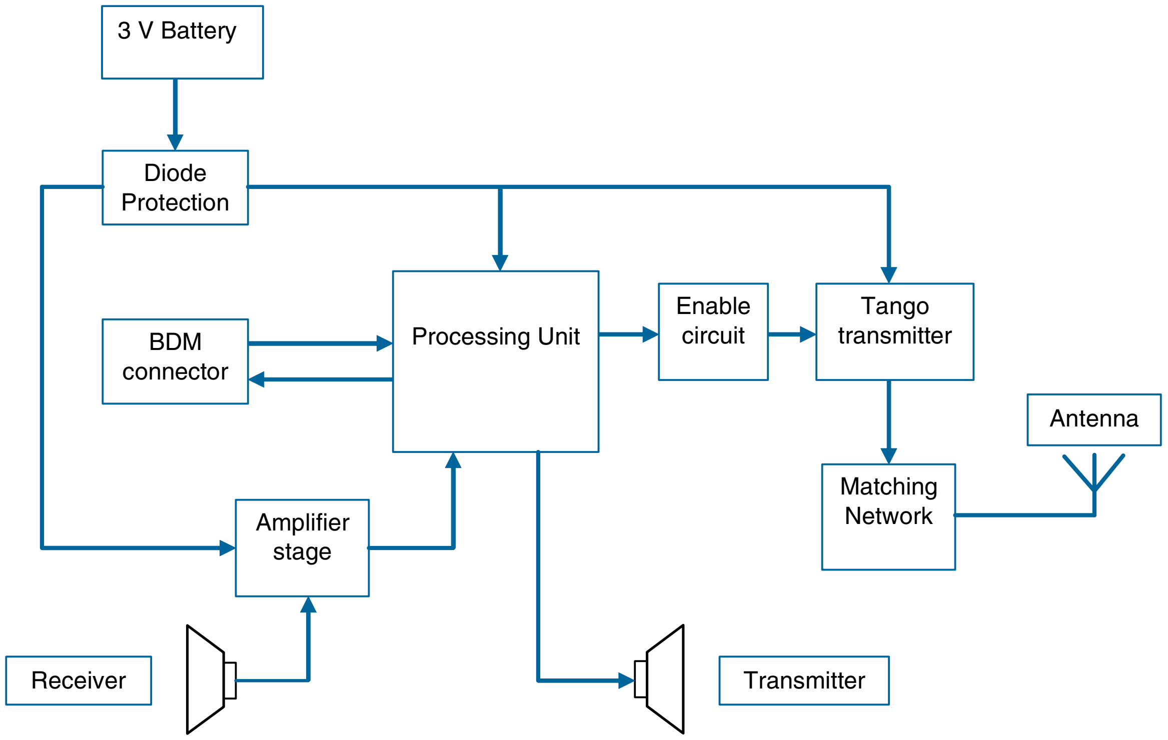


Figure 3-5. Ultrasound Module Building Block

3.2 Technical Data

This section provides technical detail on some of the main components used in this reference design.

3.2.1 Operating Environment

- Ambient Temperature: -40°C to 85°C
- Battery Voltage Range: 3 V to 3.6 V
- Reverse Voltage: 30 V

3.2.2 MC9RS08KA2 Microcontroller

The control unit is the MC9RS08KA2, which has an RS08 reduced core and various peripheral modules. It is also a member of the Freescale Controller Continuum, featured as the ultra low cost, low-end MCU.

3.2.2.1 Features

- Contains 8-bit RS08 core
  - Up to 10 MHz (bus frequency) at 1.8 V for 100 ns minimum instruction time.
  - RS08 instruction set.
  - Supports tiny/short address mode.
  - 14-byte fast-access RAM.
  - Allows emulation of HC08/HCS08 zero-offset index addressing mode instructions.
- Third-Generation Flash and RAM, extremely fast byte writable programming
  - 63 B RAM
  - 2 KB Flash (1 KB Flash available)
- Flexible Clock Options
- 4 Bidirectional I/O lines with software selectable pull-up, eliminates need for external resistors.
- Analog Comparator
- Real Time Interrupt
- 8-bit timer with 8-bit prescale
- System Protection
  - Resets an instance of runaways or corrupted code.
  - Low Voltage Detection.
  - Illegal Opcode and illegal address detection.
  - Flash security feature.
- Single wire debugging and emulation interface; eliminates need for expensive emulation tools or development hardware.

3.2.3 MC33493 RF Transmitter

The MC33493 is the main part of the transmitter block in all the LCWi modules. It is a phase locked loop (PLL) tuned, and low power ultra high frequency (UHF) transmitter. The modes of operation can be controlled through several digital input pins. The power supply voltage ranges from 1.9 V to 3.7 V allowing operation from one lithium cell.

MC33493 RF Transmitter features:

- Switchable frequency bands 315-434 MHz and 868 MHz.
- On-off keying (OOK) and frequency shift keying (FSK) modulation.
- Adjustable output power range.
- Fully integrated voltage controlled oscillator (VCO).

- Supply voltage range: 1.9 V - 3.7 V.
- Very low standby current: 0.1 nA @ T A = 25°C.
- Low supply voltage shutdown.
- Data clock output for microcontroller.
- Extended temperature range: -40°C to 125°C.
- Low external component count.
- Typical application compliant with the European telecommunication standards institute (ETSI).

The transmitter can be found on a thin-shrink small outline package (TSSOP) 14 pin package, 4.4*5.1.0P0.65.

3.2.4 MMA6261Q Acceleration Sensor

The MMA6261Q acceleration sensor is used for the acceleration module. The acceleration sensor is a capacitive micromachined accelerometer with factory-set zero-g offset, full scale span, and filter cutoff. It requires no external devices and has a full system self-test capability that verifies system functionality.

MMA6260Q features:

- High sensitivity
- Low noise
- Low power
- 2.7 V to 3.6 V operation
- 6 mm x 6 mm x 1.98 mm quad flat no-lead (QFN) package
- Integral signal conditioning with low pass filter
- Linear output
- Ratiometric performance
- Self-test
- Robust design, high shocks survivability

It can measure up to ±1.5 g with a sensitivity of 800 mV/g and a roll-off frequency of 300 Hz, making it ideal for this reference design.

3.2.5 MPXM2010GS Compesated Pressure Sensor

The pressure measurement in the pressure module is made by the MPXM2010GS compensated pressure sensor. This device is a silicon piezoresistive pressure sensor that provides a highly accurate and linear voltage output and is directly proportional to the applied pressure. The device is a single, monolithic silicon diaphragm with a strain gauge and thin-film resistor network integrated on a chip. The chip is laser trimmed for precise span, offset calibration, and temperature compensation.

Additional features:

- Temperature compensated over 0°C to 85°C.
- Unique silicon shear stress strain gauge.
- Ratiometric output to supply voltage.
- Gauge Ported and Non Ported Options.
- The maximum pressure rating is 1.45 psi (10 kPa).

3.3 Low-Cost Wireless Sensors Using an MC9RS08KA2 Functionality

This reference design is intended for the commercial markets in measuring applications. Other modules based on this reference design can be created to satisfy the user needs.

3.3.1 Low-Cost Wireless Sensors Using an MC9RS08KA2 Architecture

Schematics for the modules are provided in Appendix A. Figure 3-6 to Figure 3-9 show the building block diagrams.

By using the MCU's resources, the LCWi can handle the data transmission, enabling encryption, sensing, and power control.

The modules can be divided into these basic blocks:

- Power supply
- Processing unit
- Sensor block
- Transmitter block
- Antenna

3.3.2 Power Supply

The power supply is a 3 V CR 1/3N lithium cell. To protect against an incorrect polarized battery placement a Schottky barrier diode is used. It has a 30 V reverse voltage and a forward voltage of 0.35 V at 10 mA forward current.

Capacitor C1 is used for decoupling and to avoid spikes and ripples in the battery output voltage.

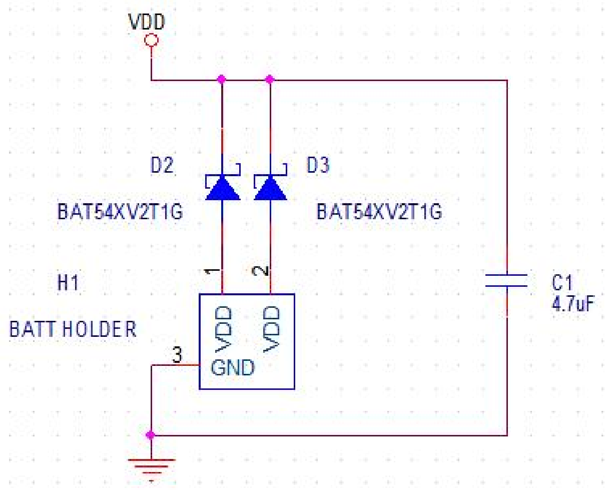


Figure 3-6. Power Supply

3.3.3 MC9RS08KA2 Processing Unit

The processing units for the acceleration, lighting, and temperature modules are similar.

Jumper J3 is used to disconnect the push-button from grounding the programming voltage pin Vpp.

R2 and C10 form the RC filter to implement the ADC on the MCU. For more detailed and specific data, refer to document RS08 Peripheral Module Quick Reference (RS08QRUG), you can find it at www.freescale.com.

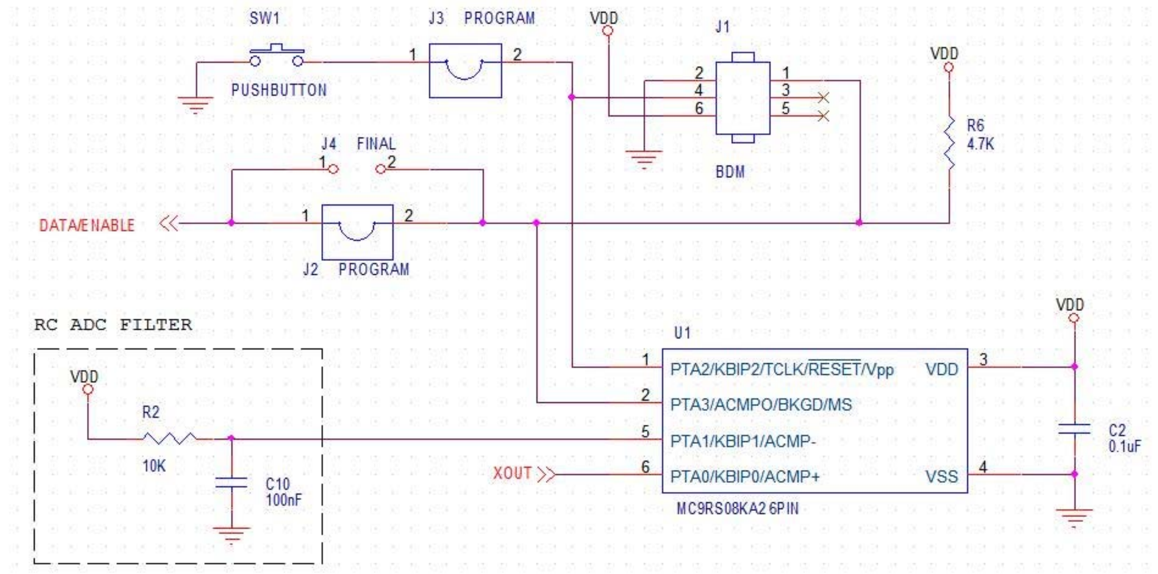


Figure 3-7. Processing Units of the Acceleration, Lighting and Temperature Modules

The pressure module does not implement the push-button. This maintains a small board size for all modules. This feature can be implemented on the acceleration, light, and temperature module boards.

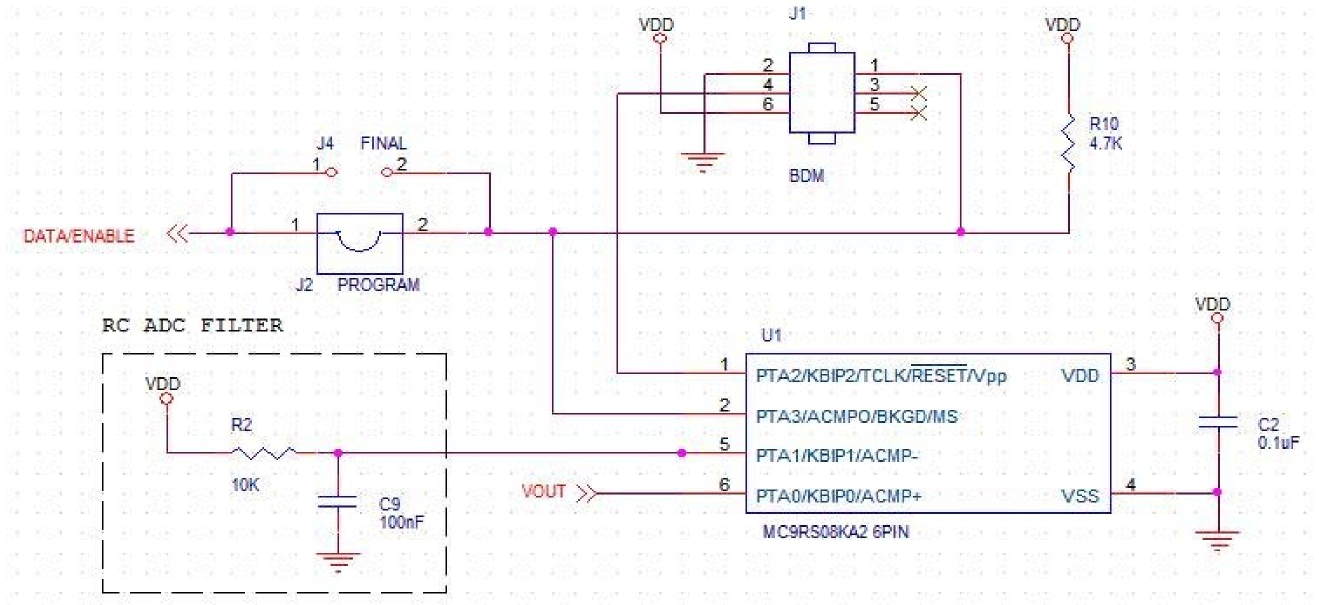


Figure 3-8. Processing Unit of the Pressure Module

The RC ADC filter is not available in the ultrasound module because the signal the amplifier sends to the processing unit is a series of digital pulses. The pulses and timing between them determines the module distance.

USTx1 and USTx2 signals of the processing unit are connected to the ultrasound transmitter.

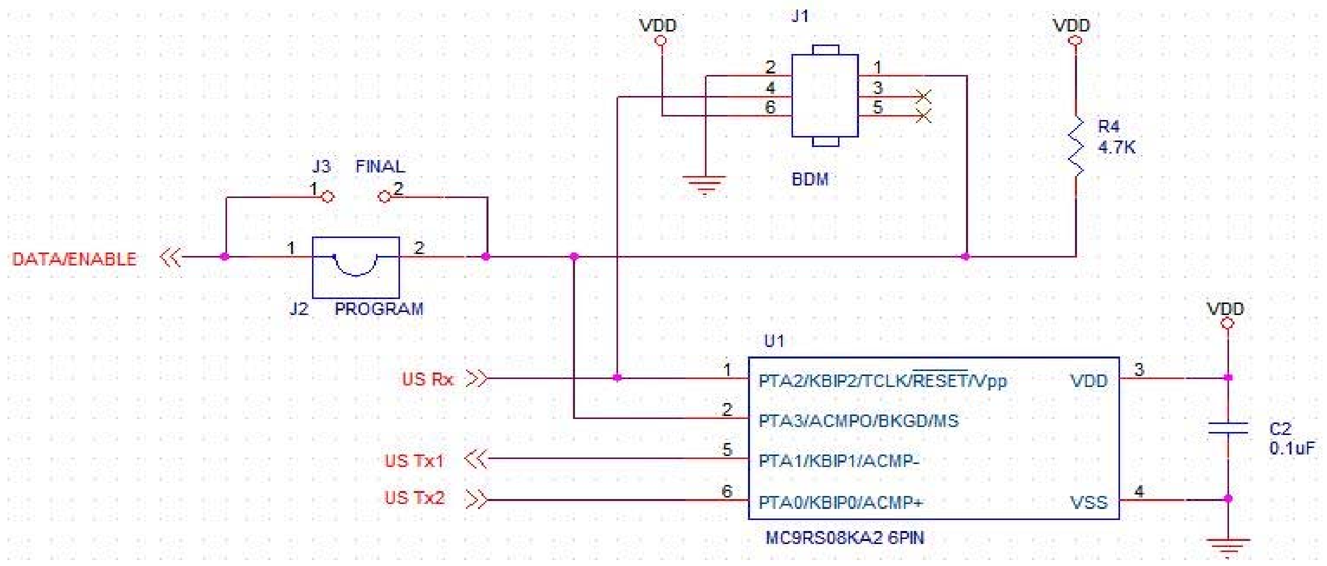


Figure 3-9. Processing Unit of the Ultrasound Module

All modules contain common components in their processing units:

- Capacitor C2 -- used as a bypass capacitor for the MCU.
- Jumper J1 -- 3x2 pin header BDM connector for programming and debugging.
- Jumpers J2 and J4 -- used to test and program the MCU.
- Resistor R4 -- used as a pull-up resistor when not debugging.

3.3.4 Sensor Block

The sensor block defines the modules purpose. The following section describes how each of them works and the considerations taken into account to implement them.

3.3.4.1 Acceleration Module

Transistors Q1 and Q2 work with the signal called ACCEL PWR that also controls the tango transmission enabling. When the signal is high the transmission pulses charge C9, and Q2 conducts and places a ground signal on the base of Q1. After this, Q1 conducts and the accelerometer sees in its Vdd pin the VDD voltage. When the signal is low (no transmission) Q2 is open, so Q1 is also open and the accelerometer receives no power.

Capacitor C12 is placed for DC coupling. Resistor R3 and capacitor C11 act as the low-pass filter for the accelerometer's X axis output (XOUT). The XOUT signal is fed to the MCU's analog compare ACMP+ pin for ADC calculation.

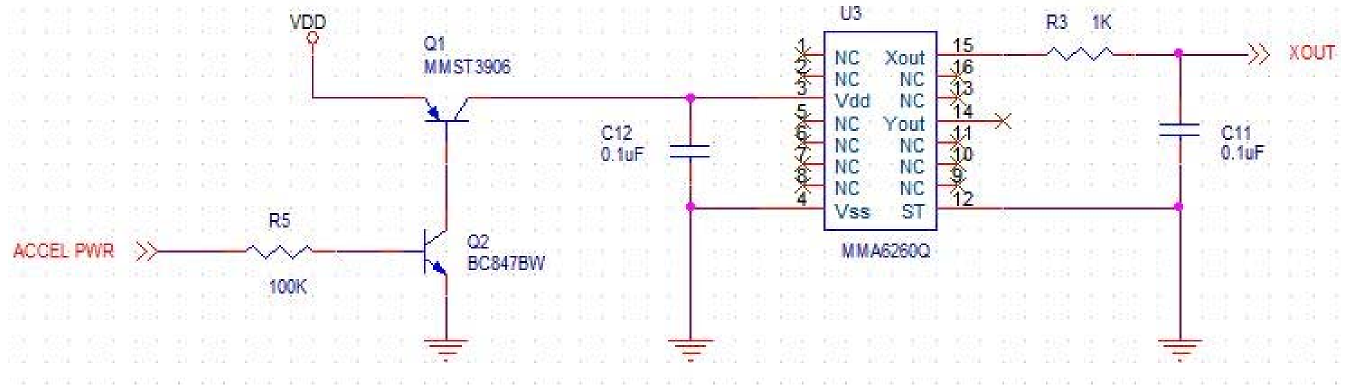


Figure 3-10. Acceleration Sensor Block

3.3.4.2 *Lighting Module*

The lighting module works as a voltage divider. The main component is a photoconductive photocell (CdS) that has a 27-60 kΩ illuminated resistance and a 0.8 Ω/Lux sensitivity. As the intensity of light increases, the photocell resistance decreases. The value of the voltage divider has approximately half the voltage of the supply on ambient light. The voltage from the divider is fed to the ACMP+ pin of the MCU for ADC calculation.

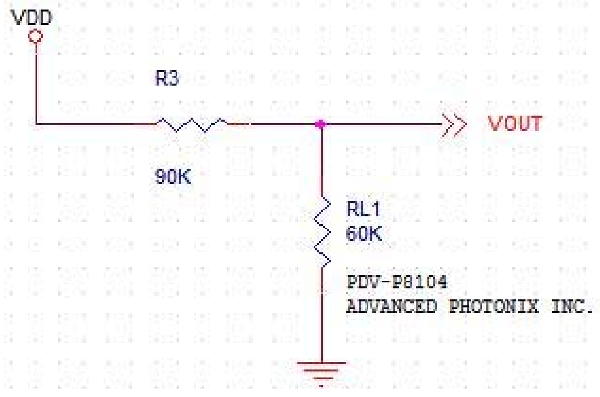


Figure 3-11. Lighting Sensor Block

3.3.4.3 *Temperature Module*

This sensor block is a voltage divider. The main component is an NTC thermistor with a 33 kΩ resistance (zero-power ambient temperature) and a 4050°K B-constant. As the temperature increases, the thermistor resistance decreases. The value of the voltage divider has approximately half the voltage of the supply on ambient temperature (25°C). The voltage from the divider is fed to the MCU's ACMP+ pin for ADC calculation.

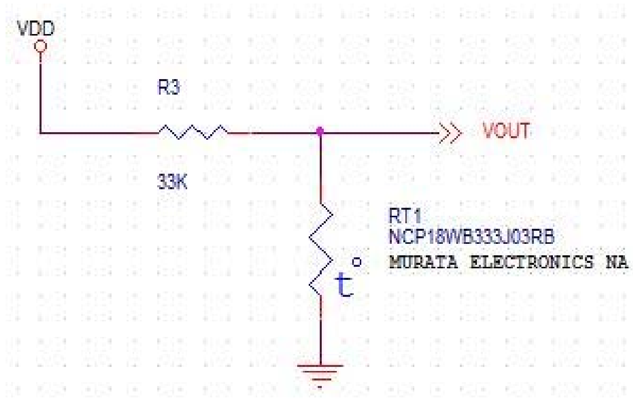


Figure 3-12. Temperature Sensor Block

3.3.4.4 Pressure Module

The sensor block for this module is made up of three parts: the sensor, the power switch transistor and the amplifying stage for the sensor. The transistor Q1 of the pressure module powers on and off the sensor and the operational amplifier (op-amp). When the DATA/ENABLE signal is high, the transistor conducts providing power to the sensor and to the op-amp. When the signal is low the transistor is open and the sensor and amplifier receive no power.

The pressure sensor has differential outputs that are fed to the inputs of the op-amp which is connected as a voltage follower. This amplifies the 40 mV maximum differential span of the pressure sensor to needed levels for the ADC filter of the MCU.

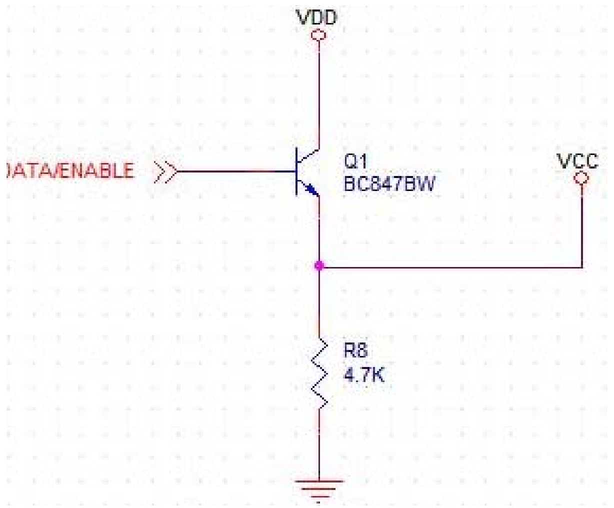


Figure 3-13. Power Enabling for Pressure Sensor

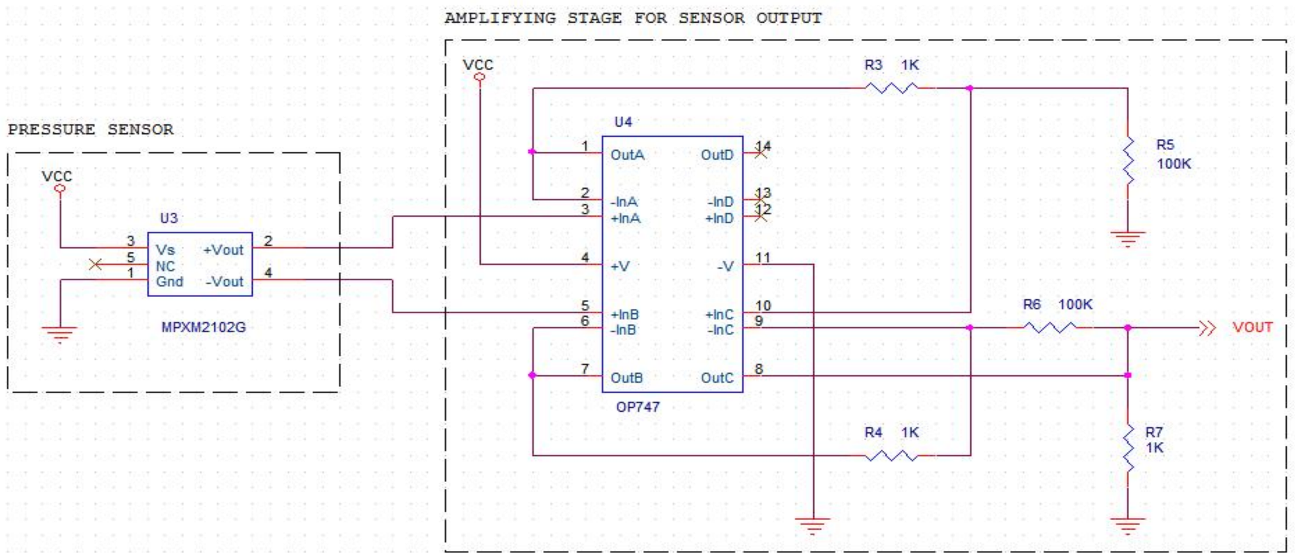


Figure 3-14. Pressure Sensor Block with Amplifier

3.3.4.5 Ultrasound Module

The receiver of the ultrasound module sensor block has an amplifier to boost the received pulses to measurable levels for the MC9RS08KA2. A filter capacitor was placed to block any unwanted interference on the receivers.

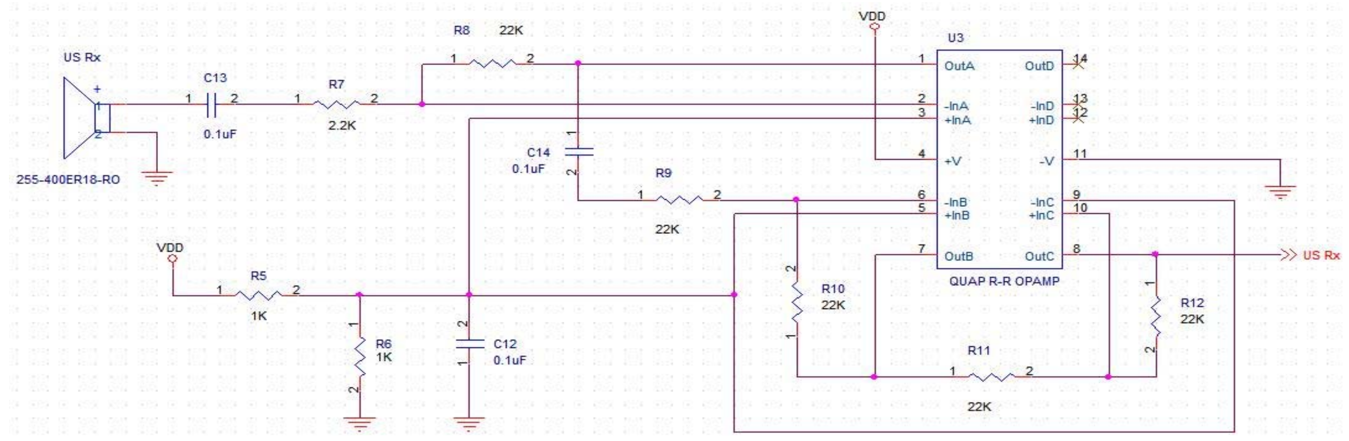


Figure 3-15. Receiver for the Ultrasound Sensor Block

The transmitter has two jumpers (J4 and J5) for transmission:

- J4 open, J5 shorted -- The USTx1 pulses come from PTA1 pin of the MCU and the signal goes through the transmitter, whose chassis is connected to ground.

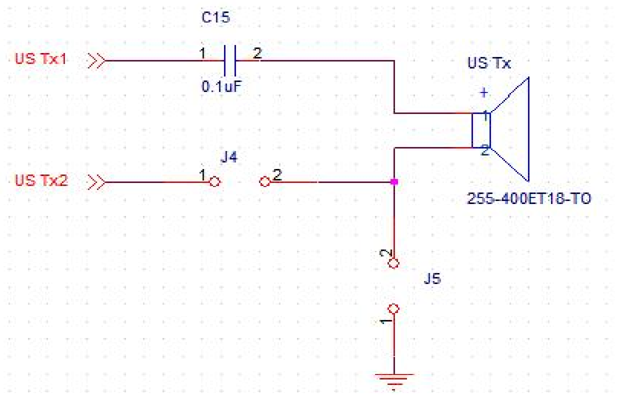


Figure 3-16. Receiver of the Ultrasound Sensor Block

The ultrasound sensors have a center frequency of 40.0 kHz ± 1.0 kHz, maximum input voltage of 20 V and a bandwidth of 1.5 kHz (-6 dB).

3.3.5 Tango MC33493 Transmitter Block

The transmitter block takes all the information the MC9RS08KA2 reads, processes, and modulates it for transmitting in UHF over the air.

The transmitter is disabled during non-transmission to save power using the capacitor C9 (acceleration module), C10 (pressure), and C11 (for lighting, temperature, and ultrasound modules) that are connected to the transmitter's ENABLE pin. The MCU sends a pulse through diode D1 and fully charges the capacitor before transferring the data. When the data pulses start, the capacitor starts to discharge, but because of the pulses' frequency, the logic level on the ENABLE pin is maintained on a high level, allowing it to transmit all the information. When no more pulses are sent, the capacitor discharges all its energy and the transmitter is disabled.

To demonstrate the MCU's handling and the benefit of using it in the LCWi, the Tango transmitter options for MODE and BAND are hardwired.

Table 3-1. Modulation Options for Tango Transmitter

MODE Input Level	Modulation
High	Frequency shift keying (FSK)
Low	On-off keying (OOK)

For more detailed and specific data about the MC33493 Tango transmitter configuration and features, refer to the data sheet, you can find it at www.freescale.com.

Table 3-2. Band Options for Tango Transmitter

BAND Input Level	Frequency Band (MHz)	PLL Divider Ratio	Crystal Oscillator Frequency (MHz)
High	315	32	9.84
	434		13.56
Low	868	64	

Crystal Y1 is a 9.84375 MHz crystal oscillator. The BAND and MODE pins are connected to VDD to select a 315 MHz transmission frequency and FSK modulation.

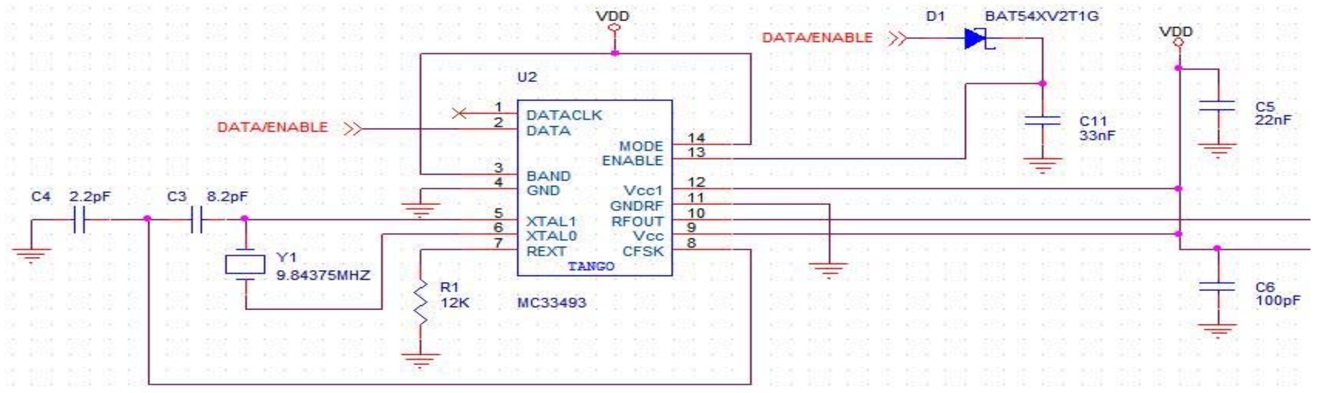


Figure 3-17. Transmitter Block

3.3.6 Antenna

3.3.6.1 RF Section

All boards use a small loop PCB antenna, since it provides a low-cost solution and does not require much board space. The disadvantage is that this type of antenna does not provide high efficiency; therefore the attainable range is usually less than what can be achieved with other common antenna types.

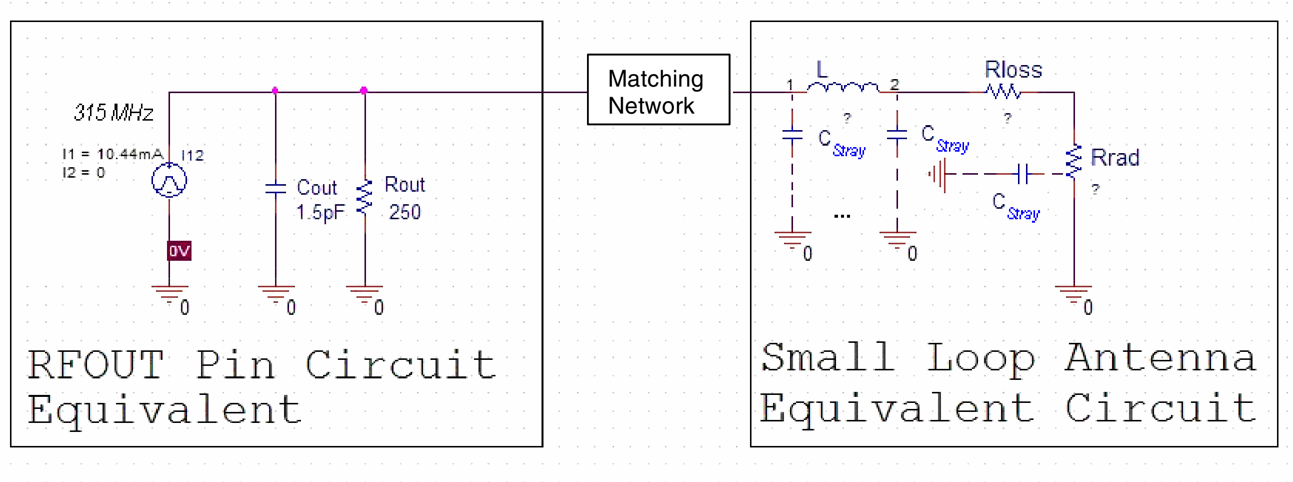


Figure 3-18. RF Section Schematic

The radiation resistance for this type of antenna is approximately:

$$Rr \approx 31{,}200\left(\frac{A}{\lambda^2}\right)^2 \ (\Omega)$$

Where A is equal to the area of the loop in square meters, and λ is the wavelength in meters.

This formula gives a good approximation for single-turn loop antennas (circular or square) with a loop perimeter of around λ/3. For a perimeter equal to λ/3, the error is about 2%, but it still gives a decent rough approximation for smaller loop antennas.

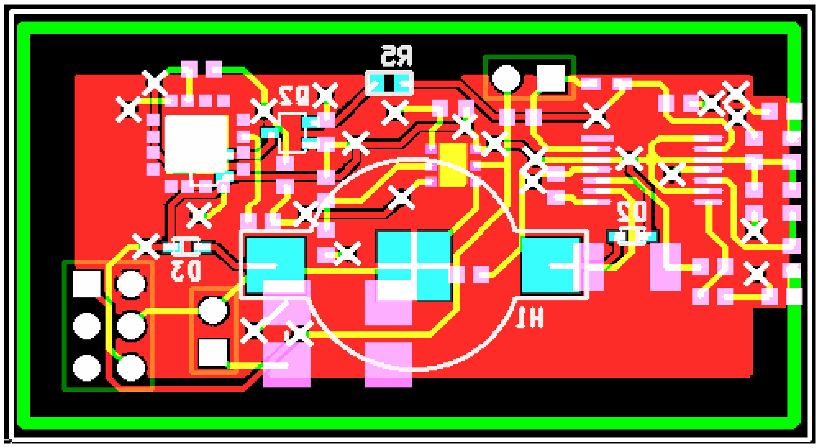


Figure 3-19. Loop Antenna on PCB

The LCWi antenna has a perimeter of 13.6 cm (l = 4.4 cm, w = 2.38 cm), at 315 MHz this is less than λ/3 (at 315 MHz λ/3 is approximately 31 cm).

Using the radiation resistance formula, the small loop antenna has a radiation resistance of approximately 0.042 Ω, which is very small, and gives a hint that this antenna won't have very high efficiency.

To calculate the efficiency, first calculate the Radiation Loss, which is approximated with this formula:

$$Rloss = \frac{l}{2w} \cdot \sqrt{\frac{\pi\ f\ \mu_0}{\sigma}}$$

Where l is the perimeter or circumference of the loop in meters, f is the frequency in Hertz, w is the width of the PCB track in meters, σ is the conductivity of the PCB track in Siemens/meter (for copper it is approximately $5.7 \cdot 10^7 S/m$), and $\mu = 4\pi \cdot 10^{-7}$.

For the LCWi antenna Rloss is approximately 0.417 Ω (the width of the trace is approximately 0.7 mm). With this number and with the radiation resistance value a rough calculation can be made of the efficiency that the LCWi antenna has. The efficiency k is:

$$k = \frac{Rrad}{Rrad\ +\ Rloss}$$

According to the formula, the LCWi antenna gives an efficiency of 0.091 or -10.38 dB. Since the efficiency is not very high, matching is indispensable to reach a decent range.

The impedance of the RFout pin and the impedance of the antenna are needed to design a matching network. To calculate the inductance L of the LCWi antenna the next formula is used:

$$L = \frac{\mu_0}{2\pi} \cdot l \cdot \ln\left(\frac{8 \cdot A}{l \cdot w}\right)$$

Where A is the area of the loop in square meters, l is the perimeter or circumference of the loop in meters, w is the width of the copper trace in meters, and $\mu = 4\pi \cdot 10^{-7}$. The result is L = 119 nH.

Because the amount of resistance is relatively small, and the inductance is relatively large, stray capacitance has a determining effect on the impedance of the antenna. Therefore to measure the impedance of the antenna a vector network analyzer (VNA) is used.

These are the results obtained for the VNA:

Table 3-3. Antenna Impedance Results

Antenna Impedance	25 - j345	Board held in hand
Antenna Impedance	36 -j502	Directly connected to VNA

This information is enough to design the matching network. It is important to note that due to the low value of the resistance component of the antenna, small loop antennas are difficult to match. Also, since the impedance of the antenna varies depending on the way the board is held, trying to make a precise matching is an impractical approach. That is why we will aim to simply make a good/decent match, trying to use few components to keep cost contained.

To design the matching network, first find out the impedance necessary to match the antenna. The output impedance of the RFOUT pin can be considered as a 250 -Ω resistor in parallel with a 1.5 -pF capacitor, which results in an impedance equal to:

$$Zout = 161.2 - 119.64\,j \;\; (\Omega)$$

This can be seen in the RF pin model shown in Figure 3-20.

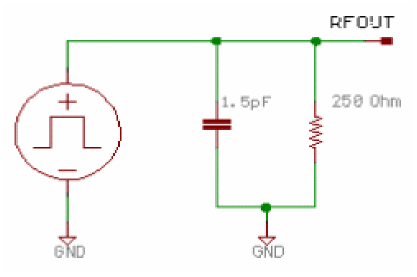


Figure 3-20. RF Pin Model

The antenna's impedance must look something like the complex conjugate of the RFout pin (Zout).

If a 68 pF capacitor is placed in series with the antenna (using the impedance measured when held in hand), and a 100 nH inductor in parallel, the following impedance results:

Zant = [(25 – 345j) + 1/(jw68pF)] // jw100nH = 39.97 + 444.98 j (Ω)

Though still far from the complex conjugate of Zout, with two passive components the matching network has a decent performance, approximately 15 m.

The matching antenna can be improved if more range is required. This requires another inductor, which increases the cost. An improved RF model uses a 68 pF capacitor with a 68 nH inductor, and a 100 nH inductor with another 68 nH inductor. The impedance of this model is:

Zant = [(25 – 345j) + jw68nH] // jw68nH = 71 + 350 j (Ω)

Remember that making an exact match is difficult with small loop antennas because of the small value of their resistance component. Therefore placing too much effort or money in achieving a perfect match is not a good idea. Another reason is that the antenna impedance varies depending on how the board is held.

