TI Designs
Daisy-chained Temperature Sensor Reference Design for SensorTag

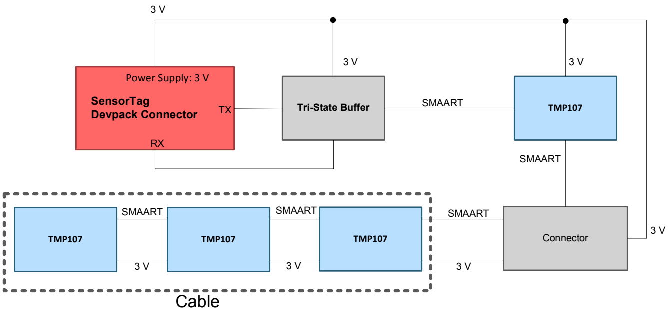
Design Overview

The TIDA-00800 reference design entails 4 temperature sensors along a daisy chain in a cabling environment. The sensors connect to the SensorTag development platform via the UART interface where the information can be transmitted wirelessly. The Bluetooth low energy wireless technology makes testing and demonstration easier due to its integration in most modern equipment. The form factor and electrical connections are compatible with TI SensorTag 2.0 ecosystem, allowing easy prototyping with other wireless technology (Zigbee, Wifi, sub 1GHz…), while the selected sensor allows industrial grade accuracy and resolution.

Design Resources

TIDA-00800	Design Folder
TMP107	Product Folder
CC2650	Product Folder
SensorTag	Product Folder

Block Diagram



Design Features

- Daisy-chained temperature sensors (TMP107)
- Bluetooth Low Energy™ link from
- SensorTag platform
- SMAART WIRE™ Interface: Allows up To 32 Daisy-Chained devices using UART interface
- Temperature range: -55°C to +125°C
- Accuracy: ±0.4°C from -20°C to +70°C
- Resolution: 14 bits (0.015625°C)

Featured Applications

- Distributed temperature sensing
- Isolated Field transmitters

Board Image

1 Key System Specifications

Parameter	Specifications and features	Details
Temperature measurement range	-55°C to +125°C	Section 3.1.1.1
Accuracy	±0.4°C from -20°C to +70°C	Section 3.1.1.1
Wireless protocol	Bluetooth Low Energy®	Section 3.1.2
Input power source	CR2032 Li-ion coin cell battery	Section 4.1.4
Operating Power supply range	2.2V to 3.6V	Section 3.1.21

Table 1: System specifications

2 System Description

Temperature measurement is an area of measurement that spans many applications such as cold-chain logistics, building automation, agricultural equipment and industrial process control.

This reference design targets especially the needs for isolated and/or distributed sensing applications that require multi-point temperature measurements with high accuracy and electrical isolation between the central control and the sensor nodes.

The design uses the SimpleLink™ SensorTag by TI. It allows quick and easy prototyping of IoT devices. It includes the CC2650 wireless MCU which is a cost-effective, ultra-low power, 2.4-GHz RF device. The SensorTag communicates with a BLE enabled smartphone; an Android application is available to read the different sensors.

The SensorTag is interfaced with four TMP107 temperature sensors mounted on a cable to enable long distance and multipoint sensing. To ensure the lowest power operation, the different TMP107s are initialized into shutdown mode, and a single one-shot conversion is periodically enabled by the MCU when it is connected to a smartphone. The different TMP107s are UART-Compatible, the MCU uses the SMAART Wire™ Interface to communication to the daisy-chained devices, and this interface is basically a one-wire communication.

