APPLICATION NOTE

AT03197: Thermostat with Touch and Wireless Connectivity Hardware User's Guide

Atmel 32-bit Microcontroller

Description

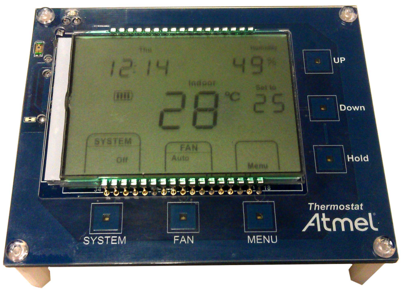
The reference design is developed to make a low-power thermostat reference design with touch control and wireless connectivity.

For this reference design, the hardware design files (schematic, BOM, and PCB Gerber) and software source code can be downloaded from the Atmel® website. The provided hardware documentation can be used with no limitations to manufacture the reference hardware solution for the design.

Features

- Atmel ARM® Cortex®-M4 ATSAM4LC microcontroller
- Atmel AT86RF233 2.4GHz RF transceiver
- 115 segment LCD display with backlit
- Temperature/Humidity/Ambient sensor
- Six capacitive touch buttons
- Buzzer control
- Battery powered (2 * AA alkaline batteries)
- Over 10 minutes backup running time for battery replacement
- USB port for FW updating
- JTAG interface for programming and debugging

Figure 1. Thermostat with Touch and Wireless Connectivity



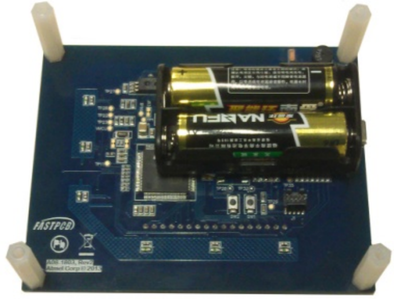


Table of Contents

1 Related Items

The following list contains links to the most relevant documents for Thermostat:

- ARM SAM4L Low Power MCU Datasheet Summary

  Atmel ATSAM4LC4C is the microcontroller used in this solution.
- Atmel AT86RF233 Datasheet

  AT86RF233 is the microcontroller used for RF transceiver.
- Atmel AT03454: SAM-BA for SAM4L

  This application note complements the SAM-BA® user guide and explains how the SAM-BA should be used in a SAM4L design.
- Atmel Studio 6

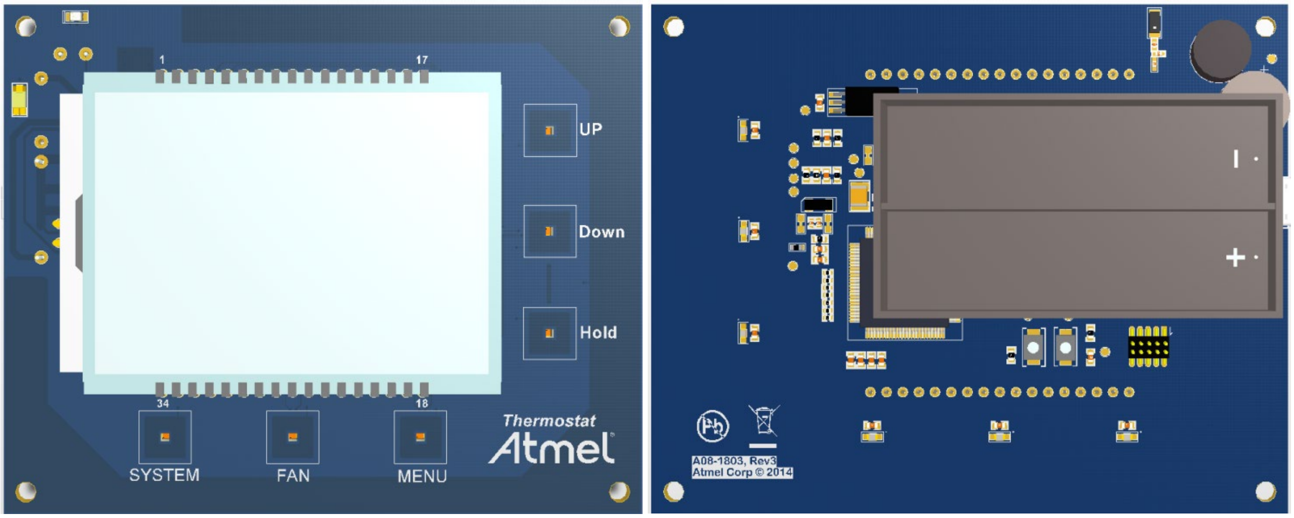
  Atmel Studio 6 is a free Atmel IDE for development of C/C++ and assembler code for Atmel microcontrollers.
- Atmel SAM-ICE

  Atmel SAM-ICE™ is a JTAG emulator designed for Atmel SAMA5, SAM3, SAM4, SAM7, and SAM9 ARM core-based microcontrollers, including the Thumb mode. It supports download speeds up to 720KB per second and maximum JTAG speeds up to 12MHZ. It also supports Serial Wire Debug (JTAG) and Serial Wire Viewer (SWV) from SAM-ICE hardware V6.