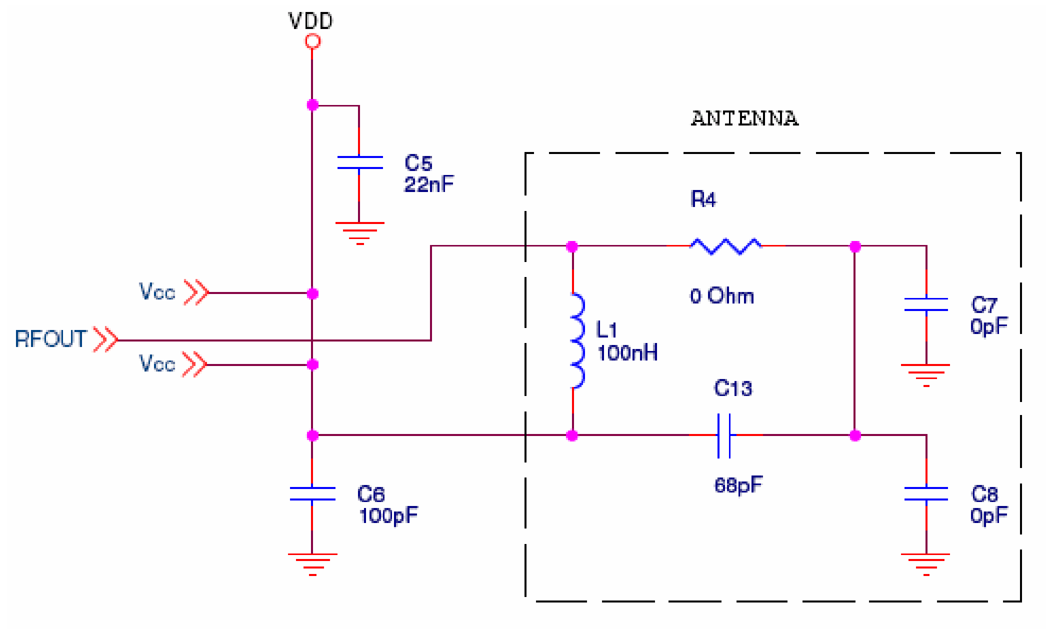


Figure 3-21. RF & Antenna Section of the Schematic

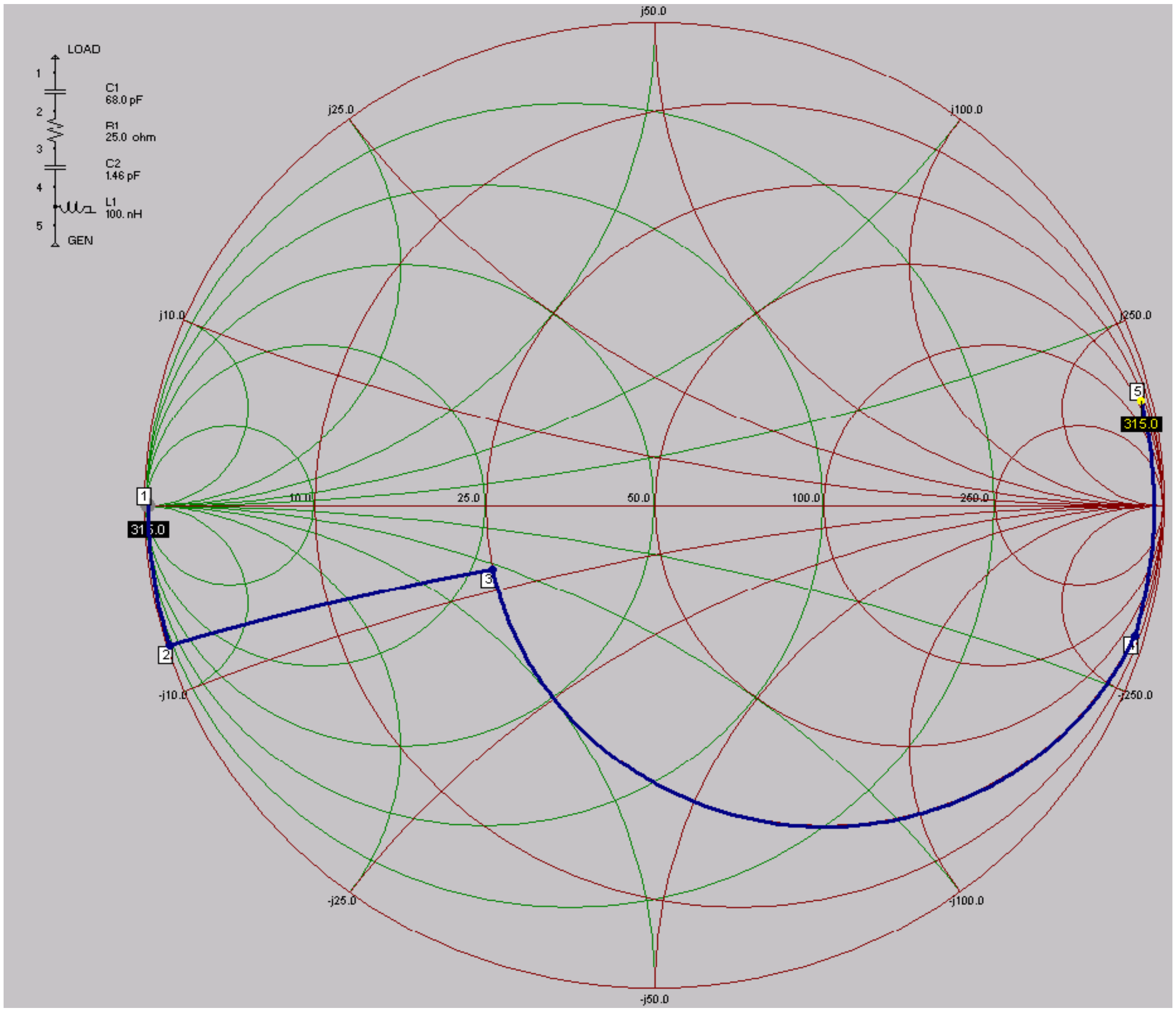


Figure 3-22. Matching Performed Using a 68 pF Capacitor (C13 in the Schematic), and a 100 nH Inductor (L1 in the Schematic)

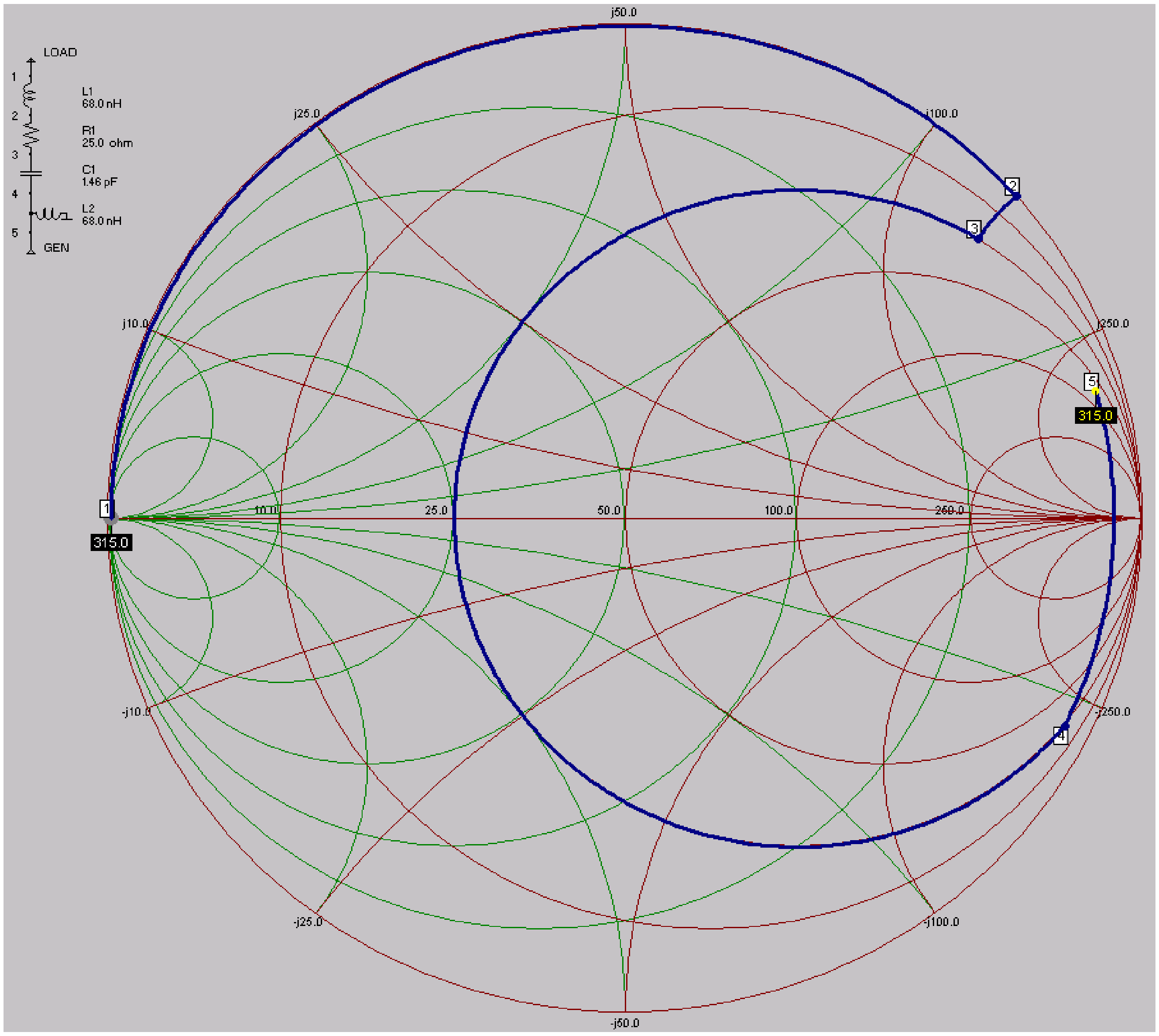


Figure 3-23. Matching Performed Using a 68 nH Inductor (C13 in the Schematic), and a 68 nH Inductor (L1 in the Schematic)

3.4 Board Layout

The detailed description of the layout for the LCWi is shown in this section.

3.4.1 Low-cost Wireless Sensors Using a MC9RS08KA2 board layout

3.4.1.1 Acceleration Module Board Component Side

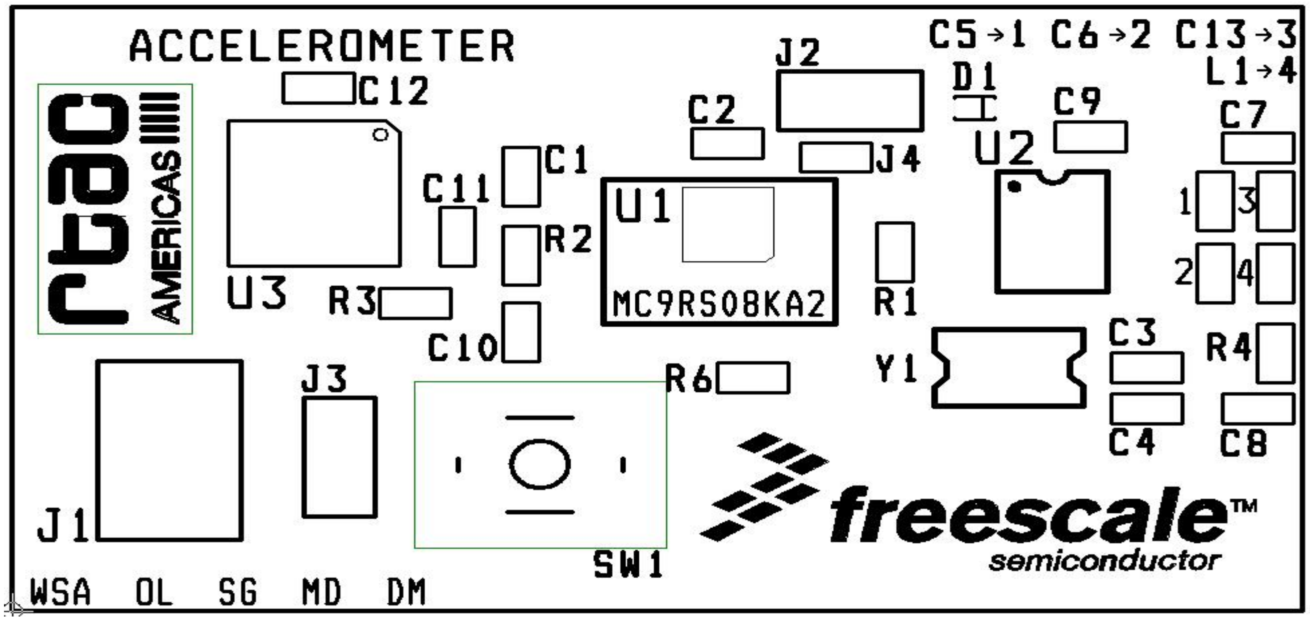


Figure 3-24. Acceleration Module Board Component Side

3.4.1.2 Lighting Module Board Component Side

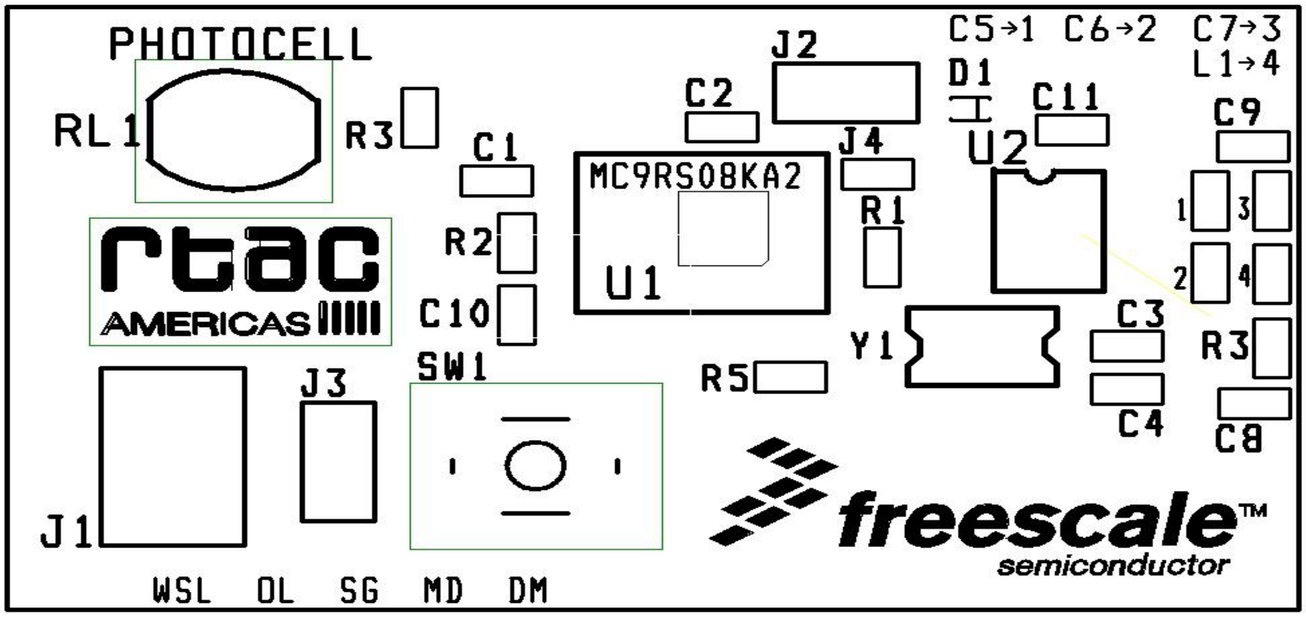


Figure 3-25. Lighting Module Board Component Side

3.4.1.3 Pressure Module Board Component Side

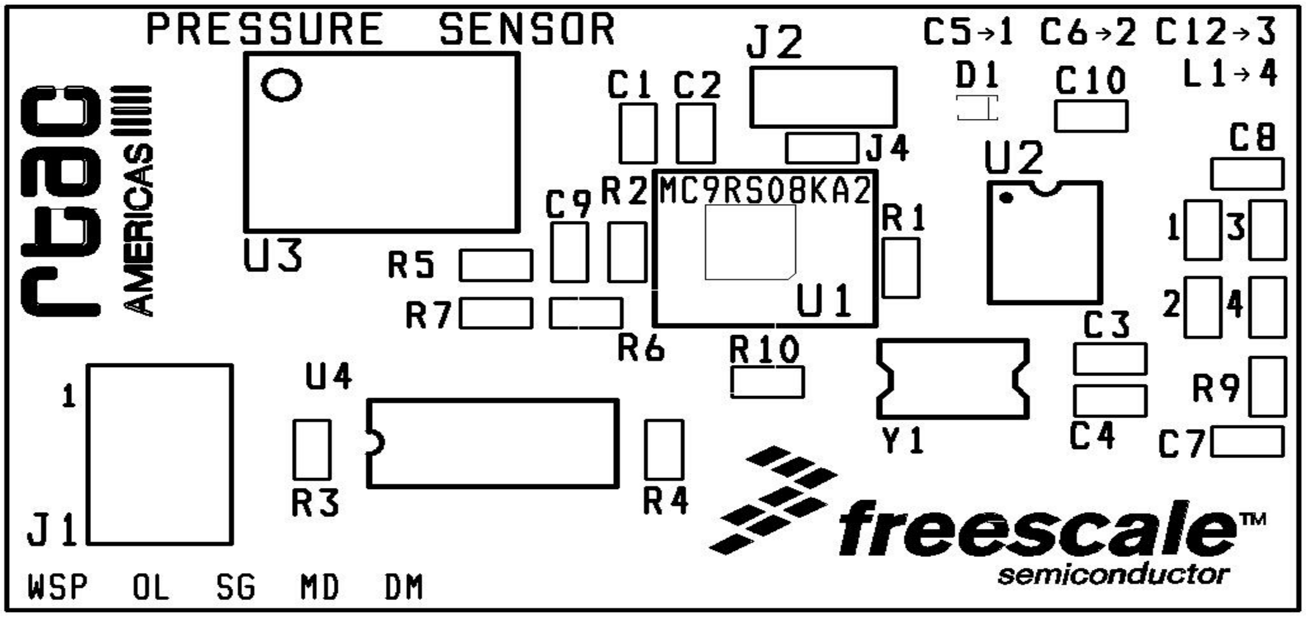


Figure 3-26. Pressure Module Board Component Side

3.4.1.4 Temperature Module Board Component Side

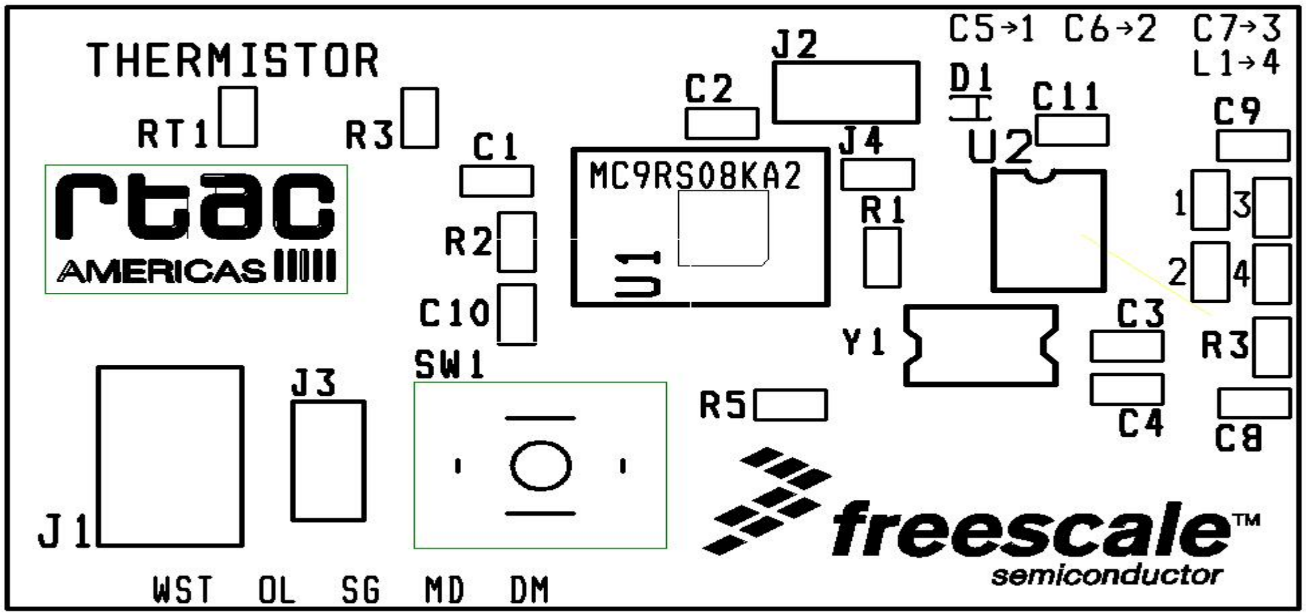


Figure 3-27. Temperature Module Board Component Side

3.4.1.5 Ultrasound Module Board Component Side

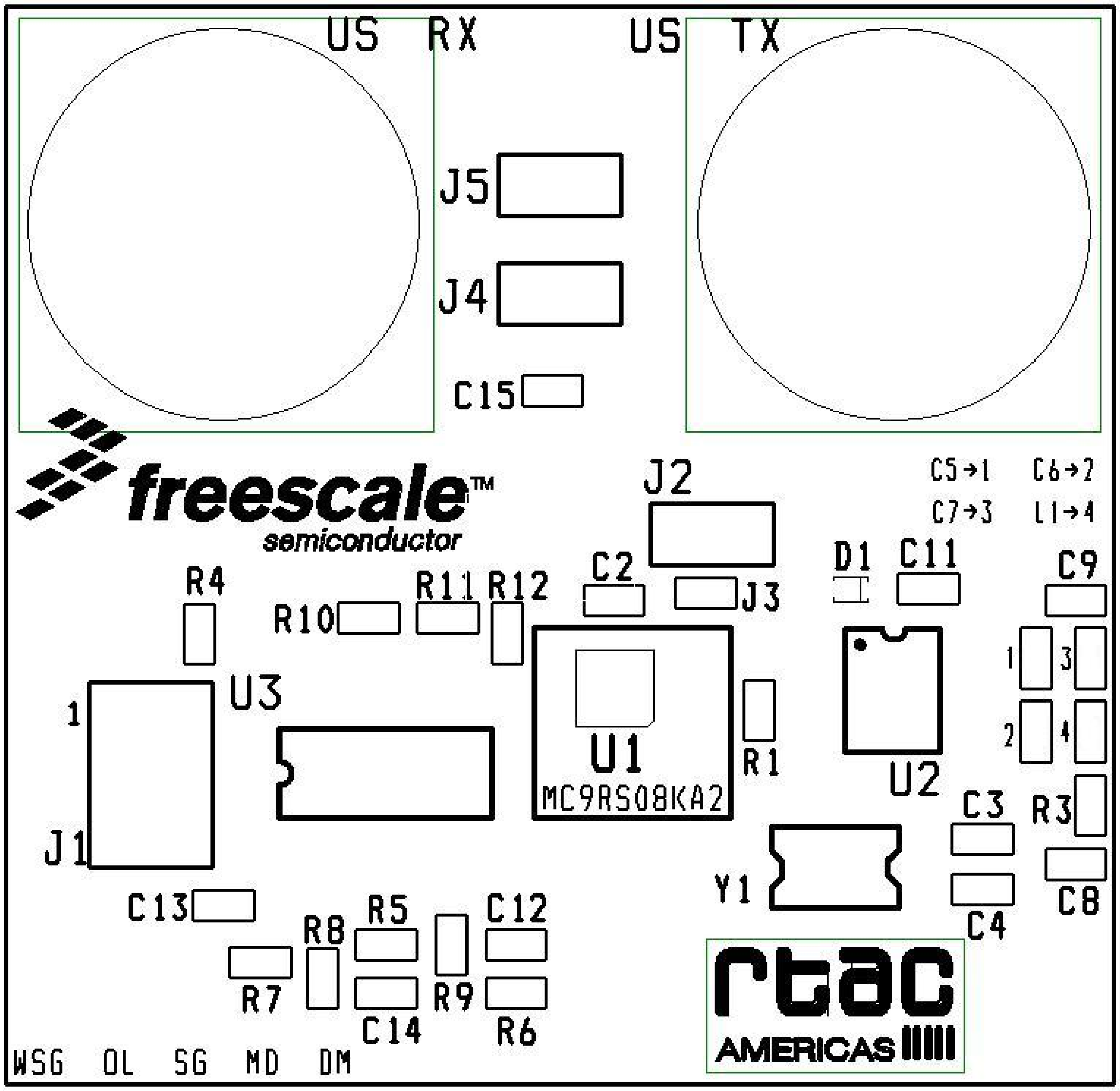


Figure 3-28. Ultrasound Module Board Component Side

3.4.2 General Layout Explanation

The circuit board layout considerations are dominated by:

- Minimum size to implement the antenna.
- Component placement to allow enough clearance to the antenna.
- Bottom ground plane for shielding antenna.

This board is not intended for mass production and must be used as a prototype.

The layout was designed to allow effective transmission parameters. The placement was designed to make user tests easier.

3.4.3 PCB Features

3.4.3.1 Board Size

The circuit board size is 1 x 1.8 inches for the acceleration, lighting, pressure, and temperature modules.

The circuit board size is 1.75 x 1.8 inches for the ultrasound module.

The form of the board was designed for a better implementation of the dipole antenna.

3.4.3.2 Two Layers

The majority of signals are routed on the top layer. Some signals are on the bottom layer because of component density and the board size. To maintain the same board size for all modules, some components are placed on the bottom side.

Ground planes were used to maintain signal integrity and to shield the antenna for effective transmission parameters.

3.4.3.3 Board Material FR-4

The FR-4 materials are predominantly used for printed circuit boards. The FR-4 materials can withstand 130°C. FR-404 and FR406 have higher temperature ratings (150°C and 170°C, respectively).

3.4.3.4 Minimum Circuit Board Trace Width for Signal Traces

Circuit board vendors indicate the following minimum trace widths for a given copper plating thickness.

- 1 oz. Cu – 5 mil lines
- 2 oz. Cu – 7 mil lines
- 3 oz. Cu – 10 mil lines

0.009 inches is the board’s minimum trace width and clearance. The LCWi uses a 1 oz Cu thickness because there are not high current signals on the board, so the 0.009 inches trace width is enough.

3.4.4 Component Placement

Figure 3-29 through Figure 3-33 illustrate how the main blocks are separated. The processing unit, sensor blocks, BDM connector, and transmitter blocks are placed with enough clearance distance to avoid interference with the antenna.

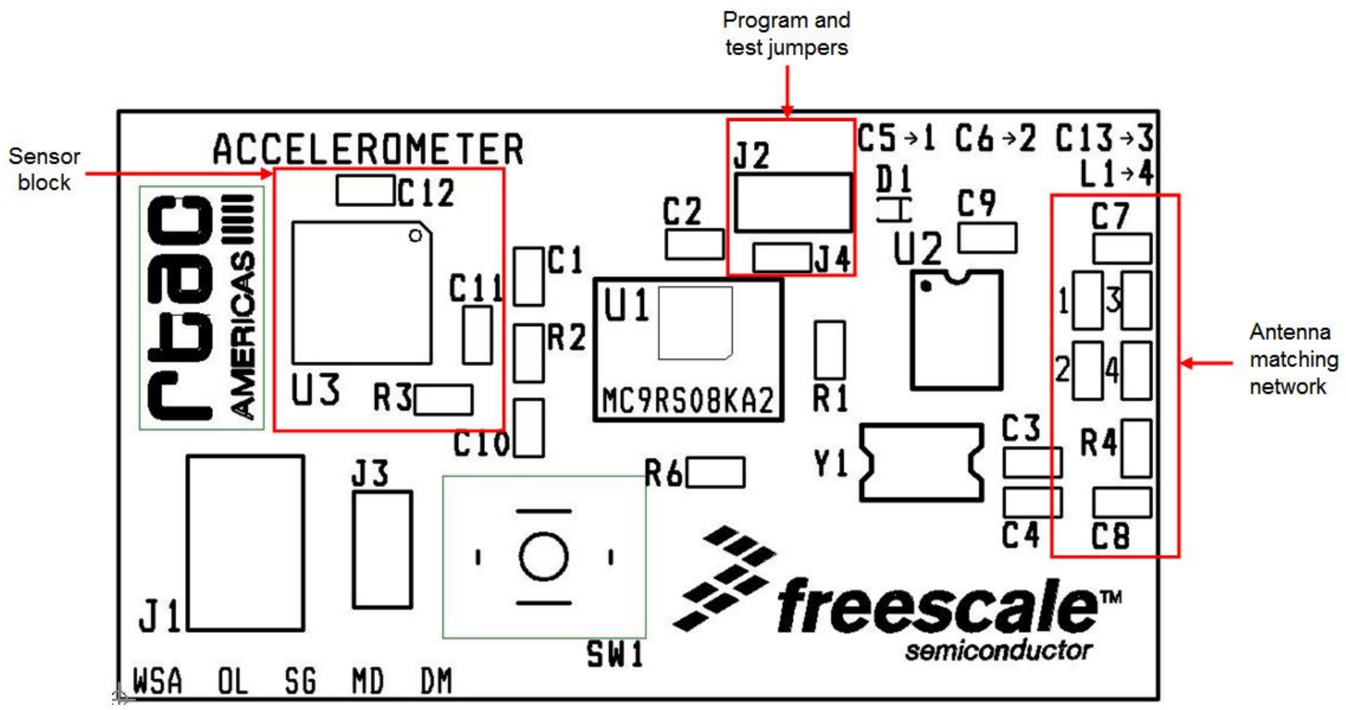


Figure 3-29. Acceleration Module Board and the Main Blocks

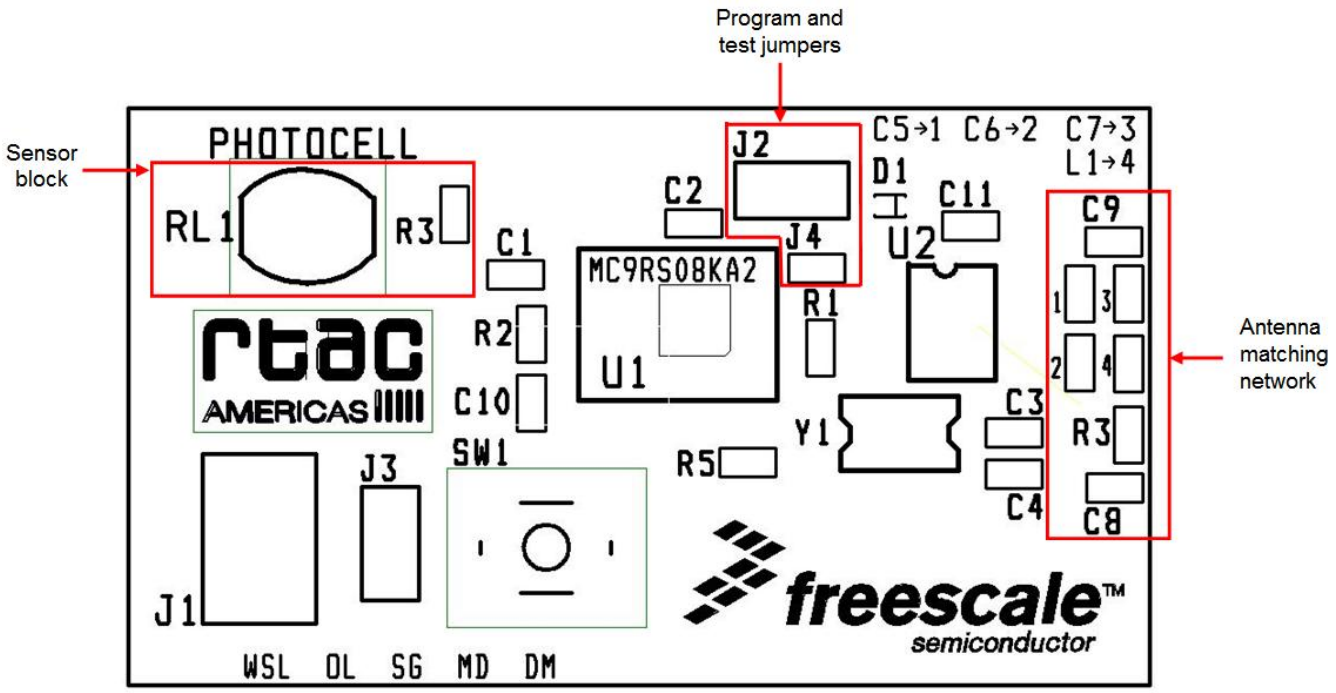


Figure 3-30. Lighting Module Board and the Main Blocks

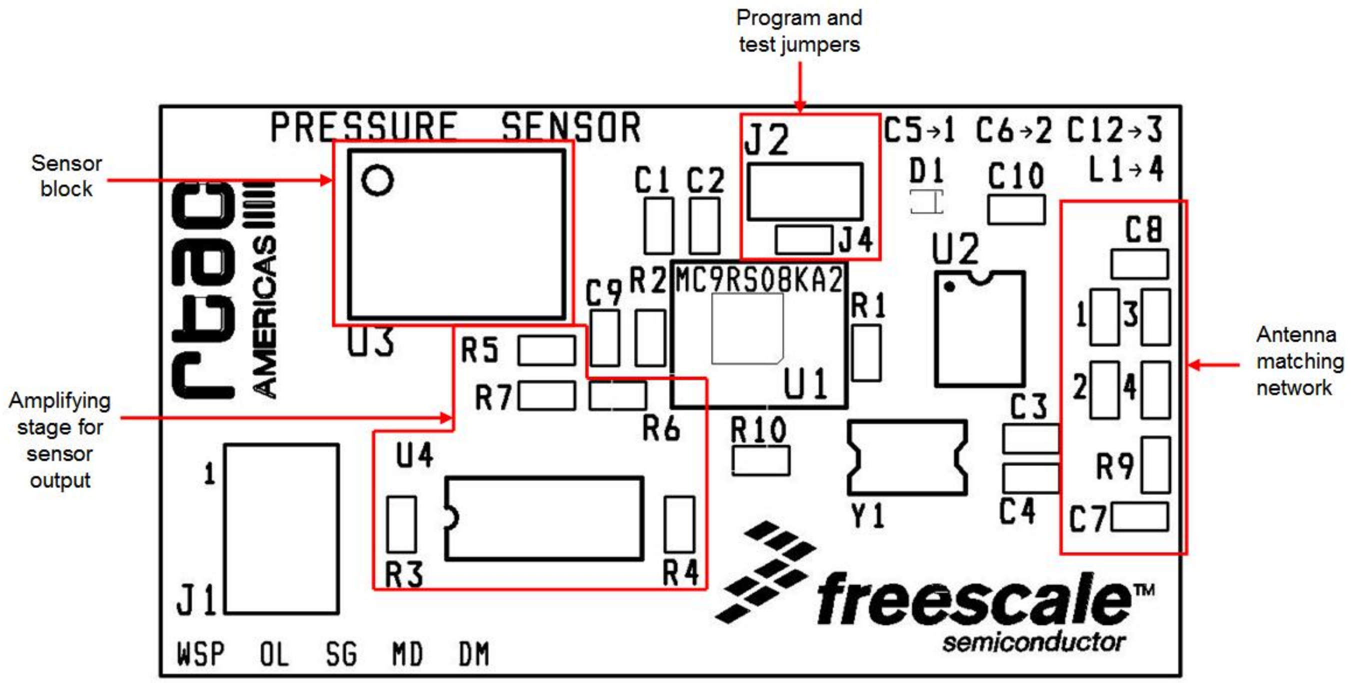


Figure 3-31. Pressure Module Board and the Main Blocks

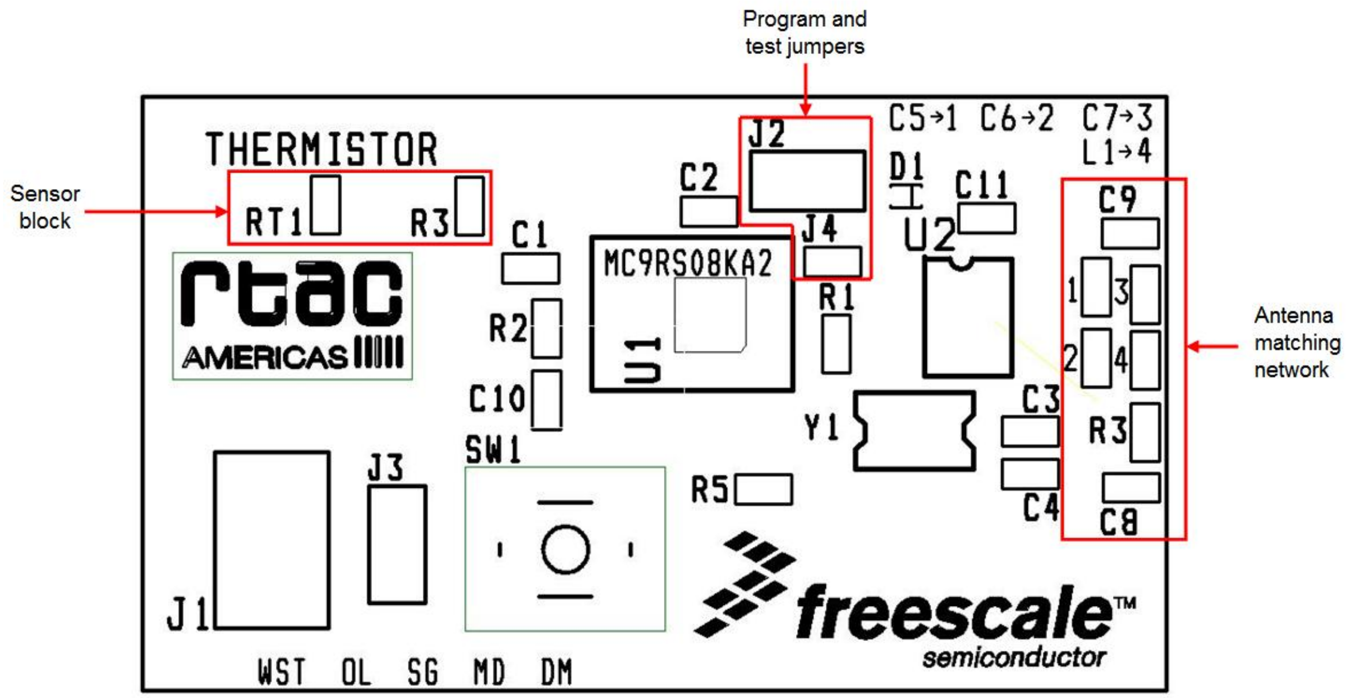


Figure 3-32. Temperature Module Board and the Main Blocks

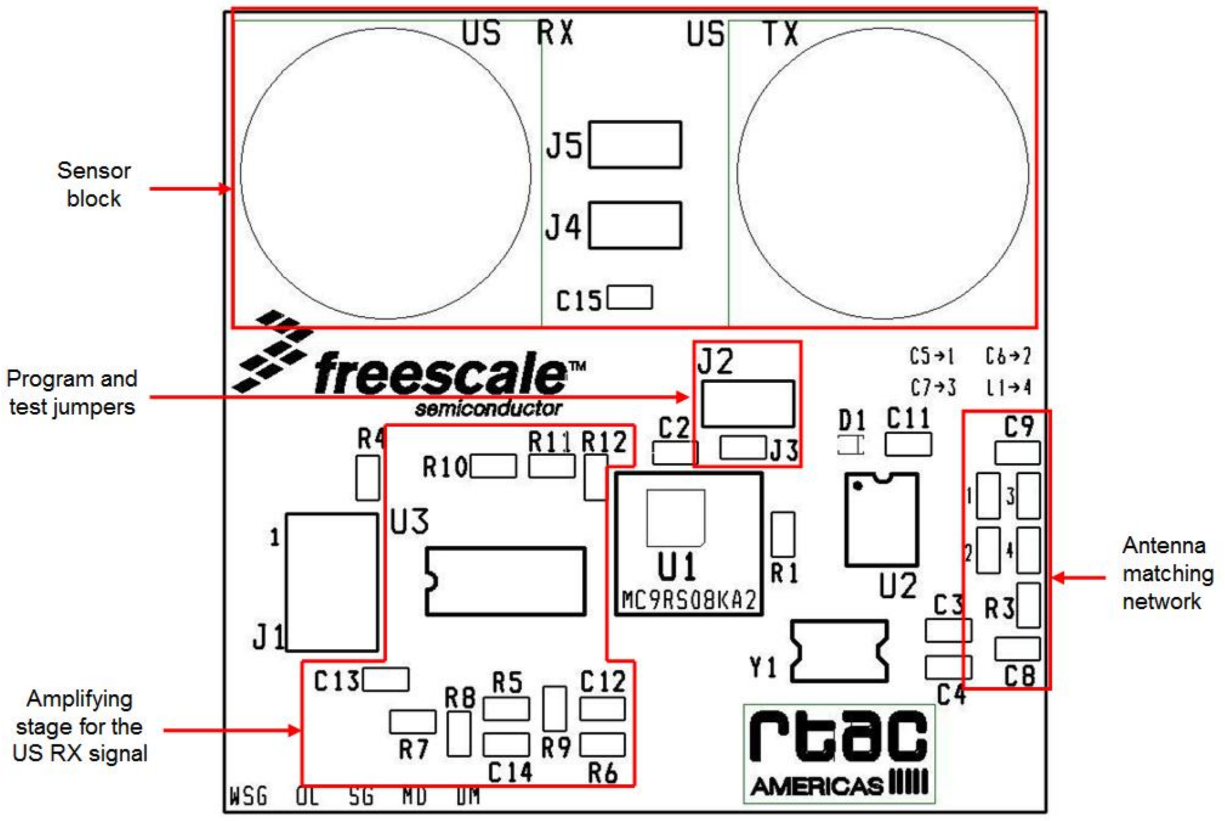


Figure 3-33. Ultrasound module board and the main blocks

3.4.4.1 Sensor block

The stand-alone sensors such as the photocell, thermistor, and the associated resistor for the voltage divider are placed next to each other to better identify the block. In the case of the pressure and the acceleration sensors, the required circuitry was placed together to help you differentiate the sensor block from the rest of the board and for the bypass capacitors to perform correctly.

For the ultrasound module, the sensors and their selection jumpers are on the upper part of the top component side; the amplifier for the receiver is on the top component side.

3.4.4.2 Transmitter Block

The PCB antenna, RF transmitter and the matching network are distributed accordingly to maximize the performance of the transmission. The parts belonging to the matching network were arranged close to each other and to the transmitter to avoid any noise induction in the transmission lines. For the PCB antenna, the ground plane was ensured to have enough clearance to it for optimizing transmission parameters and range.

3.4.4.3 BDM Connector

Table 3-4 shows the signals for the BDM connector, a 3 x 2 pin header.

Table 3-4. Pin Assignment for BDM Connector

Pin Number	Function
1	Background
2	Ground
3	No connected
4	Reset
5	No connected
6	Vcc

3.4.4.4 Processing Unit Block

For the placement of the processing unit block the only important consideration is to have the bypass capacitor for the MCU placed as close to the power supply pin as possible.

3.4.4.5 MC9RS08KA2 Footprint

Figure 3-34 shows the footprint for the MC9RS08KA2 in the 6DFN package. In order to reduce design for manufacturability (DFM) problems, the central exposed pad is designed with soldermask covering part of the pad; this is to avoid solder shorts when placing the component in a pick and place machine.

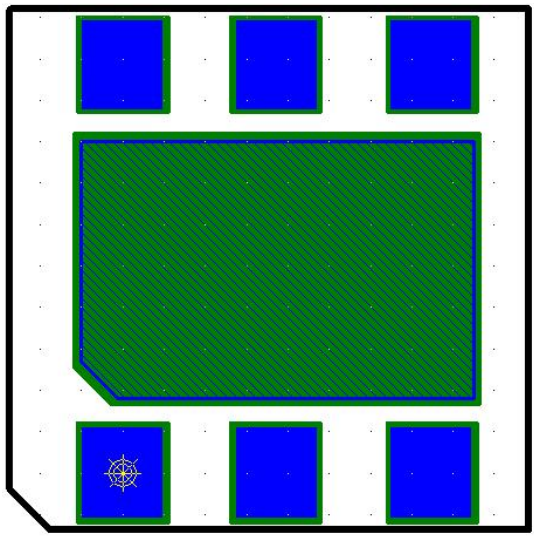


Figure 3-34. MC9RS08KA2 DFN6 Footprint

3.4.4.6 *Accelerometer Footprint*

As in the DFN6 footprint, special care needs to be taken when designing it to avoid the solder shorting from the central exposed pad to the rest of the pads. Figure 3-35 shows an image of the QFN16 footprint.