3 Block Diagram

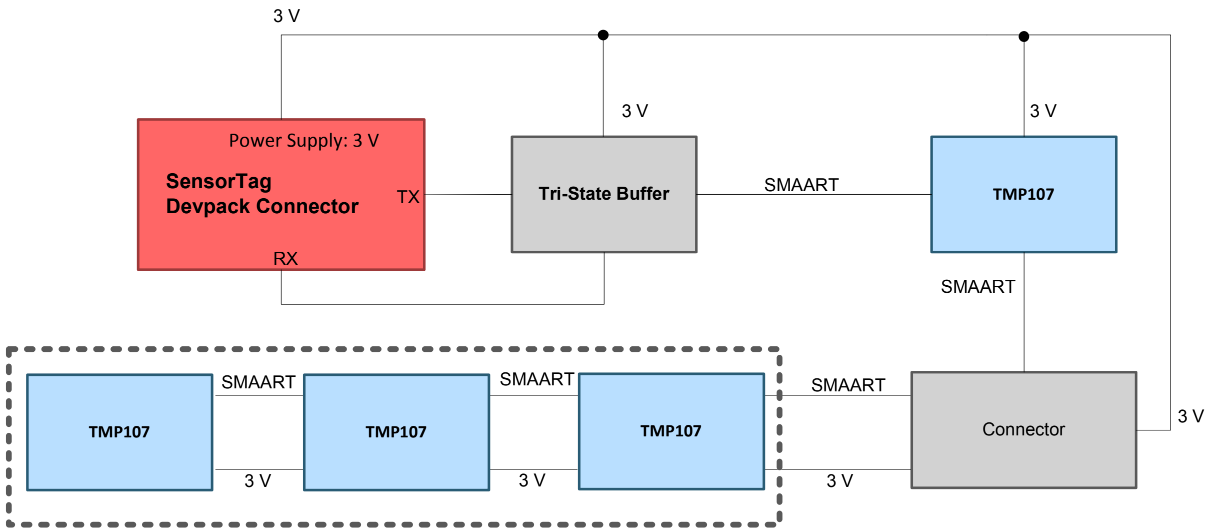


Figure 1: System Block Diagram

3.1 Highlighted Products

The *Temperature sensors in a Daisy-chained Cable for SensorTag* reference design features the following devices:

- **TMP107**
  - Digital temperature sensor with bidirectional UART one-Wire interface.
- **SensorTag**
  - TI design kit that allows quick and easy prototyping of IoT devices.
- **CC2650**
  - Wireless MCU targeting Bluetooth Smart, ZigBee and 6LoWPAN, and ZigBee RF4CE remote control applications.
- **SN74LVC1G125**
  - Single bus buffer gate with 3-State Outputs.

For more information on each of these devices, see the respective product folders at www.ti.com

3.1.1 TMP107 description

The TMP107 digital output temperature sensor supports up to 32 daisy-chained devices. Each sensor has a unique 5-bit address stored in EEPROM. The TMP107 is capable of reading temperatures with a resolution of 0.0015625°C, and is accurate to within ±0.4°C in the range from -20°C to +70°C. The TMP107 is ideal for replacing NTC and PTC thermistors where which accuracy is required.

The unique 5-bit address stored in the EEPROM is determined during the automated address assignment operation, and is based on the position of each sensor relative to the SMAART wire host. Multiple operating modes provide maximum flexibility in selecting between low power consumption for battery operation, and high update rates for real-time control applications.

The TMP107 is ideal for extended temperature measurement in a variety of industrial, instrumentation, communication, and environmental applications. The TMP107 is available in an 8-pin SOIC package and is specified for operation over a temperature range of −55°C to +125°C.