2 Overview

The thermostat kit with wireless connectivity based on the Atmel ATSAM4LC4C is intended to demonstrate the ATSAM4LC4C microcontroller with ultra-low power consumption, embedded hardware capacitive touch, and ASCII character mapping. Figure 2-1 shows the available features on the board.

Figure 2-1. Overview of Thermostat



2.1 Components for Setup

The components in Table 2-1 are necessary for performing all functions of the reference design.

Table 2-1. Components for Kit Setup

Component	Function
Reference hardware Kit	The main board
2 * AA battery	Power for the kit
SAM-ICE programming Tools	Debug and Programming
USB cable	FW updating

2.2 Power Supply

The kit is powered by 2 * AA alkaline batteries directly.

The battery voltage range is 2.0V~3.2V.

Notes: 1. USB port is used for FW updating and could power the kit in FW updating. There could be no batteries in updating process. The thermostat cannot work when powered by the USB port because the battery removal detection function will enable the kit to enter sleep mode.

2. Ensure the total battery voltage is more than 2.3V before mounting into the kit. Otherwise, the kit could not be started.

2.3 Programming the Kit

The kit can be programmed from an external programming tool through the JTAG interface or via the Micro-USB port.

3 Connectors

The thermostat kit based on Atmel ATSAM4LC4C has JTAG header J1, USB port J2. They are shown in Table 3-1.

Table 3-1. Connector and Functions

Connector	Function
J1	JTAG interface for programming and debugging
J2	Micro-USB port for FW updating

3.1 JTAG Header

The ATSAM4LC4C can be programmed and debugged via JTAG header. SAM-ICE is recommended here for programming. The definition of the JTAG interface can be found in Table 3-2.

Table 3-2. ATSAM4LC4C Programming and Debugging Interface – JTAG

Pin on programming header	JTAG
1	TCK
2	GND
3	TDO
4	V_{CC}
5	TMS
6	Reset
7	--
8	--
9	TDI
10	GND

3.2 Micro-USB Port

A Micro-USB port is used to update FW. The definition of the Micro-USB port can be found in Table 3-3.

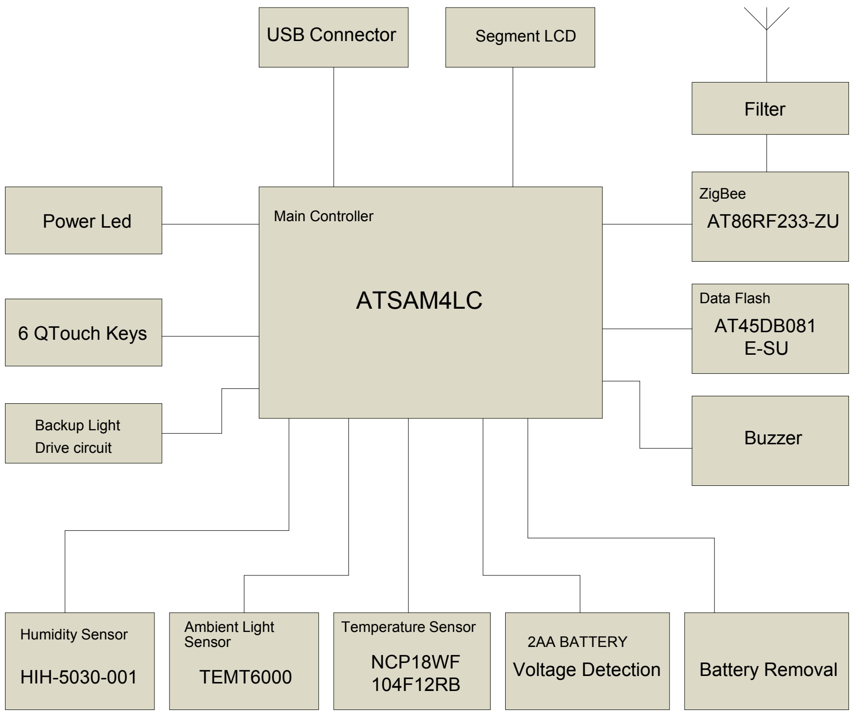
Table 3-3. Micro-USB Port

Pin on programming header	JTAG
1	VBUS
2	DM
3	DP
4	--
5	GND

4 Functional Modules

Figure 4-1 shows the thermostat system block diagram based on Atmel ATSAM4LC4C device.

Figure 4-1. Thermostat System Block Diagram



4.1 Capacitive Touch Sensors

CATB Block Diagram performs acquisition, filtering, and detection of capacitive touch sensors. The capacitive touch sensors use no mechanical components, and therefore demand less maintenance in the user application.

