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Wireless Sensing Triple Axis Reference Design

Designer Reference Manual

ZSTARRM
Rev. 3
01/2007

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Safety of Radio Frequency Energy

The manufacturer has evaluated the transmitter for safe operation for uncontrolled use in the general population. The measured power density at 1 cm is under the threshold established by the FCC and is not required to be tested for specific absorption rate. The manufacturer instructs the user that the transmitter should not be handled or placed near the body continuously for more than 30 minutes while operating.

USA:

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

– Reorient or relocate the receiving antenna.
– Increase the separation between the equipment and receiver.
– Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
– Consult the dealer or an experienced radio/TV technician for help.

This device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) this device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

The antenna(s) used for this transmitter must not be co-located or operating in conjunction with any other antenna or transmitter.

Canada:

This digital apparatus complies with Canadian ICES-003.

Cet appareil numérique est conforme à la norme NMB-003 du Canada.

Europe:

Compliant (CE)

Wireless Sensing Triple Axis Reference Design

Designer Reference Manual

by: Pavel Lajšner and Radomír Kozub
Freescale Czech Systems Laboratories
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January 2007	3	Replaced graphics, updated tables.	sections 3.4.4, 4.2.9, 4.3, and 6.1.1

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Chapter 1
Introduction

1.1 Introduction

This paper describes the design of a Wireless Sensing Triple Axis Reference design (ZSTAR), a demo for wireless demonstration of the 3-axis accelerometer MMA7260QT Sensor from Freescale.

The reference design will enable you to see how Freescale's accelerometers can add additional functionality to applications in various industries. The accelerometer measurements can be grouped into 6 sensing functions - Fall, Tilt, Motion, Positioning, Shock and Vibration - for multifunctional applications.

The RD3152MMA7260Q development tool offers robust wireless communication using the powerful, easy-to-use 2.4GHz frequency MC13191 transceiver. Minor changes can be made with pin to pin compatibility allowing implementation of the MC13192 and MC13193 for ZigBee™ wireless applications.

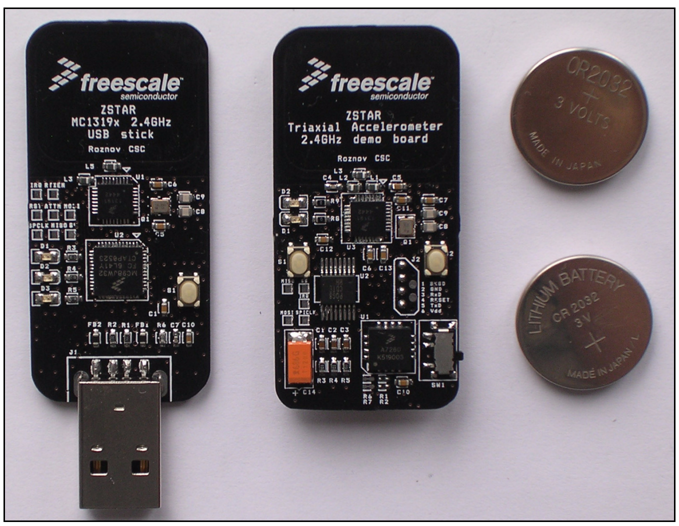

Figure 1-1. ZSTAR Demo photo **(CR2032 batteries for comparison)**

1.2 MMA7260QT 3-axis Accelerometer Sensor

The MMA7260QT low cost capacitive micromachined accelerometer features signal conditioning, a 1-pole low pass filter and temperature compensation, and g-select, which allows a selection from 4 sensitivities. Zero-g offset full scale span and filter cut-offs are factory set and require no external devices. This device includes a sleep mode making it ideal for handheld battery powered electronics.

Chapter 2
Wireless Sensing Triple Axis Reference Design Introduction

2.1 Introduction

The Wireless Sensing Triple Axis Reference Design (ZSTAR) has been designed as a wireless complement to the previous STAR (Sensing Triple Axis Reference design) RD3112MMA7260Q demo. A 2.4GHz radio-frequency (RF) link based on the low-cost MC13191 family is used for connection from the Sensor to PC, allowing the visualization of key accelerometer applications.

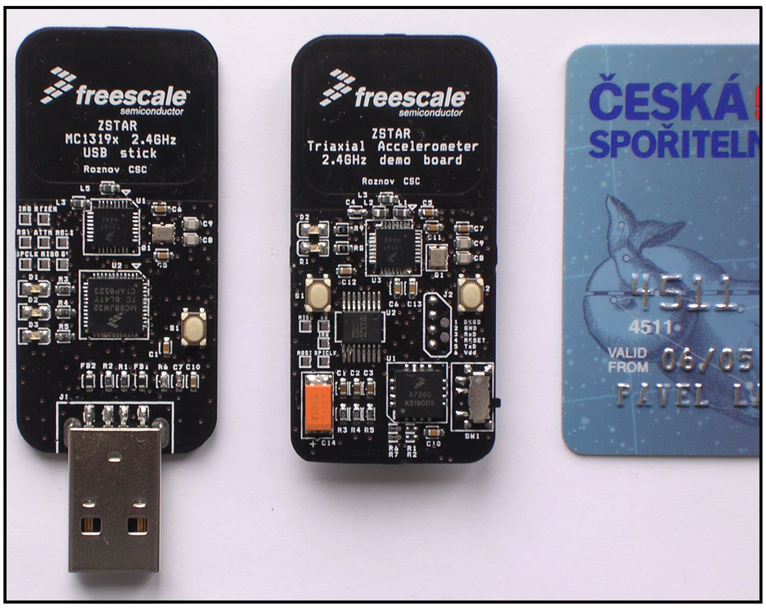

Figure 2-1. ZSTAR Demo Overview

The demo consists of the two boards:

- Sensor Board (or remote board) containing the MMA7260QT 3-axis accelerometer, S08 family MC9S08QG8 8-bit microcontroller and the 2.4GHz RF chip MC13191 for wireless communication.
- USB stick, again with the MC13191 RF front-end, and the HC08 family MCHC908JW32 for the USB communication.