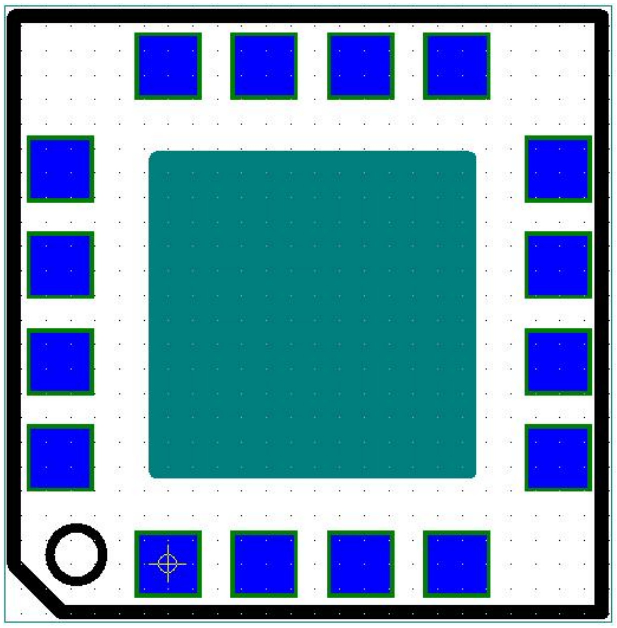


Figure 3-35. MMA6260Q footprint

3.4.4.7 *Via dimensions*

For via dimensions we used a drill diameter of 12 mils and a pad of 22 mils. The drill can be made with a lower drill bit, but this can increase cost and the proper plating through along the via needs to be considered when using small drill diameters. In this case, the pad from drill to end of pad is 5 mils, which is more than enough to avoid DFM problems.

3.4.5 Layout Layers

3.4.5.1 *Layers Stackup*

The layer stack up for modules is simple and designed for full functionality. The main components are on the top side, leaving the battery connector and the protection diodes for reverse polarization on the bottom. Some of the modules have passive components like resistors on the bottom. In the case of Acceleration and Pressure modules, the transistors that perform the on/off function for the sensors power are placed on the bottom.

3.4.5.2 Top Layer

Figure 3-36 through Figure 3-40 illustrate the module's top layer.

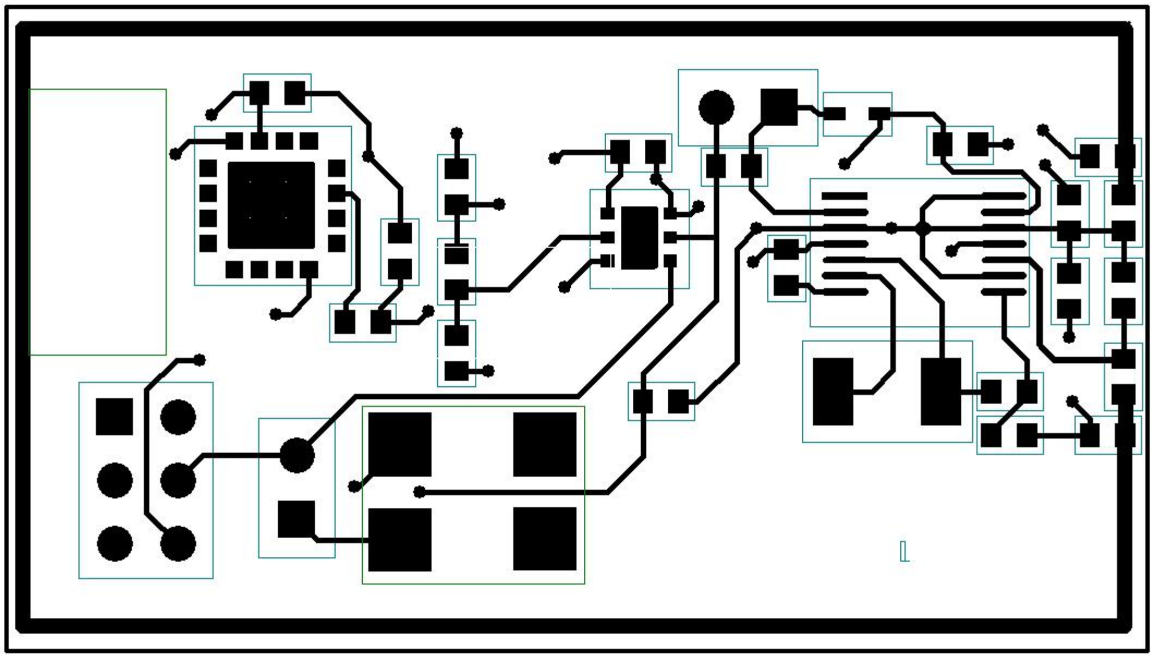


Figure 3-36. Acceleration Module Top Layer

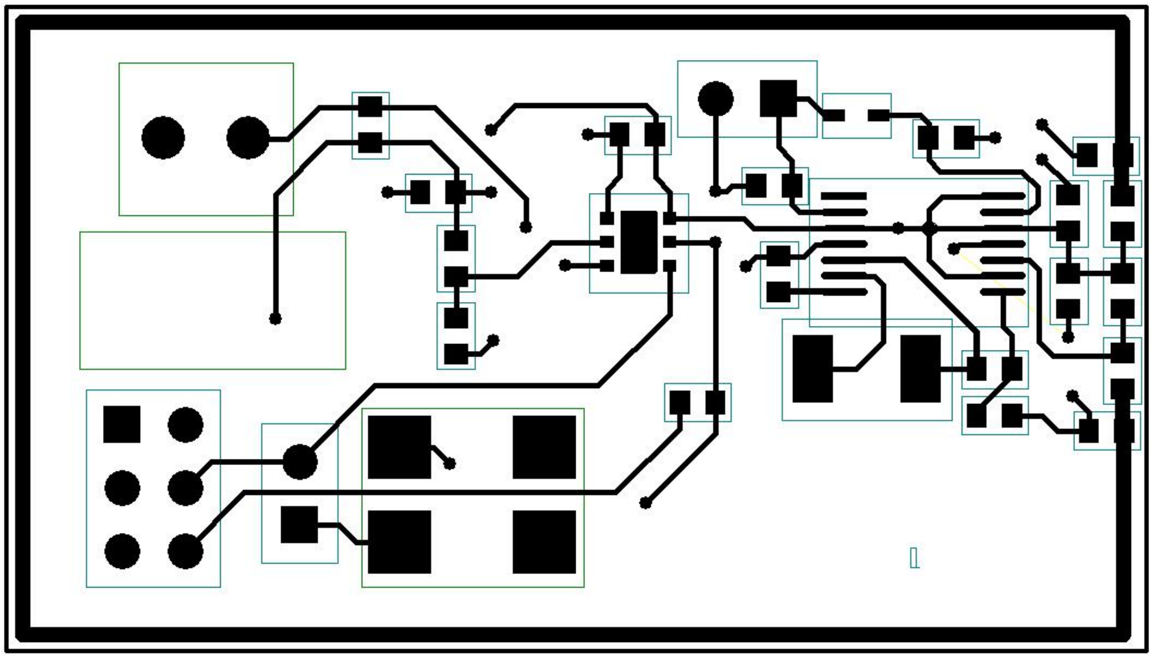


Figure 3-37. Lighting Module Top Layer

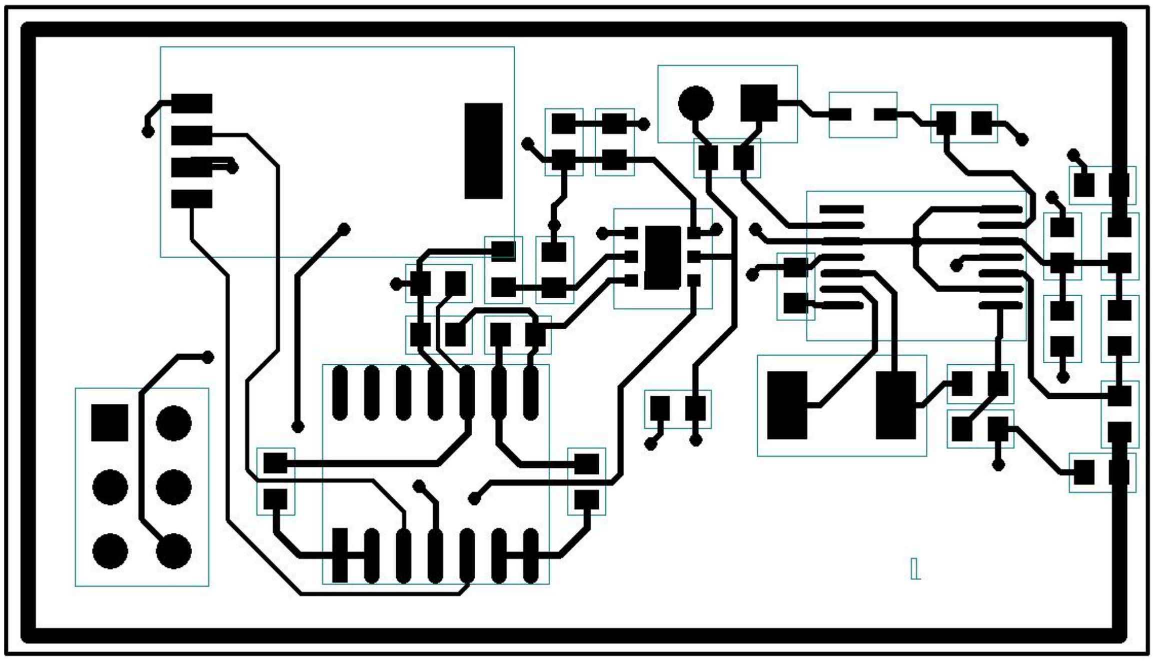


Figure 3-38. Pressure Module Top Layer

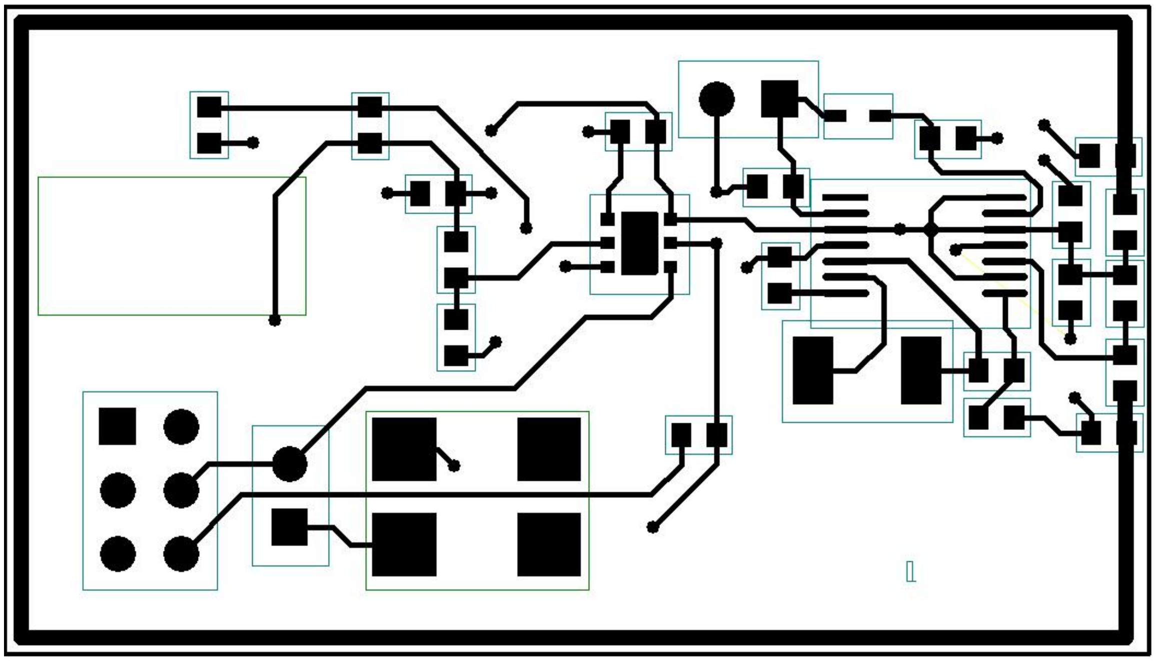


Figure 3-39. Temperature Module Top Layer

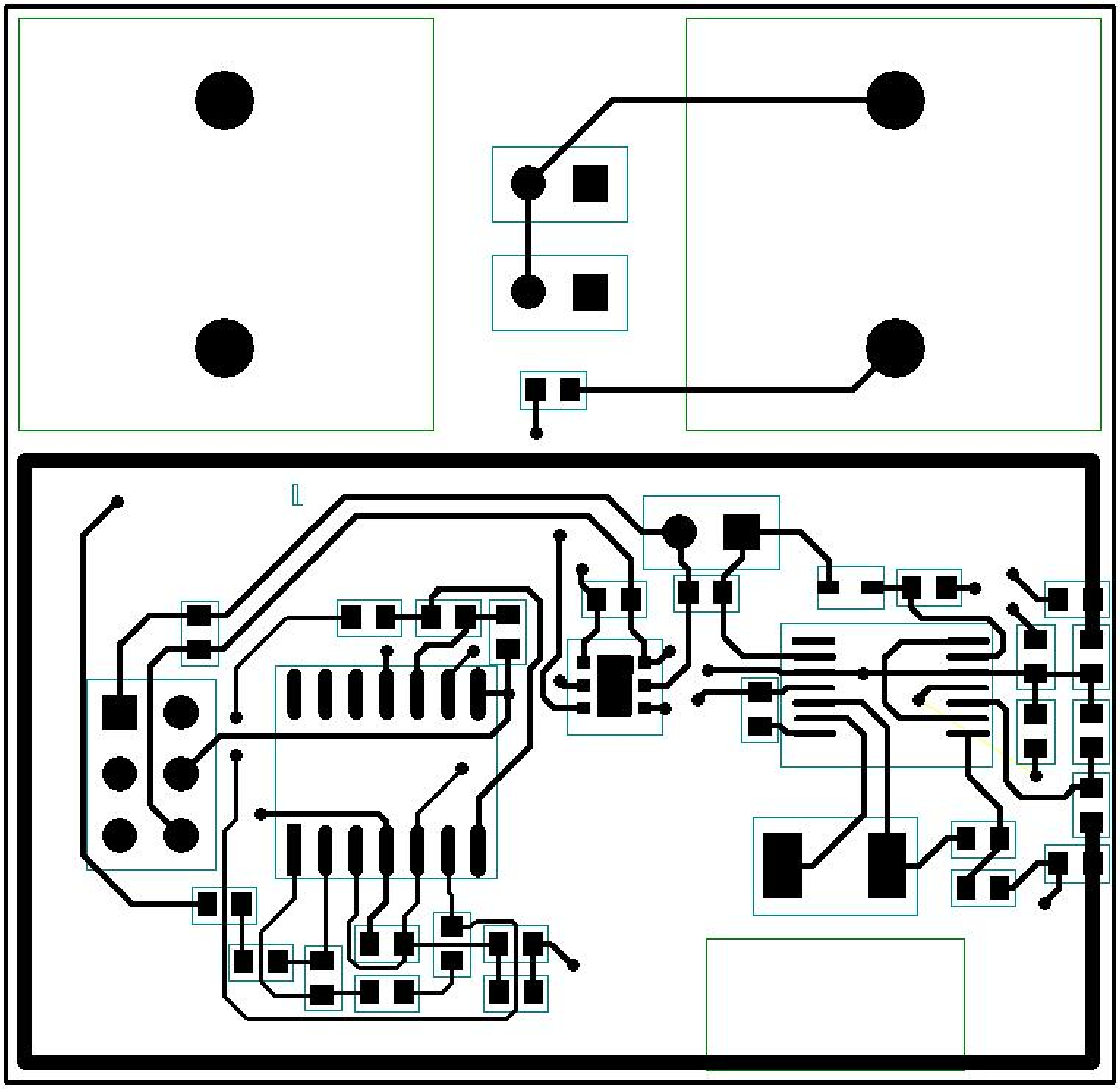


Figure 3-40. Ultrasound Module Top Layer

3.4.5.3 Bottom Layer

Figure 3-41 through Figure 3-45 illustrate the module's bottom layer.

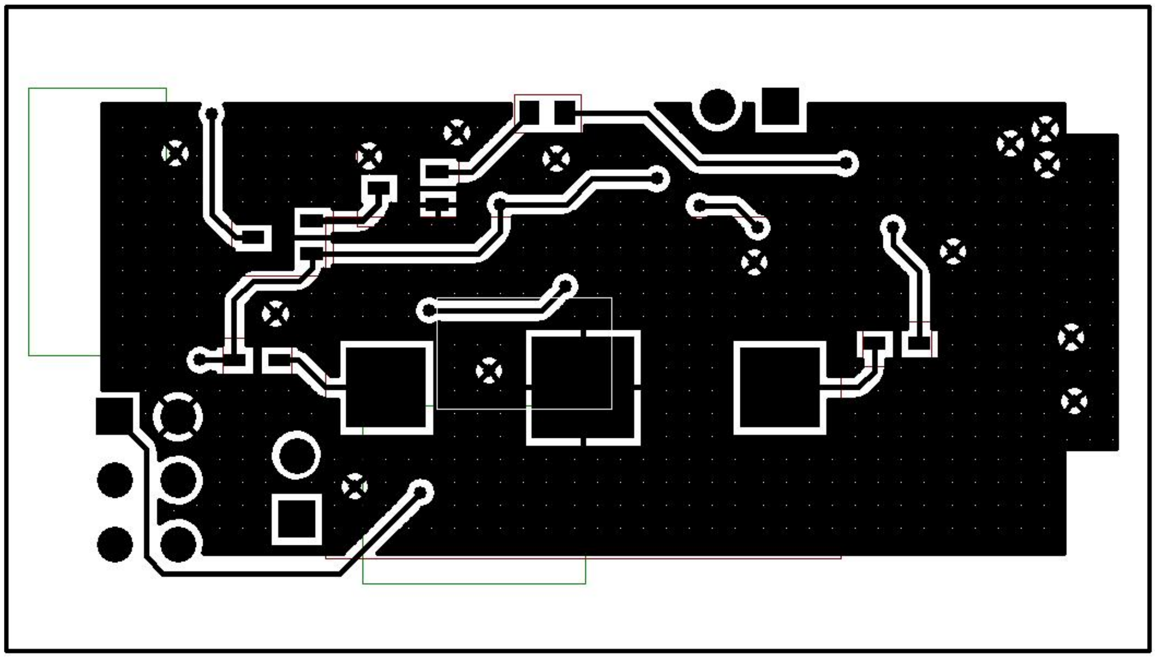


Figure 3-41. Acceleration Module Bottom Layer

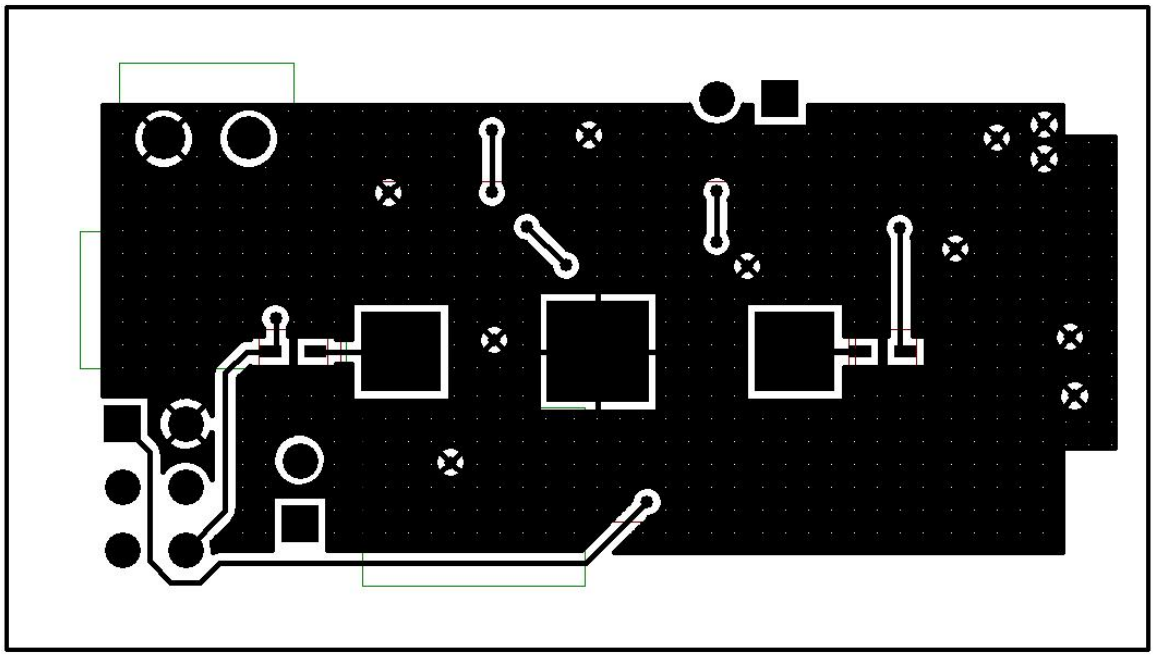


Figure 3-42. Lighting Module Bottom Layer

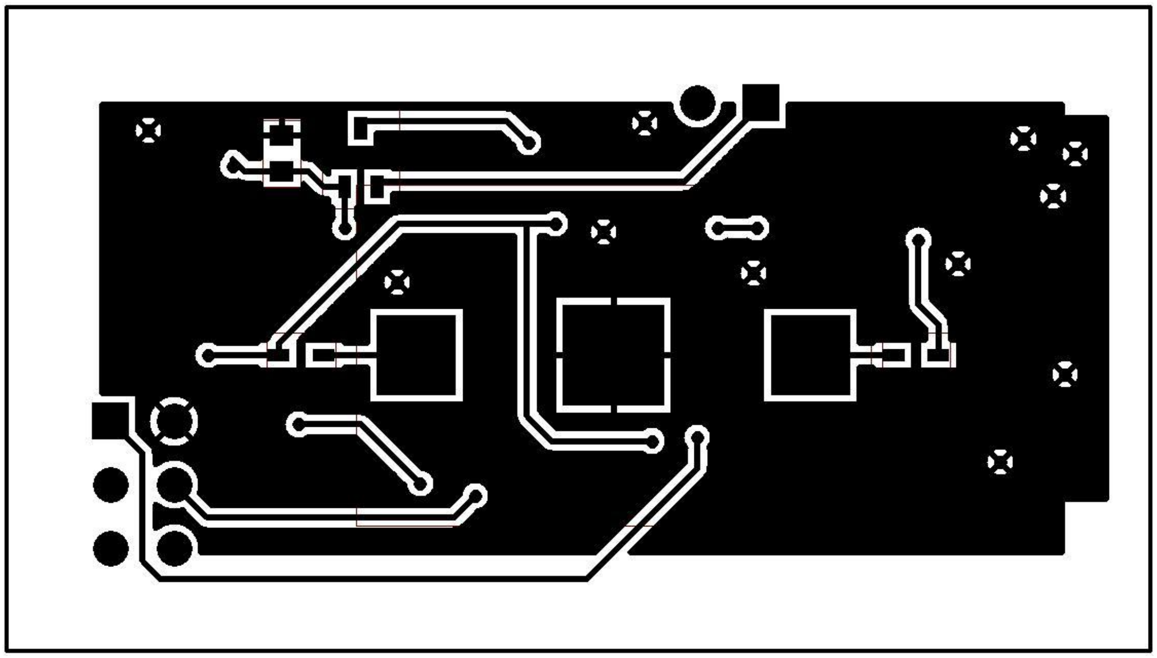


Figure 3-43. Pressure Module Bottom Layer

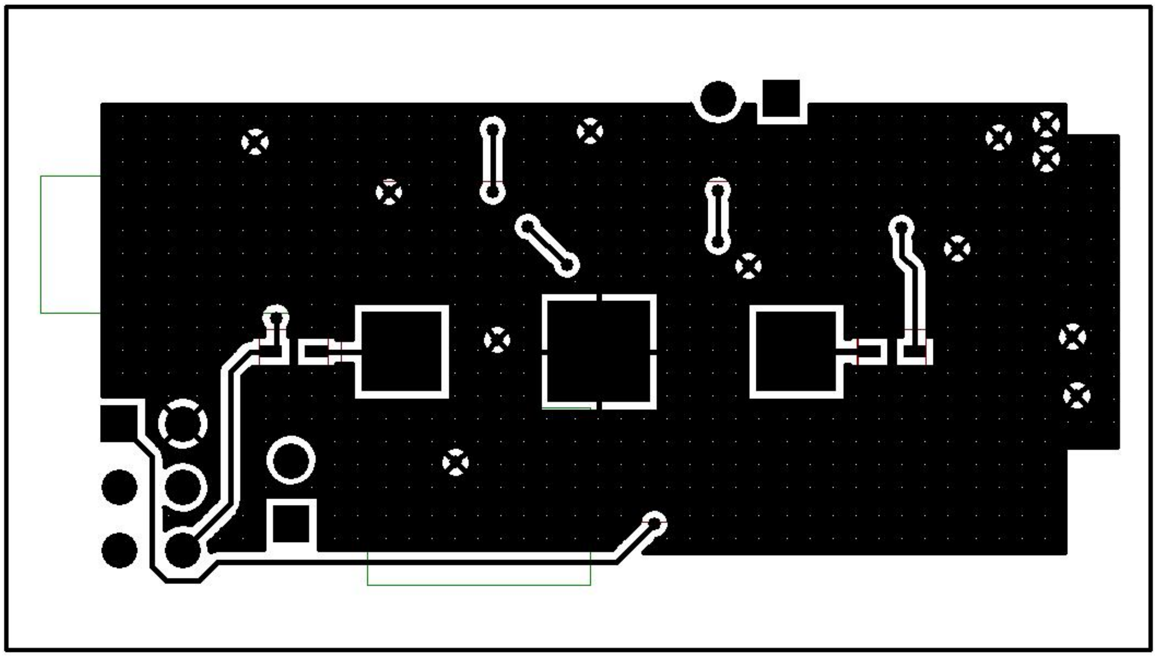


Figure 3-44. Temperature Module Bottom Layer

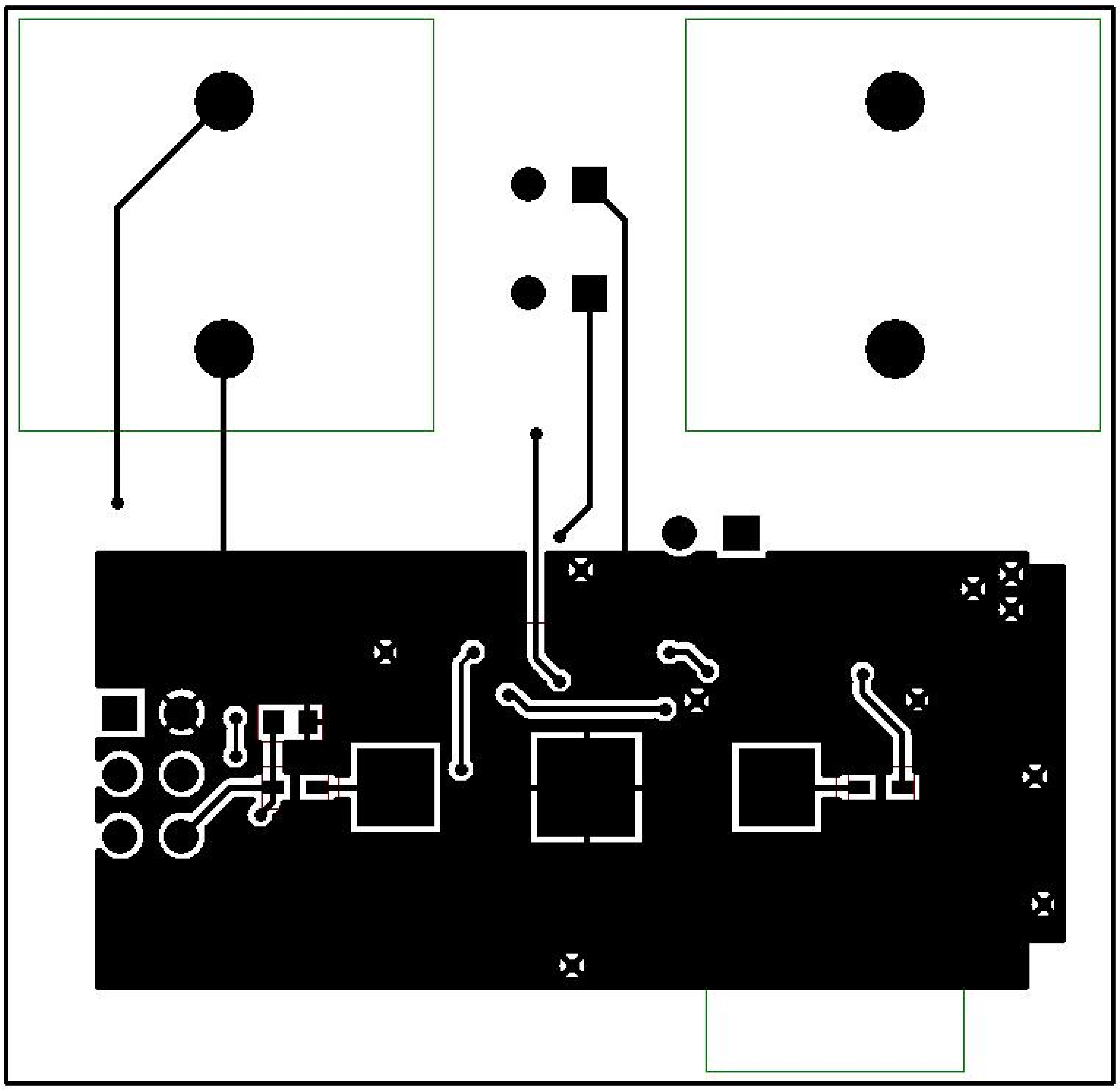


Figure 3-45. Ultrasound Module Bottom Layer

Chapter 4
Firmware Description

4.1 Introduction

This section of the reference design provides complete firmware documentation of the Low-Cost Wireless Sensors Using an MC9RS08KA2 (LCWi).

All firmware applications demonstrate the MC9RS08KA2 capacity to work with analog devices such as, the RF transmitters, sensors and op-amps. The basic analog sensors used in this reference design are: temperature, pressure, accelerometer, ultrasonic, photoresistor, and push-button

4.1.1 Firmware Basics

All embedded software of this project was written using CodeWarrior™ Development Studio for Freescale HC(S) 08/RS08 Microcontrollers, V5.1 which is Windows supported and can be downloaded at www.freescale.com.

4.1.2 Application Basics

This application's main purpose is monitoring the environment for different situations such as temperature, pressure, object positions, distance measurement, push-button, and lighting environment. These are controlled by an MC9RS08KA2 and the Tango RF Transmitter (MC33493).

4.2 Project Introduction

This section introduces and describes the firmware implementation.

4.2.1 Coding Conventions

All source codes are written in assembly language using several rules that make the final product more readable and reusable.

- Subroutines -- The main subroutine names for the Tango, ADC and TEAMAC drivers are written with capital letters and underscores after the driver name, for example, ADC_RECEIVE. Other subroutine names are written in uppercase at the beginning and underscored between words.
- Macros -- All macro names are written in capital letters, underscored, and follow the declaration, for example, TRIM_ICS: MACRO
- Tags -- All tags start in the first column of the code line.

4.2.2 Project Files

Files required for the project:

The following project files can be found inside the TANGOKA2SW folder. This folder contains three sub folders:

1. TangoKA2 -- contains the basic code to make all the wireless sensor applications (Tango driver, ADC driver, Encrypt algorithm and a basic main loop);
2. Sensor Applications -- contains all wireless sensors' applications that use the basic code from the TangoKA2 folder;
3. RomeoAP64 – contains the basic code for the Romeo RF receiver that is controlled with the 68HC908AP64.

Files for the MC9RS08KA2:

- Applications Project files (CodeWarrior tool project files):
  - Accelerometer.mcp
  - Pressure.mcp
  - Temperature.mcp
  - Ultrasonic.mcp
  - PushButton.mcp
  - Light.mcp
- Applications Source files (Contain the main application):
  - Accelerometer.asm
  - Pressure.asm
  - Temperature.asm
  - Ultrasonic.asm
  - PushButton.asm
  - Light.asm
- Driver files (must be included in all application projects):
  - TangoDriver.asm
  - RTeamac.asm
  - ADCdriver.asm (Not included in ultrasonic and push button projects).

Files for the 68HC908AP64:

- Applications Project files (CodeWarrior tool project files):
  - RomeoAP64.mcp
- Applications Source files (Contain the main application):
  - Romeo.c
  - Teamac.c
- Applications Header files
  - Teamac.h

4.2.3 Implemented MCU Peripherals

This section briefly describes the MC9RS08KA2 peripherals in the project and summarizes the necessary MCU resources.

4.2.3.1 *Implemented Interrupts*

Table 4-1 lists all interrupts used within the LCWi.

Table 4-1. Interrupts

Module	Type of Interrupt	Purpose
RTI	Asynchronous	Wakes up the MCU.
MTIM	Asynchronous	Generates the data baud rate and some clock configurations.
ACMP	Asynchronous	Make an ADC by software.

4.2.3.2 *Main Variables of Drivers*

Some of the most important variables and flags within the drivers are the following, which are also declared globally and used to control each application's functionality:

- key
- TEAMAC_DATA
- TEAMAC_CODE
- DATA
- Aux
- sum
- y
- z
- SensorReading
- ConvertedValue
- Temp_Page

4.2.3.3 *Memory Usage*

The following table shows the LCWi drivers' memory usage.

Table 4-2. Memory Usage

Driver	Type of Memory	Total Size (Bytes)	Used Memory (Bytes)	Free Memory (%)
TangoDriver.asm	Flash	800h	19Dh	Approx. 79.83%
	RAM	03Fh	00Fh	Approx. 76.19%
RTeamac.asm	Flash	800h	1C3h	Approx. 77.98%
	RAM	03Fh	003h	Approx. 95.23%
ADCdriver.asm	Flash	800h	152h	Approx. 83.5%
	RAM	03Fh	003h	Approx. 95.23%
All files	Flash	800h	4B2h	Approx. 41.31%
	RAM	03Fh	015h	Approx. 66.67%

4.3 Firmware Implementation

In this section the complete description of the key firmware modules of the LCWi is given.

4.3.1 Drivers Implementation

4.3.1.1 Tango RF Transmitter Driver

The Tango RF transmitter driver is in the TangoDriver.asm file. This driver provides the user the capability to send encrypted data via wireless.

The Tango RF transmitter driver controls the communication protocol between the MC9RS08KA2 and the Tango (MC33493). This communication protocol uses the Manchester coding and the Frequency-shift keying (FSK) modulation.

The main subroutine of this driver is TANGO_SEND_DATA. It is important to use one of the two baud rate macro configurations (BAUD_1400 or BAUD_2700) before calling this subroutine. The BAUD_2700 macro is the default baud rate configuration for all the LCWi modules. This baud rate must be configured in, the Transmitter (Tango) and the Receiver (Romeo) by firmware instructions. If you change the baud rate in the Tango RF transmitter driver you must change the baud rate in the Romeo RF receiver too.

To configure the baud rate on the Romeo RF Receiver:

1. The cr3 register is declared within the void main program.
2. If the value is 0x00, then the baud rate is set to 1400 bits per second (bps).
3. The default value is 0x40, which sets the baud rate to 2700 bps.
4. Set the desire baud rate, then build the project and download it to the 68HC908AP64. See Section 4.4 Programming LCWi boards and DEMO908AP64.

```
void main(void)
{
CONFIG1 = 0x03;       /* Disable COP, enable STOP instruction */
...

cr1 = 0x3F;
cr2 = 0xA5;
cr3 = 0x40;

Romeo_Transfer();
cr1 = cr1 | 80;
Romeo_Transfer();
...
}
```

The TANGO_SEND_DATA subroutine:

1. Sends the Preamble and ID. The ID must be recognized by the Romeo RF Receiver.
2. Then, it sends the Preamble and Header byte. The communication protocol for the Romeo2 MC33591 is explained in its technical data, which can be found in www.freescale.com.
3. Next, the information data is sent, in the following order:
    1. (TEAMAC_DATA) -- The encrypt data that is composed by two bytes of operator numbers.
    2. (TEAMAC_CODE) -- One byte of result.
    3. Sensor group -- Is the fourth byte sent, Table 4-3 shows the sensors groups and values.

4. Sensor ID -- Is the fifth byte sent, which is different to the ID received by the Romeo RF Receiver. The Sensor ID must be configured when there is more than one sensor on the same group.
5. The sixth and seventh bytes to send are the data information. The data information for this reference design belongs to the sensors.

Table 4-3. Sensors Groups and Values

Sensor	Group	Hexadecimal Value
Accelerometer	A	41h
Temperature	T	54h
Ultrasonic	U	55h
Pressure	R	52h
Light	I	49h
Push-button	P	50h

To configure or rename a Sensor ID:

1. In the TangoDriver.asm (inside the Sources folder), look for these code lines:

```
;*********************************************************************
;*                      Driver Constants                             *
;*********************************************************************
TANGO_FSK_HEADER     EQU   $60 ; FSK preamble (4 0's) and Header (0110)
DELTA                EQU   $9E
ID                   EQU   $A5 ; Romeo ID recognized

;*********** These constants can be modified by users *****************
ID2                  EQU   $01        ; Sensor ID
GROUP                EQU   $41        ; Sensor Group
```

2. The ID2 constant is the Sensor ID constant.
3. The default Sensor ID is 1 in hexadecimal format.
4. Change this value, when you have more than two sensors of the same group. The new ID must be in hexadecimal format and cannot be the same as another sensor of the same group.
5. Build the project and download it to the MC9RS08KA2. For building and downloading information see the Section 4.4 Programming LCWi boards and DEMO908AP64.

4.3.1.2 Reduce Encrypt TEAMAC Algorithm Driver

The encrypt algorithm is within the RTeamac.asm file that is included in the TangoDriver.asm file. The employed variables for this driver are in the TangoDriver.asm file.

This encrypt algorithm was based on the Teamac software algorithm, using 16 bytes instead of 64 bytes as the original. For this reason this encrypt algorithm was called reduce encrypt TEAMAC algorithm (RETA).

Basically, the encrypt algorithm generates an 8-bit message authentication code (MAC) from 16 bits of data and 16 bits of key.

The encrypt subroutine is called “ENCRYPT_TEAMAC”. This subroutine encrypts the Sensors ID stored in the variable TEAMAC_DATA, it performs a math operation with the TEAMAC_DATA and the key. The key is in the constants TEAMAC_KEY1 and TEAMAC_KEY2. At the end the result is stored in the variable TEAMAC_CODE.

Table 4-4. TEAMAC variables

Variable	Size in bytes	Description
TEAMAC_KEY1	1	Contains the first byte key for the algorithm.
TEAMAC_KEY2	1	Contains the second byte key for the algorithm.
TEAMAC_DATA	2	Contains the data to be encrypt.
TEAMAC_CODE	1	Contains the result after the algorithm finish.

TEAMAC_KEY1 and TEAMAC_KEY2

The Key for the RETA subroutine is stored in the TEAMAC_KEY1 and TEAMAC_KEY2 constants. The RETA subroutine uses the Key to encrypt the data and generates the result into the TEAMAC_CODE. In the transmitter, this Key contains a number which is configured by the manufacturer for each transmitter, but it could be reconfigured by the user for specific applications. This Key number must be the same in the receiver for to be recognized.

TEAMAC_DATA

The data to be encrypted by the RETA subroutine must be stored in the variable TEAMAC_DATA. For this reference design, this variable contains copies of the transmitter Sensors IDs and the rolling transmission counter.

TEAMAC_CODE

The MAC generated by the RETA subroutine is stored in a variable called TEAMAC_CODE. The transmitter sends this result and the encrypt data to the receiver for comparing results and verifies the MAC.

See the equivalent C code corresponding to the RETA function in the receiver.

```
extern unsigned char TEAMAC_Data[2];
extern unsigned char TEAMAC_Code;
extern unsigned char TEAMAC_Key[2];

void char2Long(unsigned char *pDest,const unsigned char *pSrce,unsigned char i)
{
         *pDest = 0;
    if (i==0){
                *pDest |= (*pSrce & 0x03);
      *pDest <<= 2;
      *pDest |= ((*pSrce & 0x0C)>>2);
      *pDest <<= 2;
      *pDest |= ((*pSrce & 0x30)>>4);
      *pDest <<= 2;
      *pDest |= ((*pSrce & 0xC0)>>6);
    }
    if (i==1){
                *pDest |= ((*pSrce & 0x0C)>>2);
      *pDest <<= 2;
      *pDest |= ((*pSrce & 0x30)>>4);
```

```
            *pDest <<= 2;
            *pDest |= ((*pSrce & 0xC0)>>6);
            *pDest <<= 2;
            *pDest |= (*(pSrce+1) & 0x03);
        }
        if (i==2){
                        *pDest |= ((*pSrce & 0x30)>>4);
            *pDest <<= 2;
            *pDest |= ((*pSrce & 0xC0)>>6);
            *pDest <<= 2;
            *pDest |= (*(pSrce+1) & 0x03);
            *pDest <<= 2;
            *pDest |= ((*(pSrce+1) & 0x0C)>>2);
        }
        if (i==4){
                        *pDest |= (*(pSrce+1) & 0x03);
            *pDest <<= 2;
            *pDest |= ((*(pSrce+1) & 0x0C)>>2);
            *pDest <<= 2;
            *pDest |= ((*(pSrce+1) & 0x30)>>4);
            *pDest <<= 2;
            *pDest |= ((*(pSrce+1) & 0xC0)>>6);
        }
}
void encipher(unsigned char *v,unsigned char *w,unsigned char *k)
{
       unsigned char y, z, sum, delta;
       unsigned char n;
       y=*v;
       z=*(v+1);
       sum=0;
       n=8;
       delta=0x9E;

       while(n-- > 0)
              {
              y += (((z << 4) ^ (z >> 5)) + z) ^ (sum + k[sum&3]);
              sum += delta;
              z += (((y << 4) ^ (y >> 5)) + y) ^ (sum + k[(sum>>3) & 3]);
              }
       w[0]=y; w[1]=z;
}
void main(void)
{
              ...

romeoReceiveBuffer[3]=RemoveFromBuffer(romeoReceiveBuffer[3],3);
romeoReceiveBuffer[4]=RemoveFromBuffer(romeoReceiveBuffer[4],4);
              romeoReceiveBuffer[5]=RemoveFromBuffer(romeoReceiveBuffer[5],5);
              romeoReceiveBuffer[6]=RemoveFromBuffer(romeoReceiveBuffer[6],6);

                        TEAMAC_Data[0]=RemoveFromBuffer(romeoReceiveBuffer[0],0);
                        TEAMAC_Data[1]=RemoveFromBuffer(romeoReceiveBuffer[1],1);
```

```
                              MACreceived=RemoveFromBuffer(romeoReceiveBuffer[2],2);

                                    char2Long(key, TEAMAC_Key,0);
                                    char2Long(key+1, TEAMAC_Key,1);
                                    char2Long(key+2, TEAMAC_Key,2);
                                    char2Long(key+3, TEAMAC_Key,4);

                                    encipher(TEAMAC_Data, cipherText, key);

                                    TEAMAC_Code = cipherText[0] ^ cipherText[1];

                                    if (MACreceived == TEAMAC_Code){
                                      EchoByte(&romeoReceiveBuffer[3]);
                                      EchoByte(&romeoReceiveBuffer[4]);
                                      EchoByte(&romeoReceiveBuffer[5]);
                                      EchoByte(&romeoReceiveBuffer[6]);
                                    ...
}
```

4.3.1.3 ADC Driver

The ADCdriver.asm file contains all the necessary resources for reading an analog signal and converting it to a digital signal. These resources use both hardware and firmware to accomplish the goal.