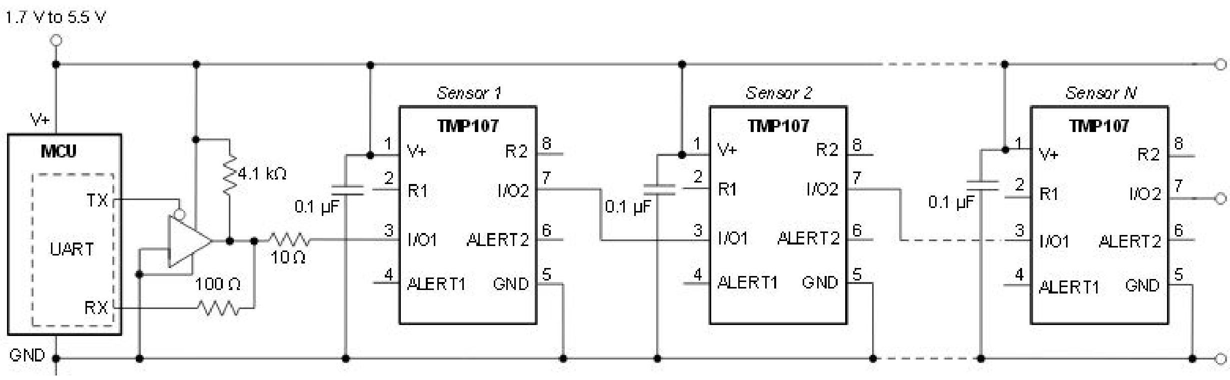


Figure 2: Typical application

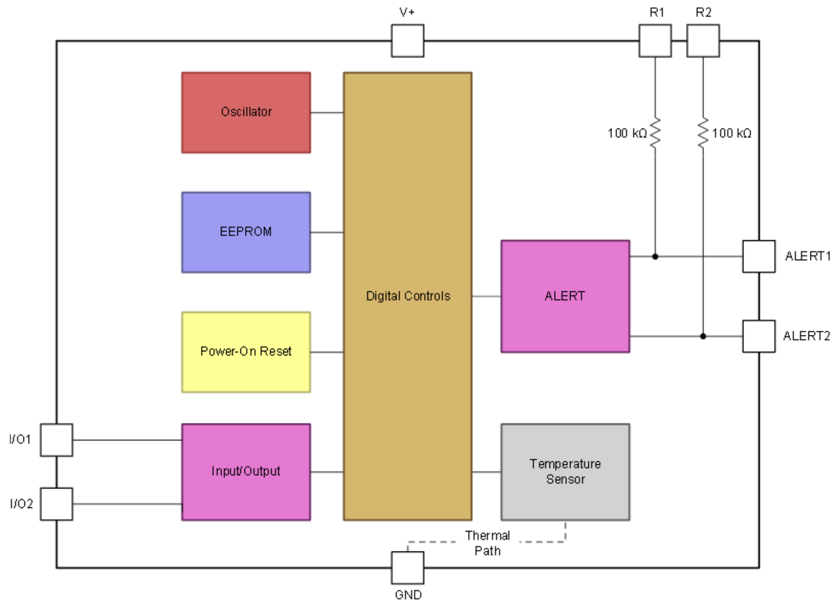


Figure 3: TMP107 block diagram

3.1.1.1 TMP107 features

- High Accuracy:
  - ±0.4°C (max) from –20°C to +70°C
  - ±0.55°C (max) from –40°C to +100°C
  - ±0.7°C (max) from –55°C to +125°C
- High Resolution: 14 Bits (0.015625°C)
- UART-Compatible, SMAART Wire™ Interface:
  - Allows Up To 32 Daisy-Chained Devices
- EEPROM Memory for Unique Addressing, Trip Level Programming, and General-Purpose Storage
- Continuous Conversion and Shutdown Mode for power Savings
- One-Shot Conversion Mode for Custom Update Rates and Power Saving
- Programmable Alert feature
- Operating Temperature Range: –55°C to +125°C
- Operating Supply Range: 1.7 V to 5.5 V
- Package: SOIC-8

3.1.2 CC2650 Description

The CC2650 is a wireless MCU targeting Bluetooth Smart, ZigBee and 6LoWPAN, and ZigBee RF4CE remote control applications. The device is a member of the CC26xx family of cost-effective, ultra-low power, 2.4-GHz RF devices. Very low active RF and MCU current, and low-power mode current consumption provides excellent battery lifetime and allows operation on small coin cell batteries and in energy-harvesting applications.

The CC2650 contains a 32-bit ARM Cortex-M3 processor running at 48-MHz as the main processor and a rich peripheral feature set, including a unique ultra-low power sensor controller, ideal for interfacing external sensors and/or collecting analog and digital data autonomously while the rest of the system is in sleep mode.