Both sides communicate over the RF medium utilizing the freely available software stack SMAC from Freescale.

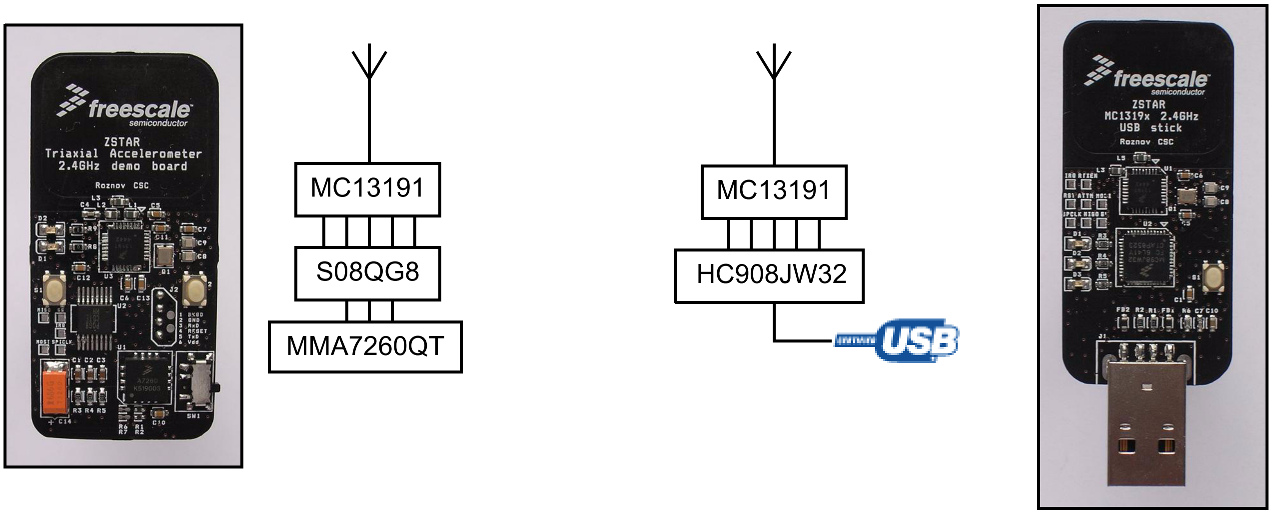

Figure 2-2. ZSTAR Block Diagram

2.2 Featured Products

This demo consists of several Freescale products whose main features are listed below.

2.2.1 Triple Axis Accelerometer MMA7260QT

The ZSTAR Board is a demonstration tool for the MMA7260QT, low-g accelerometer with selectable 1.5g to 6g range. The MMA7260QT has many unique features that make it an ideal solution for many consumer applications, such as freefall protection for laptops and MP3 players, tilt detection for e-compass compensation and mobile phone scrolling, motion detection for handheld games and game controllers, position sensing for g-mice, shock detection for warranty monitors, and vibration for out of balance detection.

Features such as low power, low current, and a sleep mode with a quick turn on time, allow the battery life to be extended in end applications. The 3-axis sensing in a small QFN package requires only a 6mm x 6mm board space, with a profile of 1.45mm, allowing easy integration into many small handheld electronics.

There are several other derivatives of the MMA7260QT:

- **MMA7261QT** XYZ-axis 2.5g/3.3g/6.7g/10g
- **MMA6270QT** XY-axis 1.5g/2g/4g/6g
- **MMA6271QT** XY-axis 2.5g/3.3g/6.7g/10g
- **MMA6280QT** XZ-axis 1.5g/2g/4g/6g
- **MMA6281QT** XZ-axis 2.5g/3.3g/6.7g/10g

All members of this Sensor family are footprint (QFN package) compatible which simplifies evaluation and design of the target application.

2.2.2 Microcontroller MC9S08QG8

The MC9S08QG8 is a highly integrated member of Freescale's 8-bit family of microcontrollers based on the high-performance, low-power consumption HCS08 core. Integrating features normally found in larger, more expensive components, the MC9S08QG8 MCU includes a **background debugging system** and on-chip in-circuit emulation (ICE) with real-time bus capture, providing a single-wire debugging and emulation interface. It also features a programmable 16-bit timer/pulse-width modulation (PWM) module (TPM), that is one of the most flexible and cost-effective of its kind.

The compact, tightly integrated MC9S08QG8 delivers a versatile combination, from wealth of Freescale peripherals and the advanced features of the HCS08 core, including **extended battery life** with a maximum performance down to 1.8V, industry-leading Flash and innovative development support. The MC9S08QG8 is an excellent solution for power and size-sensitive applications, such as wireless communications and handheld devices, small appliances, Simple Media Access Controller (SMAC)-based applications and toys.