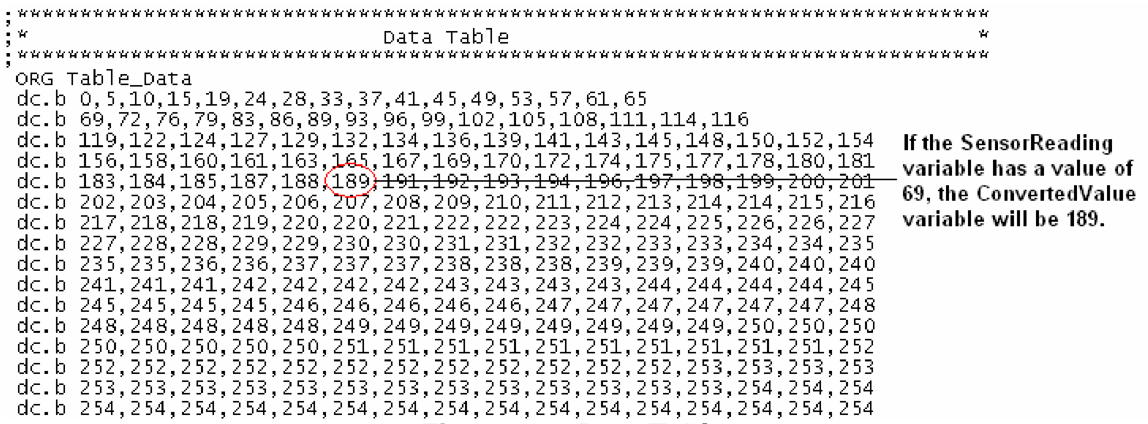
The hardware is an RC circuit that is controlled by the firmware instructions. These firmware instructions are composed by the ACMP and MTIM modules.

Pin (ACMP-) is configured as an output to charge the capacitor and reach the input value in the ACMP input pin (ACMP+) while the timer is running. Once the capacitor voltage is higher than the input voltage the ACMP module triggers an interrupt, the timer then stops counting and the timer value is saved in the SensorReading variable.

The SensorReading variable contains the capacitor’s delay time to reach the input voltage value. This time is an analog value. To obtain the digital value, a database table with the approximate ADC value depends on the timer counts, inside the SensorReading variable is used. If the SensorReading variable has a value of nine, the firmware looks for the ninth value from the database table and saves it into the ConvertedValue variable. The database table was calculated with a 2,772 voltage supply. Table 4-5 and Table 4-1 show the operation of the ADCdriver.asm file.

Table 4-5. ADCdriver

	Time	Voltage	ADC Value
0	0.000000	0.000000	0
1	0.000020	0.053620	5
2	0.000039	0.106190	10
3	0.000059	0.157760	15
4	0.000078	0.208320	19
5	0.000098	0.257910	24
6	0.000117	0.306530	28
7	0.000137	0.354220	33
8	0.000156	0.400980	37
9	0.000176	0.446840	41
10	0.000195	0.491810	45
11	0.000215	0.535920	49
12	0.000234	0.579170	53
13	0.000254	0.621580	57
14	0.000273	0.663170	61
15	0.000293	0.703960	65
16	0.000313	0.743960	69
17	0.000332	0.783190	72
18	0.000352	0.821650	76
19	0.000371	0.859380	79
20	0.000391	0.896370	83
21	0.000410	0.932650	86
22	0.000430	0.968230	89
23	0.000449	1.003110	93
24	0.000469	1.037330	96
25	0.000488	1.070880	99
26	0.000508	1.103780	102
27	0.000527	1.136050	105
28	0.000547	1.167690	108
29	0.000566	1.198720	111
30	0.000586	1.229150	114
…	…	…	…
255	0.00498	2.75295	254



```
;**************************************************************************
;*                              Data Table                               *
;**************************************************************************
 ORG Table_Data
 dc.b 0,5,10,15,19,24,28,33,37,41,45,49,53,57,61,65
 dc.b 69,72,76,79,83,86,89,93,96,99,102,105,108,111,114,116
 dc.b 119,122,124,127,129,132,134,136,139,141,143,145,148,150,152,154
 dc.b 156,158,160,161,163,165,167,169,170,172,174,175,177,178,180,181
 dc.b 183,184,185,187,188,189,191,192,193,194,196,197,198,199,200,201
 dc.b 202,203,204,205,206,207,208,209,210,211,212,213,214,214,215,216
 dc.b 217,218,218,219,220,220,221,222,222,223,224,224,225,226,226,227
 dc.b 227,228,228,229,229,230,230,231,231,232,232,233,233,234,234,235
 dc.b 235,235,236,236,237,237,237,238,238,238,239,239,239,240,240,240
 dc.b 241,241,241,242,242,242,242,243,243,243,243,244,244,244,244,245
 dc.b 245,245,245,245,246,246,246,246,246,247,247,247,247,247,247,248
 dc.b 248,248,248,248,248,249,249,249,249,249,249,249,249,250,250,250
 dc.b 250,250,250,250,250,251,251,251,251,251,251,251,251,251,251,252
 dc.b 252,252,252,252,252,252,252,252,252,252,252,252,253,253,253,253
 dc.b 253,253,253,253,253,253,253,253,253,253,253,253,253,254,254,254
 dc.b 254,254,254,254,254,254,254,254,254,254,254,254,254,254,254,254
```

If the SensorReading variable has a value of 69, the ConvertedValue variable will be 189.

Figure 4-1. Data Table

4.3.2 Sensors Applications

4.3.2.1 Accelerometer - Object Position Detection

The accelerometer is a device that can measure acceleration. It is a powerful tool that can be used in gravity measure, gyroscopes and in airbag deployment systems for modern automobiles. Accelerometers are perhaps the simplest micro electro-mechanical system (MEMS) device possible. Accelerometers are available in a wide variety of ranges like single axis, dual axis and three axis models.

For this wireless application the accelerometer is used to know exactly the side position of an object, and to know if a box inside a truck has fallen. It is then necessary to send the position information of this object using the RF transmitter device.

For this application it is important to include the TangoDriver.asm file and the ADCdriver.asm. The TangoDriver.asm provides all the necessary resources to send encrypted data via wireless to the Romeo RF receiver.

The ADCdriver.asm contains the capability to read an analog value that comes from the accelerometer sensor. This value from the accelerometer is divided in three stages to know the board position sides (front side, back side, top or bottom side). If the ADC obtains a value from 190 up to 255 (2 V– 2.753 V) the board is at front side, if the ADC value is between 120 and 190 (1.3 V– 2 V) the board is at back side, but if the ADC has a value from 35 up to 190 (0.37 V– 1.3 V) it means that the board is at top or bottom side.

For low power consumption it is necessary to maintain the accelerometer off if the MCU does not need information from it. It is very important to wait at least 24 ms before reading a value from the ADC after the accelerometer is turned on because of the signal warm up.

It is very important to make sure the two sensors do not work at the same time. They could have collisions when they transmit information via wireless. To solve that problem it is necessary to implement a simple random time algorithm that reduces collisions and ensures that data arrives. The RTI interrupt is enabled to wake up the MCU every 1.024 s. The random number permits sending the data in a range between 1 to 3 s. See next figure for understanding the accelerometer application.

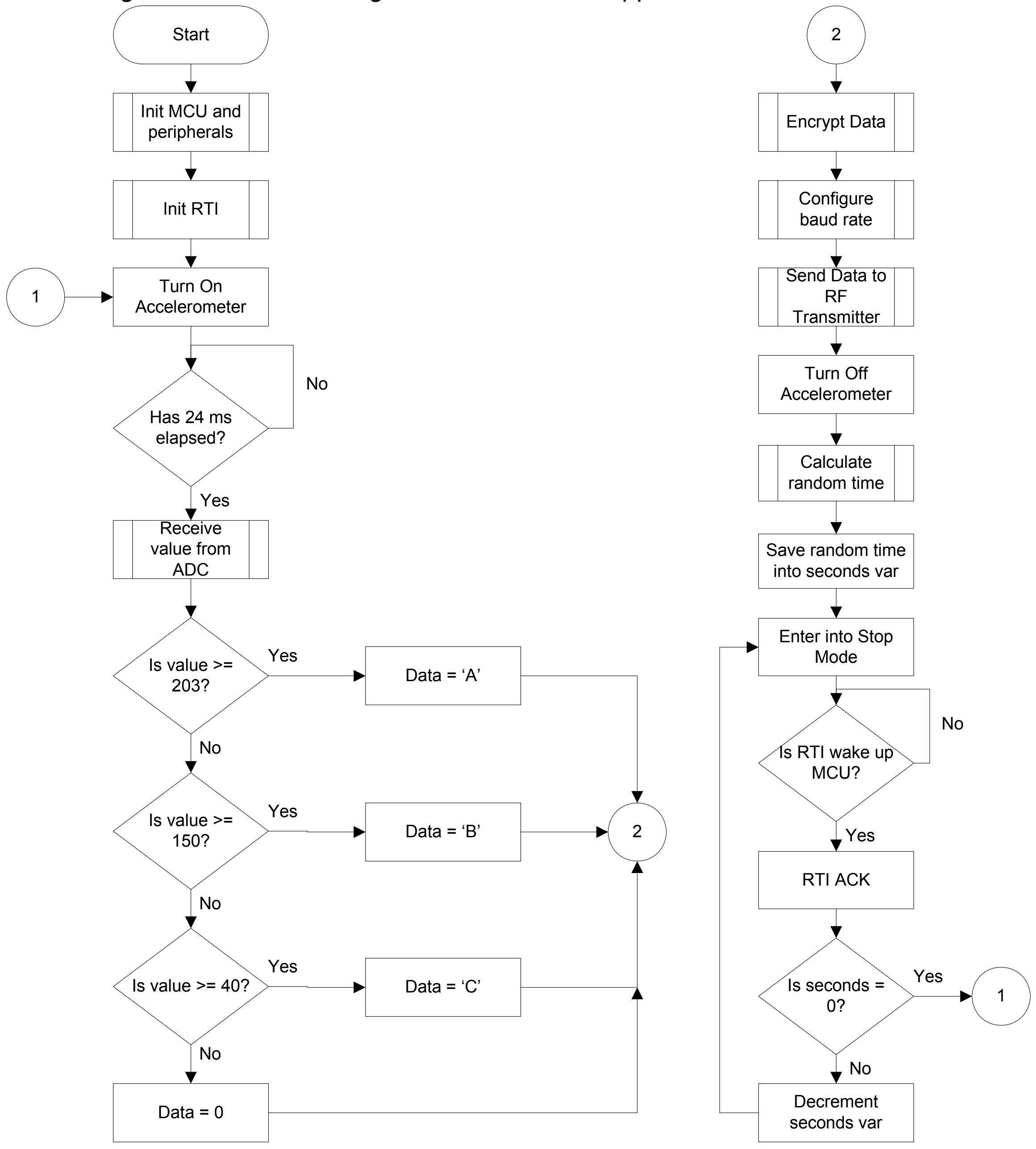


Figure 4-2. Accelerometer Firmware Block Diagram

4.3.2.2 Temperature

The temperature sensors are functional products that are used in a wide variety of applications and products such as weather measure, medical field, refrigerators, microwave ovens, irons, toaster, washing machines, dishwashers, cookers, deep freezers, ventilation, and automotive expertise to name some.

The temperature wireless sensor has some excellent features for small applications that need the temperature measure.

It is important to know the temperature range measure of these wireless sensors are from -8°C to 80°C. These sensors ensure a correct functionality within this range.

For this wireless sensor application it is important to include the TangoDriver.asm and the ADCdriver.asm files as in the accelerometer application. The TangoDriver.asm provides all the necessary resources to send encrypted data via wireless. The ADCdriver.asm contains the capability to read an analog value that comes from the thermistor voltage.

The temperature ADC table was obtained measuring the voltage on the thermistor with different temperature values from 10°C to 70°C with 5°C steps. Finally, the temperature and voltage values were put in graphics to obtain the correct voltage slope equation. After, all the temperature values from -14°C to 109°C are computed (Figure 4-3 to Figure 4-5).

Temperature	Voltage
10	1.850000
15	1.630000
20	1.520000
25	1.480000
30	1.230000
35	1.104000
40	0.978000
45	0.859000
50	0.770000
55	0.690000
60	0.617000
65	0.573000
70	0.527000

Figure 4-3. Temperature vs. Voltage

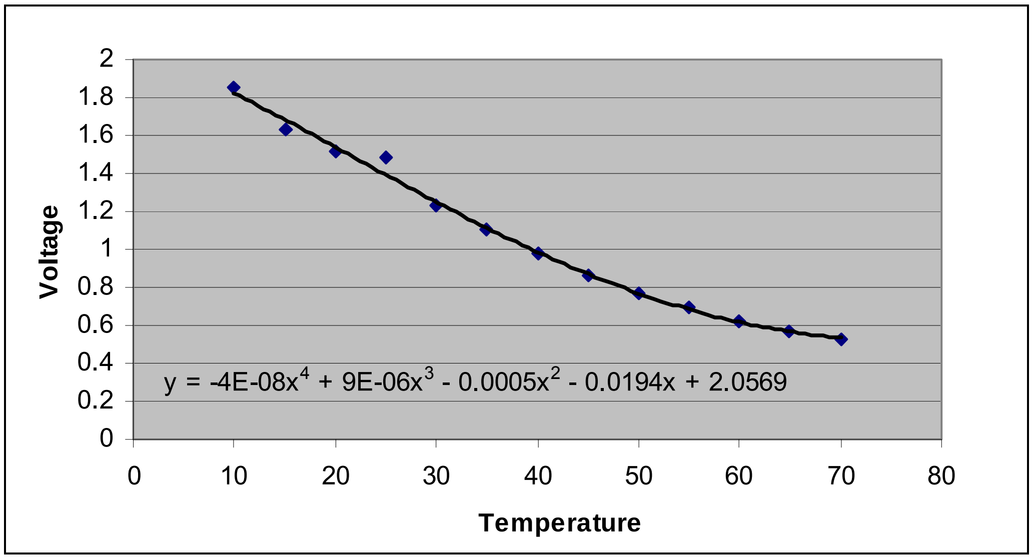


Figure 4-4. Temperature vs. Voltage Slope Equation Graphic

Temperature °C	Voltage	ADC Value
-14	2.204267	204.000000
…	…	…
5	1.948500	180.000000
6	1.924392	178.000000
7	1.899591	175.000000
8	1.874144	173.000000
9	1.848099	171.000000
10	1.821500	168.000000
11	1.794393	166.000000
12	1.766823	163.000000
13	1.738831	161.000000
14	1.710459	158.000000
15	1.681750	155.000000
16	1.652743	153.000000
17	1.623476	150.000000
18	1.593989	147.000000
19	1.564318	144.000000
20	1.534500	142.000000
21	1.504570	139.000000
22	1.474562	136.000000
23	1.444509	133.000000
24	1.414445	131.000000
25	1.384400	128.000000
…	…	…
109	0.010735	1.000000

Figure 4-5. Temperature vs. ADC Value

For low power consumption it is important to maintain the MCU in stop mode with the RTI interrupt enabled to wake-up the MCU every 1.024 s with a random number of times. This random number of times allows to send the data via wireless in a range between 1 second and 4.3 minutes to avoid collisions. Figure 4-6 illustrates this process.

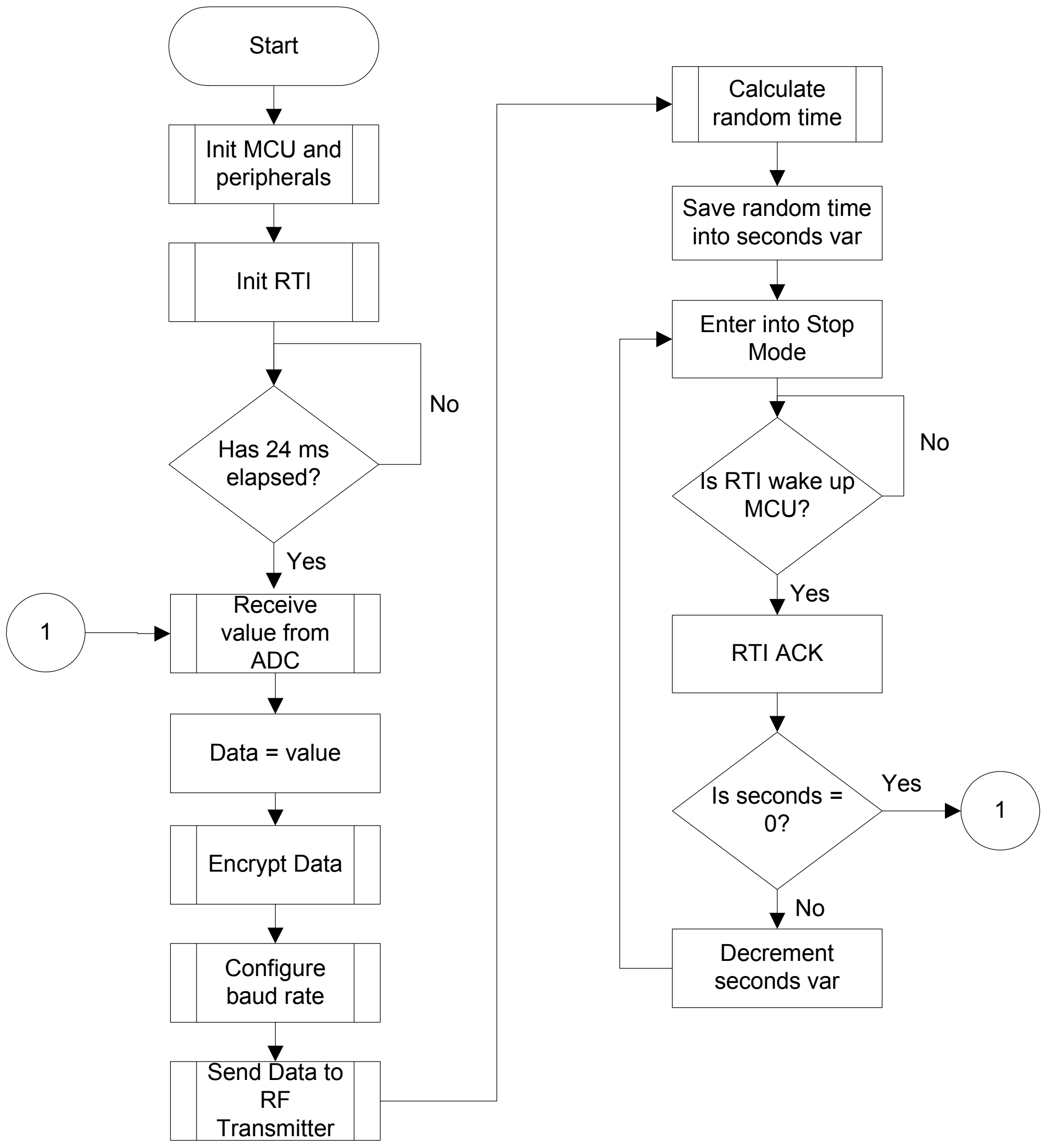


Figure 4-6. Temperature Firmware Block Diagram

4.3.2.3 Ultrasonic - Distance Measurer

The ultrasonic sensor is commonly used for non contact presence proximity or distance measuring applications. The basic use of the ultrasonic sensor in this design reference manual is for distance measured. This device transmits a short burst of ultrasonic sound (transmitter) toward a target, which reflects the sound back to another ultrasonic sensor (receiver) in a 40 kHz frequency. The MC9RS08KA2 MCU measures the time for the echo to return to the receiver and store the time value. After the MCU has reached this time, it sends the time information via wireless to the Romeo RF receiver. The Romeo RF receiver sends this to the computer to obtain the distance value from a table in the data base, that was calculated using the speed sound in the environment (330 m/s).

$$v = \frac{d}{t} \qquad\qquad d = v \cdot t$$

If you obtain a time of .00325 s there is a distance measure of (330m/s) x (.00325) = 1.0725 meters. The result time must be divided by two because this is the time the sound takes to reach the target and come back to the ultrasonic sensor receiver. The final result is (1.0725) / 2 = 0.53625 meters.

For this application it is important to include the TangoDriver.asm file for wireless encrypt communication. The ADCdriver.asm is not necessary. The ultrasonic sensor depends on the ultrasonic sound transmission, time and frequencies that are not in the voltage variation.

For low power consumption it is important to maintain the MCU in stop mode with the RTI interrupt enabled to wake up the MCU every 8 ms with a random number of times. This random number of times allows sending the data in a range of 8 ms to 2 s. Figure 4-7 illustrates this process.

The range distance measured for this application is between 20 and 124 cm. The distance from 0 to 20 cm can not be measured because of the external noise. The temperature in the environment could affect the results of the measurements.

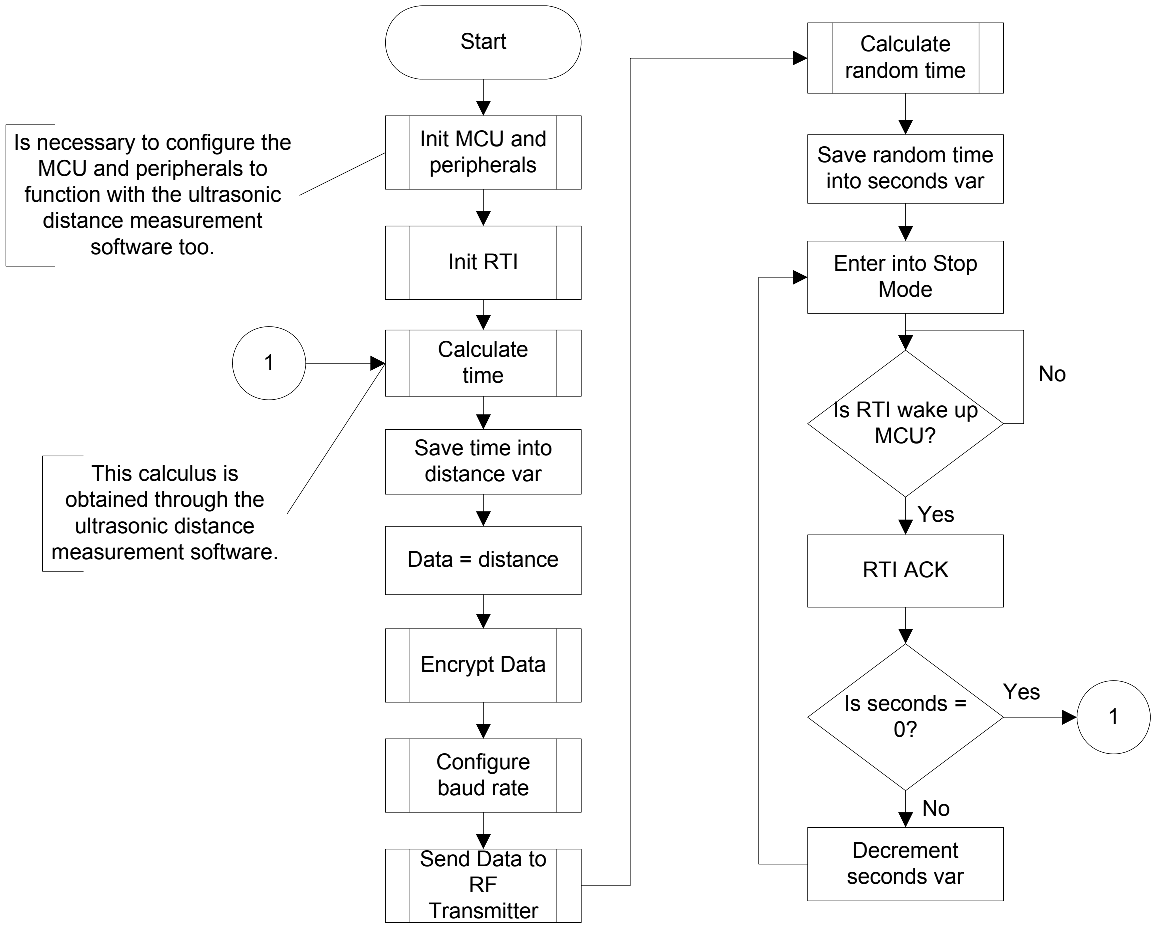

Start
Init MCU and peripherals
Is necessary to configure the MCU and peripherals to function with the ultrasonic distance measurement software too.
Init RTI
1
Calculate time
This calculus is obtained through the ultrasonic distance measurement software.
Save time into distance var
Data = distance
Encrypt Data
Configure baud rate
Send Data to RF Transmitter
Calculate random time
Save random time into seconds var
Enter into Stop Mode
Is RTI wake up MCU?
No
Yes
RTI ACK
Is seconds = 0?
Yes
1
No
Decrement seconds var

Figure 4-7. Ultrasonic Firmware Block Diagram

4.3.2.4 Pressure

A pressure sensor measures the pressure of gases or fluids. Pressure is an expression of force required to stop a gas or liquid from expanding. The main utility of pressure sensors are to monitor the pressure of fluids. In comparison with flow sensors, pressure sensors are cheaper. There are two major categories of pressure sensor applications: pressure sensing and altitude sensing. Some pressure sensing applications are weather instruments, gas pumps, cars. Some altitude sensing applications are aircraft, rockets, and satellites.

The LCWi pressure sensor application measures pressure levels from 0 to 10 kPa using a differential pressure sensor. Figure 4-8 shows the voltage measurements as a result of a 10 V source at a temperature of 25°C. It is necessary to use an op-amp to increment the differential voltage values.

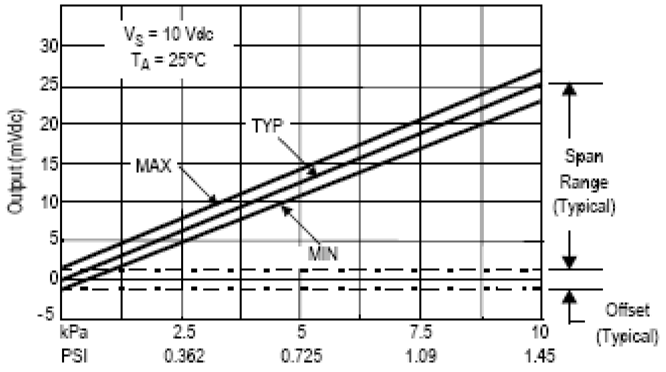


Figure 4-8. Voltage vs. Temperature

In this application the voltage supply to the pressure sensor is 2 V. It is necessary to adjust the kPa range, dividing the 10 kPa by 256 in order to obtain an ADC value.

The pressure sensor is a ratiometric device within the specified excitation range. Operating the device above the specified excitation range induces additional errors, due to device self-heating. This application does not give precise measurements because the supply voltage is out of work range. The objective of this application is to demonstrate the capability of the MC9RS08KA2 to work with analog devices.

In the LCWi pressure application it is important to include the TangoDriver.asm and the ADCdriver.asm files. The TangoDriver.asm provides all the necessary resources to send encrypted data to the Romeo RF receiver. The ADCdriver.asm contains the capability to read an analog value that comes from the differential voltage amplifier.

For low power consumption it is important to turn off the pressure sensor when the MCU does not need information.After turning on the pressure sensor, wait 24 ms before the MCU reads the data. Figure 4-9 illustrates this process.

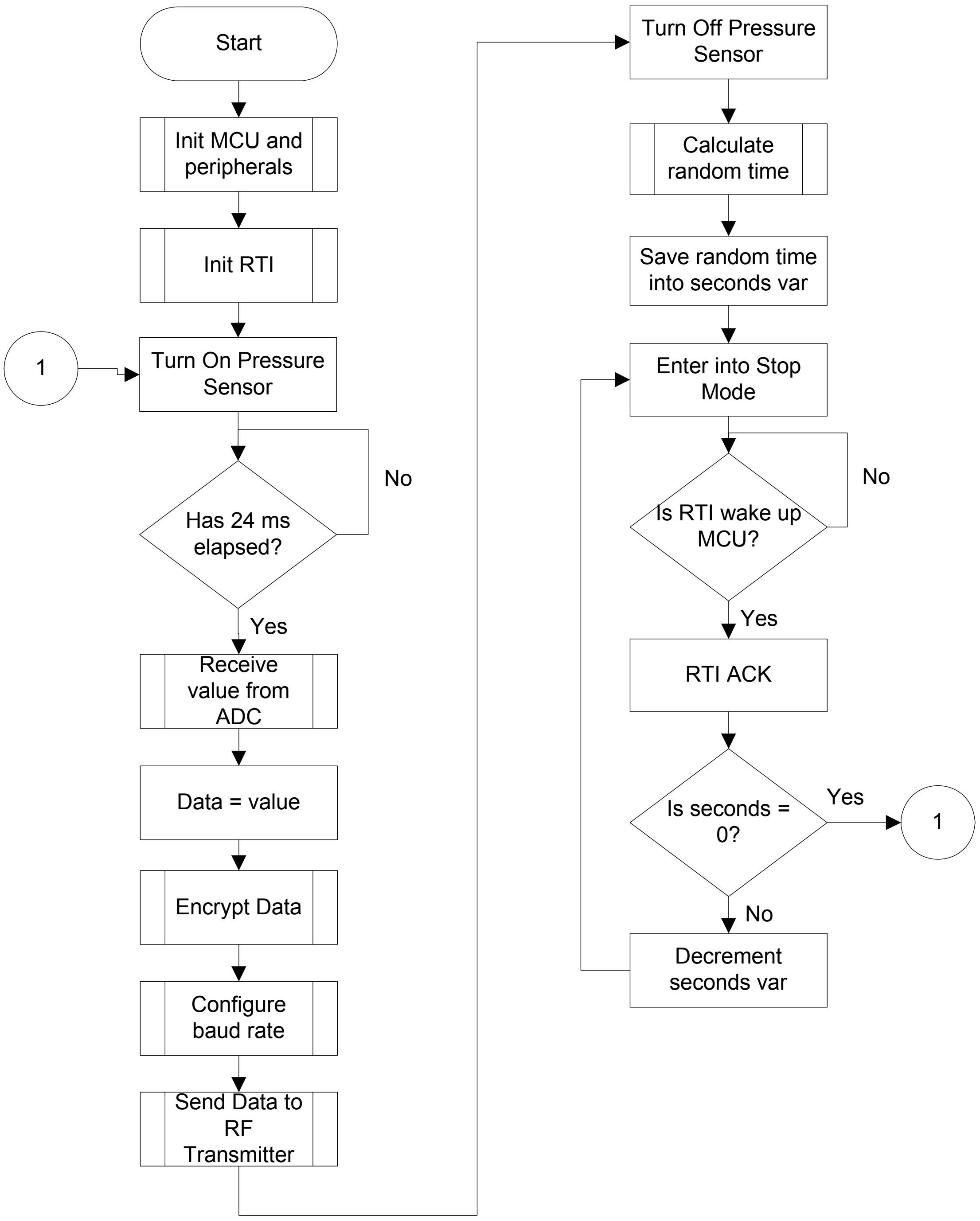


Figure 4-9. Pressure Block Diagram

4.3.2.5 Light

Light sensors are sensors that measure the amount of light. Easy applications of sensors are smoking detectors and automatic light ignitions.

In the LCWi application the sensor used measures three different ranges of light, high, medium and low intensities.

It is necessary to include the TangoDriver.asm and ADCdriver.asm files. The TangoDriver.asm file contains everything required to send encrypted data to the Romeo RF receiver via wireless. The ADCdriver.asm file has the capability to read an analog value from the photoresistor and convert it to a digital 8-bit number, 0-255. The value obtained from the photoresistor could be anything within the three ranges of light intensity. This depends on the light in the environment. If the ADC obtains a value from 150 up to 255 (1.62 V– 2.753 V) the light intensity is low; if the ADC value is between 75 and 150 (0.8 V– 1.62 V) the light intensity is medium; but if the ADC has a value from 10 up to 75 (0.11 V– 0.8 V) this means the light intensity is high.

For low power consumption it is important to maintain the MCU in stop mode with the RTI interrupt enabled to wake up the MCU every 1.024 s with a random number of times. This random number of times allows sending data in a range of 1 s to 1 min. Figure 4-10 illustrates the process.

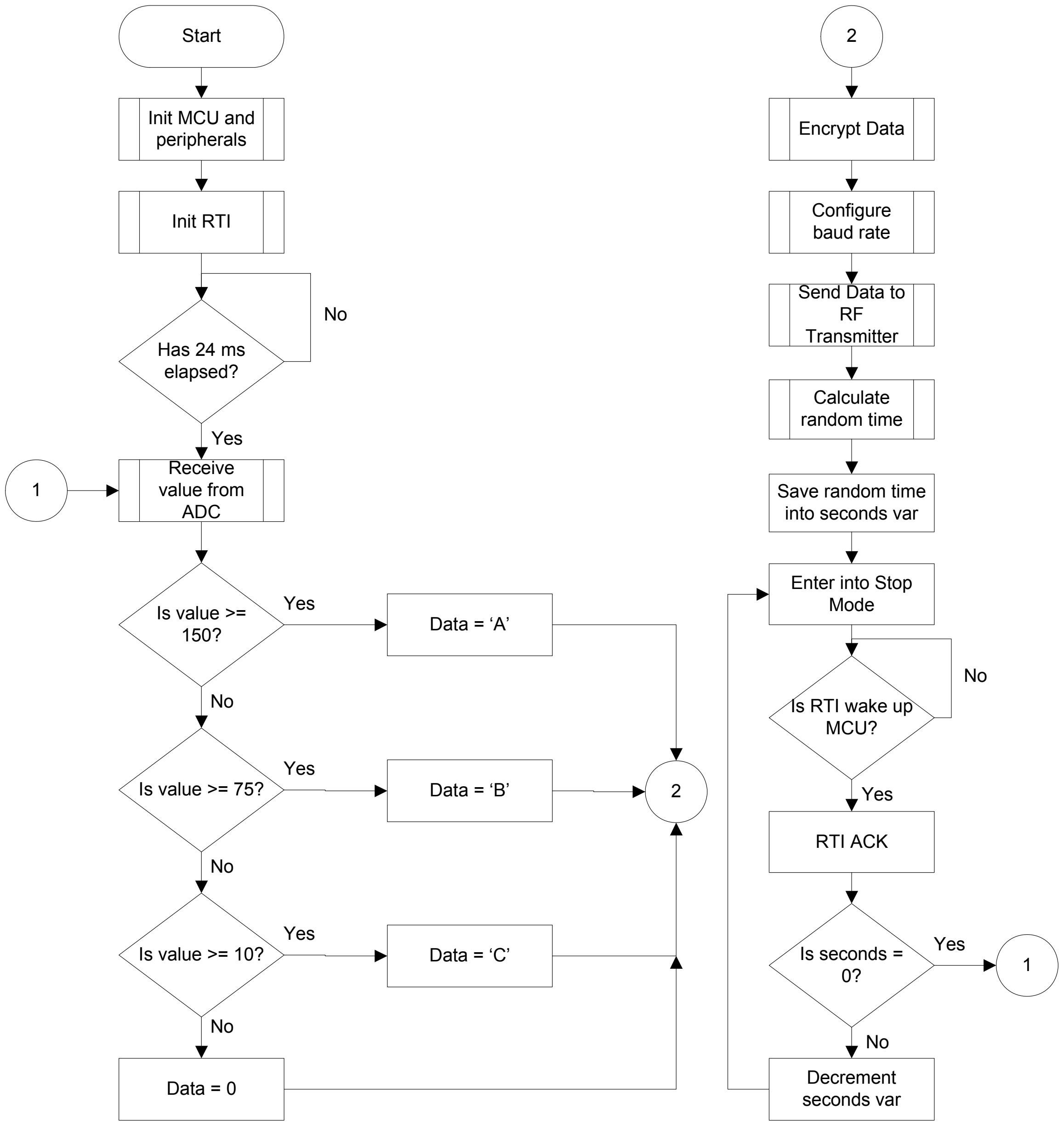


Figure 4-10. Light Firmware Block Diagram

4.3.2.6 Push-button

The LCWi push-button application was thinking for remote control consume such as toys, garage door openers, remote keyless and some other wireless control units.

For this application is necessary to include the TangoDriver.asm file only, because it only has to send an encrypting code when pressing a button, and not for monitoring the environment.

Basically the MCU is in stop mode all the time before you press the push button. Once you press the push button, two bytes of information is sending via wireless to the Romeo RF receiver to show in the Graphical

User Interface (GUI) a counter. This counter will increment every time the button had been pressed. These two bytes of information are sending encrypted. Figure 4-11 illustrates this process.

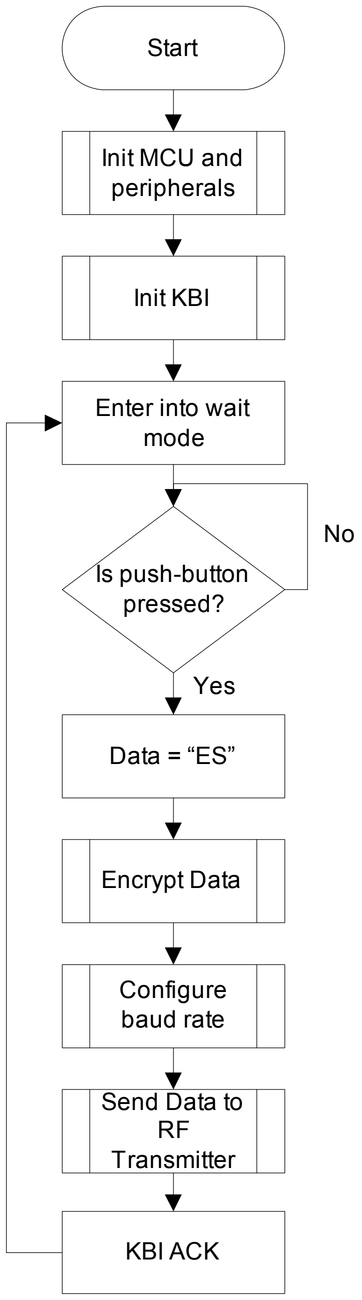


Figure 4-11. Push-button Firmware Block Diagram

4.4 Programming LCWi boards and DEMO908AP64

The CodeWarrior development tool for HC(S)08 must be installed. A copy of CodeWarrior IDE is supplied with the MC68HC908AP64 Demo Board. Follow the instructions supplied with the demo board to install CodeWarrior IDE.

4.4.1 Programming LCWi boards

4.4.1.1 Programming the Firmware

For programming the LCWi boards it is necessary to follow the next steps:

1. Open CodeWarrior integrated development environment (IDE) version 5.1.
2. Open the application.mcp file from the TANGOKA2SW/Sensors Applications/Application folder.
3. Change the MCU connections to P&E Multilink/Cyclone Pro.
4. Remove all jumpers from the boards.
5. Press the F7 function key for making the project.
6. Connect a 3.3 V power supply or battery to the power connectors on the boards.
7. Press the F5 function key to download the file into the flash memory.
8. In the ICD – Connection Manager window configuration, select USB HCS08/HCS12 Multilink (Rev C or Later) as an interface and press the Connect button.
9. When the CodeWarrior compiler asks to write into the flash memory, click on the yes button.
10. Finally the CodeWarrior compiler starts to download the file into the flash.

NOTE

If any problem occurs when trying to write into the flash memory, turn off the power supply. Turn it on again and at the same time press the Connect button again.

4.4.1.2 Using the Firmware

For using the firmware the jumpers must be place on the boards, except the Ultrasonic sensor board. For the ultrasonic sensor board place jumpers J2 and J5 only.

4.4.2 Programming DEMO908AP64

4.4.2.1 Programming the Firmware

If the RomeoAP64 has already been programmed into the MC68HC908AP64 Demo Board, the user can begin to use the Romeo RF Transmitter. To program the Romeo AP64:

1. Install power select PWR_SEL jumpers 1 and 2 on the MC68HC908AP64 Demo Board.
2. Install VST_EN jumper.
3. Install MON_EN jumper.
4. Select setting DEBUG on COM_SEL header.
5. Install jumper across pins 1 and 2 of header OSC_SEL.
6. Install all USER_EN jumpers.
7. Connect the serial port connector on the MC68HC908AP64 Demo Board to a PC comm. port using a 9-pin straight-through serial cable.
8. Connect a 9 V power supply or battery to the power connector of the MC68HC908AP64 board.
9. Unzip file RomeoAP64.zip, which is contained within the TANGOKA2SW.zip. This unzips a CodeWarrior project containing the programming file for the application.
10. Start CodeWarrior IDE.
11. Select File/Open and open the file RomeoAP64.mcp. This opens a CodeWarrior project.
12. In CodeWarrior IDE, click on file RomeoAP64 in the Target window. Then press key F5 or select

Project/Debug from the menu bar. This launches the debugger, which communicates with the MC68HC908AP64 Demo Board and attempts to burn the Romeo RF Receiver program into FLASH memory on the MCU. The Attempting to contact target and pass security window should appear. Make sure the following options are configured correctly.

   a. Target Hardware Type: Class 3.
   b. Serial Port: 1 this depends on the PC COM Port.
   c. Baud: 19200 baud rate.
   d. Target MCU security bytes: Check the, IGNORE security failure and enter monitor mode, check box.