The CATB can operate in different capacitance discharge modes:

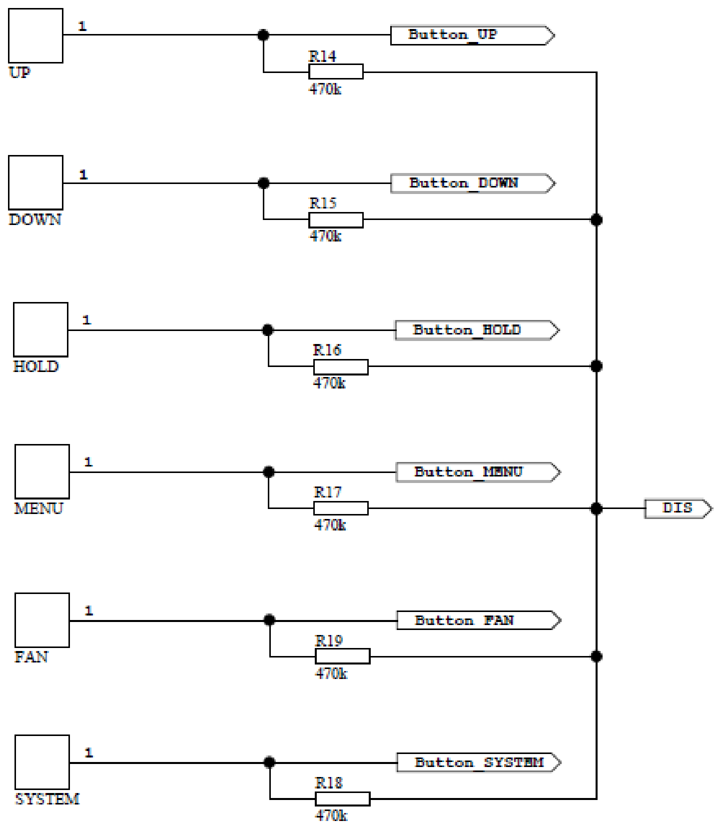
- Single-ended, with one pin per sensor
- Differential, with two pins per sensor
- External discharge resistors, with an extra pin (DIS) in single-ended mode
- Internal discharge resistors

The CATB can operate in single-ended or differential mode. A common discharge pin must be used when using external resistors in single-ended mode. And this mode is selected in this design.

Note: Find the touch library information in Atmel AT03198: Thermostat with Touch and Wireless Connectivity - Software User's Guide.

Find more information about the CATB in the datasheet of SAM4L: www.atmel.com/images/atmel-42023-arm-microcontroller-atsam4l-low-power-lcd_datasheet.pdf.

Figure 4-2. Touch Button Circuit



4.2 Touch Button Backlight LED Design

Backlight LEDs are used for touch button light and backlight.

If LEDs are close (less than 4mm away) to capacitive sensors, the change in capacitance between the LED on and off states should impact capacitor sensor actions. It is also necessary to consider the changes in the nature of their drive circuitry.

If changes in capacitance of the LED and associated drive circuit couple to a touch sensor electrode, it is possible to cause detection instability or touch keys that stick either on or off when the LED changes state.

LEDs that are judged as close must be bypassed with a capacitor that has a typical value of 1nF.

Note: Find more information in the guide of - QTAN0079 Buttons, Sliders and Wheels Sensor Design Guide. The link is: www.atmel.com/images/doc10752.pdf.

4.3 Temperature Sensor

The design is equipped with one temperature sensor (NCP18WF104FR). The power is supplied by one GPIO. The ADC reference is 0.625 * V_{CC} (GPIO output voltage) to reduce the error caused by external power. One 100kΩ resistor is paralleled with the NTC to ensure the input voltage does not exceed the ADC input range.

The NTC sense voltage could be got from the following equation:

$$V_{SENSE} = (R1//TH1) \div [R9 + (R1//TH1)] \times V_{CC}$$

For MCU, the equation for the ADC decimal code is:

$$\text{ADC Code} = 4095 \times V_{SENSE} \div (0.625 \times V_{CC}) = 6552 \times (R1//TH1) \div [R9 + (R1//TH1)]$$

Figure 4-3. Temperature Sensor Circuit

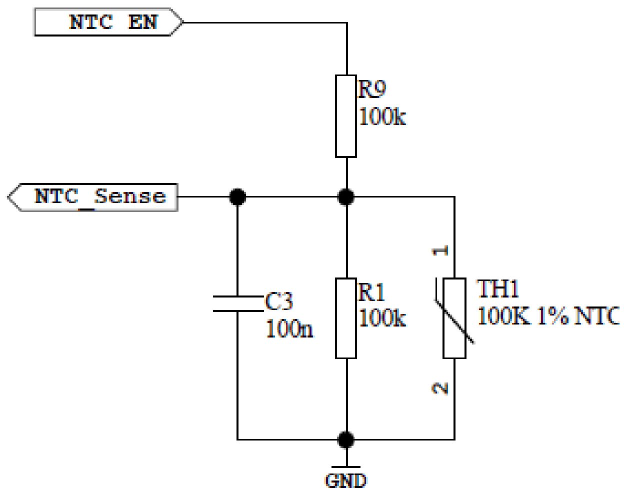


Table 4-1. NTC Table

Part number:	NCP18WF104F		
Resistance:	100kΩ ±1%		
B-constant:	4200k		
Temperature [°C]	**Resistance [kΩ]**	**Temperature [°C]**	**Resistance [kΩ]**
-40	4205.686	45	41.336
-35	2966.436	50	33.628
-30	2118.789	55	27.510
-25	1531.319	60	22.621
-20	1118.422	65	18.692
-15	825.570	70	15.525
-10	615.526	75	12.947
-5	463.104	80	10.849
0	351.706	85	9.129
5	269.305	90	7.713
10	207.891	95	6.546
15	161.722	100	5.572
20	126.723	105	4.764
25	100.000	110	4.087
30	79.222	115	3.518
35	63.509	120	3.040
40	51.084	125	2.634

4.4 Humidity Sensor

The design is equipped with one humidity sensor (HIH5030-001). Its working voltage is 3.3V. The ADC reference is internal 1.0V. Its output voltage could be got from the following equation:

$$V_{OUT} = (V_{SUPPLY}) \times (0.00636 \times (\text{sensor RH}) + 0.1515)$$

It is typically at 25˚C.