- MC9S08QG8 Features
  - Up to 20MHz operating frequencies at >2.1 volts and 16MHz at <2.1 volts
  - 8 K Flash and 512 bytes RAM
  - Support for up to 32 interrupt/reset sources
  - 8-bit modulo timer module with 8-bit prescaler
  - Enhanced 8-channel, 10-bit analog-to-digital converter (ADC)
  - Analog comparator module
  - Three communication interfaces: SCI, SPI and IIC

2.2.3 MC13191 2.4 GHz ISM Band Low Power Transceiver

The MC13191 is a short range, low power, 2.4 GHz Industrial, Scientific, and Medical (ISM) band transceivers. The MC13191 contains a complete packet data modem which is compliant with the IEEE® 802.15.4 Standard PHY (Physical) layer. This allows the development of proprietary point-to-point and star networks based on the 802.15.4 packet structure and modulation format. For full 802.15.4 compliance, the MC13192 and Freescale 802.15.4 MAC software are required.

When combined with an appropriate microcontroller (MCU), the MC13191 provides a cost-effective solution for short-range data links and networks. Interface with the MCU is accomplished using a four wire serial peripheral interface (SPI) connection and an interrupt request output, which allows the use of a variety of processors. The software and processor can be scaled to fit applications ranging from simple point-to-point to star networks.

2.2.4 Microcontroller MCHC908JW32

The MCHC908JW32 is a member of the low-cost, high-performance M68HC08 Family of 8-bit microcontroller units (MCU's). All MCU's in the family use the enhanced M68HC08 central processor unit (CPU08) and are available in a variety of modules, memory sizes and types, and package types.

- MCHC908JW32 Features
  - Maximum internal bus frequency: 8MHz at 3.5-5V operating voltage
  - Oscillators:
    - 4MHz crystal oscillator clock input with 32MHz internal phase-lock loop
    - Internal 88kHz RC oscillator for timebase wakeup
  - 32,768 bytes user program FLASH memory with security feature
  - 1,024 bytes of on-chip RAM

- 29 general-purpose input/output (I/O) ports:
- 8 keyboard interrupt with internal pull-up
  - 3 pins with direct LED drive
  - 2 pins with 10mA current drive for PS/2 connection
- 16-bit, 2-channel timer interface module (TIM) with selectable input capture, output compare, PWM capability on each channel, and external clock input option
- Timebase module
- PS/2 clock generator module
- Serial Peripheral Interface Module (SPI)
- Universal Serial Bus (USB) 2.0 Full Speed functions:
  - 12 Mbps data rate
  - Endpoint 0 with an 8-byte transmit buffer and an 8-byte receive buffer
  - 64 bytes endpoint buffer to share amongst endpoints 1–4

Chapter 3
Sensor Board Description

3.1 Board Overview

The Sensor Board utilizes a small footprint size dual-layer printed circuit board (PCB) containing all the necessary circuitry for MMA7260QT accelerometer sensing and transferring data over a radio frequency (RF).

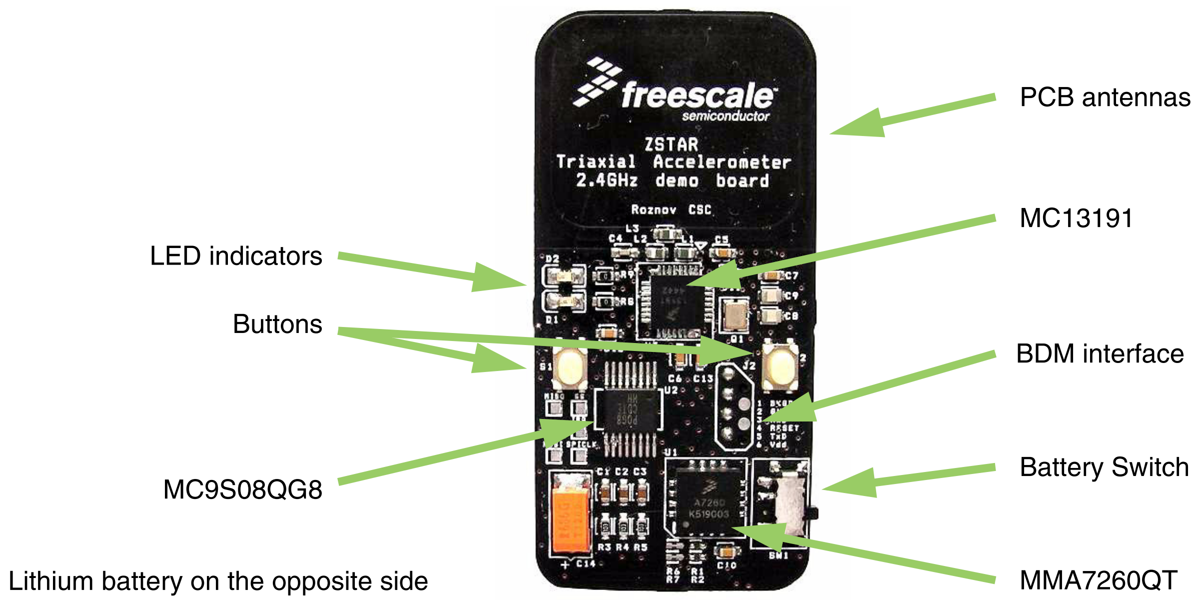

Figure 3-1. Sensor Board Overview

The board is powered by a Lithium coin-sized CR2032 battery with provisions also made for the larger capacity CR2477 size. The block diagram of the board is as follows:

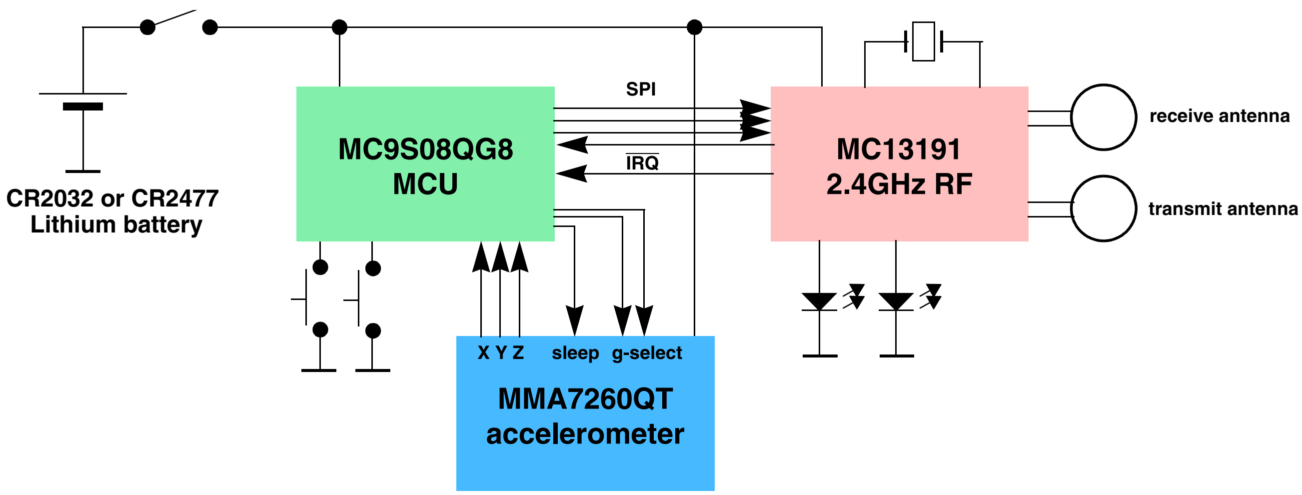

Figure 3-2. Sensor Board Block Diagram

Figure 3-3. shows in more detail, how different software and hardware modules co-operate with each other. The main task of the Sensor Board is to:

- periodically wake-up from power saving mode
- measure all three XYZ acceleration values from the Sensor
- compose a data frame using simple ZSTAR RF Protocol
- use SMAC (Simple Media Access Controller) to send this data frame over the RF link
- wait for an acknowledgment from the other end (here, the USB stick)
- go to sleep

This basic loop repeats roughly 30 times per second providing nearly a real-time response from the Sensor.

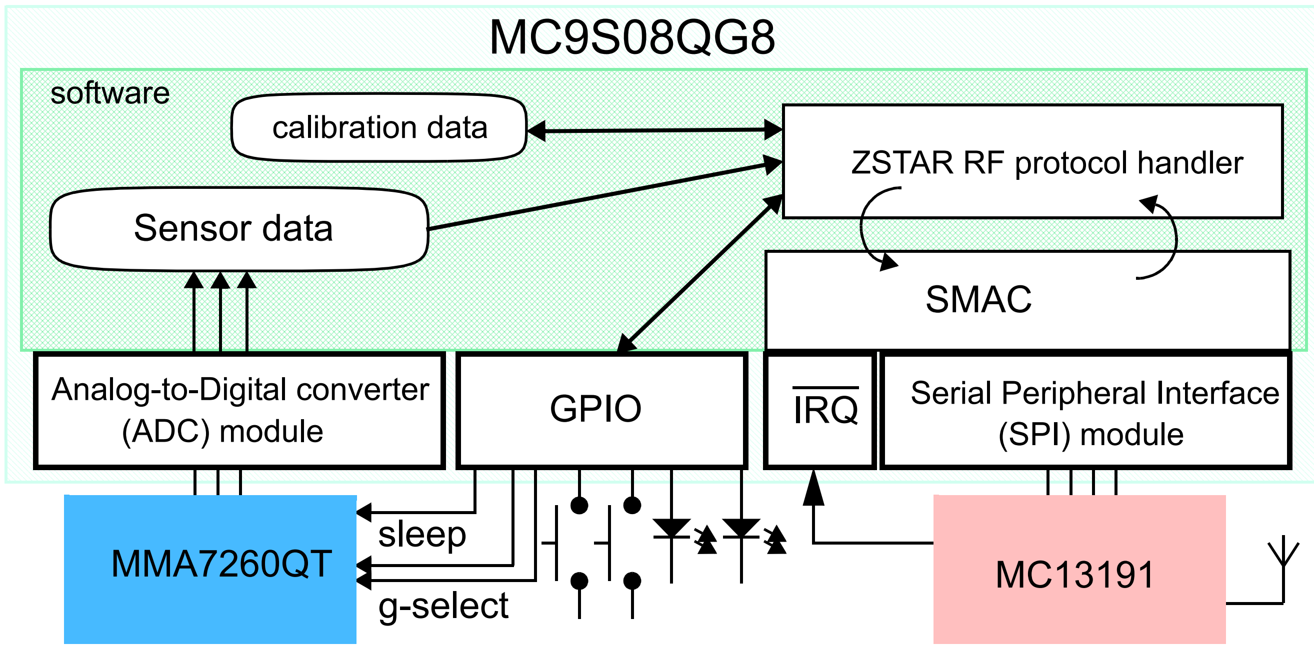

Figure 3-3. ZSTAR Sensor Board Software Overview

For the Sensor Board operation, several of the MC9S08QG8's hardware modules are used: Analog to Digital Converter (ADC), Synchronous Peripheral Interface (SPI), External Interrupt Request (IRQ) and General Purpose Input/Output (GPIO).