13. Click the Contact target with these settings button and follow the instructions on the screen. When the, Erase and Program Flash? window, appears, click the Yes button.
14. Follow the on-screen instructions for cycling the MCU power supply. The CPROG08SZ Programmer window should close after the MCU FLASH is programmed.
15. The Romeo RF Transmitter program has now been programmed into the FLASH memory of the MC68HC908AP64. CodeWarrior IDE is no longer required. Shut all CodeWarrior windows and exit the program.

4.4.3 Setting the Romeo RF Receiver

To use the Romeo RF Receiver, the hardware must be set up as follows:

NOTE

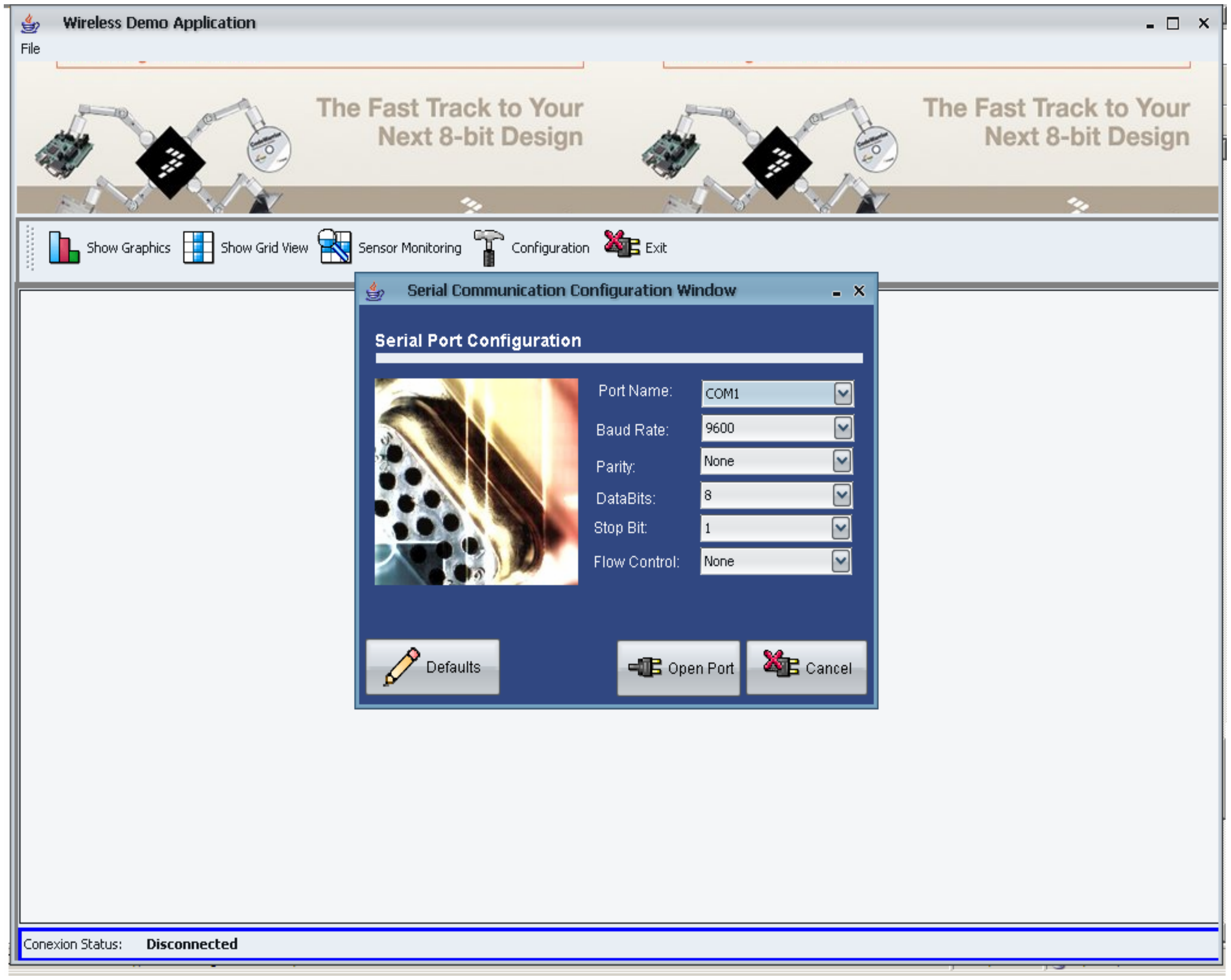
Romeo2 RF modules are available in a range of frequencies, each is supplied with an appropriate antenna.

1. Connect the Romeo2 RF Module to connector J1 on the MC68HC908AP64 Demo Board. Pin 1 on each board must be aligned.
2. Connect an antenna to the Romeo2 RF module.
3. Install power select PWR_SEL jumpers 1 and 2 on the MC68HC908AP64 Demo Board. Both jumpers must be installed.
4. Remove VST_EN jumper.
5. Remove MON_EN jumper.
6. Install jumper across pins 1 and 2 of header OSC_SEL.
7. Install jumper on COM setting of COM_SEL header.
8. Install all USER_EN jumpers.
9. Connect the serial port connector on the MC68HC908AP64 Demo Board to a PC comm. port using a 9-pin straight-through serial cable.
10. Connect a 9 V power supply or battery to power connector on MC68HC908AP64 board.

Chapter 5
Graphical User Interface

5.1 Introduction

This document demostrates how to use the Wireless Demo Application graphical user interface (GUI) quickly and effectively. There are ten sections that take you through how to configure and use the LCWi modules. Figure 5-1 shows the main Wireless Demo Application window.



Wireless Demo Application
File
The Fast Track to Your Next 8-bit Design
Show Graphics
Show Grid View
Sensor Monitoring
Configuration
Exit
Serial Communication Configuration Window
Serial Port Configuration
Defaults
Open Port
Cancel

Port Name: COM1
Baud Rate: 9600
Parity: None
DataBits: 8
Stop Bit: 1
Flow Control: None

Conexion Status: Disconnected

Figure 5-1. Wireless Demo Application

5.2 Wireless Demo Application Graphical User Interface

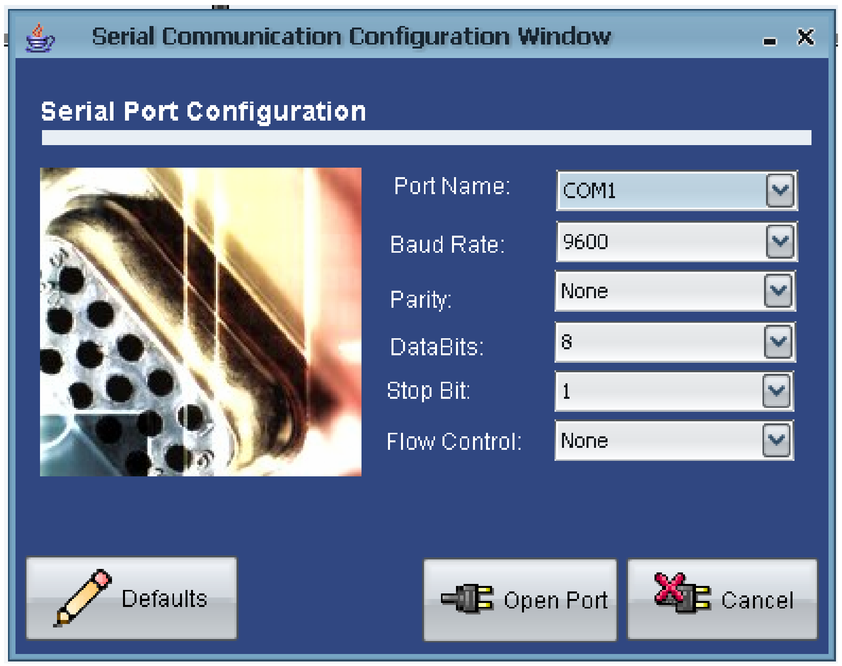
5.2.1 Port Configuration

When the LCWi software starts, it automatically scans the ports and a window pops up to configure them. Figure 5-2. shows the serial port configuration window. All ports are displayed in a pull-down menu. Select one. The baud rate must be set to 19200. The rest of the configuration options must be left as is.

When the desired configuration is set, press “Open Port”. In that moment, the LCWi scans for any available sensors on the network. A message appears on the main window: “Waiting for Incoming Sensor Data” (Figure 5-3.).

If the port chosen is busy after pressing “Open Port”, a message says “Port not available”. Select another port.

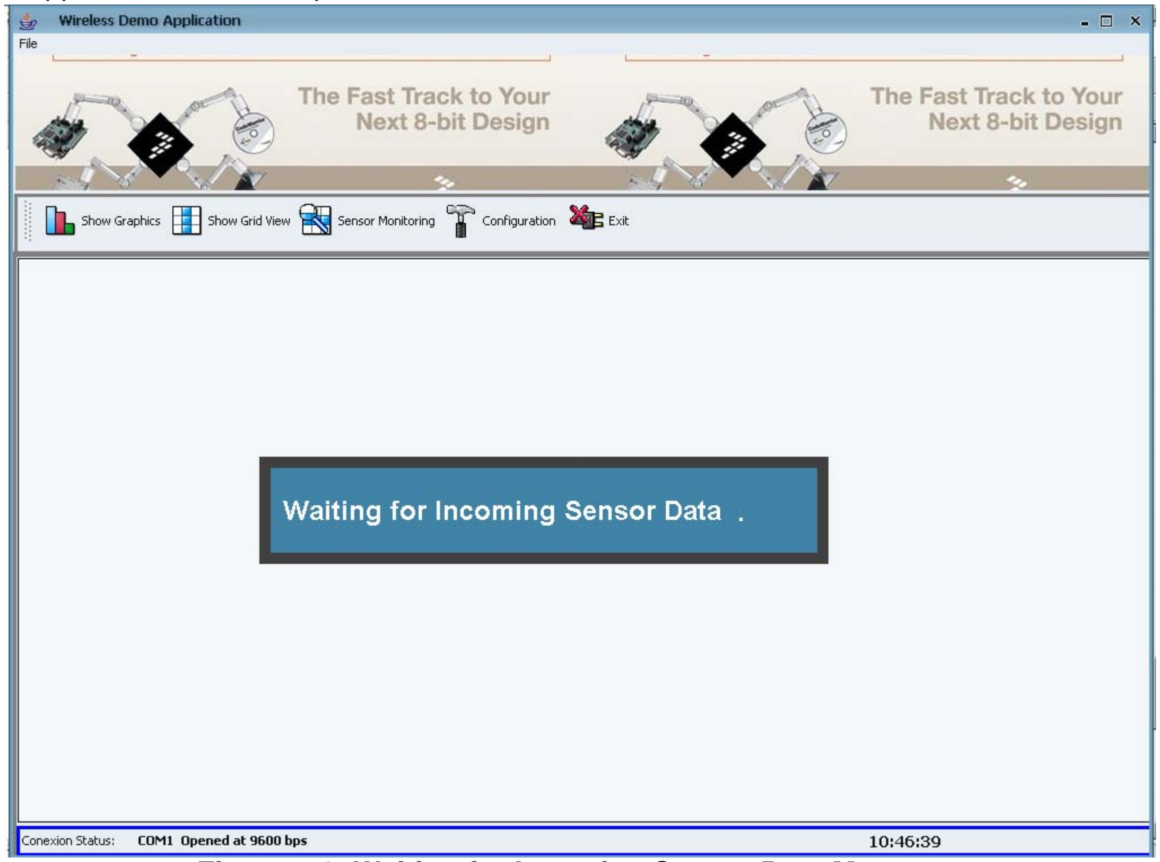
“Cancel” closes the software automatically because without configuring the ports there is no communication.


Serial Communication Configuration Window
Serial Port Configuration
Defaults
Open Port
Cancel

Port Name: COM1
Baud Rate: 9600
Parity: None
DataBits: 8
Stop Bit: 1
Flow Control: None

Figure 5-2. Serial Port Configuration

After the LCWi finishes the scan and detects the available sensors inside the network, a cascade of windows appears, one window per sensor.


Wireless Demo Application
File
The Fast Track to Your Next 8-bit Design
Show Graphics
Show Grid View
Sensor Monitoring
Configuration
Exit

Waiting for Incoming Sensor Data .

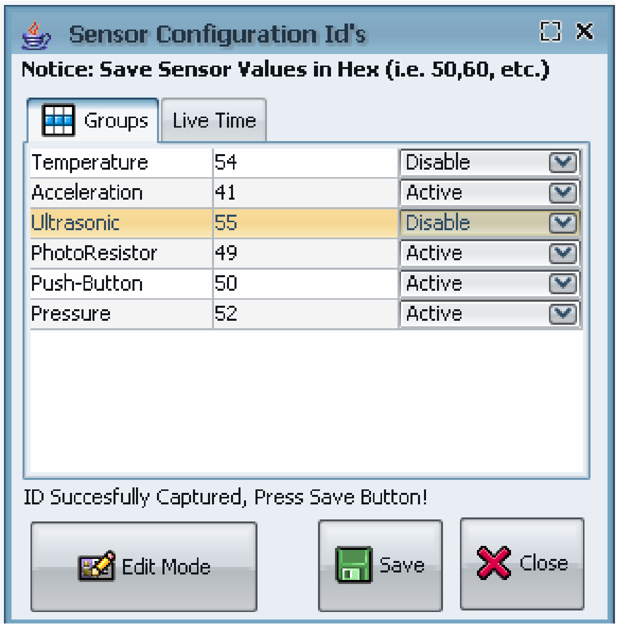
Conexion Status: COM1 Opened at 9600 bps 10:46:39

Figure 5-3. Waiting for Incoming Sensor Data Message.

5.2.2 Sensor Id Configuration

The LCWi reads a Config.dat file, if this one does not exist then is generated. That file saves the sensors configuration per id. An improper use of this file can dramatically affects the LCWi operation.

To configure the sensors click on the Configuration button in the main menu. The configuration window has two tabs: Groups and Live Time (Figure 5-4).



Notice: Save Sensor Values in Hex (i.e. 50,60, etc.)

Temperature	54	Disable
Acceleration	41	Active
Ultrasonic	55	Disable
PhotoResistor	49	Active
Push-Button	50	Active
Pressure	52	Active

ID Succesfully Captured, Press Save Button!

Figure 5-4. Groups Tab in Sensor Configuration Id's Window.

The Groups tab shows the ID for each group of sensors in the second column and their respective status in the third column. The ID must be in hexadecimal. If the status for one group is inactive, the LCWi ignores any data sent from a sensor of that group.

To change a sensor ID or status, select the Params Blocked button at the left bottom of the window. The Edit Mode is now enable, type the new id or select a status and then select save or close to cancel.

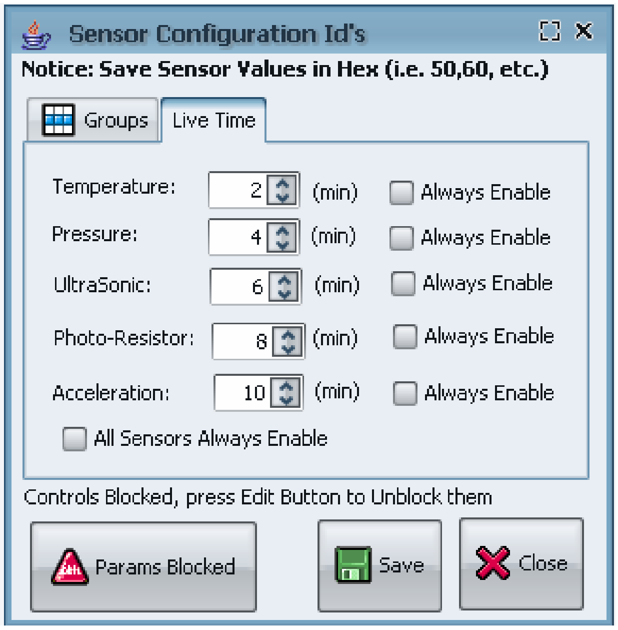
NOTE

The ids must be written in hexadecimal.

When the save button is pressed a message saying "New Configuration Succesfully Saved!" confirms the changes have been made. If the new id is already assigned to another sensor group, changes could not be save and a message saying "Identical ID's" appears.

The Live Time tab allows configuring the life time of every sensor window from 1 to 60 minutes. Once the "Live Time" period ends the sensor window automatically closes until new data arrives. If the checkbox "Always Enable" is checked then the window does not expire, eventhough the sensor is not sending data to the LCWi.

The checkbox “All Sensors Always Enable” when selected enables all the sensor windows to be opened without expire time. Figure 5-5 shows the Live Time tab.


Sensor Configuration Id's

Notice: Save Sensor Values in Hex (i.e. 50,60, etc.)

Temperature: 2 (min) ☐ Always Enable

Pressure: 4 (min) ☐ Always Enable

UltraSonic: 6 (min) ☐ Always Enable

Photo-Resistor: 8 (min) ☐ Always Enable

Acceleration: 10 (min) ☐ Always Enable

☐ All Sensors Always Enable

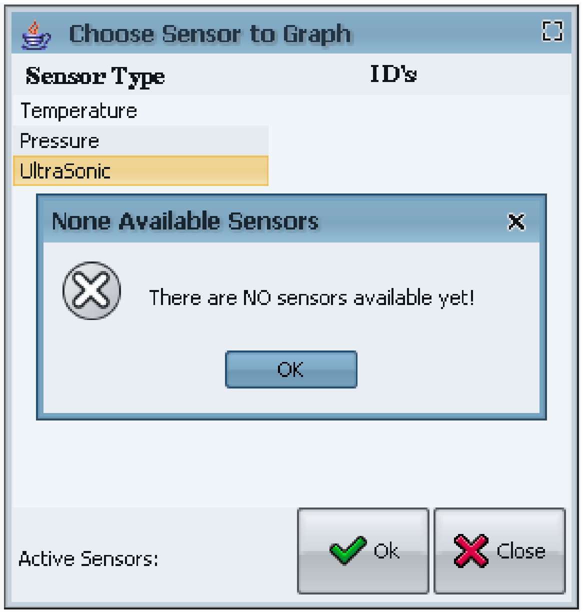
Controls Blocked, press Edit Button to Unblock them

Figure 5-5. Live Time Tab in Sensor Configuration Id’s Window

5.2.3 Show Graphics

First off, go to the Show Graphics button on the menu bar and then select the sensor to graph in the "Sensor Type" column. The options to graph are the temperature, pressure and ultrasonic groups, one group at the time. In the “ID’s” column select the id to graph.

When the selection is set press the Ok button, to select more than one use CTRL. If there are not sensors at that moment a message saying “There are NO sensors available yet!” appears, click OK and make the selection again. Figure 5-6 shows the “Choose Sensor to Graph” window.



There are NO sensors available yet!

Figure 5-6. Choose Sensor to Graph

The graphs are time based and as default show the three thresholds set for each sensor group (v, a y r). To remove them from the graph select the “Remove Markers” checkbox. The “Display Items Info” if selected shows the value readen by the sensor.

The “Keep Track Progress” option allows to set an specific number of tracks to show in the graph, write the desired number in the blank space. When disable, the graph displays as many data as readen by the sensor.

The column “Add & Remove Sensors” shows all sensors available for that group and their status in the graphic, to remove any sensor from the graph change the status. The graph can be save in pdf format and the default name is Chart.pdf, after save the message “Document Succesfully Saved!” is displayed (Figure 5-7).

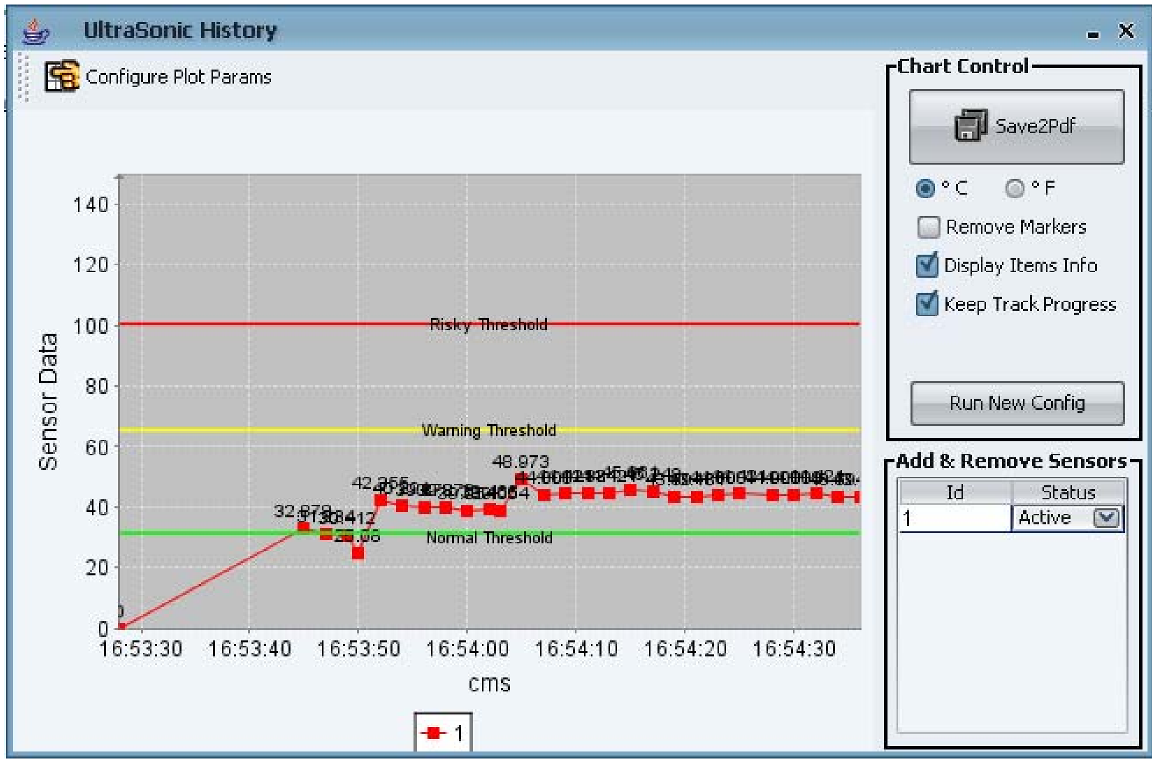


Figure 5-7. Graphs View

5.2.4 Sensor Viewer

On the menu bar go to “Show Grid View”, a sensor viewer window displays a table with four columns, Sensor ID, time, data 1 and data 2. Only the ultrasonic sensor sends informatation to data 2. Each group has a different color.

5.3 LCWi Modules View in Graphical User Interface

5.3.1 Temperature

Figure 5-8 shows the temperature window. On the left side the thermometer displays the current data readen by the temperature sensor.

On the right side, at the top select the favourite degrees lecture fahrenheit (°F) or celcius (°C). The three bars in the middle show the default thresholds for every state, from left to right, normal (green line), alert (yellow line) and warning (red line). To edit a state, press the Set button on the bottom of the desired state bar and select the new state.

The normal state can never be higher than alert or warning states. And the alert state can not be lower than normal state or higher than warning state. The same happens with the warning state.

The range for the thermometer is set at the very bottom of the right side, the limits are -10°C (50°F) for Low and 125°C (257°F) for High, which are the sensor's maximum and minimun values.

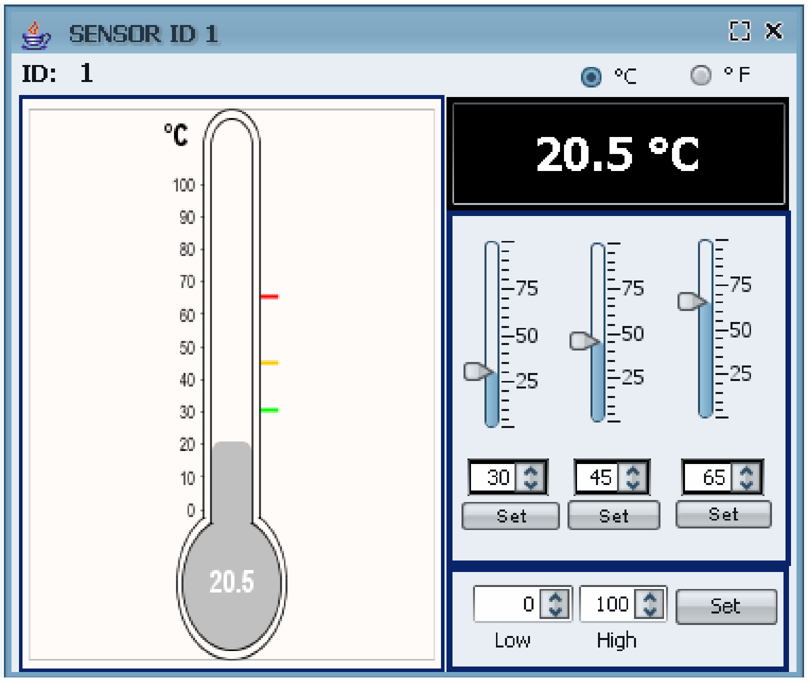


Figure 5-8. Temperature Window

5.3.2 Acceleration Sensor

The Acceleration Sensor window shows five blocks display as the points of the compass Up, Down, Right, Left and another one in the center, where a trafic light illustrates the sensor position status according to the parameters specified in the Trigger Alarms. When the LCWi sensor module is in one of the four define positions the respective block displays an arrow. The LCWi is not able to detect left or right position, when that happens both blocks display an arrow (Figure 5-9).

The Trigger Alarms are set at the bottom of the window, to modify them press the Set button and then select the desired checkbox. If the Up chekbox is checked and the aceeleration sensor is up then in the center block a message saying “Warning” is displayed. And the UP block displays an arrow.

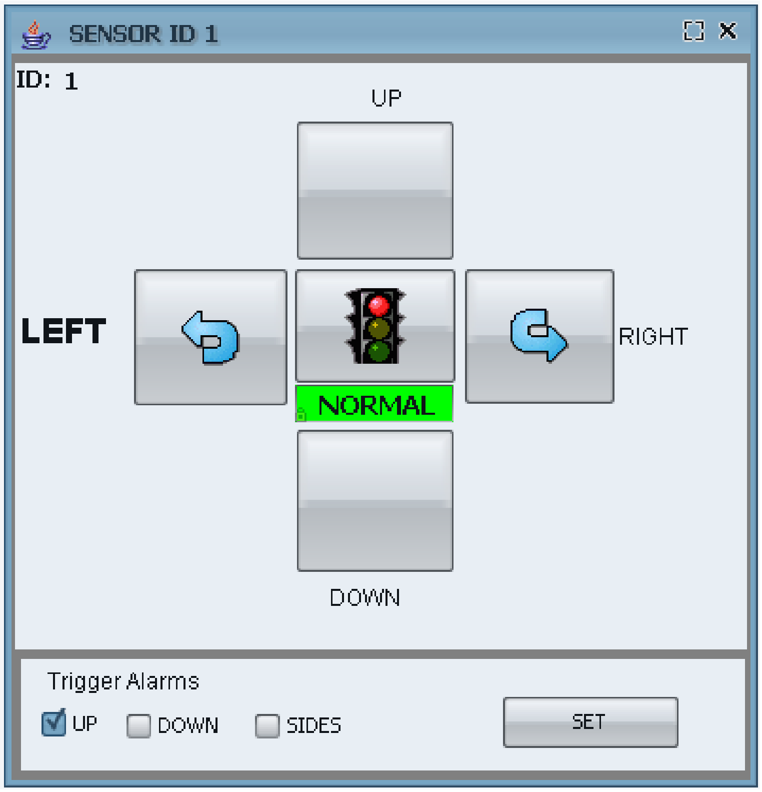


Figure 5-9. Acceleration Sensor Window.

5.3.3 Push-button

The push-button window is an ascendant counter, when the push button is pressed in the board it increases in one the number in the window. The Reset button clears the counter and sets it to 0. Figure 5-10 shows the Push Button window.

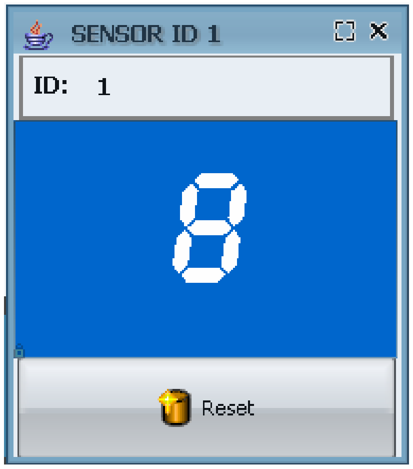


Figure 5-10. Push-button Window

5.3.4 PhotoResistor

The PhotoResistor window shows a bar where the value readen by the PhotoResistor sensor is illustrated, a full bar indicates 100% of light and displays a message saying “NORMAL LIGHT”, a half bar indicates 30% of light and the message is “BARELY LIGHT” and an empty bar indicates 0% of light and the message is “LACK OF LIGHT”. Figure 5-11 shows the PhotoResistor window. The light levels are not configurable.

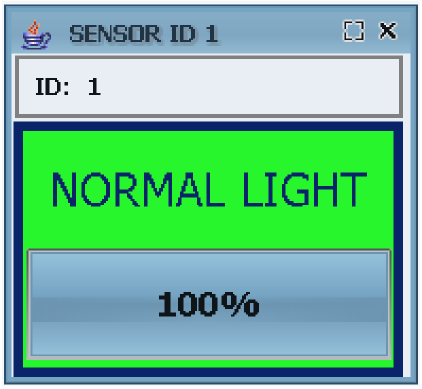


Figure 5-11. PhotoResistor Window.

5.3.5 Pressure Sensor

Figure 5-12 shows the Pressure window. On the left side the compass chart displays the current data readen by the pressure sensor in Pa with a maximum of 10000 Pa.

On the right side, the three bars in the middle show the default thresholds for every state, from left to right, normal (green area), alert (yellow area) and warning (red area). To edit a state, press the Set button on the bottom of the desired state bar and select the new state. When Blocked is selected the state can not be edited

The normal state can never be higher than alert or warning states. And the alert state can not be lower than normal state or higher than warning state. The same happens with the warning state. Set Angle specifies the circumference range.

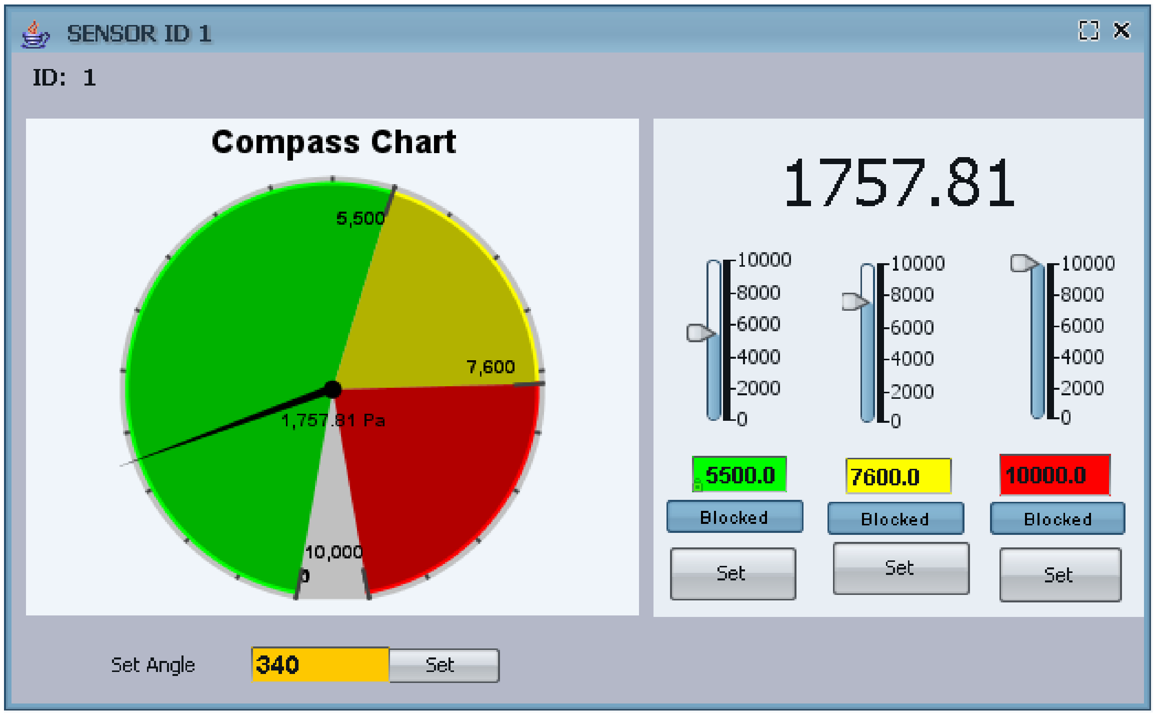


Figure 5-12. Pressure Sensor Window

5.3.6 Ultrasonic Sensor

The LCWi ultrasonic sensor module gives the distance in centimeters from 20 to 124 cm. The measured distance is shown on the left side of the Ultrasonic sensor window in two ways, with numbers and with a percentage represented in a bar. Upper and lower limits can be configured on the right side of the window (Figure 5-13).

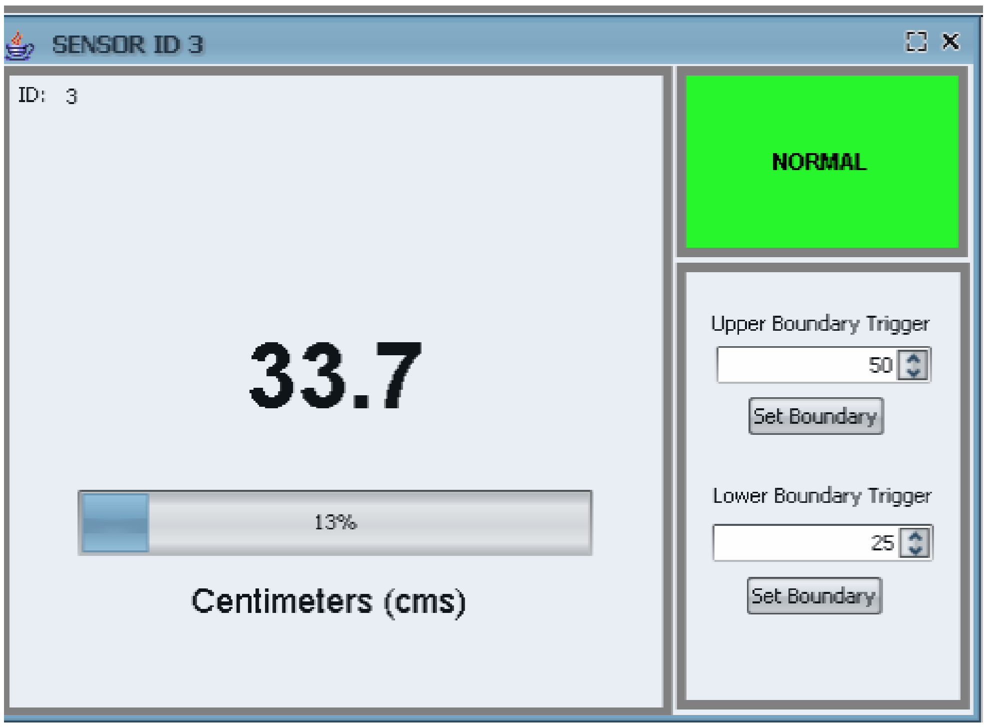


Figure 5-13. Ultrasonic Sensor Window

The “Upper Boundary Trigger” sets the upper limit, when the measured distance by the LCWi sensor is higher a message saying “High Boundary Reached” is displayed in the top right corner of the window (Figure 5-14). To configure this limit write a new value and press the “Set Boundary” button.

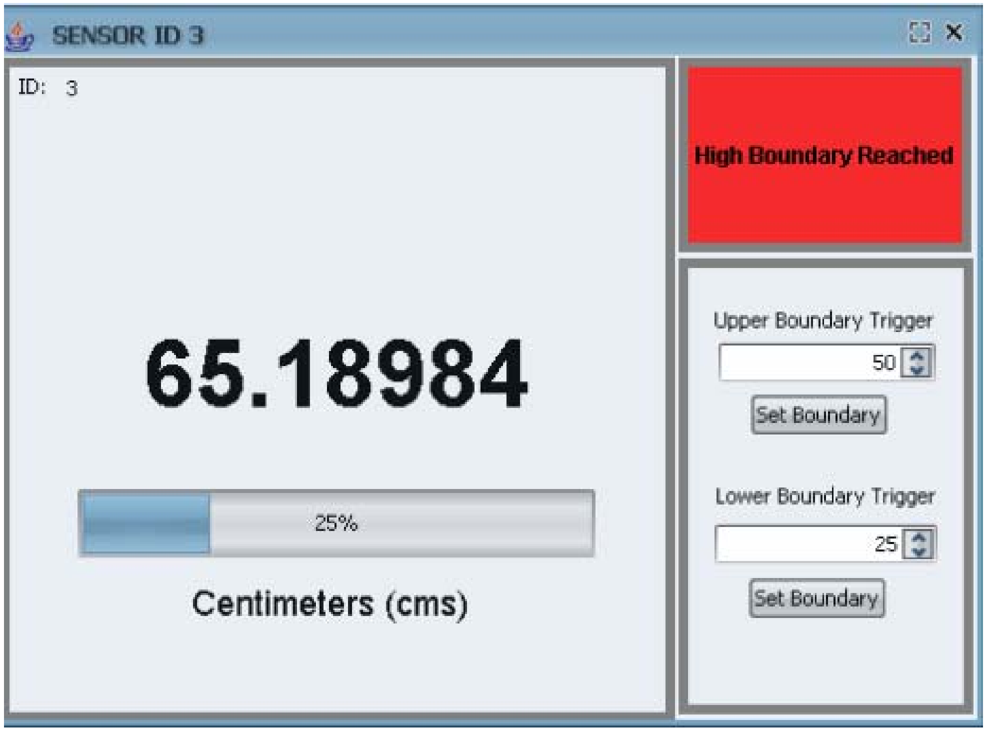


Figure 5-14. High Boundary Reached Alarm

The “Lower Boundary Trigger” works in the same way. These limits can not be higher than 124 or lower than 20 respectively (Figure 5-15).

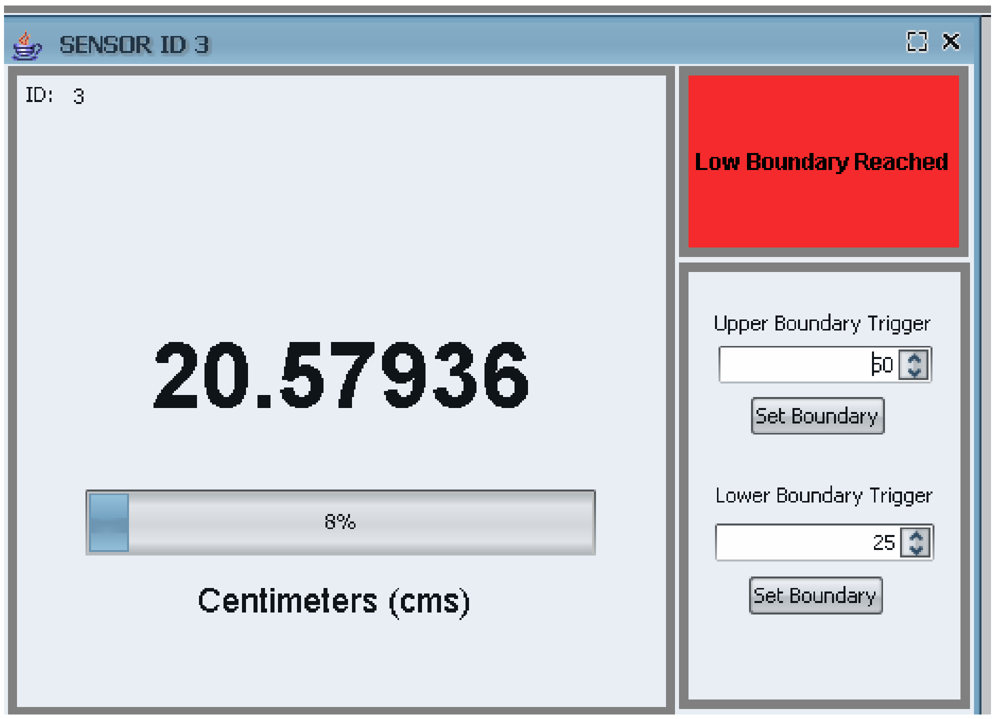


Figure 5-15. Low Boundary Reached Window

Appendix A.
BOM and Schematics

A.1 BOM

The bill of materials for the LCWi modules can be found from Table A-1 through Table A-5.