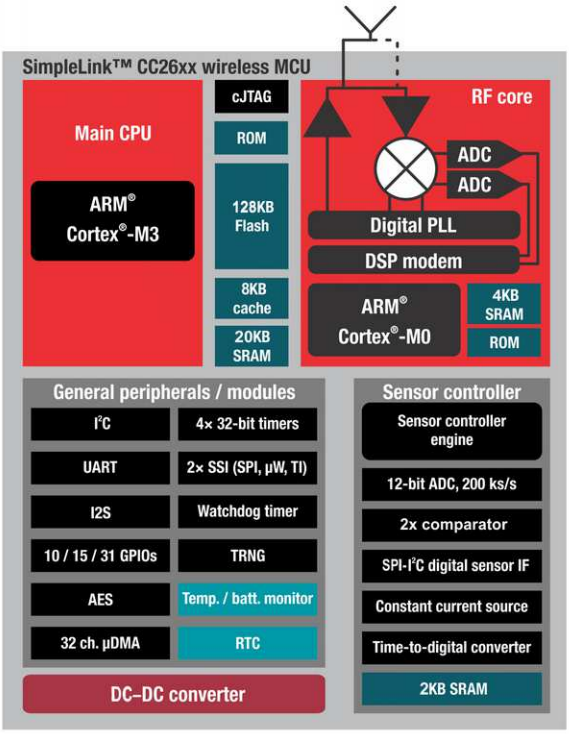


Figure 4: CC2650 block diagram

3.1.2.1 CC2650 features

- Microcontroller
  - Powerful ARM Cortex-M3
  - EEMBC CoreMark Score: 142
  - Up to 48-MHz Clock Speed
  - 128KB of In-System Programmable Flash
  - 8-KB SRAM for Cache
  - 20-KB Ultra-Low Leakage SRAM
  - 2-Pin cJTAG and JTAG Debugging
  - Supports Over-The-Air Upgrade (OTA)
- Ultra-Low Power Sensor Controller
  - Can Run Autonomous From the Rest of the System
  - 16-Bit Architecture
  - 2-KB Ultra-Low Leakage SRAM for Code and Data

- Efficient Code Size Architecture, Placing Drivers, Bluetooth Low Energy Controller, IEEE 802.15.4 MAC, and Bootloader in ROM
- RoHS-Compliant Packages
  - 4-mm × 4-mm RSM QFN32 (10 GPIOs)
  - 5-mm × 5-mm RHB QFN32 (15 GPIOs)
  - 7-mm × 7-mm RGZ QFN48 (31 GPIOs)
- Peripherals
  - All Digital Peripheral Pins can be Routed to any GPIO
  - General-Purpose Timer Modules (8 × 16-Bit or 4 × 32-Bit Timer, PWM Each)
  - 12-Bit ADC, 200-ksamples/s, 8-Channel Analog MUX
  - Continuous Time Comparator
  - Ultra-Low Power Analog Comparator
  - Programmable Current Source
  - UART
  - 2x SSI (SPI, µW, TI)
  - I^2C
  - I2S
  - Real-Time Clock (RTC)
  - AES-128 Security Module
  - True Random Number Generator (TRNG)
  - 10, 15, or 31 GPIOs, Depending on Package Option
  - Support for 8 Capacitive Sensing Buttons
  - Integrated Temperature Sensor
- External System
  - On-Chip internal DC-DC Converter
  - Very Few External Components
  - Seamless Integration With the SimpleLink CC2590 and CC2592 Range Extenders
  - Pin Compatible With the SimpleLink CC13xx in 4-mm × 4-mm and 5-mm × 5-mm QFN Packages
- Low Power
  - Wide Supply Voltage Range
  - Normal Operation: 1.8 to 3.8 V
  - External Regulator Mode: 1.7 to 1.95 V
  - Active-mode RX: 5.9 mA
  - Active-mode TX at 0 dBm: 6.1 mA
  - Active-mode TX at +5 dBm: 9.1 mA
  - Active-mode MCU: 61 µA/MHz
  - Active-mode MCU: 48.5 CoreMark/mA
  - Active-mode Sensor Controller: 8.2 µA/MHz
  - Standby: 1 µA (RTC Running and RAM/CPU Retention)
  - Shutdown: 100 nA (Wakeup on External Events)
- RF Section
  - 2.4-GHz RF Transceiver Compatible With Bluetooth Low Energy (BLE) 4.1 Specification and IEEE 802.15.4 PHY and MAC
  - Excellent Receiver Sensitivity (–97 dBm for BLE and –100 dBm for 802.15.4), Selectivity, and Blocking Performance
  - Programmable Output Power up to +5 dBm
  - Single-ended or Differential RF Interface
  - Suitable for Systems Targeting Compliance With Worldwide Radio Frequency Regulations
    - ETSI EN 300 328 (Europe)