3.2 A/D Conversion of XYZ Levels

The 3-axis accelerometer Sensor MMA7260QT provides three separate analog levels for the X, Y and Z axis. These outputs are ratiometric which means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. This is a key feature when interfacing to a microcontroller with A/D converter reference levels tied to a power supply, because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

During the analog-to-digital conversion in the microcontroller, 10-bit resolution is used. MC9S08QG8 A/D channels 0, 1 and 2 are connected to X (channel 1), Y (channel 2) and Z (channel 0) outputs of the MMA7260QT. The microcontroller's `APCTL1` register enables these ADC channels for pin I/O control by the ADC module.

The `ADCCFG` register controls the selected mode of operation, clock source, clock divide, and configuration for low power or long sample time.

3.2.1 ADC Module init

```
APCTL1 = 0b00000111; /* 0,1,2 channels are ADC */
ADCCFG = 0b01111000; /* set prescale to 8, ADICLK=BUS, 10-bit, high speed */
```

Actual ADC measurements are done in the main software loop. There is a macro (called `POWSUM`) that allows configuration of measurement to take several measurements of each channel during one loop, e.g. changing `POWSUM` to 3, 2^3 = 8, each channel will be measured 8 times, with `POWSUM 6`, each channel is measured 64 times. By default, POWSUM is 4, for 16 measurements of each channel. Before result values are provided, the accumulated values are left justified to the 16-bit range and inverted where necessary (may be required depending on the physical MMA7260QT device orientation relative to the earth's gravity).

Raw (i.e. not calibrated) values are actually sent, the calibration and calculation of an exact g value is done internally in the PC software.

3.2.2 ADC Measurement

The following routine is used for accelerometer measurement (together with temperature and bandgap voltage, refer to Section 5.4.2.1 Extended Accelerometer Data Transfer 'v' (0x76)):

```
unsigned int xx = 0;
unsigned int yy = 0;
unsigned int zz = 0;
unsigned int tt = 0;
unsigned int bb = 0;

unsigned int xxx, yyy, zzz, ttt, bbb;

#define POWSUM 4

 for (i = 0; i < (1 << POWSUM); i++)
 {
   ADCSC1 = 0x01;//read X channel
   while(!ADCSC1_COCO);
   xx += ADCR;

   ADCSC1 = 0x02;//read Y channel
   while(!ADCSC1_COCO);
   yy += ADCR;

   ADCSC1 = 0x00;//read Z channel
   while(!ADCSC1_COCO);
   zz += ADCR;

   ADCSC1 = 0x1A;//read temp sensor
   while(!ADCSC1_COCO);
   tt += ADCR;

   ADCSC1 = 0x1B;//read bandgap reference
   while(!ADCSC1_COCO);
   bb += ADCR;
 }
TRIAXSLEEP = 0;   /* go sleep for triax */

xxx.w = ~(xx << (16-(10+POWSUM)));
yyy.w = ~(yy << (16-(10+POWSUM)));
zzz.w =  (zz << (16-(10+POWSUM)));
ttt.w =  (tt << (16-(10+POWSUM)));
bbb.w =  (bb << (16-(10+POWSUM)));
```

3.3 Power Management

A CR2032 (or CR2477) Lithium battery provides a fairly limited charge for such a realtime-like demo that demands frequent transmissions. Some sort of power management has to be implemented in order to keep the current consumption at a reasonable level.

Typically, current consumptions of Sensor Board components are as follows:

- 2.4GHz transceiver MC13191
  - in Hibernate mode, 2.3µA
  - in Doze mode, 35µA
  - in Idle mode, 500µA
  - in Transmit mode, 30mA
  - in Receive mode, 37mA
- 8-bit microcontroller MC9S08QG8
  - in Stop mode, 750nA
  - in Wait mode, 1mA
  - in Run mode, 3.5mA
- low-g triaxial Sensor MMA7260QT
  - in Sleep mode, 3µA
  - in Normal mode, 500µA

It is obvious that in a battery operated application care must be taken to ensure the lowest possible current consumption, especially when the maximum current (provided by the battery) is somehow limited. A CR2032 Lithium battery cannot provide current in the range of 40mA for long periods of time. To alleviate high current surges, an additional large capacitor has been designed - see Section 3.4.10 Power Supply.

For transmission and reception using the MC13191, a specific scheme has been used to ensure the battery is not depleted or overloaded. Targeting a 30 samples per second (33ms period) transmission rate, the following scheme for one transmission/sleep cycle is used for the data transfer:

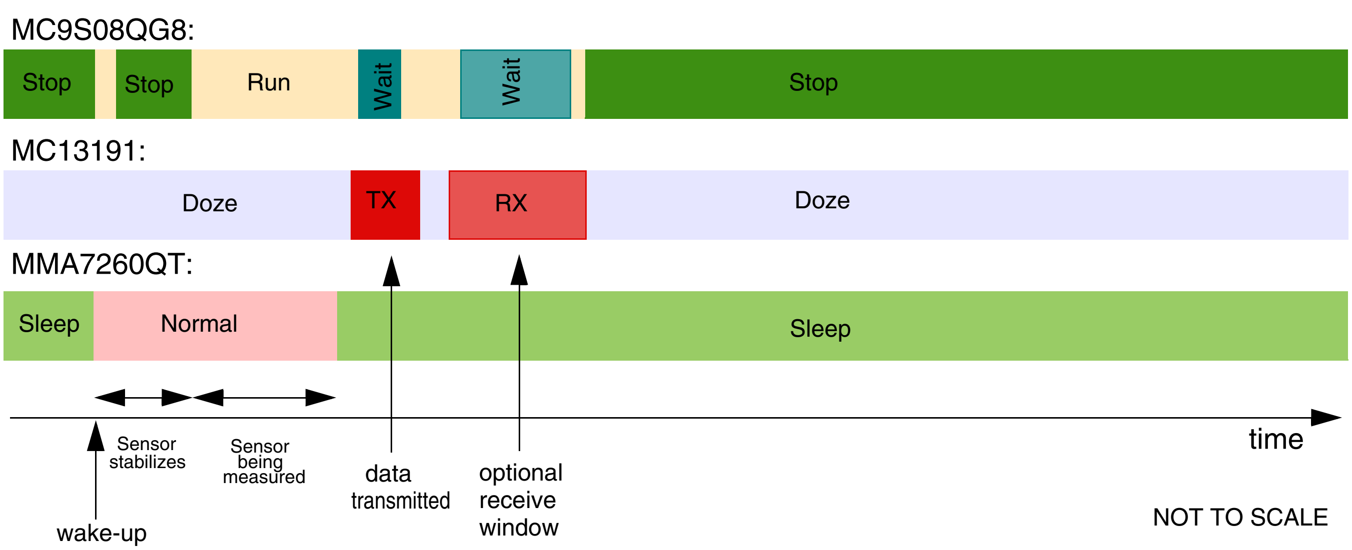

Figure 3-4. Transmission/Sleep Cycle Details

As shown on the previous diagram, all parts of the Sensor Board remain most of the time in Sleep/Doze/Stop modes, in which the total current consumption is below 10μA.

During each loop, once the data has been acquired from the sensor, transmission over the MC13191 transceiver is initiated. The current consumption of the transmitter is ~30mA at that time, but only for a short period of time (typically ~600μs).

In order to keep the Sensor Board informed on the status of connection (for example, if the data-receiving side - USB stick - is out of range, disconnected, etc.), the reception has to be turned on after the data has been transmitted. This is not really required within each loop cycle, and in the actual implementation only on every 8th loop the receive window opens (receiver is enabled to receive the acknowledgment). More in Section 5.3 ZSTAR RF Protocol description.

The reception window is larger to fit any incoming receive data and the current consumption is also higher during reception, so this portion of current consumption would be one of the largest if the acknowledgment was received in every loop cycle.

The “optional receive” feature allows huge power savings, still keeping the reception of acknowledgment data from the data-receiving side.

Some further savings might be incorporated by utilizing the timer-triggered transceiver events that are described in the MC13191 Reference Manual.The MC13191, for example, latches a so-called time-stamp of each received frame. The data-receiving side may read this value and trigger the acknowledgment to be sent at exactly specified time after reception (also, a start of data frame transmission can be programmed as timer-triggered). The Sensor Board might then narrow its own receive window to perfectly match the expected time of the acknowledgment frame. For the simplicity of code, this has not been implemented in the current version of ZSTAR firmware.

3.3.1 MC13191 Power Management Features

MC13191 provides several power saving modes. One of them is called **Doze mode** in which the MC13191 crystal oscillator remains active. An internal timer comparator is functional too, providing a power efficient and accurately timed way of waking-up the application after a specified time.

This feature is fully utilized within the Sensor Board. The microcontroller calculates the time period for which the application should be in power saving mode, then fills in the timer comparator registers in the MC13191, and the microcontroller goes into Stop mode (MC13191 into Doze mode).

Once the timer reaches the pre-programmed time (a timer compare occurs), the MC13191’s IRQ signal is asserted which brings the microcontroller out of the Stop mode. There are various scaling possibilities that allow periods from a few μs up to 1073 seconds (~17 minutes) to be programmed, without intervention of the microcontroller.

3.4 ZSTAR Sensor Board Hardware Overview

This section describes the Sensor Board in terms of hardware design. The MC9S08QG8 microcontroller drives both the MMA7260QT Sensor and the MC13191 RF transceiver.

3.4.1 Analog Connections

The MMA7260QT Sensor is connected to AD0, AD1, and AD2 inputs to analog-to-digital converter via RC filters formed by R3, C3, R4, C2, R5, C1. These are recommended to minimize clock noise from the switched capacitor filter circuit inside the Sensor. Once the software filtering (also described in) is employed, these RC filters may be completely omitted.

3.4.2 g-select Connections

R1, R2, R6 and R7 components are made on the PCB. R1 and R2 are just footprints with no components assembled, while R6 and R7 are connected with copper trace allowing the user to disconnect (cut) these lines. By default, g-sel1 and g-sel2 MMA7260QT Sensor input pins (used to select the acceleration range) are connected to pins PTB0 and PTB1 of the microcontroller. The range can be controlled by software.

If user does not want to use this feature, the g-range can be selected by placing 0R resistors in the R1 and/or R2 positions. If no resistors are assembled, MMA7260QT internal pull-down resistors will automatically select the 1.5g range (both g-sel inputs low).

Once R6 and R7 are cut, PTB0 and PTB1 (or their alternate SCI functionality of RxD1 and TxD1, or KBI or AD inputs) may be used. These signals are also routed to BDM connector, pins 3 and 5.

3.4.3 BDM (Background Debug Mode) Connections

A J2 connector is a non-standard footprint primarily intended for in-factory programming and testing via “spring-needle” type of connections. The J2 connector carries all standard signals for Background Debug Mode communication so if required, one may solder wires and a standard 2x3 pins 2.54mm (100mil) pitch header for regular BDM re-programming. The pin numbering is shown on Figure 3-5.