QTY	Reference	Value	Description	Manufacturer	Part Number
1	C1	4.7 uF	CAP CERAMIC 4.7UF 0603	Any	Any
4	C2, C10, C11, C12	0.1 uF	CAP CERAMIC .10UF 0603	Any	Any
1	C3	8.2 pF	CAP CERAMIC 8.2PF 0603	Any	Any
1	C4	2.2 pF	CAP CERAMIC 2.2PF 0603	Any	Any
1	C5	22 nF	CAP CERAMIC .022UF 0603	Any	Any
1	C6	100 pF	CAP CERAMIC 100PF 0603	Any	Any
2	C7, C8	DNP	This is a ‘Do Not Populate’ item	----	-----
1	C9	33 nF	CAP CERAMIC 33000PF 0603	Any	Any
1	C13	68 pF	CAP CERAMIC 68PF 0603	Any	Any
3	D1, D2, D3	----	DIODE SHOTTKY SOD523	On Semiconductor	BAT54XV2T1G
1	H1	----	BATT HOLDER FOR CR-1/3-N 3V	Any	Any
1	J1	----	PIN HEADER 2 POSITIONS	----	----
2	J2, J3	----	PIN HEADER 2 POSITIONS	----	----
1	J4	----	FOOTPRINT FOR 0603 PACKAGE	----	----
1	L1	100 nH	INDUCTOR 100NH 0603	Any	Any
1	Q1	----	TRANSISTOR PNP GP SOT323	Any	Any
1	Q2	----	TRANS SS NPN SOT-323	Any	Any
1	R1	12 kohms	RES 12.0K OHM 1/10W 0603	Any	Any
1	R2	10 kohms	RES 10.0K OHM 1/10W 0603	Any	Any
1	R3	1 kohms	RES 1.0K OHM 1/10W 0603	Any	Any
1	R4	0 kohms	RES 0 OHM 1/10W 0603	Any	Any
1	R5	100 kohms	RES 100.0K OHM 1/10W 0603	Any	Any
1	R6	4.7 kohms	RES 4.7K OHM 1/10W 0603	Any	Any
1	SW1	----	LT SWITCH 6MM	Any	Any
1	U1	----	IC 8BIT MCU QFN-D 6EP	Freescale Semiconductor	MC9RS08KA2CDB
1	U2	----	IC RF TRANS 315-434, 868 14TSSOP	Freescale Semiconductor	MC33493DTB
1	U3	----	IC +/- 1.5G ACCELERATION SENSOR QFN 16EP	Freescale Semiconductor	MMA6261Q
1	Y1	9.84375 MHz	XTAL 9.84375 MHZ	NDK	9.84375-NX5032GA

Table A-1. Acceleration Module BOM

QTY	Reference	Value	Description	Manufacturer	Part Number
1	C1	4.7 uF	CAP CERAMIC 4.7UF 0603	Any	Any
1	C2	0.1 uF	CAP CERAMIC .10UF 0603	Any	Any
1	C3	8.2 pF	CAP CERAMIC 8.2PF 0603	Any	Any
1	C4	2.2 pF	CAP CERAMIC 2.2PF 0603	Any	Any
1	C5	22 nF	CAP CERAMIC .022UF 0603	Any	Any
1	C6	100 pF	CAP CERAMIC 100PF 0603	Any	Any
1	C7	68 pF	CAP CERAMIC 68PF 0603	Any	Any
2	C8, C9	33 nF	CAP CERAMIC 33000PF 0603	Any	Any
1	C10	100 nF	CAP CERAMIC .10UF 0603	Any	Any
1	C11	33 nF	CAP CERAMIC 33000PF 0603	Any	Any
3	D1, D2, D3	----	DIODE SHOTTKY SOD523	On Semiconductor	BAT54XV2T1G
1	H1	----	BATT HOLDER FOR CR-1/3-N 3V	Any	Any
1	J1	----	PIN HEADER 2 POSITIONS	----	----
2	J2, J3	----	PIN HEADER 2 POSITIONS	----	----
1	J4	----	FOOTPRINT FOR 0603 PACKAGE	----	----
1	L1	100 nH	INDUCTOR 100NH 0603	Any	Any
1	RL1	27-60K	PHOTOCELL 27-60KOHM	Advanced Photonix Inc	PDV-P8103
1	R1	12 K	RES 12.0K OHM 1/10W 0603	Any	Any
1	R2	10 K	RES 10.0K OHM 1/10W 0603	Any	Any
1	R3	90 K	RES 90.0K OHM 1/10W 0603	Any	Any
1	R4	0	RES 0 OHM 1/10W 0603	Any	Any
1	R5	4.7 K	RES 4.7K OHM 1/10W 0603	Any	Any
1	SW1	----	LT SWITCH 6MM	Any	Any
1	U1	----	IC 8BIT MCU QFN-D 6EP	Freescale Semiconductor	MC9RS08KA2CDB
1	U2	----	IC RF TRANS 315-434, 868 14TSSOP	Freescale Semiconductor	MC33493DTB

Table A-2. Lighting Module BOM

QTY	Reference	Value	Description	Manufacturer	Part Number
1	C1	4.7 uF	CAP CERAMIC 4.7UF 0603	Any	Any
1	C2	0.1 uF	CAP CERAMIC .10UF 0603	Any	Any
1	C3	8.2 pF	CAP CERAMIC 8.2PF 0603	Any	Any
1	C4	2.2 pF	CAP CERAMIC 2.2PF 0603	Any	Any
1	C5	22 nF	CAP CERAMIC .022UF 0603	Any	Any
1	C6	100 pF	CAP CERAMIC 100PF 0603	Any	Any
2	C7, C8	DNP	This is a 'Do Not Populate' item	----	-----
1	C9	100 nF	CAP CERAMIC .10UF 0603	Any	Any
1	C10	33 nF	CAP CERAMIC 33000PF 0603	Any	Any
1	C12	68 pF	CAP CERAMIC 68PF 0603	Any	Any
3	D1, D2, D3	----	DIODE SHOTTKY SOD523	On Semiconductor	BAT54XV2T1G
1	H1	----	BATT HOLDER FOR CR-1/3-N 3V	Any	Any
1	J1	----	PIN HEADER 2 POSITIONS	----	----
2	J2	----	PIN HEADER 2 POSITIONS	----	----
1	J4	----	FOOTPRINT FOR 0603 PACKAGE	----	----
1	L1	100 nH	INDUCTOR 100NH 0603	Any	Any
1	Q1	----	TRANS SS NPN SOT-323	Any	Any
1	R1	12 K	RES 12.0K OHM 1/10W 0603	Any	Any
1	R2	10 K	RES 10.0K OHM 1/10W 0603	Any	Any
3	R3, R4, R7	1 K	RES 1.0K OHM 1/10W 0603	Any	Any
2	R5, R6	100 K	RES 100.0K OHM 1/10W 0603	Any	Any
1	R8	4.7 K	RES 4.7K OHM 1/10W 0603	Any	Any
1	R9	0	RES 0 OHM 1/10W 0603	Any	Any
1	SW1	----	LT SWITCH 6MM	Any	Any
1	U1	----	IC 8BIT MCU QFN-D 6EP	Freescale Semiconductor	MC9RS08KA2CDB
1	U2	----	IC RF TRANS 315-434, 868 14TSSOP	Freescale Semiconductor	MC33493DTB
1	U3	----	IC 100 KPa TEMP COMP PRESS SENSOR	Freescale Semiconductor	MPXM2010GS
1	Y1	9.84375 MHz	XTAL 9.84375 MHZ	NDK	9.84375-NX5032GA

Table A-3. Pressure Module BOM

QTY	Reference	Value	Description	Manufacturer	Part Number
1	C1	4.7 uF	CAP CERAMIC 4.7UF 0603	Any	Any
1	C2	0.1 uF	CAP CERAMIC .10UF 0603	Any	Any
1	C3	8.2 pF	CAP CERAMIC 8.2PF 0603	Any	Any
1	C4	2.2 pF	CAP CERAMIC 2.2PF 0603	Any	Any
1	C5	22 nF	CAP CERAMIC .022UF 0603	Any	Any
1	C6	100 pF	CAP CERAMIC 100PF 0603	Any	Any
1	C7	68 pF	CAP CERAMIC 68PF 0603	Any	Any
2	C8, C9	33 nF	CAP CERAMIC 33000PF 0603	Any	Any
1	C10	100 nF	CAP CERAMIC .10UF 0603	Any	Any
1	C11	33 nF	CAP CERAMIC 33000PF 0603	Any	Any
3	D1, D2, D3	----	DIODE SHOTTKY SOD523	On Semiconductor	BAT54XV2T1G
1	H1	----	BATT HOLDER FOR CR-1/3-N 3V	Any	Any
1	J1	----	PIN HEADER 2 POSITIONS	----	----
2	J2, J3	----	PIN HEADER 2 POSITIONS	----	----
1	J4	----	FOOTPRINT FOR 0603 PACKAGE	----	----
1	L1	100 nH	INDUCTOR 100NH 0603	Any	Any
1	RT1	27-60 kohms	THERMISTOR 33K OHM NTC 0603	Murata Electronics North America	NCP18WB333J03RB
1	R1	12 kohms	RES 12.0K OHM 1/10W 0603	Any	Any
1	R2	10 kohms	RES 10.0K OHM 1/10W 0603	Any	Any
1	R3	33 kohms	RES 33.0K OHM 1/10W 0603	Any	Any
1	R4	0 ohms	RES 0 OHM 1/10W 0603	Any	Any
1	R5	4.7 kohms	RES 4.7K OHM 1/10W 0603	Any	Any
1	SW1	----	LT SWITCH 6MM	Any	Any
1	U1	----	IC 8BIT MCU QFN-D 6EP	Freescale Semiconductor	MC9RS08KA2CDB
1	U2	----	IC RF TRANS 315-434, 868 14TSSOP	Freescale Semiconductor	MC33493DTB
1	Y1	9.84375 MHz	XTAL 9.84375 MHZ	NDK	9.84375-NX5032GA

Table A-4. Temperature Module BOM

QTY	Reference	Value	Description	Manufacturer	Part Number
1	C1	4.7 uF	CAP CERAMIC 4.7UF 0603	Any	Any
5	C2, C12, C13, C14, C15	0.1 uF	CAP CERAMIC .10UF 0603	Any	Any
1	C3	8.2 pF	CAP CERAMIC 8.2PF 0603	Any	Any
1	C4	2.2 pF	CAP CERAMIC 2.2PF 0603	Any	Any
1	C5	22 nF	CAP CERAMIC .022UF 0603	Any	Any
1	C6	100 pF	CAP CERAMIC 100PF 0603	Any	Any
2	C7	68 pF	CAP CERAMIC 68PF 0603	Any	Any
1	C8, C9	DNP	This is a ‘Do Not Populate’ item	----	-----
1	C11	33 nF	CAP CERAMIC 33000PF 0603	Any	Any
3	D1, D2, D3	----	DIODE SHOTTKY SOD523	On Semiconductor	BAT54XV2T1G
1	H1	----	BATT HOLDER FOR CR-1/3-N 3V	Any	Any
1	J1	----	PIN HEADER 2 POSITIONS	----	----
2	J2, J6	----	PIN HEADER 2 POSITIONS	----	----
1	J3	----	FOOTPRINT FOR 0603 PACKAGE	----	----
2	J4, J5	----	PIN HEADER 2 POSITIONS	----	----
1	L1	100 nH	INDUCTOR 100NH 0603	Any	Any
1	R1	12 kohms	RES 12.0K OHM 1/10W 0603	Any	Any
1	R3	0 ohms	RES 0 OHM 1/10W 0603	Any	Any
1	R4	4.7 kohms	RES 4.7K OHM 1/10W 0603	Any	Any
1	R5, R6	1 kohms	RES 1.0K OHM 1/10W 0603	Any	Any
1	R7	2.2 kohms	RES 2.2K OHM 1/10W 0603	Any	Any
1	R8, R9, R10, R11, R12	22 kohms	RES 22.0K OHM 1/10W 0603	Any	Any
1	U1	----	IC 8BIT MCU QFN-D 6EP	Freescale Semiconductor	MC9RS08KA2CDB
1	U2	----	IC RF TRANS 315-434, 868 14TSSOP	Freescale Semiconductor	MC33493DTB
1	U3	OPA4342UA	IC QUAD UPWR R-R OPAMP 14-SOIC	Any	Any
1	US Rx	----	ULTRASONIC TRANSDUCER 40KHZ .70' RCVR	Kobitone	250-400ER18-RO
	US Tx	----	ULTRASONIC TRANSDUCER 40KHZ .70' TRANSMITT	Kobitone	250-400ET18-RO

Table A-5. Ultrasound Module BOM

5.4 Schematics

The complete schematics for the Low-cost Wireless Sensors Using a MC9RS08KA2 Reference Design can be found from Figure A-1 to Figure A-10.

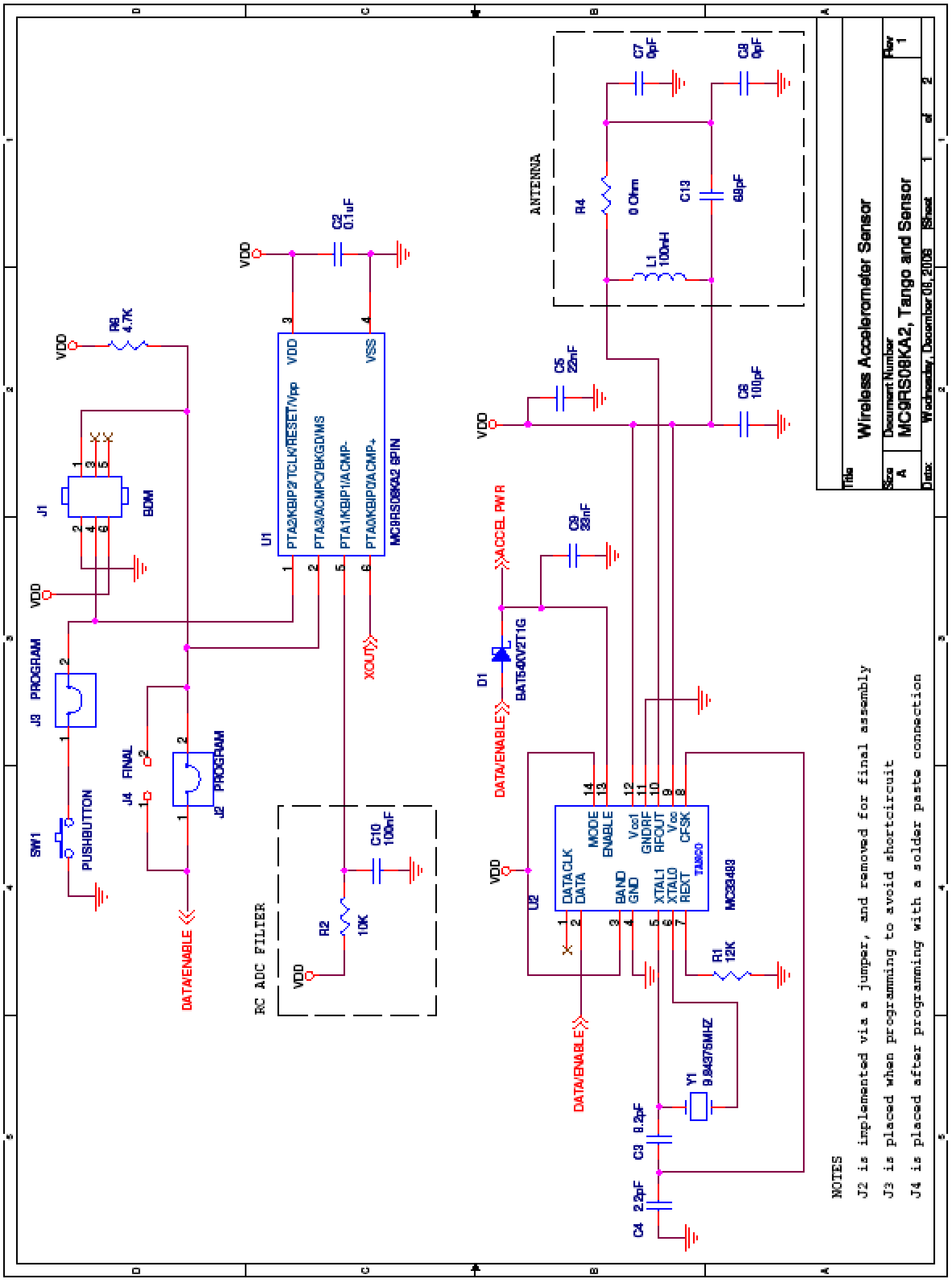


Figure A-1. Acceleration Module Schematics 1

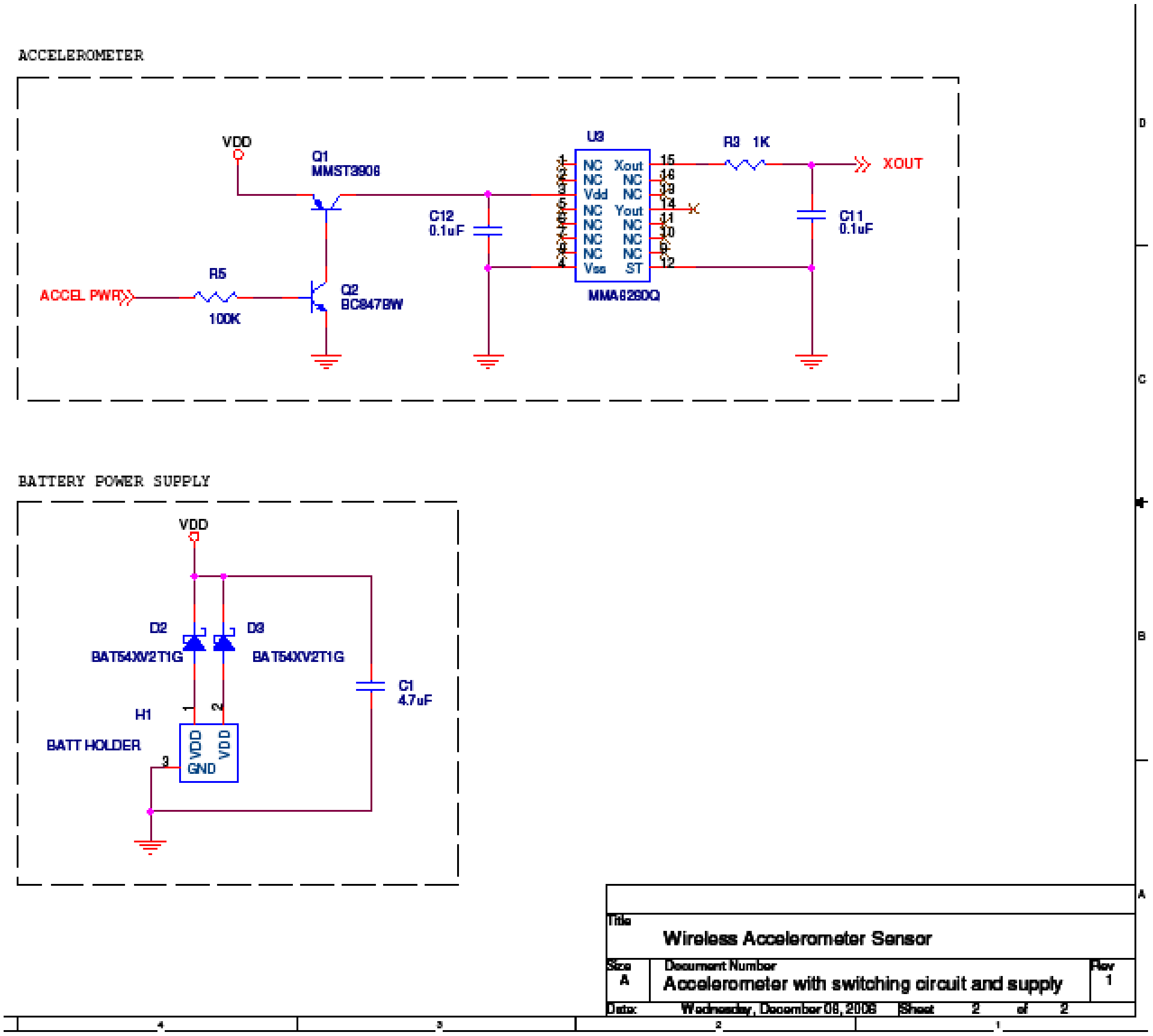
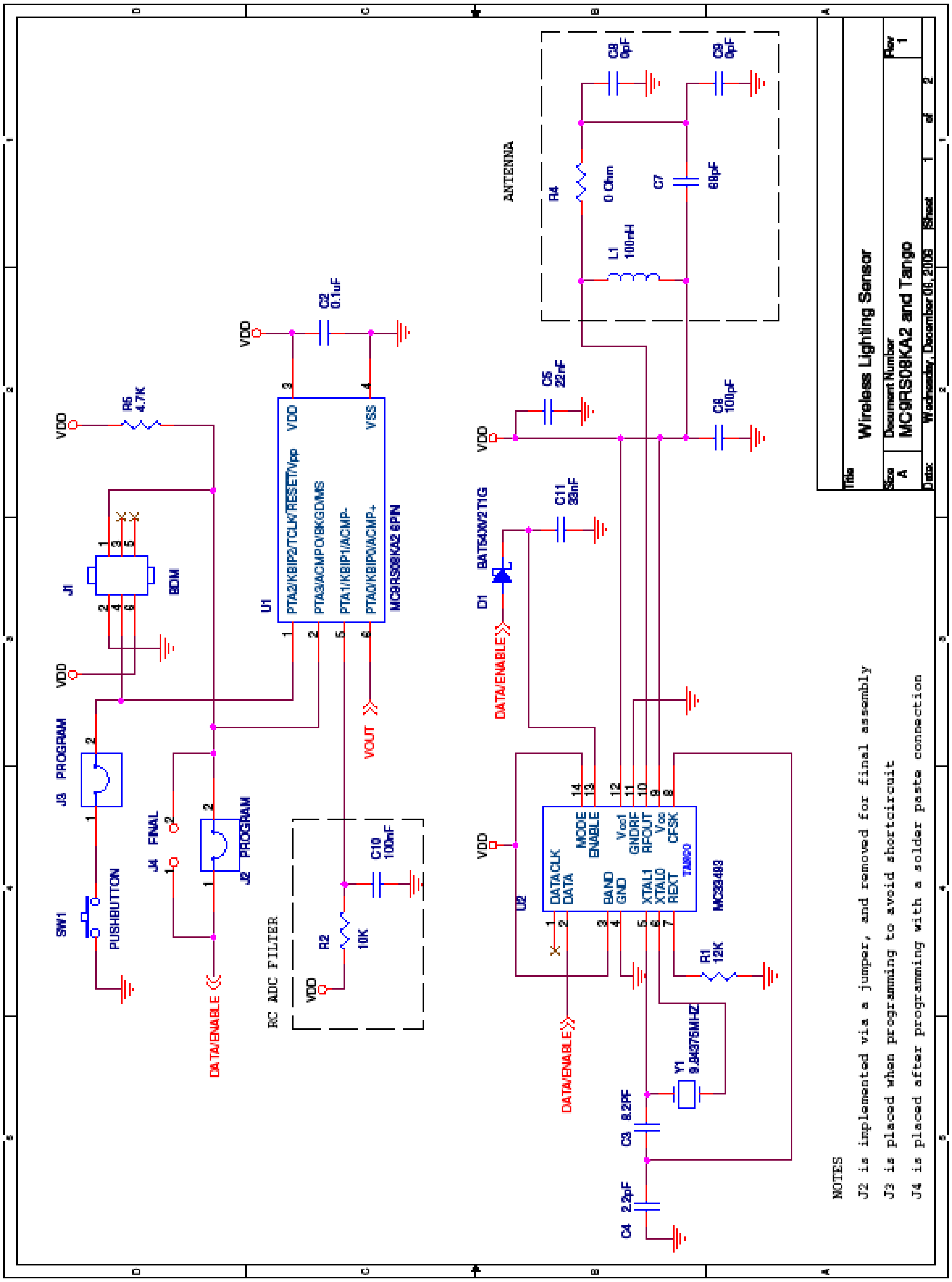


Figure A-2. Acceleration Module Schematics 2



NOTES
J2 is implemented via a jumper, and removed for final assembly
J3 is placed when programming to avoid shortcircuit
J4 is placed after programming with a solder paste connection

Title	Wireless Lighting Sensor
Size A	Document Number MC9RS08KA2 and Tango
Rev	1
Date	Wednesday, December 03, 2008
Sheet	1 of 2