  - EN 300 440 Class 2 (Europe)
  - FCC CFR47 Part 15 (US)
  - ARIB STD-T66 (Japan)
- Tools and Development Environment
  - Full-Feature and Low-Cost Development Kits
  - Multiple Reference Designs for Different RF Configurations
  - Packet Sniffer PC Software
  - Sensor Controller Studio
  - SmartRF Studio
  - SmartRF Flash Programmer 2
  - IAR Embedded Workbench for ARM
  - Code Composer Studio

4 System Design Theory

4.1 Component selection

4.1.1 SensorTag 2.0 platform

The SensorTag has been chosen to build the wireless daisy-chained temperature sensors design because it allows the developer to extend its functionality and add features including display, lighting, capacitive touch, new sensors and much more.

The SensorTag includes a samtec connector that allows connecting a daughter board to it. The pinout of this connector has direct connection to the CC2650. The embedded software platform and the android application also make it a good platform to easily build wireless new applications.

In addition to these great features, the SensorTag and its debugger are very low cost solutions, allowing any interested person to build his own application. For more information about the SensorTag, please visit the following link www.ti.com/sensortag-bn

4.1.2 TMP107

The TMP107 digital temperature sensor device was chose for this TI design to provide high accuracy temperature measurement on long distance. The daisy-chained sensors are built in parallel in a3 wire cable. The robust UART-compatible SMAART wire interface transfers data over a single wire at distances up to 1000 feet (300 meters) between consecutive devices in the chain, and is capable of communicating in a daisy-chained configuration with up to 32 devices on a single bus.

4.1.3 SN74LVC1G125

To avoid any bus contention between the host and the TMP107 devices, the tri-state buffer is used.

4.1.4 Coin cell Battery

The CR2032 lithium–ion coin cell battery is used as the power source for the SensorTag and the temperature sensor add-on board due to its ability of providing long shelf life, continuous voltage supply (220mAh at 3V) and its great availability on the market.

5 Getting Started Hardware

5.1 Hardware overview

The Wireless daisy-chained temperature sensors reference design is based on stacking up the SensorTag with an addition on board that interfaces with the long haul cable. It is recommended to keep the SensorTag in its plastic case to isolate it from the addition on board; it also helps to have good mechanical mounting.

Figure 5 Hardware Setup

Interfacing the SensorTag with the add-on board for the TMP107s requires programming the appropriate firmware in the SensorTag, which is different from the one provided originally with the TI BLE SDK.

To evaluate the reference design, please follow these steps:

1. Download the firmware for SensorTag and the android application from the following link: http://www.ti.com/tool/TIDA-00800
2. Connect the SensorTag to the PC through an appropriate debugger probe. Do not remove the battery from the SensorTag.
3. Upload the Firmware to the SensorTag. Please see section 5.2 for more details on how to do it.
4. Disconnect the debugger probe and reset the SensorTag by removing the battery.
5. Connect the temperature sensing cable to the add-on board.
6. Connect the add-on board to the SensorTag.
7. Start the application on the Android device.
8. Read the temperature values on the Android device.

5.2 Uploading firmware to the SensorTag

For general information about SensorTag, refer to the SensorTag wiki (http://processors.wiki.ti.com/index.php/SensorTag2015)

Many options are available to debug or flash SensorTag, the TMP107 reference design has been tested using option XDS110 USB debugger, because of its low cost and availability. For information about the different debuggers options refer to the following wiki: (http://processors.wiki.ti.com/index.php?title=CC13xx_CC26xx_Tools_Overview#XDS110)

In this section we will describe how to upload the binary files to the SensorTag using the low cost debugger XDS110 and using free TI tools.