Notes: 1. The minimum output resistor is 65kΩ.

2. V_{CC} = 3.3V.

Figure 4-4. Humidity Sensor Circuit

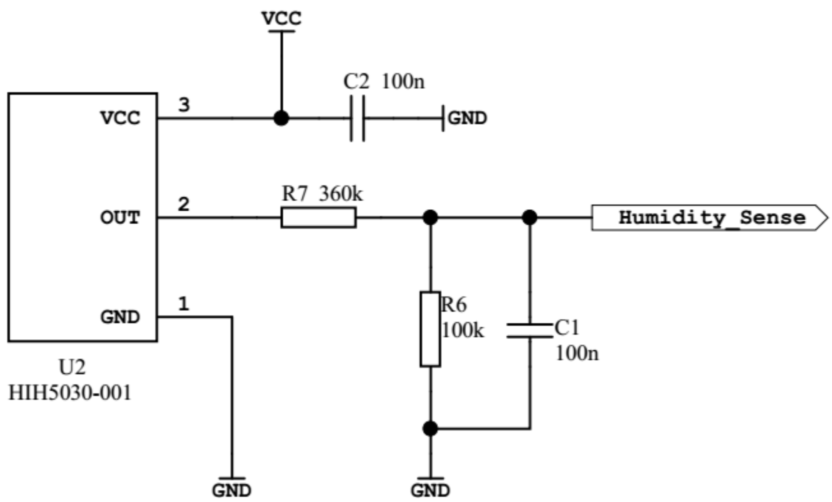


Table 4-2. Humidity Sense Voltage vs. Humidity (V_{CC} = 3.3V)

RH%	V_{OUT}	V_{IN}	RH%	V_{OUT}	V_{IN}
5	0.60489	0.131498	55	1.65429	0.359628
10	0.70983	0.154311	60	1.75923	0.382441
15	0.81477	0.177124	65	1.86417	0.405254
20	0.91971	0.199937	70	1.96911	0.428067
25	1.02465	0.22275	75	2.07405	0.45088
30	1.12959	0.245563	80	2.17899	0.473693
35	1.23453	0.268376	85	2.28393	0.496507
40	1.33947	0.291189	90	2.38887	0.51932
45	1.44441	0.314002	95	2.49381	0.542133
50	1.54935	0.336815			

4.5 Light Sensor

The design is equipped with one light sensor TEMT6000. Thermostat can enable or disable the backlight based on the ambient light strength. The ADC reference is internal 1.0V. MCU will sense the ambient light every five seconds. The sense voltage can be found from the following equation:

$$V_{SENSE} = I_{CA} \times 10\text{-}6 \times 10 \times 103 \text{ (V)}$$

Figure 4-5. Light Sensor Circuit

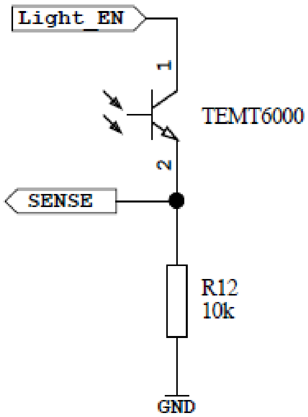


Figure 4-6. The Curve of Collector Light Current vs. Ambient Illuminance

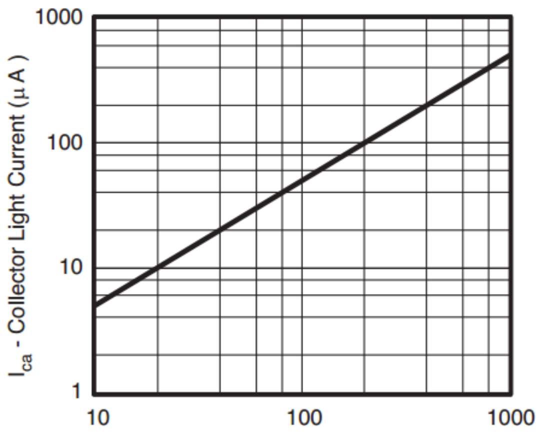


Table 4-3. Light Sense Voltage vs. Illuminance

Illuminance [lx]	Current [µA]	V_{SENSE} [V]	Illuminance [lx]	Current [µA]	V_{SENSE} [V]	Illuminance [lx]	Current [µA]	V_{SENSE} [V]
10	5	0.05	75	37.5	0.375	140	70	0.7
15	7.5	0.075	80	40	0.4	145	72.5	0.725
20	10	0.1	85	42.5	0.425	150	75	0.75
25	12.5	0.125	90	45	0.45	155	77.5	0.775
30	15	0.15	95	47.5	0.475	160	80	0.8
35	17.5	0.175	100	50	0.5	165	82.5	0.825
40	20	0.2	105	52.5	0.525	170	85	0.85
45	22.5	0.225	110	55	0.55	175	87.5	0.875
50	25	0.25	115	57.5	0.575	180	90	0.9
55	27.5	0.275	120	60	0.6	185	92.5	0.925
60	30	0.3	125	62.5	0.625	190	95	0.95
65	32.5	0.325	130	65	0.65	195	97.5	0.975
70	35	0.35	135	67.5	0.675	200	100	1