Figure A-3. Lighting Module Schematics 1

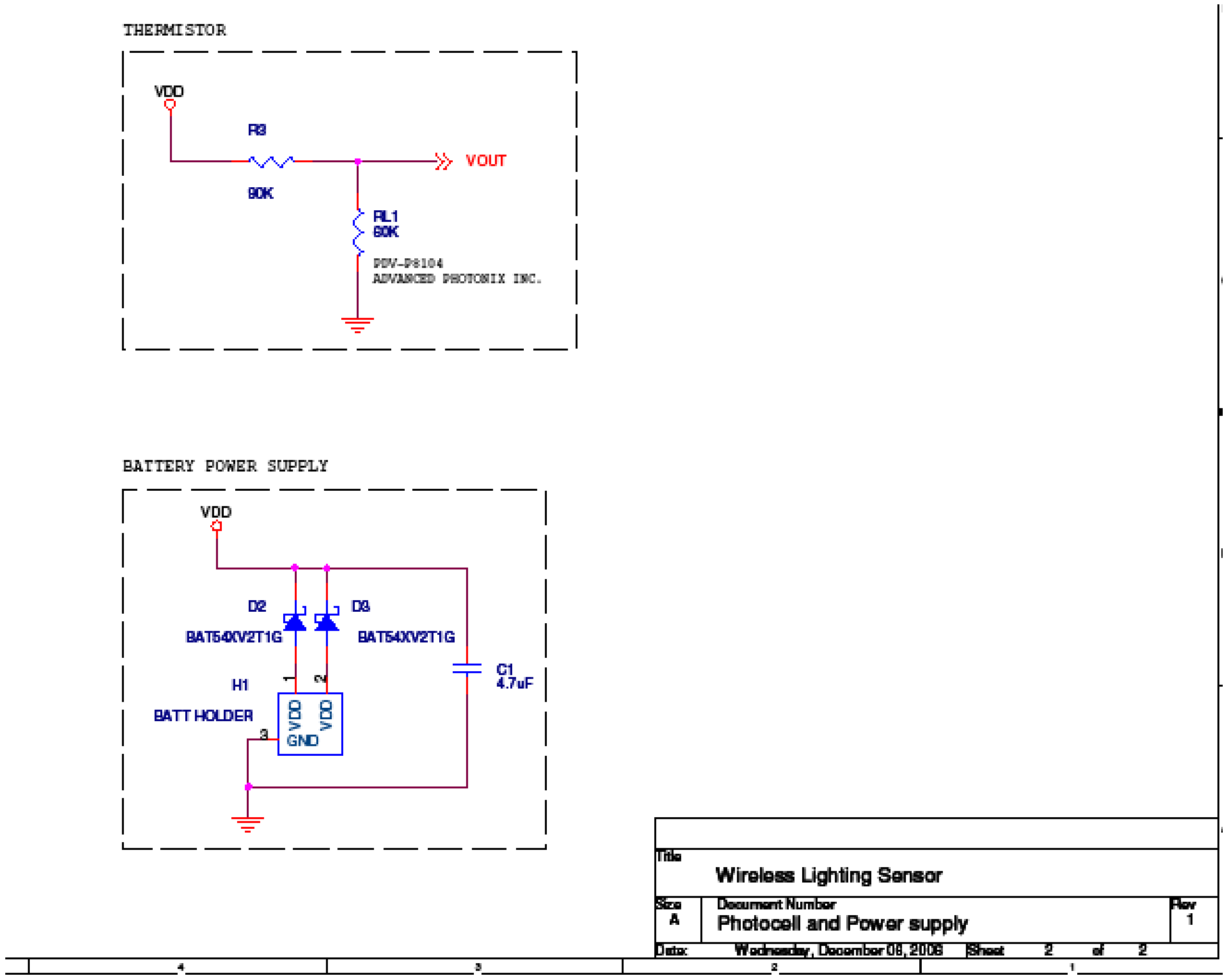


Figure A-4. Lighting Module Schematics 2

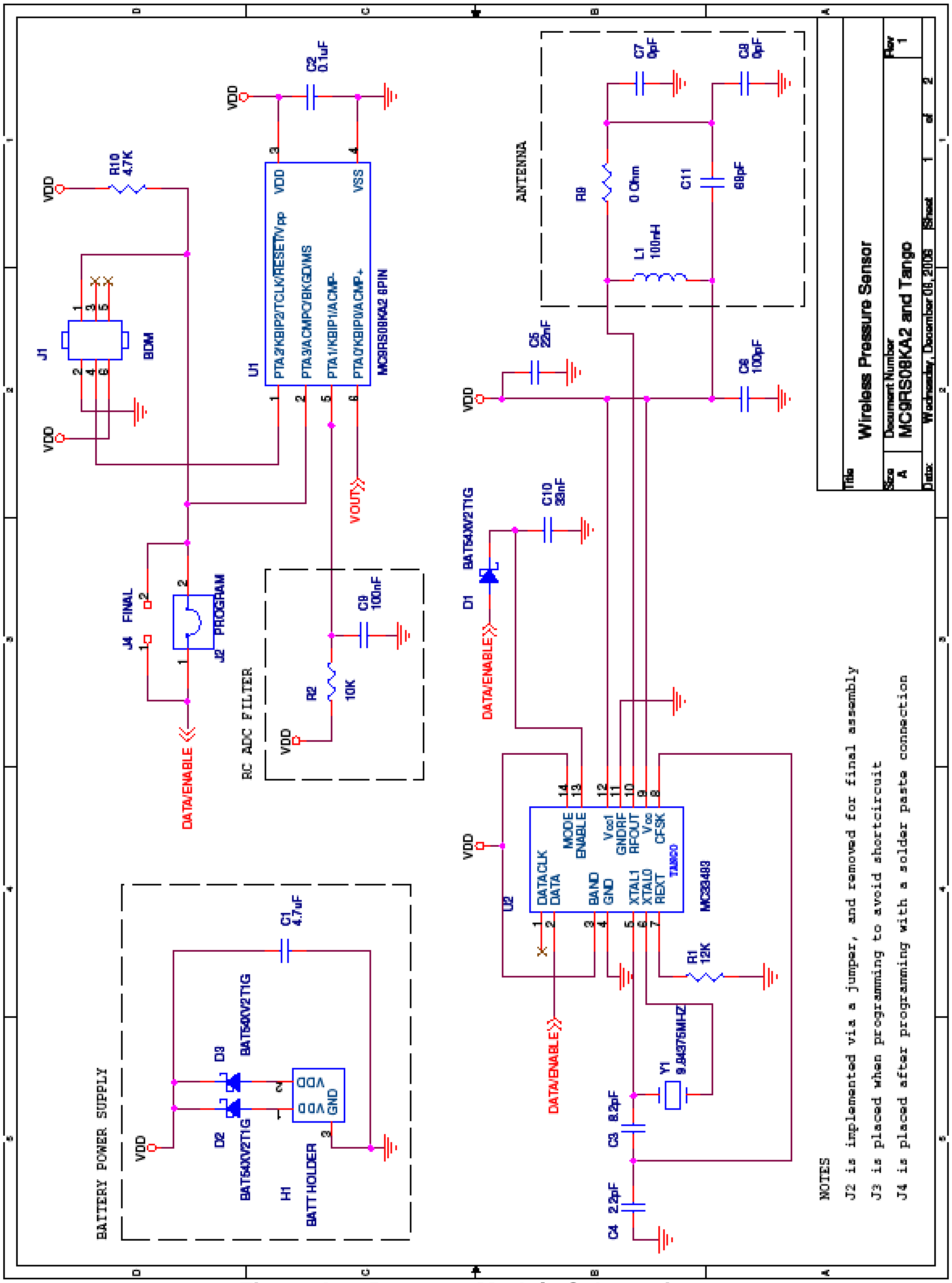


Figure A-5. Pressure Module Schematics 1

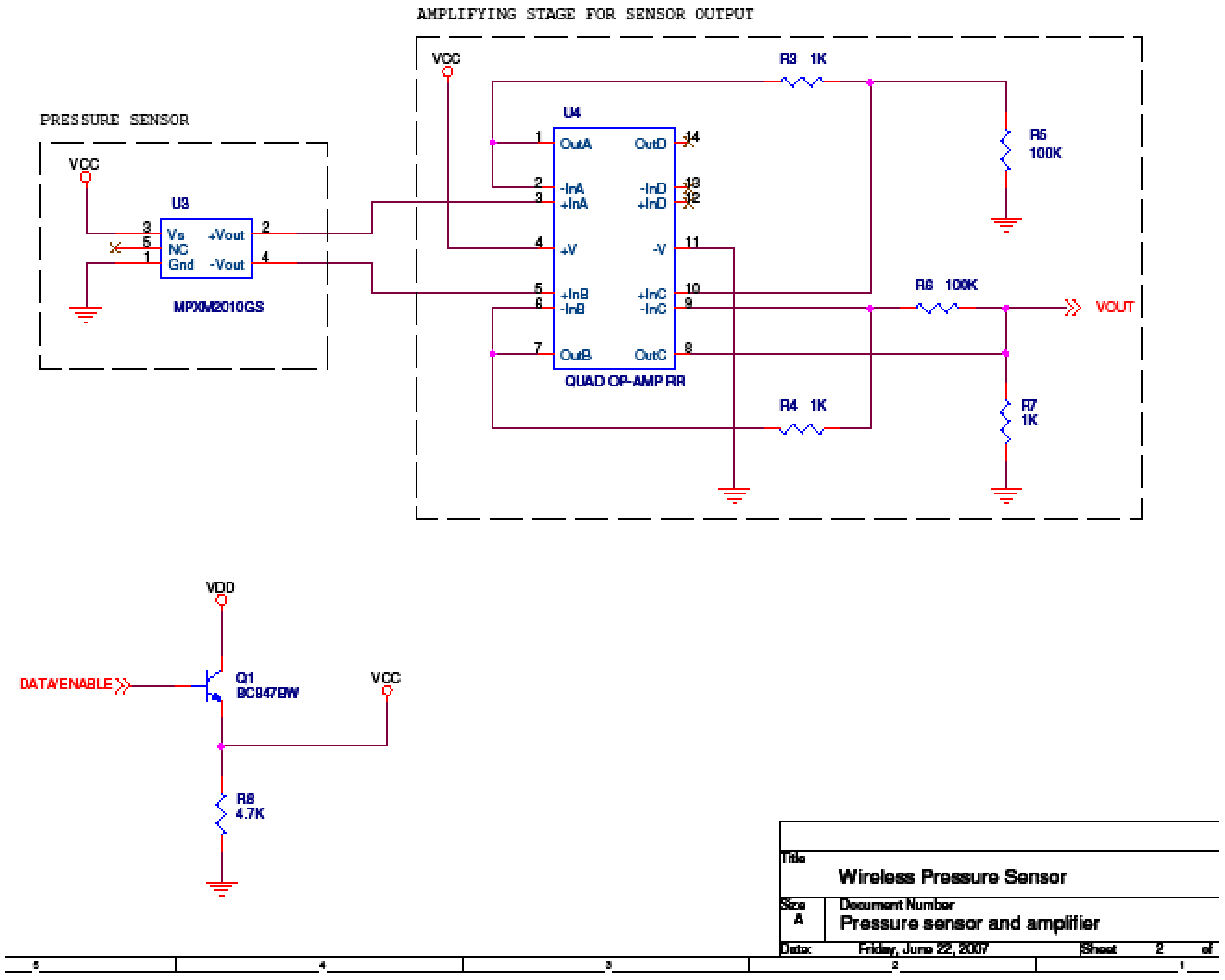


Figure A-6. Pressure Module Schematics 2

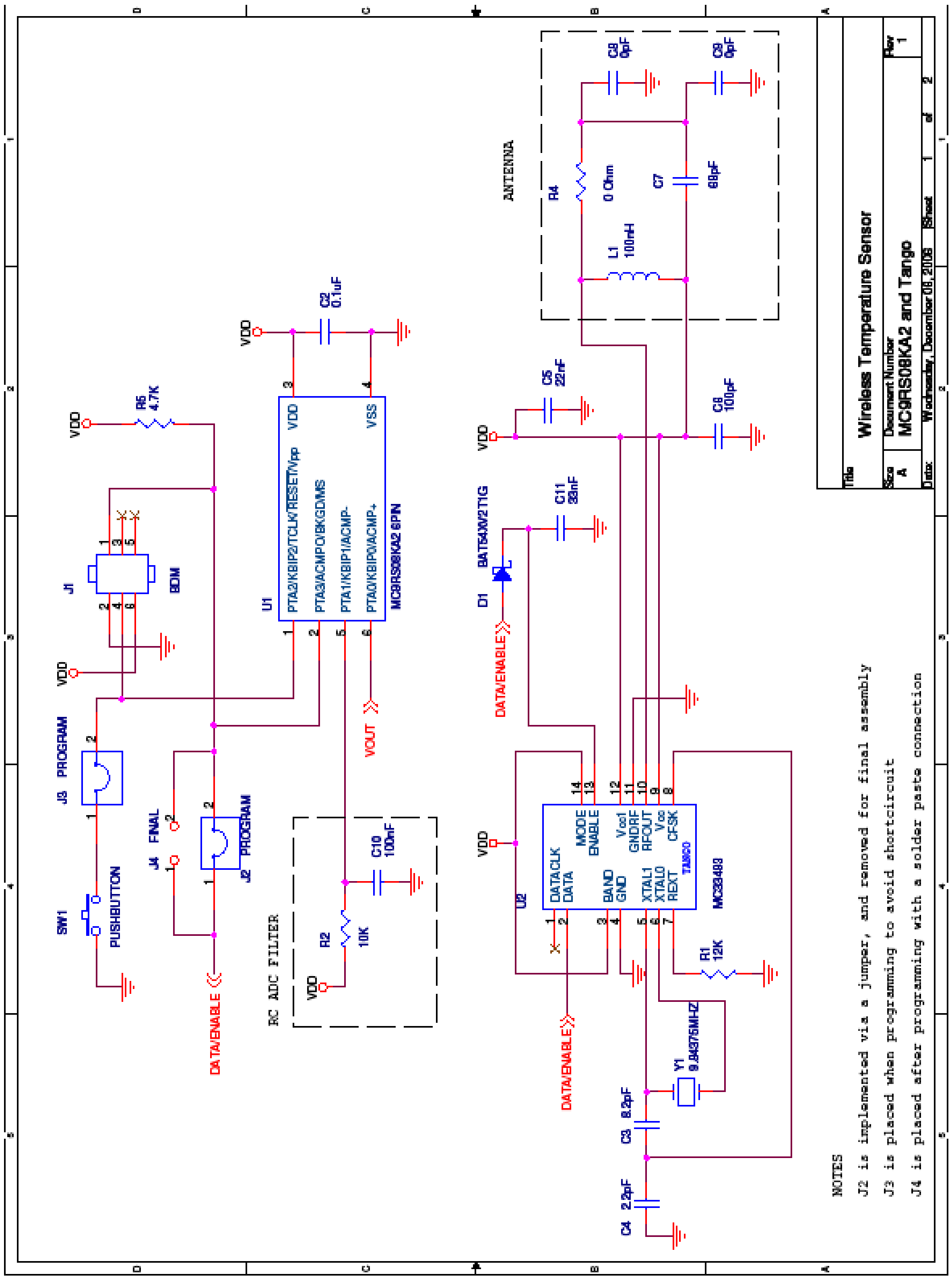


Figure A-7. Temperature Module Schematics 1

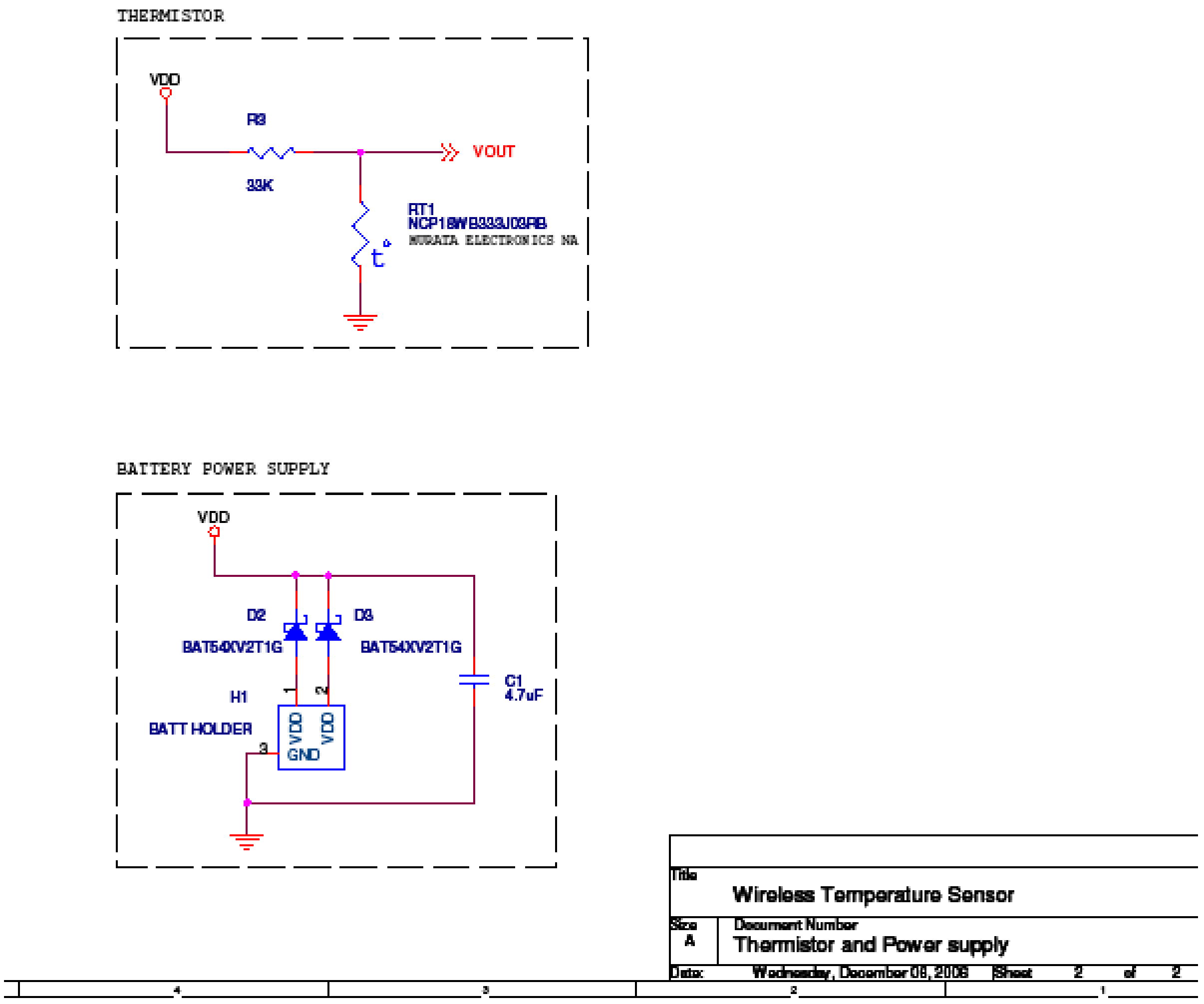


Figure A-8. Temperature Module Schematics 2

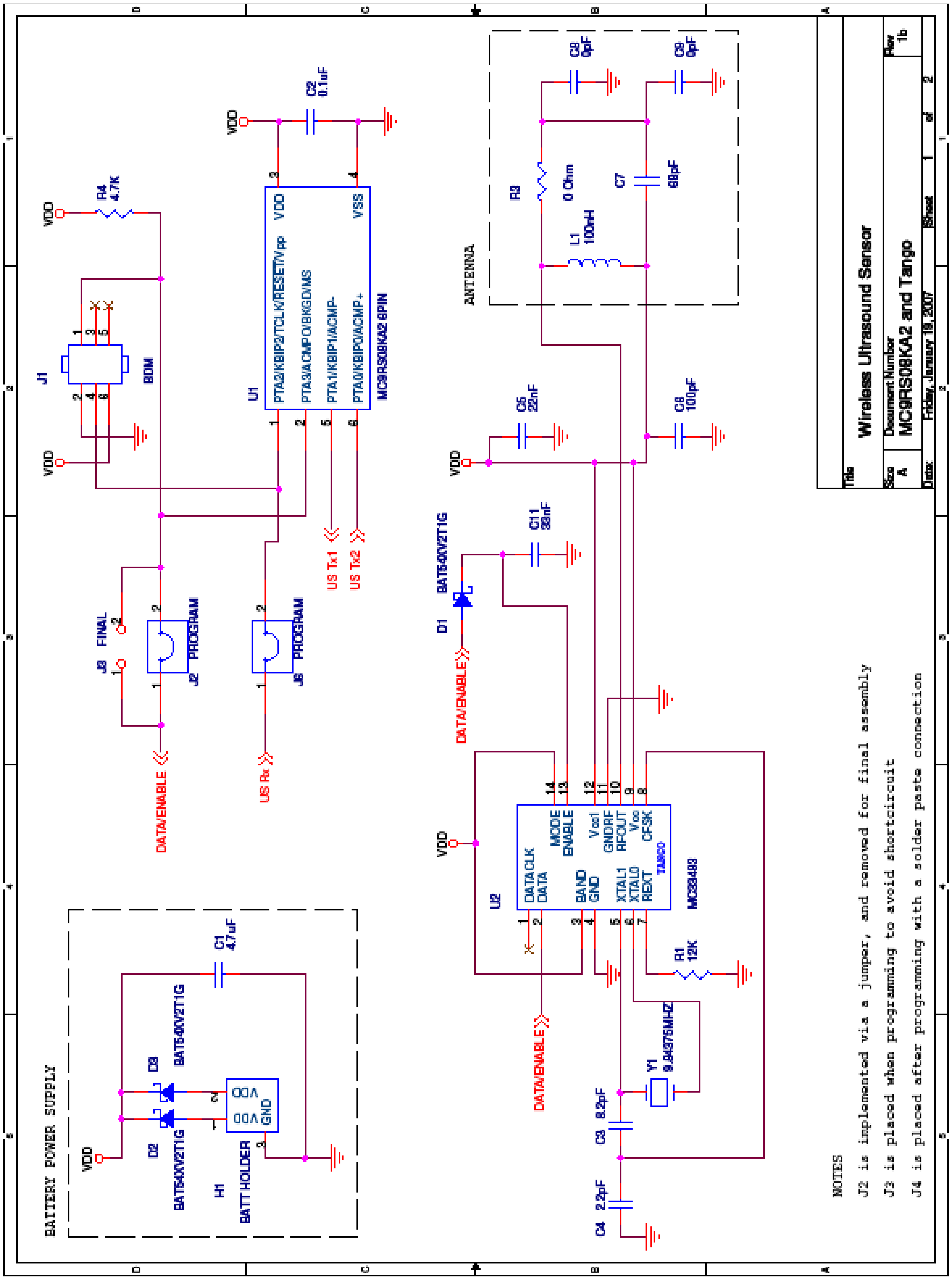


Figure A-9. Ultrasound Module Schematics 1

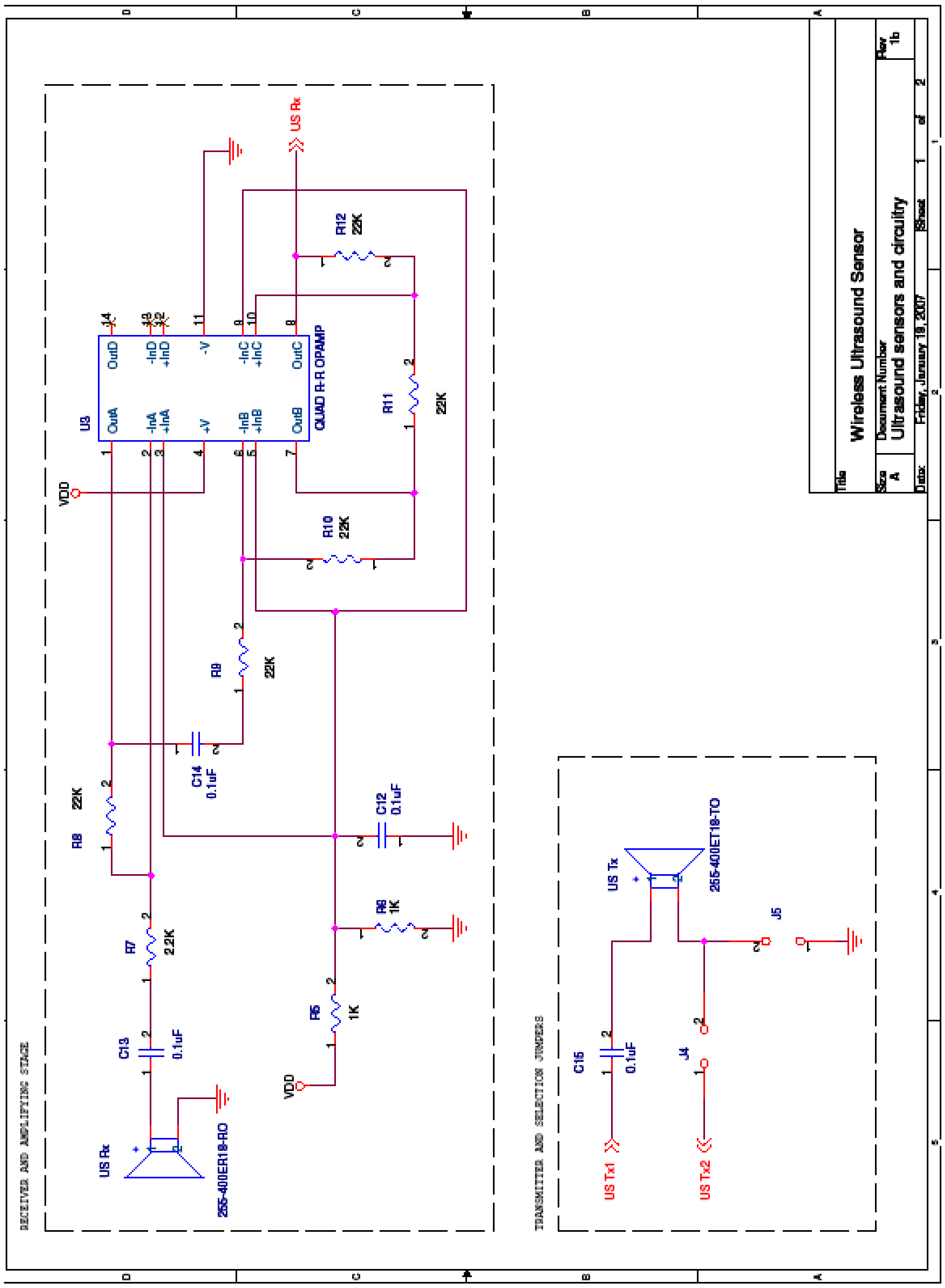


Figure A-10. Ultrasound Module Schematics 2

Appendix B. Firmware

B.1 Drivers

B.1.1 Tango Driver

```
      org RAMStart
;*****************************************************************************
;*                            Driver Variables                               *
;*****************************************************************************
key                  DS.B  4
TEAMAC_DATA          DS.B  2         ; First and Second Bytes to send
TEAMAC_CODE          DS.B  1         ; Third Byte to send
DATA                 DS.B  2         ; Fifth Byte to send
nibble               DS.B  1
roll_bit             DS.B  1
sbyte                DS.B  1
c1                   DS.B  1
c2                   DS.B  1
Aux                  DS.B  1
sum                  DS.B  1
y                    DS.B  1
z                    DS.B  1

;*****************************************************************************
;*                            Driver Constants                               *
;*****************************************************************************
TANGO_FSK_HEADER     EQU   $60        ; FSK preamble (4 0's) and Header (0110)
DELTA                EQU   $9E
ID                   EQU   $A5        ; Romeo ID recognized

;******************* These constants can be modified by users *****************
ID2                  EQU   $01        ; Sensor ID
GROUP                EQU   $54        ; Sensor Group

;*****************************************************************************
;*                            Driver definitions                             *
;*****************************************************************************
TEAMAC_KEY1          SET   $20        ; First byte key
TEAMAC_KEY2          SET   $34        ; Second byte key

      org ROMStart
;*****************************************************************************
;*          MACRO declarations Define Data Rate for the Tango                *
;*****************************************************************************
BAUD_2700: MACRO
```

```
      mov #$70, MTIMSC    ; Enables interrupt, stops and resets timer counter
      mov #$17, MTIMMOD   ; MTIM counts
     mov #$07, MTIMCLK   ; Selects internal clock as reference bus and 128 preescaler
      ENDM

BAUD_4600: MACRO
     mov #$70, MTIMSC            ; Enables interrupt, stops and resets timer counter
      mov #$37, MTIMMOD               ; MTIM counts
      mov #$05, MTIMCLK          ; Selects internal clock as reference bus and 32
preescaler
      ENDM

      include "RTeamac.asm"

;*****************************************************************************
;*                            Tango Send Function                            *
;*****************************************************************************
TANGO_SEND_DATA:
      mov #64,sbyte
      mov #20,Aux
ChargeCapacitor:
      bset 3,PTAD
      mov #$00,c1
      mov #$61,c2
loop:
      dbnz c1,loop
      dbnz c2,loop
      bclr 4,MTIMSC    ; MTIM counter is Active
SendPreamble
      mov #4,nibble
Preamble:
      brclr 7,MTIMSC,Preamble
      bset 5,MTIMSC                                     ; Reset MTIM Counter, Clear
overflow flag
      bset 3,PTAD
time:
      brclr 7,MTIMSC,time
      bset 5,MTIMSC                                     ; Reset MTIM Counter, Clear
overflow flag
      bclr 3,PTAD
      dbnz nibble,Preamble
      mov #1,roll_bit
      mov #8,c1
SendID:
      brclr 7,MTIMSC,SendID
      bset 5,MTIMSC                                     ; Reset MTIM Counter, Clear
overflow flag
      lda #ID
      and roll_bit
      beq ClrID
SetID:
      bset 3,PTAD
TimeSet:
      brclr 7,MTIMSC,TimeSet
      bset 5,MTIMSC                                ; Reset MTIM Counter, Clear
overflow flag
      bclr 3,PTAD
      bra rotateID
ClrID:
      bclr 3,PTAD
TimeClr:
      brclr 7,MTIMSC,TimeClr
      bset 5,MTIMSC                                ; Reset MTIM Counter, Clear
overflow flag
      bset 3,PTAD
rotateID:
      lda roll_bit
      asla
      sta roll_bit
      dbnz c1,SendID
      dbnz Aux,ChargeCapacitor
      mov #1,roll_bit
SendByte:
      lda #56
      sub sbyte
      blo SendPreambleHeader
      lda #48
      sub sbyte
      blo SendData1
      lda #40
      sub sbyte
      blo SendData2
      lda #32
      sub sbyte
      blo SendData3
      lda #24
      sub sbyte
      blo _SendData4
      lda #16
      sub sbyte
      blo _SendData5
      lda #8
      sub sbyte
      blo _SendData6
      bra _SendData7
SendPreambleHeader:
      lda roll_bit
      cbeqa #0,reset_rollPH
      bra timePH
reset_rollPH:
      mov #$01,roll_bit
timePH:
      brclr 7,MTIMSC,timePH
      bset 5,MTIMSC                                ; Reset MTIM Counter, Clear
overflow flag
      lda #TANGO_FSK_HEADER
```

```
roll:
      and roll_bit
      beq Clrb
Setb:
      bset 3,PTAD
timeSet:
      brclr 7,MTIMSC,timeSet
      bset 5,MTIMSC                                     ; Reset MTIM Counter, Clear
overflow flag
      bclr 3,PTAD
      bra rotate
_SendData4:
      bra SendData4
Clrb:
      bclr 3,PTAD
timeClr:
      brclr 7,MTIMSC,timeClr
      bset 5,MTIMSC                                     ; Reset MTIM Counter, Clear
overflow flag
      bset 3,PTAD
rotate:
      lda roll_bit
      asla
      sta roll_bit
      dbnz sbyte,SendByte
      bra _EndOfMessage
_SendData5:
      bra SendData5
_SendData6:
      bra SendData6
_SendData7:
      bra SendData7
SendData1:
      lda roll_bit
      cbeqa #0,reset_rollData1
      bra timeData1
reset_rollData1:
      mov #$01,roll_bit
timeData1:
      brclr 7,MTIMSC,timeData1
      bset 5,MTIMSC                                     ; Reset MTIM Counter, Clear
overflow flag
      lda TEAMAC_DATA+0
      bra roll
SendData2:
      lda roll_bit
      cbeqa #0,reset_rollData2
      bra timeData2
reset_rollData2:
      mov #$01,roll_bit
timeData2:
      brclr 7,MTIMSC,timeData2
      bset 5,MTIMSC                                     ; Reset MTIM Counter, Clear
```

```
overflow flag
      lda TEAMAC_DATA+1
      bra roll
_EndOfMessage:
      bra EndOfMessage
SendData3:
      lda roll_bit
      cbeqa #0,reset_rollData3
      bra timeData3
reset_rollData3:
      mov #$01,roll_bit
timeData3:
      brclr 7,MTIMSC,timeData3
      bset 5,MTIMSC                                  ; Reset MTIM Counter, Clear
overflow flag
      lda TEAMAC_CODE
      bra roll
_roll:
      bra roll
SendData4:
      lda roll_bit
      cbeqa #0,reset_rollData4
      bra timeData4
reset_rollData4:
      mov #$01,roll_bit
timeData4:
      brclr 7,MTIMSC,timeData4
      bset 5,MTIMSC                                  ; Reset MTIM Counter, Clear
overflow flag
      lda #GROUP
      bra roll
SendData5:
      lda roll_bit
      cbeqa #0,reset_rollData5
      bra timeData5
reset_rollData5:
      mov #$01,roll_bit
timeData5:
      brclr 7,MTIMSC,timeData5
      bset 5,MTIMSC                                  ; Reset MTIM Counter, Clear
overflow flag
      lda #ID2
      bra _roll
SendData6:
      lda roll_bit
      cbeqa #0,reset_rollData6
      bra timeData6
reset_rollData6:
      mov #$01,roll_bit
timeData6:
      brclr 7,MTIMSC,timeData6
      bset 5,MTIMSC                                  ; Reset MTIM Counter, Clear
overflow flag
```

```
      lda DATA+1
      bra _roll
SendData7:
      lda roll_bit
      cbeqa #0,reset_rollData7
      bra timeData7
reset_rollData7:
      mov #$01,roll_bit
timeData7:
      brclr 7,MTIMSC,timeData7
      bset 5,MTIMSC                                      ; Reset MTIM Counter, Clear
overflow flag
      lda DATA
      bra _roll
EndOfMessage:
      brclr 7,MTIMSC,EndOfMessage
      bset 5,MTIMSC                                      ; Reset MTIM Counter, Clear
overflow flag
      bclr 3,PTAD
wait1:
      brclr 7,MTIMSC,wait1
      bset 5,MTIMSC                                      ; Reset MTIM Counter, Clear
overflow flag
wait2:
      brclr 7,MTIMSC,wait2
      bset 5,MTIMSC                                      ; Reset MTIM Counter, Clear
overflow flag
wait3:
      brclr 7,MTIMSC,wait3
      bset 5,MTIMSC                                      ; Reset MTIM Counter, Clear
overflow flag
wait4:
      brclr 7,MTIMSC,wait4
      bset 5,MTIMSC                                      ; Reset MTIM Counter, Clear
overflow flag
wait5:
      brclr 7,MTIMSC,wait5
      bset 5,MTIMSC                                      ; Reset MTIM Counter, Clear
overflow flag
      bset 4,MTIMSC                                    ; MTIM counter is not Active
      bset 5,MTIMSC                                      ; Reset MTIM Counter, Clear
overflow flag
      rts
```

B.1.2 Reduce Encrypt Teamac Algorithm

```
;*****************************************************************************
;*                             TEAMAC Encrypt Function                       *
;*****************************************************************************
ENCRYPT_TEAMAC:
      lda TEAMAC_DATA
      add #$03
      sta TEAMAC_DATA
```

```
       lda TEAMAC_DATA+1
       add #$02
       sta TEAMAC_DATA+1
       mov #4,c1
       clr key
       clr key+1
       clr key+2
       clr key+3
while1:
       lda key
       lsla
       lsla
       sta key
       lda c1
       cbeqa #4,and3
       cbeqa #3,and12
       cbeqa #2,and48
       bra and192
and3:
       lda #TEAMAC_KEY1
       and #3
       bra or
and12:
       lda #TEAMAC_KEY1
       and #12
       lsra
       lsra
       bra or
and48:
       lda #TEAMAC_KEY1
       and #48
       lsra
       lsra
       lsra
       lsra
       bra or
and192:
       lda #TEAMAC_KEY1
       and #192
       lsra
       lsra
       lsra
       lsra
       lsra
       lsra
or:
       sta Aux
       lda key
       ora Aux
       sta key
       dbnz c1,while1
       mov #4,c1
while2:
       lda key+1
       lsla
       lsla
       sta key+1
       lda c1
       cbeqa #4,an12
       cbeqa #3,an48
       cbeqa #2,an192
       bra an3
 an12:
       lda #TEAMAC_KEY1
       and #12
       lsra
       lsra
       bra or2
 an48:
       lda #TEAMAC_KEY1
       and #48
       lsra
       lsra
       lsra
       lsra
       bra or2
 an192:
       lda #TEAMAC_KEY1
       and #192
       lsra
       lsra
       lsra
       lsra
       lsra
       lsra
       bra or2
 an3:
       lda #TEAMAC_KEY2
       and #3
 or2:
       sta Aux
       lda key+1
       ora Aux
       sta key+1
       dbnz c1,while2
       mov #4,c1
 while3:
       lda key+2
       lsla
       lsla
       sta key+2
       lda c1
       cbeqa #4,andd48
       cbeqa #3,andd192
       cbeqa #2,andd3
       bra andd12
```

```
andd48:
        lda #TEAMAC_KEY1
        and #48
        lsra
        lsra
        lsra
        lsra
        bra or3
andd192:
        lda #TEAMAC_KEY1
        and #192
        lsra
        lsra
        lsra
        lsra
        lsra
        lsra
        bra or3
andd3:
        lda #TEAMAC_KEY2
        and #3
        bra or3
andd12:
        lda #TEAMAC_KEY2
        and #12
        lsra
        lsra
or3:
        sta Aux
        lda key+2
        ora Aux
        sta key+2
        dbnz c1,while3
        mov #4,c1
while4:
        lda key+3
        lsla
        lsla
        sta key+3
        lda c1
        cbeqa #4,ann3
        cbeqa #3,ann12
        cbeqa #2,ann48
        bra ann192
ann3:
        lda #TEAMAC_KEY2
        and #3
        bra or4
ann12:
        lda #TEAMAC_KEY2
        and #12
        lsra
        lsra
```

```
      bra or4
ann48:
      lda #TEAMAC_KEY2
      and #48
      lsra
      lsra
      lsra
      lsra
      bra or4
ann192:
      lda #TEAMAC_KEY2
      and #192
      lsra
      lsra
      lsra
      lsra
      lsra
      lsra
or4:
      sta Aux
      lda key+3
      ora Aux
      sta key+3
      dbnz c1,while4
      mov #8,c1
      mov TEAMAC_DATA,y
      mov TEAMAC_DATA+1,z
      mov #$00,sum
while:
      ;y += (((z << 4) ^ (z >> 5)) + z) ^ (sum + k[sum&3]);
      lda z
      lsla
      lsla
      lsla
      lsla
      sta Aux
      lda z
      lsra
      lsra
      lsra
      lsra
      lsra
      eor Aux
      add z
      sta Aux
      lda sum
      and #3
      cbeqa #0,k0
      cbeqa #1,k1
      cbeqa #2,k2
      cbeqa #3,k3
k0:
      lda key
      bra adds
k1:
      lda key+1
      bra adds
k2:
      lda key+2
      bra adds
k3:
      lda key+3
      bra adds
_while:
      bra while
adds:
      add sum
      eor Aux
      sta Aux
      lda y
      add Aux
      sta y
      ;sum += delta;
      lda sum
      add #DELTA
      sta sum
      ;z += (((y << 4) ^ (y >> 5)) + y) ^ (sum + k[(sum>>3) & 3]);
      lda y
      lsla
      lsla
      lsla
      lsla
      sta Aux
      lda y
      lsra
      lsra
      lsra
      lsra
      lsra
      eor Aux
      add y
      sta Aux
      lda sum
      lsra
      lsra
      lsra
      and #$03
      cbeqa #0,K0
      cbeqa #1,K1
      cbeqa #2,K2
      cbeqa #3,K3
K0:
      lda key
      bra Adds
K1:
      lda key+1
      bra Adds
K2:
      lda key+2
      bra Adds
K3:
      lda key+3
      bra Adds
Adds:
      add sum
      eor Aux
      sta Aux
      lda z
      add Aux
      sta z
      dbnz c1,_while
      lda y
      eor z
      sta TEAMAC_CODE
      rts
```

B.1.3 ADC Driver

```
;*****************************************************************************
;*                              Driver Constant                              *
;*****************************************************************************
Table_Data EQU $3E00

      org RAMStart+18
;*****************************************************************************
;*                              Driver definitions                           *
;*****************************************************************************
ACMP_ENABLE         SET   $92
ACMP_DISABLED       SET   $20
MTIM_ENABLE         SET   $40
MTIM_STOP_RESET     SET   $30
MTIM_128_DIV        SET   $07
FREE_RUN            SET   $00

;*****************************************************************************
;*                              Driver Variables                             *
;*****************************************************************************
SensorReading       DS.B  1         ; Store ACMP read value
ConvertedValue      DS.B  1         ; This varible store converted value
Temp_Page           DS.B  1         ; Temporal backup Page

      org ROMStart+821
;*****************************************************************************
;*                              ADC Receive Function                         *
;*****************************************************************************
ADC_RECEIVE:
      bra MTIM_ADC_Init                ; Configure MITM
next:
      bra Discharge_Cap                ; Discharge Capacitor
```

```
next2:
      bra ACMP_Conf                      ; Configure ACMP+ and ACMP-
next3:
      mov #MTIM_ENABLE,MTIMSC            ; Timer Counter Enabled
      wait                               ; Wait for ACMP interrupt
      bset 4,MTIMSC
      lda MTIMCNT                        ; read counter timer value
      sta SensorReading                  ; store counter value
      mov #HIGH_6_13(SIP1), PAGESEL
      brset 3, MAP_ADDR_6(SIP1),ReadVal ; branch if ACMP interrupt arrives
      bra next
ReadVal:
      MOV #MTIM_STOP_RESET,MTIMSC        ; Stop and reset counter
      MOV #ACMP_DISABLED, ACMPSC
LookupTable:
      lda SensorReading
      rola                               ; Getting 2 MSB
      rola
      rola
      and #$03
      add #(Table_Data>>6)               ; Page Calculating
      mov #PAGESEL,Temp_Page             ; Backup actual page
      sta PAGESEL                        ; Page Change
      lda SensorReading
      and #$3F                           ; Extract 6 LSB
      add #$C0                           ; Index to paging window
      tax
      lda ,x                             ; Load table result
      sta ConvertedValue                 ; Store result
      mov #Temp_Page, PAGESEL            ; Back Page
      rts
MTIM_ADC_Init:
     mov #MTIM_128_DIV,MTIMCLK         ; Select bus clock as reference, Set prescaler
with 64
      mov #FREE_RUN,MTIMMOD              ; Configure Timer as free running
      mov #MTIM_STOP_RESET,MTIMSC
      bra next
Discharge_Cap:
      bset 1,PTADD                       ; Configure PTA1 as Output
      bclr 1,PTAD                        ; Start Capacitor discharging
      lda  #$FE                          ; Set delay time
waste_time:
      dbnza waste_time                   ; wait until Delay = 0
      bra next2
ACMP_Conf:
      MOV #ACMP_ENABLE,ACMPSC            ; ACMP Enabled, ACMP+ pin active, Interrupt
enabled, Rising edges detections
      bra next3

;*****************************************************************************
;*                             Data Table                                    *
;*****************************************************************************
 ORG Table_Data
```

```
dc.b 0,0,0,0,0,9,13,18,22,26,30,34,38,42,46,50
dc.b 54,57,61,64,68,71,74,78,81,84,87,90,93,96,99,101
dc.b 104,107,109,112,114,117,119,121,124,126,128,130,133,135,137,139
dc.b 141,143,145,146,148,150,152,154,155,157,159,160,162,163,165,166
dc.b 168,169,170,172,173,174,176,177,178,179,181,182,183,184,185,186
dc.b 187,188,189,190,191,192,193,194,195,196,197,198,199,199,200,201
dc.b 202,203,203,204,205,205,206,207,207,208,209,209,210,211,211,212
dc.b 212,213,213,214,214,215,215,216,216,217,217,218,218,219,219,220
dc.b 220,220,221,221,222,222,222,223,223,223,224,224,224,225,225,225
dc.b 226,226,226,227,227,227,227,228,228,228,228,229,229,229,229,230
dc.b 230,230,230,230,231,231,231,231,231,232,232,232,232,232,232,233
dc.b 233,233,233,233,233,234,234,234,234,234,234,234,234,235,235,235
dc.b 235,235,235,235,235,236,236,236,236,236,236,236,236,236,236,237
dc.b 237,237,237,237,237,237,237,237,237,237,237,237,238,238,238,238
dc.b 238,238,238,238,238,238,238,238,238,238,238,238,238,239,239,239
dc.b 239,239,239,239,239,239,239,239,239,239,239,239,239,239,239,239
```

B.2 APPLICATIONS

B.2.1 Accelerometer

```
;**************************************************************************
;*                            DISCLAIMER                                  *
;* Services performed by FREESCALE in this matter are performed          *
;* AS IS and without any warranty. CUSTOMER retains the final decision   *
;* relative to the total design and functionality of the end product.    *
;* FREESCALE neither guarantees nor will be held liable by CUSTOMER      *
;* for the success of this project. FREESCALE disclaims all warranties,  *
;* express, implied or statutory including, but not limited to,          *
;* implied warranty of merchantability or fitness for a particular       *
;* purpose on any hardware, software ore advise supplied to the project  *
;* by FREESCALE, and or any product resulting from FREESCALE services.   *
;* In no event shall FREESCALE be liable for incidental or consequential *
;* damages arising out of this agreement. CUSTOMER agrees to hold        *
;* FREESCALE harmless against any and all claims demands or actions      *
;* by anyone on account of any damage, or injury, whether commercial,    *
;* contractual, or tortuous, rising directly or indirectly as a result   *
;* of the advise or assistance supplied CUSTOMER in connection with      *
;* product, services or goods supplied under this Agreement.             *
;**************************************************************************

;**************************************************************************
;* This stationery serves as the framework for a user application.       *
;* For a more comprehensive program that demonstrates the more           *
;* advanced functionality of this processor, please see the              *
;* demonstration applications, located in the examples                   *
;* subdirectory of the "Freescale CodeWarrior for HC08" program          *
;* directory.                                                            *
;**************************************************************************

; Include derivative-specific definitions
            INCLUDE 'derivative.inc'
```

```
; export symbols

            XDEF _Startup
            ABSENTRY _Startup

; variable/data section

      include "TangoDriver.asm"       ; Include before ADCdriver.asm
      include "ADCdriver.asm"         ; Include after TangoDriver.asm

      ORG    RAMStart+21              ; If ADCdriver.asm is include RAMStart+21
                                      ; else RAMStart+18

      ; Insert your data definition here
;*******************************************************************************
;*                            User Variables                                   *
;*******************************************************************************

                ;******* Add your variables here *******

seconds              DS.B  1
VarRandom            DS.B  1

;*******************************************************************************

MODE                 EQU   1    ; Operation Mode (1:Run Mode, 0:Background Mode)


; code section

            ORG    ROMStart+903       ; If ADCdriver.asm is include ROMStart+903
                                      ; else ROMStart+821
;*******************************************************************************
;*                            MACRO declarations                               *
;*******************************************************************************
TRIM_ICS: MACRO                    ; Macro used to configure the ICS with TRIM
      mov   #$FF,PAGESEL           ; change to last page
      ldx   #$FA                   ; load the content which TRIM value is store
      lda   ,x                     ; read D[X]
      cbeqa #$FF,No_Trim           ; Omit the 0xFF value if $3FFA location content it
      sta   ICSTRM                 ; Store TRIM value into ICSTRM register
      mov   #$01,ICSSC             ; Fine TRIM
No_Trim:
      ENDM

MTIM2ms: MACRO
      mov #$70, MTIMSC     ; Enables interrupt, stops and resets timer
      mov #$7D, MTIMMOD    ; MTIM modulo with 256 counts before interrupt.
      mov #$07, MTIMCLK    ; Bus clock at 8MHz with prescaler 128
                                ;          Bus Clk
                                ; ---------------------- = Timer interrupt
                                ;  (preescaler)*(MTIMMOD)
```

```
 ;(increments timer counter every 16 us)(flag interrupt every 2ms)

           ENDM
;*****************************************************************************
;*                          Init Microcontroller                              *
;*****************************************************************************
Init_Conf:
      IFNE  MODE
      mov #HIGH_6_13(SOPT), PAGESEL
    mov #$21, MAP_ADDR_6(SOPT)    ; Disables COP and RESET (PTA2) pin
      ELSE
      mov #HIGH_6_13(SOPT), PAGESEL
     mov #$23, MAP_ADDR_6(SOPT)     ; Disables COP and RESET, enables BKGD (PTA3)
ENDIF
      clr  ICSC1                       ; FLL is selected as Bus Clock
      TRIM_ICS                         ; Trim MCU to work at 8MHz
      clr  ICSC2
      mov #ID2,TEAMAC_DATA+1
      mov #ID2,TEAMAC_DATA
      rts
;*****************************************************************************
;*                               Init PTA                                     *
;*****************************************************************************
Init_PTA:
      mov #HIGH_6_13(PTAPE),PAGESEL
      mov #$FE, MAP_ADDR_6(PTAPE)       ; Enables internal Pulling device

      mov #HIGH_6_13(PTAPUD),PAGESEL
      mov #$00, MAP_ADDR_6(PTAPUD)      ; Configures Internal pull up/pull down

      mov #$FA,PTADD

      clr PTAD

      rts
;*****************************************************************************
;*                               Init RTI                                     *
;*****************************************************************************
InitRTI:
      mov #HIGH_6_13(SRTISC), PAGESEL ; RTI register access
      mov #$37,MAP_ADDR_6(SRTISC)     ; 32-KHz trimmed internal source selected,
                                  ; Interrupt enabled, 1.024s interrupt period base
      lda ICSC1
      ora #$01                         ; IREFSTEN enable
      sta ICSC1
      rts

;*****************************************************************************
;*                          Random Function                                   *
;*****************************************************************************
randomize:
      lda VarRandom
      add #ID2
      adc ConvertedValue
      add TEAMAC_CODE
      sta VarRandom
      lda #$03
      and VarRandom
      sta VarRandom
      rts
;*****************************************************************************
;*                            Main Program                                   *
;*****************************************************************************
_Startup:
      jsr Init_Conf
      jsr Init_PTA
      jsr InitRTI
r:
      bclr 4,MAP_ADDR_6(SRTISC)          ; RTI Interrupt Disable
      bset 3,PTAD
      jsr delay26ms
      jsr ADC_RECEIVE
      mov #HIGH_6_13(SPMSC1), PAGESEL
      mov #$00, MAP_ADDR_6(SPMSC1)       ; Disables LVDIE, LVDRE, LVDSE, LVDE
      lda ConvertedValue
      sub #190
      bhs SideFront
      lda ConvertedValue
      sub #120
      bhs TopOrDown
      lda ConvertedValue
      sub #35
      bhs SideBack
      mov #0,DATA+1
      bra sendData
SideFront:
      mov #$41,DATA+1
      bra sendData
TopOrDown:
      mov #$42,DATA+1
      bra sendData
SideBack:
      mov #$43,DATA+1
sendData:
      mov #0,DATA
      jsr ENCRYPT_TEAMAC
      BAUD_4600
      jsr TANGO_SEND_DATA
      bset 4,MAP_ADDR_6(SRTISC)          ; RTI Interrupt Enable
      jsr randomize
      lda VarRandom
      cbeqa #0,nZ
      mov VarRandom,seconds
      bra Loop2
nZ:
      mov #1,seconds
```

```
Loop2:
      bset 6,MAP_ADDR_6(SRTISC)           ; Clear RTI interrupt flag (ACK)
      stop
           dbnz seconds,Loop2
      bra r
delay26ms:
      mov #13,seconds
      MTIM2ms
      bclr 4,MTIMSC    ; MTIM counter is Active
LoopTimer:
      brclr 7,MTIMSC,LoopTimer
      bset 5,MTIMSC
      dbnz seconds,LoopTimer
      bset 4,MTIMSC
      rts
;*****************************************************************************
;*                            Startup Vector                                  *
;*****************************************************************************

      ORG   $3FFD
      JMP _Startup          ; Reset
```

B.2.2 Temperature

```
;*************************************************************************
;*                            DISCLAIMER                                 *
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;* purpose on any hardware, software ore advise supplied to the project  *
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;* In no event shall FREESCALE be liable for incidental or consequential *
;* damages arising out of this agreement. CUSTOMER agrees to hold        *
;* FREESCALE harmless against any and all claims demands or actions      *
;* by anyone on account of any damage, or injury, whether commercial,    *
;* contractual, or tortuous, rising directly or indirectly as a result   *
;* of the advise or assistance supplied CUSTOMER in connection with      *
;* product, services or goods supplied under this Agreement.             *
;*************************************************************************

;*************************************************************************
;* This stationery serves as the framework for a user application.       *
;* For a more comprehensive program that demonstrates the more           *
;* advanced functionality of this processor, please see the              *
;* demonstration applications, located in the examples                   *
;* subdirectory of the "Freescale CodeWarrior for HC08" program          *
;* directory.                                                            *
;*************************************************************************
```

```
; Include derivative-specific definitions
            INCLUDE 'derivative.inc'
; export symbols

            XDEF _Startup
            ABSENTRY _Startup
; variable/data section

      include "TangoDriver.asm"       ; Include before ADCdriver.asm
      include "ADCdriver.asm"         ; Include after TangoDriver.asm

      ORG    RAMStart+21              ; If ADCdriver.asm is include RAMStart+21
                                      ; else RAMStart+18

      ; Insert your data definition here
;**************************************************************************
;*                            User Variables                             *
;**************************************************************************

                ;******* Add your variables here *******

seconds             DS.B  1
VarRandom           DS.B  1
;**************************************************************************
MODE               EQU   1          ; Operation Mode (1:Run Mode, 0:Background Mode)
; code section

            ORG    ROMStart+903       ; If ADCdriver.asm is include ROMStart+903
                                      ; else ROMStart+821
;**************************************************************************
;*                            MACRO declarations                         *
;**************************************************************************
TRIM_ICS: MACRO                       ; Macro used to configure the ICS with TRIM
      mov    #$FF,PAGESEL             ; change to last page
      ldx    #$FA                     ; load the content which TRIM value is store
      lda    ,x                       ; read D[X]
      cbeqa #$FF,No_Trim             ; Omit the 0xFF value if $3FFA location content
the value
      sta    ICSTRM                   ; Store TRIM value into ICSTRM register
      ;mov   #$01,ICSSC               ; Fine TRIM
No_Trim:
      ENDM

MTIM2ms: MACRO
     mov #$70, MTIMSC             ; Enables interrupt, stops and resets timer counter
      mov #$7D, MTIMMOD                     ; MTIM modulo with 256 counts before
interrupt.
      mov #$07, MTIMCLK               ; Bus clock 8 MHz with prescaler 128

                                      ;         Bus Clk
                                           ; ----------------------- = Timer
interrupt
                                           ;  (preescaler)*(MTIMMOD)
            ; (increments timer counter every 16 us)(flag interrupt every 2ms)

           ENDM
;*****************************************************************************
;*                          Init Microcontroller                             *
;*****************************************************************************
Init_Conf:
      IFNE  MODE
      mov #HIGH_6_13(SOPT), PAGESEL
   mov #$21, MAP_ADDR_6(SOPT)   ; Disables COP and enables RESET (PTA2) pin
      ELSE
      mov #HIGH_6_13(SOPT), PAGESEL
      mov #$23, MAP_ADDR_6(SOPT)      ; Disables COP, enables BKGD (PTA3) and RESET
(PTA2) pins
      ENDIF
      clr  ICSC1                      ; FLL is selected as Bus Clock
      TRIM_ICS                        ; Trim MCU to work at 8MHz
      clr  ICSC2
      mov #ID2,TEAMAC_DATA+1
      mov #ID2,TEAMAC_DATA
      rts
;*****************************************************************************
;*                               Init PTA                                    *
;*****************************************************************************
Init_PTA:
      mov #HIGH_6_13(PTAPE),PAGESEL
      mov #$FE, MAP_ADDR_6(PTAPE)  ; Enables internal Pulling device

      mov #HIGH_6_13(PTAPUD),PAGESEL
      mov #$00, MAP_ADDR_6(PTAPUD)    ; Configures Internal pull up/pull down device
in PTA

      mov #$FA,PTADD

      clr PTAD

      rts
;*****************************************************************************
;*                               Init RTI                                    *
;*****************************************************************************
InitRTI:
      mov #HIGH_6_13(SRTISC), PAGESEL ; RTI register access
      mov #$37,MAP_ADDR_6(SRTISC)     ; 32-KHz trimmed internal source selected,
                                   ; Interrupt enabled, 1.024s interrupt period base
      lda ICSC1
      ora #$01                        ; IREFSTEN enable
      sta ICSC1
      rts
;*****************************************************************************
;*                            Random Function                                *
;*****************************************************************************
randomize:
      lda VarRandom
      add #ID2
      adc ConvertedValue
      add TEAMAC_CODE
      sta VarRandom
      lda #$FF
      and VarRandom
      sta VarRandom
      rts
;*****************************************************************************
;*                            Main Program                                   *
;*****************************************************************************
_Startup:
      jsr Init_Conf
      jsr Init_PTA
      jsr InitRTI
r:
      bclr 4,MAP_ADDR_6(SRTISC)           ; RTI Interrupt Disable
      jsr delay26ms
      jsr ADC_RECEIVE
      mov #HIGH_6_13(SPMSC1), PAGESEL
  mov #$00, MAP_ADDR_6(SPMSC1)   ; Disables LVDIE, LVDRE, LVDSE, LVDE
      mov #0,DATA
      mov ConvertedValue, DATA+1
      jsr ENCRYPT_TEAMAC
      BAUD_4600
      jsr TANGO_SEND_DATA
      bset 4,MAP_ADDR_6(SRTISC)           ; RTI Interrupt Enable
      jsr randomize
      lda VarRandom
      cbeqa #0,nZ
      mov VarRandom,seconds
      bra Loop2
nZ:
      mov #1,seconds
Loop2:
      bset 6,MAP_ADDR_6(SRTISC)           ; Clear RTI interrupt flag (ACK)
      stop
      dbnz seconds,Loop2
      bra r

delay26ms:
      mov #13,seconds
      MTIM2ms
      bclr 4,MTIMSC                              ; MTIM counter is Active
LoopTimer:
      brclr 7,MTIMSC,LoopTimer
      bset 5,MTIMSC
      dbnz seconds,LoopTimer
      bset 4,MTIMSC
      rts

;*****************************************************************************
```

```
;*                              Startup Vector                                 *
;*******************************************************************************

      ORG   $3FFD
      JMP _Startup          ; Reset
```