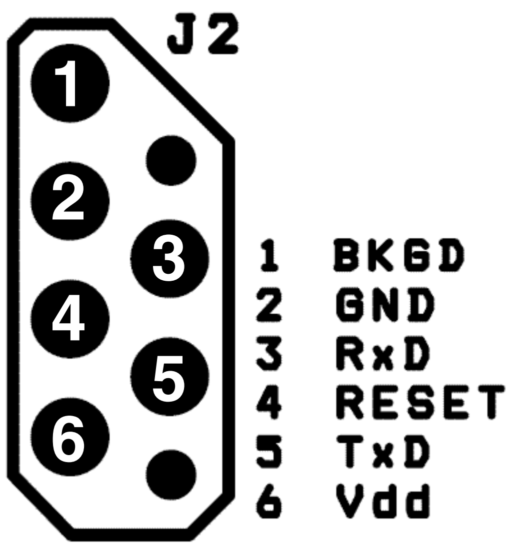

Figure 3-5. BDM Connector Layout

3.4.4 Sensor Board schematics

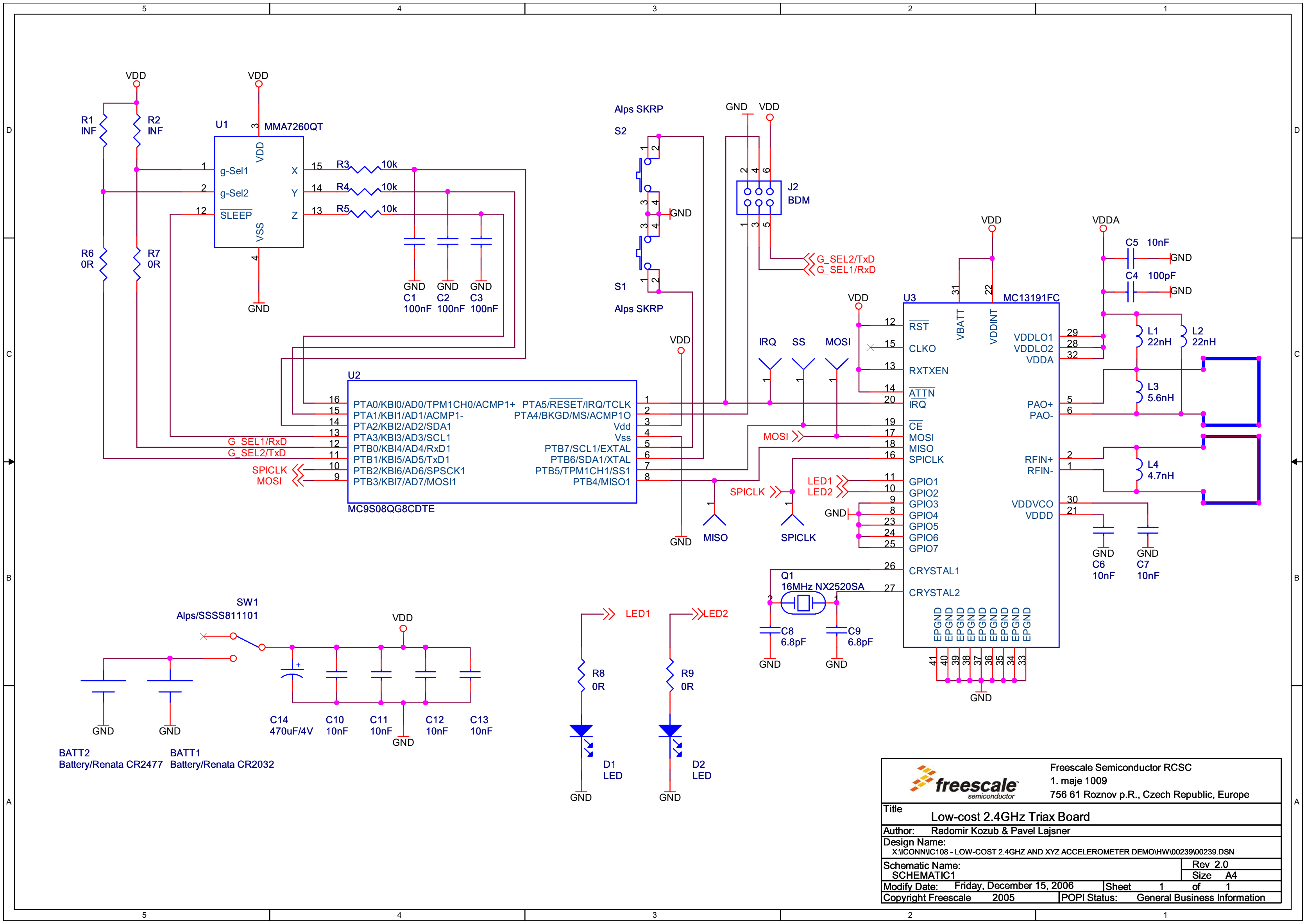

Figure 3-6. Sensor Board Schematics

3.4.5 Button Connections

Two buttons (S1 and S2) are connected directly to pins PTB6 and PTB7. Both have internal pull-up resistors, but are not part of the Keyboard Interrupt module, therefore don't allow a direct microcontroller wake-up from the Stop modes.

3.4.6 MC13191 to MC9S08QG8 Microcontroller Interface

In order to fit all the necessary circuitry onto a 16-pin microcontroller, the full recommended MC13191 interface had to be reduced. The full interface includes the following connections:

- 4-wire Synchronous Peripheral Interface (SPI) connection (MISO, MOSI, SPICLK, $\overline{\text{CE}}$)
- Interrupt Request signal ($\overline{\text{IRQ}}$)
- Attention ($\overline{\text{ATTN}}$) wake-up signal
- Receive/Transmit Enable (RXTXEN) signal
- External Reset ($\overline{\text{RST}}$) signal

SPI and **$\overline{\text{IRQ}}$** are vital for the communication and configuration of the MC13191. SPI is connected to the MC9S08QG8 SPI module (pins PTB4/MISO1, PTB3/MOSI1, PTB2/SPSCK1, and GPIO pin PTB5 for $\overline{\text{CE}}$).