4.6 Battery Removal Detection and Backup Mode

When the battery is removed, an external interrupt signal will be detected by MCU, and then MCU will go to backup mode to reduce current consumption. In this mode, LCD display is disabled. MCU will be powered by the backup capacitor after battery is removed. When the battery is plugged in again, MCU will be automatically waked up.

When the battery voltage is less than 2.0V, MCU also will enter into backup mode. In this mode, MCU only maintains the least function. If the batteries are removed, but new batteries are not implemented, the backup capacitor could ensure the MCU working about 10 minutes (from 2.0V to 1.7V). If the new batteries are still not mounted within 10 minutes, the users have to wait about more than one hour before mounting new batteries so that the voltage on the backup capacitor could be discharged to under 0.9V, which is less than the valid reset voltage for MCU. Otherwise, MCU may be reset from a fault state.

This situation could be avoided by adding an external MOSFET of capacitor discharge circuit, which will create a POR reset by discharging out the backup capacitor when MCU detects the voltage of V_{CC} below 1.8V. And it also needs firmware support to enable the BOD function and one GPIO should be selected to drive an external MOSFET to discharge the backup capacitor.

Figure 4-7. Backup Circuit

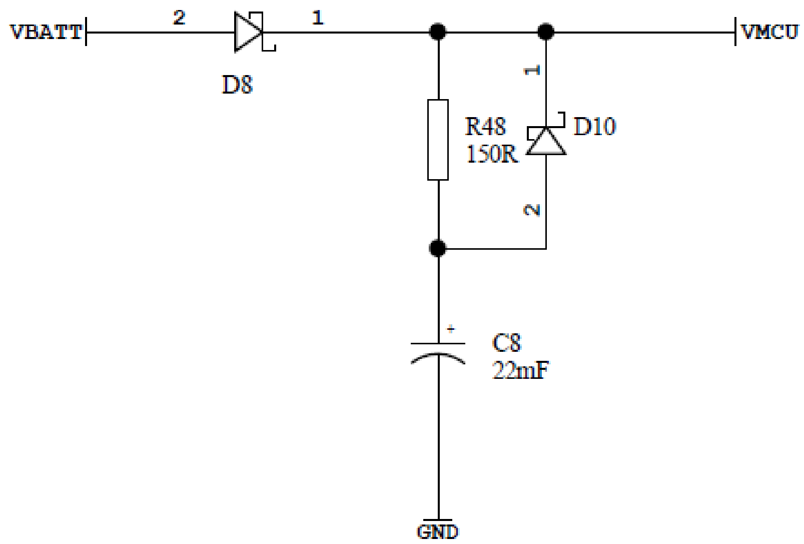
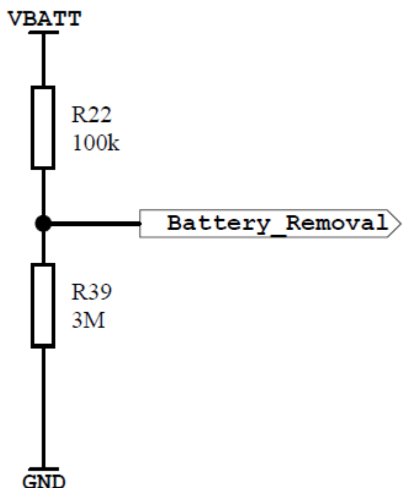


Figure 4-8. Battery Removal Detection



4.7 Power Indication (not mounted)

One LED is used to indicate the demo is powered well. It is driven by a transistor and can be driven by external source.

4.8 External Flash (not mounted)

The serial-interface (SPI) sequential access flash memory Atmel AT45DB081D-SU is optional for user to storing any application needs.