B.2.3 Ultrasonic Distance Measure

```
;***************************************************************************
;*                              DISCLAIMER                                 *
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;* by anyone on account of any damage, or injury, whether commercial,      *
;* contractual, or tortuous, rising directly or indirectly as a result     *
;* of the advise or assistance supplied CUSTOMER in connection with        *
;* product, services or goods supplied under this Agreement.               *
;***************************************************************************

;***************************************************************************
;* This stationery serves as the framework for a user application.         *
;* For a more comprehensive program that demonstrates the more             *
;* advanced functionality of this processor, please see the                *
;* demonstration applications, located in the examples                     *
;* subdirectory of the "Freescale CodeWarrior for HC08" program            *
;* directory.                                                              *
;***************************************************************************
; Include derivative-specific definitions
            INCLUDE 'derivative.inc'
            INCLUDE 'macros.asm'
; export symbols

            XDEF _Startup
            ABSENTRY _Startup
; variable/data section

      include "TangoDriver.asm"       ; Include before ADCdriver.asm

      ORG    RAMStart+18              ; If ADCdriver.asm is include RAMStart+21
                                      ; else RAMStart+18

      ; Insert your data definition here
;*******************************************************************************
;*                               RAM Variables                                 *
```

```
;*****************************************************************************
time_dist             DS.B  1          ; distance timer with a resolution of 25useg
distance:             DS.B  1          ; last distance value
input_filt            DS.B  1          ; filter input register
cont_cycles:          DS.B  1          ; pulses to send
repeat                DS.B  1
;*****************************************************************************
;*                             User Variables                                *
;*****************************************************************************

                ;******* Add your variables here *******

seconds               DS.B  1
VarRandom             DS.B  1
;*****************************************************************************
FILTERTIME           EQU  20         ; Time constant to determine the response of the
filter
                                      ; A lower value means a fast response (this may
lead to hear nosie)
                                        ; A higher value means a lower response (but
tends to be more accurate)
MAXDISTANCE           EQU 255          ; Maximum distance to detect (this is not in
distance units)

MODE                 EQU   1          ; Operation Mode (1:Run Mode, 0:Background Mode)
NUM_CYCLES            EQU  40           ; Burst cycles/2


; code section

            ORG    ROMStart+821        ; If ADCdriver.asm is include ROMStart+903
                                       ; else ROMStart+821
;*****************************************************************************
;*                             MACRO declarations                            *
;*****************************************************************************
TRIM_ICS: MACRO                        ; Macro used to configure the ICS with TRIM
      mov   #$FF,PAGESEL               ; change to last page
      ldx   #$FA                       ; load the content which TRIM value is store
      lda   ,x                         ; read D[X]
      cbeqa #$FF,No_Trim              ; Omit the 0xFF value if $3FFA location content
the value
      sta   ICSTRM                     ; Store TRIM value into ICSTRM register
      ;mov   #$01,ICSSC                 ; Fine TRIM
No_Trim:
      ENDM

MTIM2ms: MACRO
     mov #$70, MTIMSC               ; Enables interrupt, stops and resets timer counter
      mov #$7D, MTIMMOD                        ; MTIM modulo with 256 counts before
interrupt.
      mov #$07, MTIMCLK               ; Selects internal clock as reference bus clock
(8 MHz) with prescaler 128
```

```
                                        ;         Bus Clk
                                             ; ----------------------- = Timer
interrupt
                                             ;  (preescaler)*(MTIMMOD)

                                        ; (increments timer counter every 16 us)(flag
interrupt every 2ms)
           ENDM
;**************************************************************************
;*                           Init Microcontroller                            *
;**************************************************************************
Init_Conf:
      IFNE  MODE
      mov #HIGH_6_13(SOPT), PAGESEL
    mov #$20, MAP_ADDR_6(SOPT)    ; Disables COP and enables Stop mode
      ELSE
      mov #HIGH_6_13(SOPT), PAGESEL
  mov #$23, MAP_ADDR_6(SOPT)  ; Disables COP, enables BKGD (PTA3) and Stop mode
      ENDIF
      clr  ICSC1                       ; FLL is selected as Bus Clock
      TRIM_ICS                         ; Trim MCU to work at 8MHz
      clr  ICSC2
      mov #ID2,TEAMAC_DATA+1
      mov #ID2,TEAMAC_DATA
      rts
;**************************************************************************
;*                                Init PTA                                   *
;**************************************************************************
Init_PTA:
      mov #HIGH_6_13(PTAPE),PAGESEL
      mov #$FF, MAP_ADDR_6(PTAPE); Enables internal Pulling device

      mov #HIGH_6_13(PTAPUD),PAGESEL
      mov #$00, MAP_ADDR_6(PTAPUD)    ; Configures Internal pull up/pull down device
in PTA

      mov #(mPTADD_PTADD1),PTADD  ; Set direction of PTAD pins
      clr PTAD

      rts

;**************************************************************************
;*                                Init RTI                                   *
;**************************************************************************
InitRTI:
      mov #HIGH_6_13(SRTISC), PAGESEL ; RTI register access
      mov #$31,MAP_ADDR_6(SRTISC)     ; 32-KHz trimmed internal source selected,
                                      ; Interrupt enabled, 8 ms interrupt period base
      lda ICSC1
      ora #$01                         ; IREFSTEN enable
      sta ICSC1
      rts
;**************************************************************************
```

```
;*                                  Init KBI                                 *
;*****************************************************************************
InitKBI:
        bset    KBIPE_KBIPE2,KBIPE          ; KBI2 as input
        bset    KBIES_KBEDG2,KBIES          ; Select only rising edges or low level
condition
     clr   KBISC                ; KBI interrupt request enable , detects edges only
        rts
;*****************************************************************************
;*                            Random Function                                *
;*****************************************************************************
randomize:
      lda VarRandom
      add #ID2
      adc distance
      add TEAMAC_CODE
      sta VarRandom
      lda #$FF
      and VarRandom
      sta VarRandom
      rts
;*****************************************************************************
;*                             Main Program                                  *
;*****************************************************************************
_Startup:
      jsr Init_Conf
      jsr Init_PTA
      jsr InitRTI
      jsr InitKBI
rep:
      mov #10,repeat
main:
;***********************************************************************************
;*  ULTRASOUND TRANSMISSION MODE
;*
;*  1.   In TX mode, system should be 'deaf', so it doesn’t listen its own ultrasound
while transmitting.
;*  2.   Send pulses through the ultrasound transmitter.
;*  3.   Wait 1 ms, so the sound travels enough to rebound.
;*  4.   Prepare to 'listen' ultrasound echo (change mode to Ultrasound RX).
;*
;***********************************************************************************
        jsr delay24ms
; System is 'deaf' by default because KBI interrupts are disabled
; 10 cycles 40 KHZ burst generation
        mov     #NUM_CYCLES,cont_cycles ; load number of pulses to send
; Configure timer to send pulses @ 80 kHz (toogling at 80 kHz means pulses at 40 kHz)

      mov    #$70, MTIMSC          ; Enables interrupt, stops and resets timer counter
       clr     MTIMCLK               ; Selects internal clock as reference bus clock
(8 MHz) with prescaler 1
       mov     #100, MTIMMOD          ; MTIM modulo with 100 counts before interrupt.
100*125ns = 12.5 us => 80 kHz
```

```
        bclr    MTIMSC_TSTP,MTIMSC    ; Starts timer
; Start sending pulses @ 40kHz to the UltraSound transmitter
wait80: wait                                    ; Enter into WAIT mode until an
interruption arrives
                                             ; An interruption arrived, Read MTIMSC
register to check Timer Overflow Flag (TOF)
        brset   MTIMSC_TOF, MTIMSC, sendPulse   ; branch if MTIM interrupt pending
        bra     wait80                         ; If any other interrupt arrived, go
to wait (this condition shouldn't occur)
sendPulse:
        bclr    MTIMSC_TOF,MTIMSC               ; clear Timer overflow flag
        lda     PTAD                            ; toggle output pin
        eor     #mPTAD_PTAD1
        sta     PTAD
        dbnz    cont_cycles, wait80             ; continue till all pulses are sent

       bclr    PTAD_PTAD1,PTAD                ; clear ultrasound output
; Finished ultrasound pulse tx, system must wait 1 ms
       mov     #$70, MTIMSC                ; Enables interrupt, stops and resets timer
counter
      mov     #250, MTIMMOD             ; MTIM modulo with 250 counts before interrupt.
       mov     #$05, MTIMCLK               ; Selects internal clock as reference bus
clock (8 MHz) with prescaler 32

        bclr    MTIMSC_TSTP,MTIMSC; MTIM counter is Active
wait1ms:wait
        brset   MTIMSC_TOF, MTIMSC, hear    ; branch if MTIM interrupt pending
        bra     wait1ms                     ; else, wait
; Prepare for hearing
hear:   bclr    MTIMSC_TOF,MTIMSC       ; clear Timer overflow flag
        bset    KBIPE_KBIPE2,KBIPE      ; enable reception on KBI on pin 2
        mov     #$06,KBISC         ; KBI interrupt request enable , detects edges only
        clr     time_dist               ; resets time_dist variable to 0
        clr     time_dist+1
        clr     input_filt              ; reset input filter counter
;*****************************************************************************
;*  ULTRASOUND RECEPTION MODE
;*
;*  1.  Start counting the time it takes for ultrasound to echo.
;*  2.  Filter the signal so system knows when echo is strong enough to be considered.
;*         - If echo time is too large, the obstacle is too far away.
;*  3.  Save the time it took to echo.
;*  4.  Prepare to generate tones (change to Tone Mode).
;*
;*****************************************************************************
; Configure timer to interrupt every 25 us (40 kHz); Prescaler = 4; MTIMMOD = 50
       mov     #$70, MTIMSC                ; Enables interrupt, stops and resets timer
counter
      mov     #50, MTIMMOD               ; MTIM modulo with 50 counts before interrupt.
       mov     #$02, MTIMCLK               ; Selects internal clock as reference bus
clock (8 MHz) with prescaler 4
        bclr    MTIMSC_TSTP,MTIMSC; Starts timer
;*************************************************************************
```

```
; Receive Ultrasound echo and count the time it took to travel
;*****************************************************************************
wait40: wait                                    ; Enter into WAIT mode until an
interruption arrives
                                              ; An interruption arrived, Read MTIMSC
register to check Timer Overflow Flag (TOF)
        brset   KBISC_KBF, KBISC, KBI_Isr       ; branch if KBI interrupt pending
        brset   MTIMSC_TOF, MTIMSC, rx_timer    ; branch if MTIM interrupt pending
        bra     wait40                          ; If any other interrupt arrived, go
to wait (this condition shouldn't occur)


rx_timer:                                  ; This interrupt occurrs every 40 kHz (25 us)
        bclr    MTIMSC_TOF,MTIMSC               ; clear Timer overflow flag
        inc     time_dist                       ; increment the time that the signal
took to arrive (measured in 40 kHz pulses)
;*****************************************************************************
;* Filter algorithm
;*    When #FILTERTIME echoes are detected or #MAXDISTANCE is reached, finish
detection.
;*    If less than #FILTERTIME echoes detected, consider that as noise or interference
;*****************************************************************************
        lda     time_dist
        cmpa    #MAXDISTANCE
        bhs     end_rx                  ; if time_dist >= MAXDISTANCE branch to end_rx

        lda     input_filt
      cmp     #FILTERTIME           ; if input_filt < #FILTERTIME, branch to no_signal
        blo     no_signal
end_rx: mov     time_dist,distance      ; save last distance measured
        mov     #$00,KBISC              ; Disable KBI interrupt
        clr     MTIMSC                  ; Stop timer

        dbnz    repeat,main
        bra     send_mode
no_signal:
        lda     input_filt              ; if input_filt == 0, go to no_sign
        beq     no_sign
        dec     input_filt
no_sign:bra     wait40
; KBI_Isr: is executed on falling edge of the ECHO
KBI_Isr:
        bset    KBISC_KBACK,KBISC           ; Acknowledge to KBI
        lda     input_filt                  ; Add 3 to input_filt to determine the
time constant
        add     #3
        sta     input_filt
        bra     wait40
send_mode:
      mov #HIGH_6_13(SPMSC1), PAGESEL
  mov #$00, MAP_ADDR_6(SPMSC1)   ;Disables LVDIE, LVDRE, LVDSE, LVDE
      mov #0,DATA
      mov distance,DATA+1
      jsr ENCRYPT_TEAMAC
      BAUD_4600
      jsr TANGO_SEND_DATA
      jsr randomize
      lda VarRandom
      cbeqa #0,nZ
      mov VarRandom,seconds
      bra Loop2
nZ:
      mov #1,seconds
Loop2:
      bset 6,MAP_ADDR_6(SRTISC)           ; Clear RTI interrupt flag (ACK)
      stop
           dbnz seconds,Loop2
      jmp rep
delay24ms:
      mov #50,seconds
      MTIM2ms
      bclr 4,MTIMSC                              ; MTIM counter is Active
LoopTimer:
      brclr 7,MTIMSC,LoopTimer
      bset 5,MTIMSC
      dbnz seconds,LoopTimer
      bset 4,MTIMSC
      rts
;*****************************************************************************
;*                            Startup Vector                                 *
;*****************************************************************************

      ORG   $3FFD
      JMP _Startup          ; Reset
```

B.2.4 Pressure

```
;*************************************************************************
;*                            DISCLAIMER                                 *
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;* contractual, or tortuous, rising directly or indirectly as a result   *
;* of the advise or assistance supplied CUSTOMER in connection with      *
;* product, services or goods supplied under this Agreement.             *
;*************************************************************************
```

```
;**************************************************************************
;* This stationery serves as the framework for a user application.       *
;* For a more comprehensive program that demonstrates the more            *
;* advanced functionality of this processor, please see the              *
;* demonstration applications, located in the examples                    *
;* subdirectory of the "Freescale CodeWarrior for HC08" program           *
;* directory.                                                             *
;**************************************************************************
; Include derivative-specific definitions
            INCLUDE 'derivative.inc'
; export symbols

            XDEF _Startup
            ABSENTRY _Startup
; variable/data section

      include "TangoDriver.asm"       ; Include before ADCdriver.asm
      include "ADCdriver.asm"         ; Include after TangoDriver.asm

      ORG    RAMStart+21              ; If ADCdriver.asm is include RAMStart+21
                                      ; else RAMStart+18

      ; Insert your data definition here
;******************************************************************************
;*                            User Variables                                  *
;******************************************************************************

                ;******* Add your variables here *******
seconds               DS.B  1
VarRandom             DS.B  1
;******************************************************************************
MODE                 EQU   1         ; Operation Mode (1:Run Mode, 0:Background Mode)
; code section

            ORG    ROMStart+903       ; If ADCdriver.asm is include ROMStart+903
                                      ; else ROMStart+821
;******************************************************************************
;*                            MACRO declarations                              *
;******************************************************************************
TRIM_ICS: MACRO                       ; Macro used to configure the ICS with TRIM
      mov   #$FF,PAGESEL              ; change to last page
      ldx   #$FA                      ; load the content which TRIM value is store
      lda   ,x                        ; read D[X]
     cbeqa #$FF,No_Trim              ; Omit the 0xFF value if $3FFA location content
the value
      sta   ICSTRM                    ; Store TRIM value into ICSTRM register
      ;mov   #$01,ICSSC                ; Fine TRIM
No_Trim:
      ENDM
MTIM2ms: MACRO
     mov #$70, MTIMSC             ; Enables interrupt, stops and resets timer counter
      mov #$7D, MTIMMOD                     ; MTIM modulo with 125 counts before
```

```
interrupt.
      mov #$07, MTIMCLK              ; Selects internal clock as reference bus clock
(8 MHz) with prescaler 128

                                      ;          Bus Clk
                                           ; ----------------------- = Timer
interrupt
                                           ;  (preescaler)*(MTIMMOD)

                                      ; (increments timer counter every 16 us)(flag
interrupt every 2ms)

           ENDM
;*****************************************************************************
;*                            Init Microcontroller                           *
;*****************************************************************************
Init_Conf:
      IFNE  MODE
      mov #HIGH_6_13(SOPT), PAGESEL
   mov #$21, MAP_ADDR_6(SOPT)   ; Disables COP and enables RESET (PTA2) pin
      ELSE
      mov #HIGH_6_13(SOPT), PAGESEL
      mov #$23, MAP_ADDR_6(SOPT)      ; Disables COP, enables BKGD (PTA3) and RESET
(PTA2) pins
      ENDIF
      clr  ICSC1                      ; FLL is selected as Bus Clock
      TRIM_ICS                        ; Trim MCU to work at 8MHz
      clr  ICSC2
      mov #ID2,TEAMAC_DATA+1
      mov #ID2,TEAMAC_DATA
      rts
;*****************************************************************************
;*                                 Init PTA                                  *
;*****************************************************************************
Init_PTA:
      mov #HIGH_6_13(PTAPE),PAGESEL
      mov #$FE, MAP_ADDR_6(PTAPE); Enables internal Pulling device

      mov #HIGH_6_13(PTAPUD),PAGESEL
      mov #$00, MAP_ADDR_6(PTAPUD)    ; Configures Internal pull up/pull down device
in PTA

      mov #$FA,PTADD
      clr PTAD

      rts
;*****************************************************************************
;*                                 Init RTI                                  *
;*****************************************************************************
InitRTI:
      mov #HIGH_6_13(SRTISC), PAGESEL ; RTI register access
      mov #$34,MAP_ADDR_6(SRTISC)     ; 32-KHz trimmed internal source selected,
                                   ; Interrupt enabled, 1.024s interrupt period base
      lda ICSC1
      ora #$01                        ; IREFSTEN enable
      sta ICSC1
      rts
;*****************************************************************************
;*                           Random Function                                 *
;*****************************************************************************
randomize:
      lda VarRandom
      add #ID2
      adc ConvertedValue
      add TEAMAC_CODE
      sta VarRandom
      lda #$0F
      and VarRandom
      sta VarRandom
      rts
;*****************************************************************************
;*                            Main Program                                   *
;*****************************************************************************
_Startup:
      jsr Init_Conf
      jsr Init_PTA
      jsr InitRTI
r:
      bclr 4,MAP_ADDR_6(SRTISC)           ; RTI Interrupt Disable
      bset 3,PTAD
      jsr delay26ms
      jsr ADC_RECEIVE
      mov #HIGH_6_13(SPMSC1), PAGESEL
  mov #$00, MAP_ADDR_6(SPMSC1)   ; Disables LVDIE, LVDRE, LVDSE, LVDE
      mov #0,DATA
      mov ConvertedValue, DATA+1
      jsr ENCRYPT_TEAMAC
      BAUD_4600
      jsr TANGO_SEND_DATA
      bset 4,MAP_ADDR_6(SRTISC)           ; RTI Interrupt Enable
      jsr randomize
      lda VarRandom
      cbeqa #0,nZ
      mov VarRandom,seconds
      bra Loop2
nZ:
      mov #1,seconds
Loop2:
      bset 6,MAP_ADDR_6(SRTISC)           ; Clear RTI interrupt flag (ACK)
      stop
           dbnz seconds,Loop2
      bra r
delay26ms:
      mov #13,seconds
      MTIM2ms
      bclr 4,MTIMSC                              ; MTIM counter is Active
```

```
LoopTimer:
      brclr 7,MTIMSC,LoopTimer
      bset 5,MTIMSC
      dbnz seconds,LoopTimer
      bset 4,MTIMSC
      rts
;*****************************************************************************
;*                            Startup Vector                                 *
;*****************************************************************************

      ORG   $3FFD
      JMP _Startup          ; Reset
```

B.2.5 Light

```
;*************************************************************************
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;* product, services or goods supplied under this Agreement.             *
;*************************************************************************

;*************************************************************************
;* This stationery serves as the framework for a user application.       *
;* For a more comprehensive program that demonstrates the more           *
;* advanced functionality of this processor, please see the              *
;* demonstration applications, located in the examples                   *
;* subdirectory of the "Freescale CodeWarrior for HC08" program          *
;* directory.                                                            *
;*************************************************************************
; Include derivative-specific definitions
            INCLUDE 'derivative.inc'
; export symbols

            XDEF _Startup
            ABSENTRY _Startup
; variable/data section


      include "TangoDriver.asm"       ; Include before ADCdriver.asm
      include "ADCdriver.asm"         ; Include after TangoDriver.asm

      ORG    RAMStart+21              ; If ADCdriver.asm is include RAMStart+21
                                      ; else RAMStart+18

      ; Insert your data definition here
;*****************************************************************************
;*                              User Variables                               *
;*****************************************************************************

                ;******* Add your variables here *******
seconds              DS.B  1
VarRandom            DS.B  1
;*****************************************************************************
MODE                EQU   1          ; Operation Mode (1:Run Mode, 0:Background Mode)
; code section

            ORG    ROMStart+903       ; If ADCdriver.asm is include ROMStart+903
                                      ; else ROMStart+821
;*****************************************************************************
;*                              MACRO declarations                           *
;*****************************************************************************
TRIM_ICS: MACRO                       ; Macro used to configure the ICS with TRIM
      mov   #$FF,PAGESEL              ; change to last page
      ldx   #$FA                      ; load the content which TRIM value is store
      lda   ,x                        ; read D[X]
      cbeqa #$FF,No_Trim             ; Omit the 0xFF value if $3FFA location content
the value
      sta   ICSTRM                    ; Store TRIM value into ICSTRM register
      mov   #$01,ICSSC                ; Fine TRIM
No_Trim:
      ENDM

MTIM2ms: MACRO
     mov #$70, MTIMSC              ; Enables interrupt, stops and resets timer counter
      mov #$7D, MTIMMOD                      ; MTIM modulo with 256 counts before
interrupt.
      mov #$07, MTIMCLK              ; Selects internal clock as reference bus clock
(8 MHz) with prescaler 128

                                      ;          Bus Clk
                                           ; ----------------------- = Timer
interrupt
                                           ;  (preescaler)*(MTIMMOD)

                                      ; (increments timer counter every 16 us)(flag
interrupt every 2ms)

           ENDM
;*****************************************************************************
;*                              Init Microcontroller                         *
;*****************************************************************************
Init_Conf:
      IFNE  MODE
      mov #HIGH_6_13(SOPT), PAGESEL
   mov #$21, MAP_ADDR_6(SOPT)   ; Disables COP and enables RESET (PTA2) pin
      ELSE
      mov #HIGH_6_13(SOPT), PAGESEL
      mov #$23, MAP_ADDR_6(SOPT)      ; Disables COP, enables BKGD (PTA3) and RESET
(PTA2) pins
      ENDIF
      clr  ICSC1                      ; FLL is selected as Bus Clock
      TRIM_ICS                        ; Trim MCU to work at 8MHz
      clr  ICSC2
      mov #ID2,TEAMAC_DATA+1
      mov #ID2,TEAMAC_DATA
      rts
;******************************************************************************
;*                                Init PTA                                    *
;******************************************************************************
Init_PTA:
      mov #HIGH_6_13(PTAPE),PAGESEL
      mov #$FE, MAP_ADDR_6(PTAPE); Enables internal Pulling device

      mov #HIGH_6_13(PTAPUD),PAGESEL
      mov #$00, MAP_ADDR_6(PTAPUD)    ; Configures Internal pull up/pull down device
in PTA

      mov #$FA,PTADD
      clr PTAD

      rts
;******************************************************************************
;*                                Init RTI                                    *
;******************************************************************************
InitRTI:
      mov #HIGH_6_13(SRTISC), PAGESEL ; RTI register access
      mov #$37,MAP_ADDR_6(SRTISC)     ; 32-KHz trimmed internal source selected,
                                   ; Interrupt enabled, 1.024s interrupt period base
      lda ICSC1
      ora #$01                        ; IREFSTEN enable
      sta ICSC1
      rts
;******************************************************************************
;*                          Random Function                                   *
;******************************************************************************
randomize:
      lda VarRandom
      add #ID2
      adc ConvertedValue
      add TEAMAC_CODE
      sta VarRandom
      lda #$3F
      and VarRandom
      sta VarRandom
      rts
```

```
;***************************************************************************
;*                              Main Program                               *
;***************************************************************************
_Startup:
      jsr Init_Conf
      jsr Init_PTA
      jsr InitRTI
r:
      bclr 4,MAP_ADDR_6(SRTISC)           ; RTI Interrupt Disable
      jsr delay26ms
      jsr ADC_RECEIVE
      mov #HIGH_6_13(SPMSC1), PAGESEL
      mov #$00, MAP_ADDR_6(SPMSC1)        ; Disables LVDIE, LVDRE, LVDSE, LVDE
      lda ConvertedValue
      sub #150
      bhs LOW_
      lda ConvertedValue
      sub #75
      bhs MEDIUM
      lda ConvertedValue
      sub #10
      bhs HIGH_
      mov #0,DATA+1
      bra sendData
LOW_:
      mov #$41,DATA+1
      bra sendData
MEDIUM:
      mov #$42,DATA+1
      bra sendData
HIGH_:
      mov #$43,DATA+1
sendData:
      mov #0,DATA
      jsr ENCRYPT_TEAMAC
      BAUD_4600
      jsr TANGO_SEND_DATA
      bset 4,MAP_ADDR_6(SRTISC)           ; RTI Interrupt Enable
      jsr randomize
      lda VarRandom
      cbeqa #0,nZ
      mov VarRandom,seconds
      bra Loop2
nZ:
      mov #1,seconds
Loop2:
      bset 6,MAP_ADDR_6(SRTISC)           ; Clear RTI interrupt flag (ACK)
      stop
           dbnz seconds,Loop2
      bra r
delay26ms:
      mov #13,seconds
      MTIM2ms
      bclr 4,MTIMSC                            ; MTIM counter is Active
LoopTimer:
      brclr 7,MTIMSC,LoopTimer
      bset 5,MTIMSC
      dbnz seconds,LoopTimer
      bset 4,MTIMSC
      rts
;**************************************************************
;*                            Startup Vector                            *
;**************************************************************

      ORG   $3FFD
      JMP _Startup          ; Reset
```

B.2.6 Push Button

```
;*******************************************************************
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;* FREESCALE harmless against any and all claims demands or actions     *
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;* contractual, or tortuous, rising directly or indirectly as a result  *
;* of the advise or assistance supplied CUSTOMER in connection with     *
;* product, services or goods supplied under this Agreement.            *
;*******************************************************************
; Include derivative-specific definitions
            INCLUDE 'derivative.inc'
; export symbols

            XDEF _Startup
            ABSENTRY _Startup
; variable/data section

      include "TangoDriver.asm"       ; Include before ADCdriver.asm

      ORG    RAMStart+18              ; If ADCdriver.asm is include RAMStart+21
                                      ; else RAMStart+18

      ; Insert your data definition here
;**************************************************************
;*                            User Variables                            *
;**************************************************************
```

```
                ;******* Add your variables here *******
;*****************************************************************************

MODE                EQU   1         ; Operation Mode (1:Run Mode, 0:Background Mode)


; code section

            ORG    ROMStart+821       ; If ADCdriver.asm is include ROMStart+909
                                      ; else ROMStart+821
;*****************************************************************************
;*                             MACRO declarations                            *
;*****************************************************************************
TRIM_ICS: MACRO                       ; Macro used to configure the ICS with TRIM
      mov   #$FF,PAGESEL              ; change to last page
      ldx   #$FA                      ; load the content which TRIM value is store
      lda   ,x                        ; read D[X]
     cbeqa #$FF,No_Trim              ; Omit the 0xFF value if $3FFA location content
the value
      sta   ICSTRM                    ; Store TRIM value into ICSTRM register
      mov   #$01,ICSSC                ; Fine TRIM
No_Trim:
      ENDM

MTIM1MS: MACRO
      mov #$70,MTIMSC
      mov #$7D,MTIMMOD
      mov #$06,MTIMCLK
      ENDM
;*****************************************************************************
;*                             Init Microcontroller                          *
;*****************************************************************************
Init_Conf:
      IFNE  MODE
      mov #HIGH_6_13(SOPT), PAGESEL
   mov #$20, MAP_ADDR_6(SOPT)    ; Disables COP and RESET (PTA2) pin
      ELSE
      mov #HIGH_6_13(SOPT), PAGESEL
      mov #$22, MAP_ADDR_6(SOPT)      ; Disables COP and RESET (PTA2) pin, enables
BKGD (PTA3)
      ENDIF
      clr  ICSC1                      ; FLL is selected as Bus Clock
      TRIM_ICS                        ; Trim MCU to work at 8MHz
      clr  ICSC2
      mov #0,TEAMAC_DATA+1
      mov #0,TEAMAC_DATA
      rts
;*****************************************************************************
;*                                  Init PTA                                 *
;*****************************************************************************
Init_PTA:
      mov #HIGH_6_13(PTAPE),PAGESEL
      mov #$FC, MAP_ADDR_6(PTAPE); Enables internal Pulling device
      mov #HIGH_6_13(PTAPUD),PAGESEL
      clr MAP_ADDR_6(PTAPUD)    ; Configures Internal pull up device in PTA

      bset 3,PTADD                    ; PTA3 as output
      bclr 2,PTADD
      mov #$00,PTAD                   ; Clear PTAD
      rts
;*****************************************************************************
;*                                Init KBI                                  *
;*****************************************************************************
Init_KBI:
      mov #(mKBIPE_KBIPE2),KBIPE
      mov #(mKBISC_KBIE | mKBISC_KBACK),KBISC
      rts
;*****************************************************************************
;*                              Main Program                                *
;*****************************************************************************
_Startup:
      jsr Init_Conf
      jsr Init_PTA
      jsr Init_KBI
Loop2:
      mov #(mKBISC_KBACK | mKBISC_KBIE),KBISC
      jsr debounce
      stop
      mov #'E',DATA+1
      mov #'S',DATA
      BAUD_4600
      jsr TEAMAC
      jsr TangoSendData
      bra Loop2
debounce:
      mov #24,c1
      MTIM1MS
      bclr 4,MTIMSC
MTIMIsr1ms:
      brclr 7,MTIMSC,MTIMIsr1ms
      bset 5,MTIMSC
      dbnz c1,MTIMIsr1ms
      bset 4,MTIMSC
      rts
;*****************************************************************************
;*                              Startup Vector                              *
;*****************************************************************************

      ORG   $3FFD
      JMP _Startup          ; Reset
```

B.2.7 Romeo RF Receiver

```
/************************************************************************
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* contractual, or tortuous, rising directly or indirectly as a result    *
* of the advise or assistance supplied CUSTOMER in connection with       *
* product, services or goods supplied under this Agreement.              *
*************************************************************************/


#include <hidef.h>              /* for EnableInterrupts macro */
#include "MC68HC908AP64.h"      /* include peripheral declarations */
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

#ifndef teamac_h
#define teamac_h

void char2Long(unsigned char *pDest,const unsigned char *pSrce,unsigned char i);
void encipher(unsigned char *v, unsigned char *w,unsigned char *k);

#endif

extern unsigned char TEAMAC_Data[2];
extern unsigned char TEAMAC_Code;
extern unsigned char TEAMAC_Key[2];


unsigned char romeoReceiveBuffer[9]; /* Declare Romeo receive buffer    */

#define NULL_STRING '\0'    // Null at end of strings


/*************** Function Prototypes ***************************************/

void SCI1_Setup(unsigned char BaudRate);
void TransmitMessage(char *Message);
void interrupt SPIRxInt(void);
void EchoByte(char *Message);
void Romeo_Transfer(void);
unsigned char RemoveFromBuffer(unsigned char byte, unsigned char x);
```

```
void romeo_receive_data_enable(void);
void romeo_receive_data_disable(void);


/*************** Global variables ********************************************/
volatile unsigned char  Reset,Agc,Strobe,Lna;   /* Hold values of each pin   */

volatile unsigned char cr1, cr2, cr3;/* Hold current values of cr1, cr2, cr3 */

unsigned char x;
unsigned char MACreceived;
unsigned char cipherText[2];
unsigned char key[4];
unsigned char TEAMAC_Data[2];
unsigned char TEAMAC_Code;
const unsigned char TEAMAC_Key[2]={0x20,0x34};

/* Specify start adress of SPI registers */
#define ROMEO_SPI_ADDRESS   0x10                /* Address varies from mcu to mcu */

/* SPI clock speed */
#define ROMEO_SPI_CLOCK_SPEED   9830400

/* Register address offsets for normal HC08 SPI */
#define ROMEO_SPCR  *(unsigned char *)(ROMEO_SPI_ADDRESS+0) /* SPI Control reg */
#define ROMEO_SPSCR *(unsigned char *)(ROMEO_SPI_ADDRESS+1) /* SPI St/Ctrl reg */
#define ROMEO_SPDR  *(unsigned char *)(ROMEO_SPI_ADDRESS+2) /* SPI Data reg */

/* SPI baud rate divider */
/* Chooses appropriate baud rate divisor to provide max comms speed to Romeo */
#if (ROMEO_SPI_CLOCK_SPEED/307000) <= 2
    #define ROMEO_SPI_BAUD_RATE_DIVISOR  0

#elif (ROMEO_SPI_CLOCK_SPEED/307000) <= 8
    #define ROMEO_SPI_BAUD_RATE_DIVISOR  1

#elif (ROMEO_SPI_CLOCK_SPEED/307000) <= 32
    #define ROMEO_SPI_BAUD_RATE_DIVISOR  2

#elif (ROMEO_SPI_CLOCK_SPEED/307000) <= 128
    #define ROMEO_SPI_BAUD_RATE_DIVISOR  3
#endif

/* Set Romeo reset pin */
#define ROMEO_RESET         PTD_PTD3         /* Define pin used for Reset */
#define ROMEO_RESET_DDR     DDRD_DDRD3

#define ROMEO_STROBE    PTD_PTD1         /* #defines for STROBE pin */
#define ROMEO_STROBE_DDR  DDRD_DDRD1       /* If hardwired,delete #defines */

#define ROMEO_AGC                  PTB_PTB4         /* #defines for AGC pin */
#define ROMEO_AGC_DDR    DDRB_DDRB4       /* If hardwired,delete #defines */
```

```
#define ROMEO_ENABLELNA  PTD_PTD2         /* #defines for LNA pin */
#define ROMEO_ENABLELNA_DDR DDRD_DDRD2       /* If hardwired,delete #defines */

#define VERBOSE_ON  1
#define VERBOSE_OFF 0
unsigned char VerboseMode = VERBOSE_ON;

#define  BAUD_9600  0x22
#define  BAUD_19200 0x21
#define  BAUD_38400 0x20



/*
 ** Romeo_Transfer
 *
 *   FILENAME:
 *
 *   PARAMETERS:
 *
 *   DESCRIPTION:
 * Reads/writes data from/to Romeo
 * Can enter with Romeo in master or slave mode
 * Exits with Romeo reset pin in same mode as on entry
 * Exits with Romeo in same mode as on entry mode
 * Reads/writes data from/to Romeo
 * Can enter with Romeo in master or slave mode
 * Exits with Romeo reset pin in same mode as on entry
 * Exits with Romeo in same mode as on entry mode
 *
 *   RETURNS:
 *
 */
void Romeo_Transfer(void)
{
    volatile unsigned char temp;
    volatile unsigned char i;

    ROMEO_SPCR = 0;             /* Disable SPI */
    ROMEO_RESET = 0;            /* Romeo  slave mode*/
    ROMEO_RESET_DDR = 1;

    for(i=0; i < 0x40; i++) {}  /* Delay */


    ROMEO_SPCR = 0x2a;          /* Enable SPI, mcu master */


    temp = ROMEO_SPSCR;
    temp = ROMEO_SPDR;        /* Read data reg to clear receive flag) */

    ROMEO_SPDR = cr1;           /* Send first control byte              */
    while( (ROMEO_SPSCR & 0x80) == 0 ) {}   /* SPSCR_SPRF == 0 Wait until byte gone */
    cr1 = ROMEO_SPDR;      /* Read cr1  */
    ROMEO_SPDR = cr2;                  /* Send second control byte             */

    while( (ROMEO_SPSCR & 0x80) == 0 ) {}   /* SPSCR_SPRF == 0 Wait until byte gone */
    cr2 = ROMEO_SPDR;            /* Read cr2 */
    ROMEO_SPDR = cr3;                /* Send third control byte              */

    while( (ROMEO_SPSCR & 0x80) == 0 ) {}   /* SPSCR_SPRF == 0 Wait until byte gone */
    cr3 = ROMEO_SPDR;                    /* Read cr3 */

    if (Reset == 0)                         /* If Romeo was slave */
    {
        ROMEO_RESET = 0;
        ROMEO_RESET_DDR = 1;
        ROMEO_SPCR = ROMEO_SPCR | 0x20;     /* Mcu to master, Romeo to slave */
        ROMEO_SPCR = 0x2a;                  /* Enable SPI */
    }
    else  if (Reset == 1)
    {
       ROMEO_SPCR = 0x0a;             /* Mcu to slave, Romeo to master, enable SPI */
        ROMEO_RESET = 1;
        ROMEO_RESET_DDR = 1;
    }
    else                                     /* if pin high impedance */
    {
        ROMEO_RESET_DDR = 0;
    }


}



/*
 ** SCI1_Setup
 *
 *  FILENAME:
 *
 *  PARAMETERS:
 *
 *  DESCRIPTION: Setup SCI1 for 9600, no parity, 1 stop bit
 *
 *  RETURNS:
 *
 */
void SCI1_Setup(unsigned char BaudRate)
{
  SCC2  = 0;   /* Disable sci1 */
  SCBR = BaudRate; /* Set baud rate  */
  SCC1 = 0;   /* 8 bits, 1 start, 1 stop, no parity */
  SCC1_ENSCI = 1;  /*Enable SCI module */
  SCC2_SCRIE = 1;  /* Enable receive ints  */
  SCC2_TE = 1;   /* Enable tx */
  //SCC2_RE = 1;   /* Enable rx */
}

void TransmitMessage(char *Message)
{
  volatile char temp;
  temp =  SCS1;
  while(*Message != NULL_STRING)
  {
    SCDR = *Message;
    while ( SCS1_TC != 1)   {} //Loop until byte sent
    temp =  SCS1;         //Read byte to  clear tc flag
    Message++;
  }
}

 ** SPIRxInt
 *
 *  FILENAME:
 *
 *  PARAMETERS:
 *
 *  DESCRIPTION: Reads received byte from SPI into Buffer
 *
 *  RETURNS:
 *
 */
interrupt void SPIRxInt(void){

 romeoReceiveBuffer[x] = ROMEO_SPSCR;/* Read control reg with sprf flag set */
 romeoReceiveBuffer[x] = ROMEO_SPDR;/* Read data from SPI */
 x++;
}

/*
 ** EchoByte
 *
 *  FILENAME:
 *
 *  PARAMETERS:
 *
 *  DESCRIPTION: Writes byte to SCI
 *
 *  RETURNS:
 *
 */
void EchoByte(char *Message)
{
  volatile char temp;
  temp =  SCS1;
  SCDR = *Message ;
  while (SCS1_TC != 1) {}  //Loop until byte sent
  temp =  SCS1;   //Read byte to  clear tc flag
}

/*
 ** AddToBuffer
 *
 *  FILENAME:
 *
 *  PARAMETERS:
 *
 *  DESCRIPTION: Take byte and add binary equivilent to buffer as ascii text
 *               For example, if byte = 0x55, '01010101' is added to buffer
 *
 *  RETURNS:
 *
 */
unsigned char RemoveFromBuffer(unsigned char byte, unsigned char x)
{
    unsigned char i;

      for(i=0; i<8;i++)
      {
        if ( (byte & 0x01) != 0 )
          romeoReceiveBuffer[x] |= 0x01;
        else
          romeoReceiveBuffer[x] |= 0x00;

        if (i<=6) romeoReceiveBuffer[x] <<=1;  /* Shift byte left */
        else romeoReceiveBuffer[x]=romeoReceiveBuffer[x];
        byte >>= 1;            /* Shift byte right */
      }
    return romeoReceiveBuffer[x];
}



/* Receive data from romeo enable */
void romeo_receive_data_enable(void){
  unsigned char temp;
  ROMEO_SPCR = ROMEO_SPCR & 0xdd;        /* clear spe and spmstr                  */
  ROMEO_SPCR = ROMEO_SPCR | 0x02;        /* SPCR_SPE = 1                          */
  ROMEO_SPCR = ROMEO_SPCR | 0x80;        /* SPCR_SPRIE = 1 enable SPI receive ints */

  for(temp=0; temp < 0x40; temp++) {}     /* Delay */

  temp = ROMEO_SPSCR;
  temp = ROMEO_SPDR;
}



/* Receive data from romeo disable */
```

```
void romeo_receive_data_disable(void)
{
  unsigned char temp;

  ROMEO_SPCR = ROMEO_SPCR & 0xfd;           /*SPE = 0*/
  ROMEO_SPCR = ROMEO_SPCR & 0x7f;           /*SPCR_SPRIE = 0*/

  for(temp=0; temp < 0x40; temp++) {}
}

void char2Long(unsigned char *pDest,const unsigned char *pSrce,unsigned char i)
{
    *pDest = 0;
    if (i==0)
    {
      *pDest |= (*pSrce & 0x03);
      *pDest <<= 2;
      *pDest |= ((*pSrce & 0x0C)>>2);
      *pDest <<= 2;
      *pDest |= ((*pSrce & 0x30)>>4);
      *pDest <<= 2;
      *pDest |= ((*pSrce & 0xC0)>>6);
    }
    if (i==1)
    {
      *pDest |= ((*pSrce & 0x0C)>>2);
      *pDest <<= 2;
      *pDest |= ((*pSrce & 0x30)>>4);
      *pDest <<= 2;
      *pDest |= ((*pSrce & 0xC0)>>6);
      *pDest <<= 2;
      *pDest |= (*(pSrce+1) & 0x03);
    }
    if (i==2)
    {
      *pDest |= ((*pSrce & 0x30)>>4);
      *pDest <<= 2;
      *pDest |= ((*pSrce & 0xC0)>>6);
      *pDest <<= 2;
      *pDest |= (*(pSrce+1) & 0x03);
      *pDest <<= 2;
      *pDest |= ((*(pSrce+1) & 0x0C)>>2);
    }
    if (i==4)
    {
      *pDest |= (*(pSrce+1) & 0x03);
      *pDest <<= 2;
      *pDest |= ((*(pSrce+1) & 0x0C)>>2);
      *pDest <<= 2;
      *pDest |= ((*(pSrce+1) & 0x30)>>4);
      *pDest <<= 2;
      *pDest |= ((*(pSrce+1) & 0xC0)>>6);
    }
```

```
}

void encipher(unsigned char *v,unsigned char *w,unsigned char *k)
{
       unsigned char y, z, sum, delta;
       unsigned char n;

       y=*v;
       z=*(v+1);
       sum=0;
       n=8;
       delta=0x9E;


       while(n-- > 0)
              {
              y += (((z << 4) ^ (z >> 5)) + z) ^ (sum + k[sum&3]);
              sum += delta;
              z += (((y << 4) ^ (y >> 5)) + y) ^ (sum + k[(sum>>3) & 3]);
              }
       w[0]=y; w[1]=z;
}



/*
 ** main
 *
 *  FILENAME:
 *
 *  PARAMETERS:
 *
 *  DESCRIPTION: Main program loop
 *
 *  RETURNS:
 *
 */
 void main(void) {

  //unsigned char temp;

  CONFIG1 = 0x03;       /* Disable COP, enable STOP instruction */

  SCI1_Setup(BAUD_19200);

  VerboseMode = VERBOSE_ON;


  ROMEO_SPSCR = ROMEO_SPI_BAUD_RATE_DIVISOR;  /* Initialise SPI */


  Reset = 1;                /* Reset = 1 (Romeo is master) */
  Strobe = 1;
  Agc = 1;
  Lna = 1;  /* Set these pins */

  ROMEO_RESET = 1;
  ROMEO_RESET_DDR = 1;            /* Set RESET pin to 1 */

  ROMEO_AGC = 1;
  ROMEO_AGC_DDR = 1;              /* Set AGC pin to 1 */

  ROMEO_STROBE = 1;
  ROMEO_STROBE_DDR = 1;           /* Set STROBE pin to 1 */

  ROMEO_ENABLELNA = 1;
  ROMEO_ENABLELNA_DDR = 1;       /* Set ENABLE_LNA pin to 1 */

  //cr1 = 0x80;                /* Set cr1 to read Romeo contents */
  //cr2 = cr3 = 0;             /* Initialise cr1, cr2, cr3 */

  //Romeo_Transfer();          /* Read from Romeo */

  cr1 = 0x3F;
  cr2 = 0xA5;
  cr3 = 0x40;

  Romeo_Transfer();

  cr1 = cr1 | 80;

  Romeo_Transfer();

  EnableInterrupts;            /* enable interrupts */
  romeo_receive_data_enable();

  x=0;
  for(;;)
  {
                     if ((x==7 && cr3==0x40)||(x==8 && cr3==0x00))
                     {
                       //romeo_receive_data_disable();

romeoReceiveBuffer[3]=RemoveFromBuffer(romeoReceiveBuffer[3],3);

romeoReceiveBuffer[4]=RemoveFromBuffer(romeoReceiveBuffer[4],4);

romeoReceiveBuffer[5]=RemoveFromBuffer(romeoReceiveBuffer[5],5);

romeoReceiveBuffer[6]=RemoveFromBuffer(romeoReceiveBuffer[6],6);

                       TEAMAC_Data[0]=RemoveFromBuffer(romeoReceiveBuffer[0],0);
                       TEAMAC_Data[1]=RemoveFromBuffer(romeoReceiveBuffer[1],1);
                       MACreceived=RemoveFromBuffer(romeoReceiveBuffer[2],2);
```

```
                               char2Long(key, TEAMAC_Key,0);
                               char2Long(key+1, TEAMAC_Key,1);
                               char2Long(key+2, TEAMAC_Key,2);
                               char2Long(key+3, TEAMAC_Key,4);

                               encipher(TEAMAC_Data, cipherText, key);

                               TEAMAC_Code = cipherText[0] ^ cipherText[1];

                               if (MACreceived == TEAMAC_Code)
                               {
                                 EchoByte(&romeoReceiveBuffer[3]);
                                 EchoByte(&romeoReceiveBuffer[4]);
                                 EchoByte(&romeoReceiveBuffer[5]);
                                 EchoByte(&romeoReceiveBuffer[6]);
                               }
                               //romeo_receive_data_enable();
                               x=0;
                       }
  }
}
```