Interrupt Request ($\overline{\text{IRQ}}$) is connected to the microcontroller $\overline{\text{IRQ}}$ pin sharing its alternate $\overline{\text{RESET}}$ function when BDM communication is active.

Attention ($\overline{\text{ATTN}}$) signal is intended to externally wake-up the MC13191 from Doze and Hibernate modes. Since this feature is not used and exit from the Doze mode is done using a timer compare event, the $\overline{\text{ATTN}}$ pin is not routed to the microcontroller and needs to be connected to V_{dd}.

Receive/Transmit Enable (RXTXEN) signal is used to control transitions to/from receive and transmit modes. Since this can be accomplished just by software programming and/or timer compare events, this connection to the microcontroller may also be omitted, saving an additional pin. RXTXEN is connected to V_{dd}.

External Reset ($\overline{\text{RST}}$) signal places the transceiver in a complete reset condition (Off mode and power down). Alternative Software reset is also possible and since Off mode (the one with the lowest possible power consumption) is not required too, $\overline{\text{RST}}$ is connected to V_{dd} too.

3.4.7 MC13191 RF Interface

The RF interface (antennas) were designed with the cost and board size in mind. Among several designs, the PCB layout antennas were in the main consideration (cost). Of several PCB antenna designs available for the 2.4GHz band (F-antenna, dipole, loop), the loop antenna has been selected mainly because of the size required on the PCB.

The MC13191 transceiver is designed with separated RF IN (receive) and PA OUT (transmit) paths. To avoid the need for an antenna switch, two separate antennas need to be used. Both ZSTAR boards (USB stick and Sensor Board) use the same antenna layout, there are two antennas on the PCB, just on the opposite sides of the PCB.

The antenna is designed as a rectangle, 20x24mm (780x940mils), made of 1.25mm (50mils) wide trace of copper. The corners are rounded with a 3.8mm (150mils) radius.

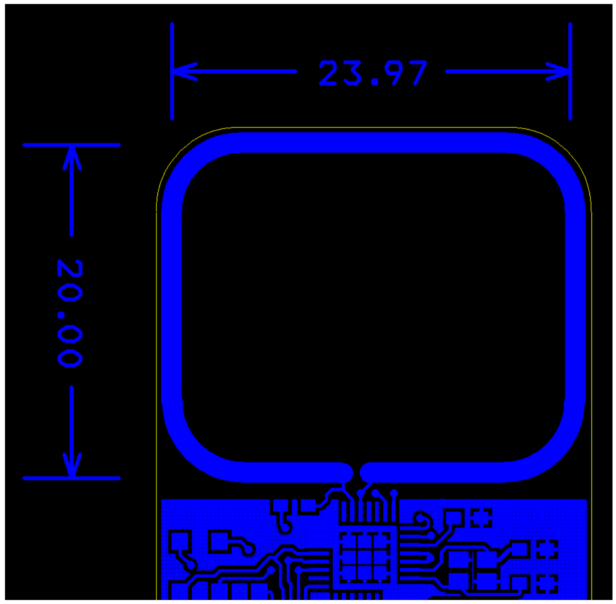

Figure 3-7. ZSTAR Antenna Layout

The matching is provided by L3 (transmit antenna) and L4 (receive antenna) coils. L1 and L2 coils bias the transmitter output transistors to the V_{DDA} level.

The inductors used in this design are from TDK:

L3 (5.6nH) MLG1608B5N6DT

L4 (4.7nH) MLG1608B4N7ST

L1, L2 (22nH) MLG1608B22NJT

3.4.8 Clocking Options of MC9S08QG8

Due to the availability of accurate timing provided by the MC13191 transceiver, an internal oscillator (ICG) in the MC9S08QG8 is used as the main clock source for the microcontroller. The protocol related timing is derived from MC13191 timers, the microcontroller itself is clocked from an internal oscillator, leaving the oscillator pins as GPIO. This is highly beneficial to the limited pin count microcontroller.

3.4.9 LED Indicators Connections

The MC13191 allows extension to the number of general I/O pins by 7 additional GPIO connections. Two of these (GPIO1 and GPIO2) are used for LED indicators. R8 and R9 are their current limiting resistors, and in the actual design orange LED's are used, with a threshold voltage around 2.0-2.5V.

The remaining unused GPIO3-GPIO7 signals are connected to ground, improving the physical PCB layout of the MC13191.

3.4.10 Power Supply

The Sensor Board is powered by a Lithium coin-sized battery. The primary choice was the popular CR2032, with a PCB layout provision made for the CR2477 size. This bigger battery holds roughly 4 times more charge (~1000mAh), but it is not as popular as CR2032 size.

A surface mounted SMTU series battery holder from Renata™ is placed on the underside of the PCB. The SMTU series holders provide (by mechanical construction) battery reverse protection, so no additional circuitry is required. Slide switch SW1 disconnects the battery from the application when not in use.

A large tantalum capacitor (C14, 470μF/4V) improves the response of the power supply to current peaks caused by reception or transmission. Coin-sized Lithium CR2032 batteries are targeted at a maximum continuous discharge current in the range of 3mA. Such a large capacitor helps to supply enough current to the MC13191 during a receive/transmit without significant V_{dd} voltage drops.