4.9 ZigBee Transceiver

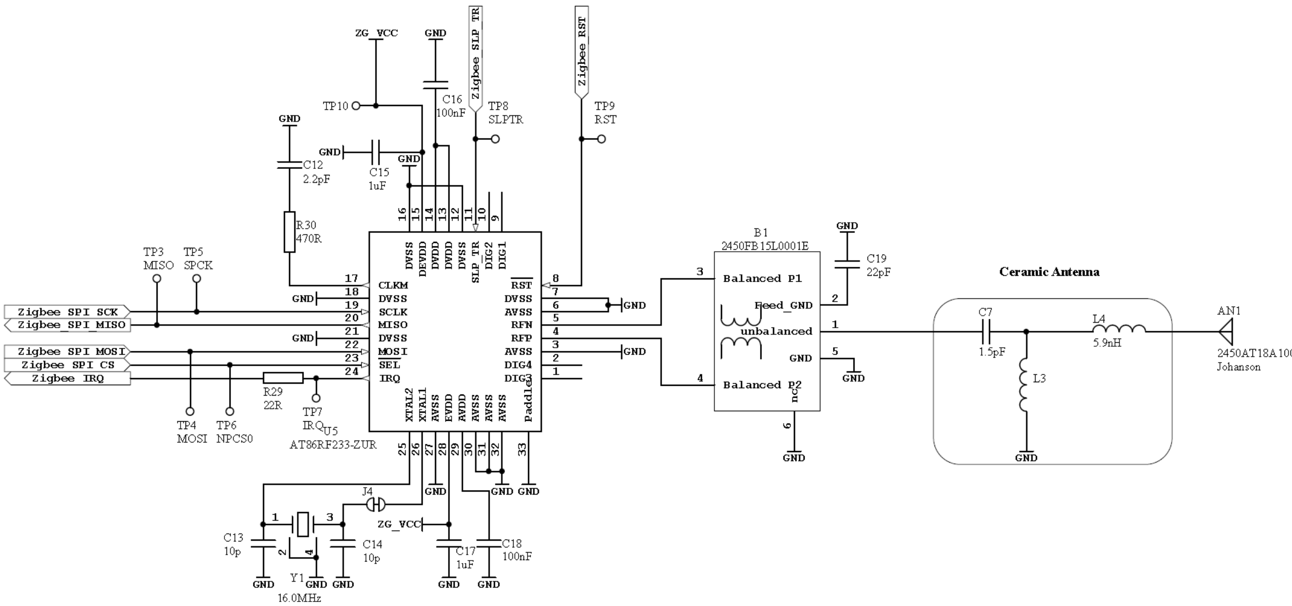
The Atmel AT86RF233 is a feature rich, extremely low-power 2.4GHz radio transceiver designed for industrial and consumer ZigBee®/IEEE® 802.15.4, RF4CE, 6LoWPAN, and high data rate 2.4GHz ISM band applications.

In this design, a balun-filter and a chip antenna are also used. The output power is about 2.0dB without PA.

Refer to the design guide for the RF design in the following link: www.atmel.com/images/doc8182.pdf.

Note: There are no relative certifications for this kit, such as FCC/ETSI.

Figure 4-9. ZigBee Transceiver Circuit



4.10 USB Connection

To be able to use the USB programming function, the SAM-BA bootloader image file (generally named sam4l_sam-ba_image.hex) should be programmed in advance. Refer to application note Atmel T03454: SAM-BA for SAM4L for more information. A regulator circuit is used to convert the 5.0V to 3.3V to supply the kit in case the batteries are not mounted. Besides, one GPIO is used to force MCU entry bootloader mode. Press button SW2 and the reset button SW1; MCU will go to bootloader mode. Then MCU could be programmed via the USB cable with SAM-BA tools. This GPIO number and its active level could be defined in the flash user page.

Figure 4-10. USB Connection

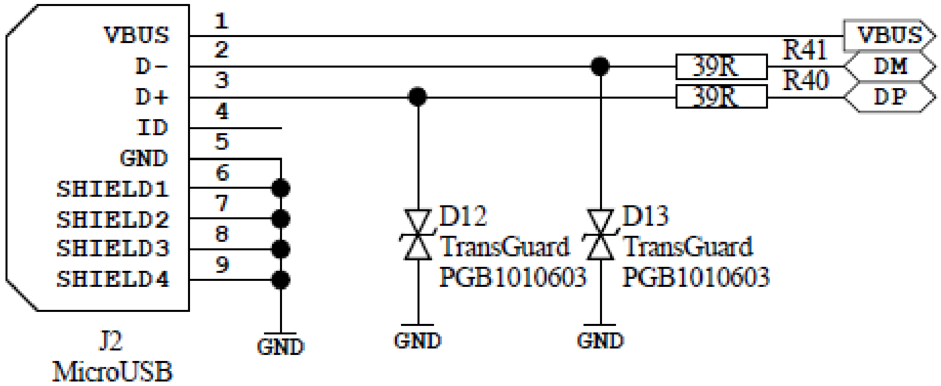


Figure 4-11. 3.3V Regulator

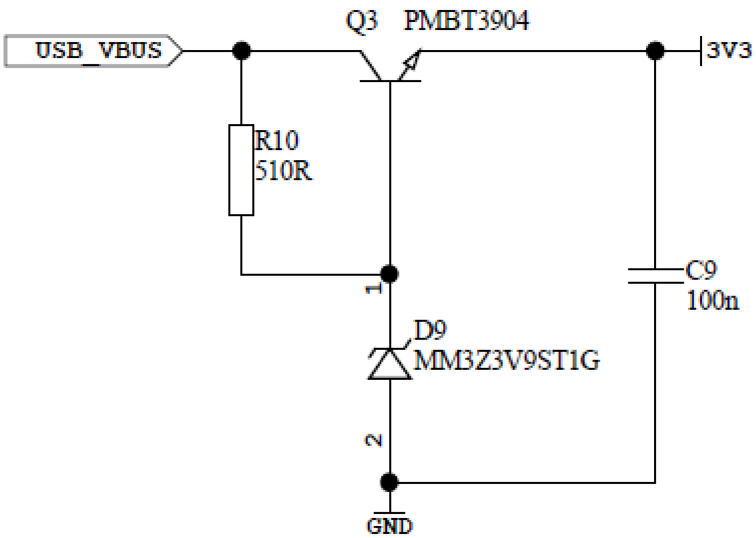
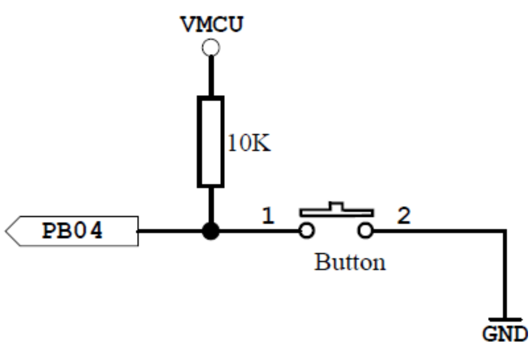


Figure 4-12. Boot Loader Button Circuit



Note: If the boot loader won't pull up or pull down the pin, the level has to be set externally. Find more information about the setting of bootloader in the checklist of SAM4L: www.atmel.com/images/atmel-42025-at01777-sam4l-schematic-checklist_application-note.pdf.

4.11 LCD Display

In this design, a 115 segment LCD is used to display the relative information, such as temperature, humidity, time, and menu, and so on.

For SAM4LC, the display capacity is up to 40 segments and up to four common terminals. It supports ASCII character mapping and automated segments display. The LCD pads are divided into three clusters that can be powered independently namely clusters A, B, and C. A cluster can either be in GPIO mode or in LCD mode.

When a cluster is in GPIO mode, its VDDIO pin must be powered externally. None of its GPIO pin can be used as a LCD line. When a cluster is in LCD mode, each clusters VDDIO pin can be either forced externally (1.8V - 3.6V) or unconnected (NC). GPIOs in a cluster are not available when it is in LCD mode.

Table 4-4. LCD Powering when Using the Internal Voltage Pump

Package	Segments in use	VDDIO LCDB	VDDIO LCDC
100-pin packages	[1, 24]	1.8V – 3.6V	1.8V – 3.6V
	[1, 32]	NC	1.8V – 3.6V
	[1, 40]	NC	NC
64-pin packages	[1, 15]	-	1.8V – 3.6V
	[1, 23]	-	NC
48-pin packages	[1, 9]	-	1.8V – 3.6V
	[1, 13]	-	NC

Figure 4-13. LCD Connection

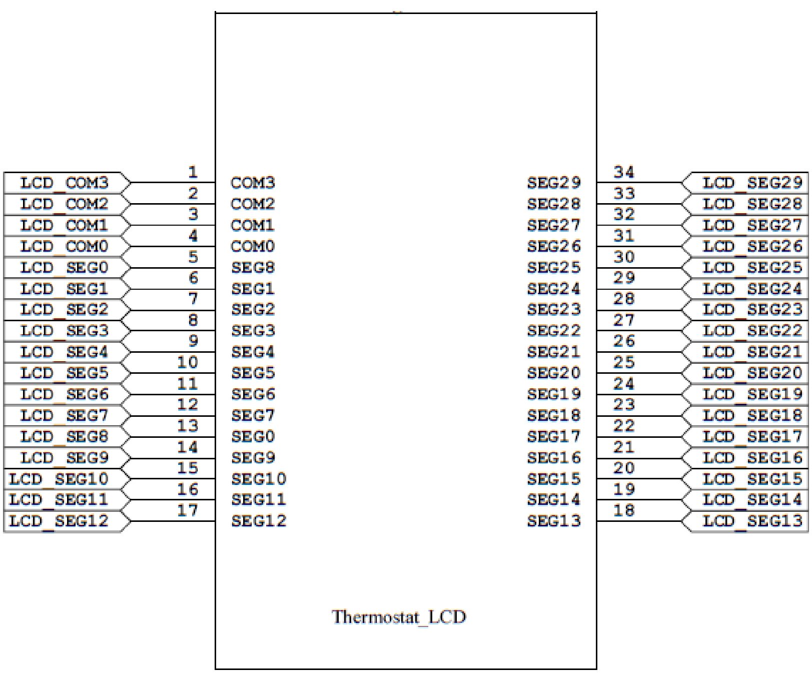
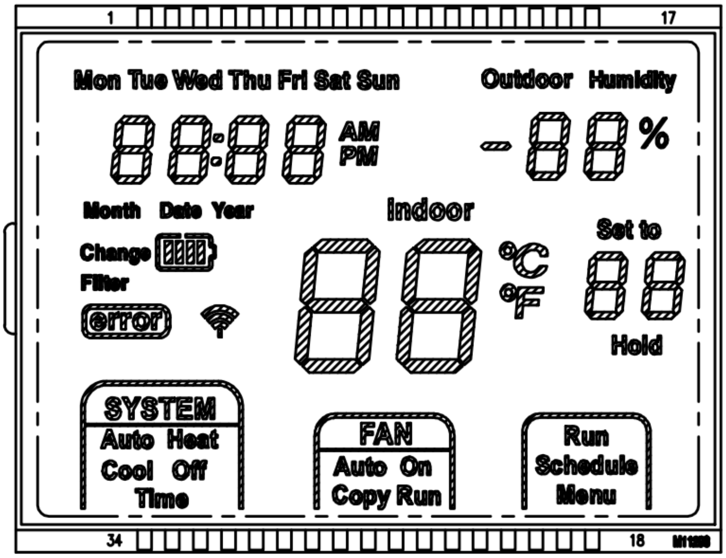


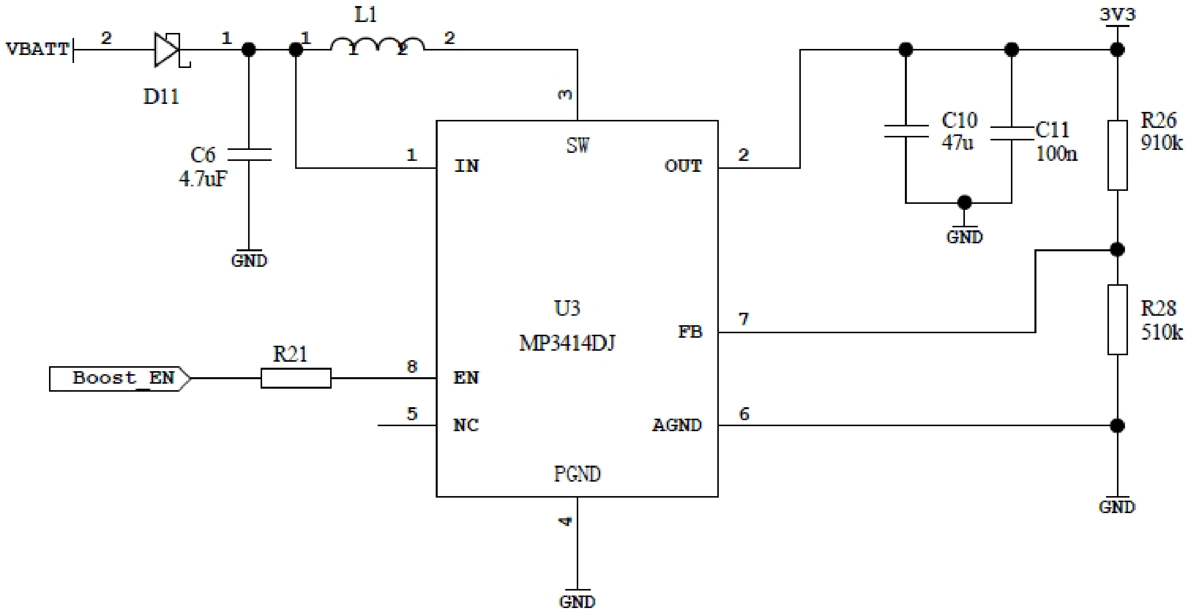
Figure 4-14. LCD Full Display



4.12 Boost Circuit

A step-up converter MP3414DJ is selected to boost the battery voltage to 3.3V to power the humidity sensor, backlight LEDs and LCD backlight. A diode is added between the battery and MP3414DJ. This could reduce the IRQ latency when battery is removed.

Figure 4-15. Boost Circuit



Note: If $V_{OUT} < V_{BATTERY} + 200mV$, then MP3414DJ will work in down mode.

You can find the datasheet of MP3414 in the following link:
http://www.monolithicpower.com/Page/DownLoad.aspx?ListID=7316f5f0-d23a-4d27-8f3b-e135e96a23e5&&ItemID=16.

5 Electrical Characteristics

5.1 Absolute Maximum Ratings

Stresses beyond the values listed in Table 5-1 may cause permanent damage to the board. This is a stress rating only and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of this manual are not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability. For more details about these parameters, refer to individual datasheets of the components used.

Table 5-1. Absolute Maximum Ratings

No.	Parameter	Condition	Minimum	Typical	Maximum	Unit
1	Storage temperature range		-10		+60	
2	Humidity	Non-condensing			90	%r.H.
3	Supply		-0.3		+3.6	V
4	EXT I/O pin voltage		-0.3		V_{CC} + 0.3	V

5.2 Recommended Operating Range

Table 5-2. Recommended Operating Range

No.	Parameter	Condition	Minimum	Typical	Maximum	Unit
1	Operating temperature range		0		+50	
2	Supply voltage		2		3.3	V

5.3 Current Consumption

Test conditions (unless otherwise stated):

V_{DD} = 3.0V, T_{OP}= 25°C

Table 5-3. Average Current Consumption

No.	Parameter	Condition	Minimum	Typical	Maximum	Unit
1	Average current consumption	The backlight LEDs are off		230	308	µA
2	Average current consumption in wait mode			6		µA

6 Code Examples

The example application is based on the Atmel Software Framework included in the Atmel Studio 6. The Atmel Software Framework can also be found as a separate package online at: http://www.atmel.com/tools/avrsoftwareframework.aspx

For more information about the code example, see the application note: Atmel AT03198: Thermostat with Touch and Wireless Connectivity - Software User's Guide.

7 Revision History

Doc Rev.	Date	Comments
42209B	07/2014	• Figure 2-1, page 3, has been updated to latest version • Redundant value in Table 4-3, page 10, has been deleted • The schematic in ZigBee Transceiver, page 12, has been updated
42209A	02/2014	Initial document release.

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