To upload the binary (hex) files to the SensorTag:

1. Download & Install Flash Programmer 2 : http://www.ti.com/tool/flash-programmer
2. Run Flash Programmer 2 , connect your debugger and make sure that it appears in Connected devices section along with CC2650 chip as described in Figure 6 :
3.

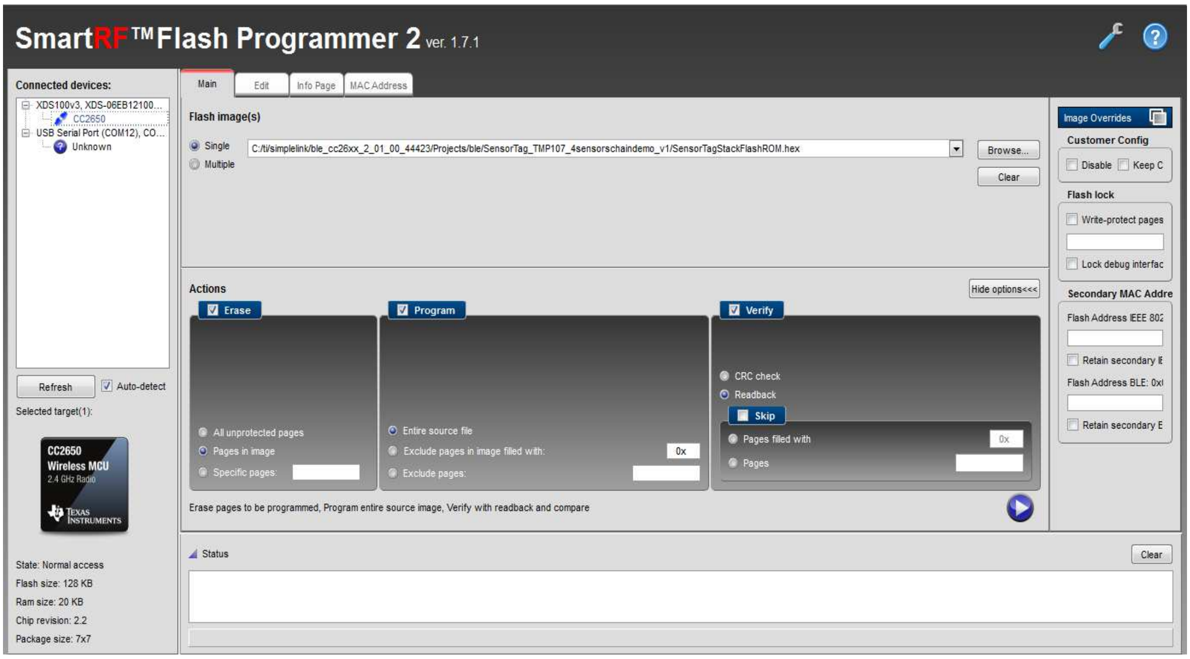


Figure 6: SmartRF Flash Programmer 2 interface

4. Two hex files have to be downloaded to the CC2650, one for the application and one for the stack.
   a. In main tab, select in “Flash image(s)” **section** “Single” **option** and browse for the application hex file SensorTagAppFlashOnlyOAD.hex as described in figure 7.

   b. In “Actions” section check **Erase**, **Program** and **Verify** and **MAKE SURE** that in Erase section Pages in image is selected NOT ALL unprotected pages!!
   c. Finally hit Play button. A successful download should led to something similar in the following picture.
   d. Repeat the same actions for the stack hex file SensorTagStackFlashROM.hex Restart the SensorTag, the new FW should work properly.

Note: If the CC2650 doesn't appear when connecting the XDS110, the XDS110 firmware might be out of date. To update the XDS110 firmware using xdsdfu please refer to README under C:\ti\ccs_base\common\uscif\xds110 in your computer.

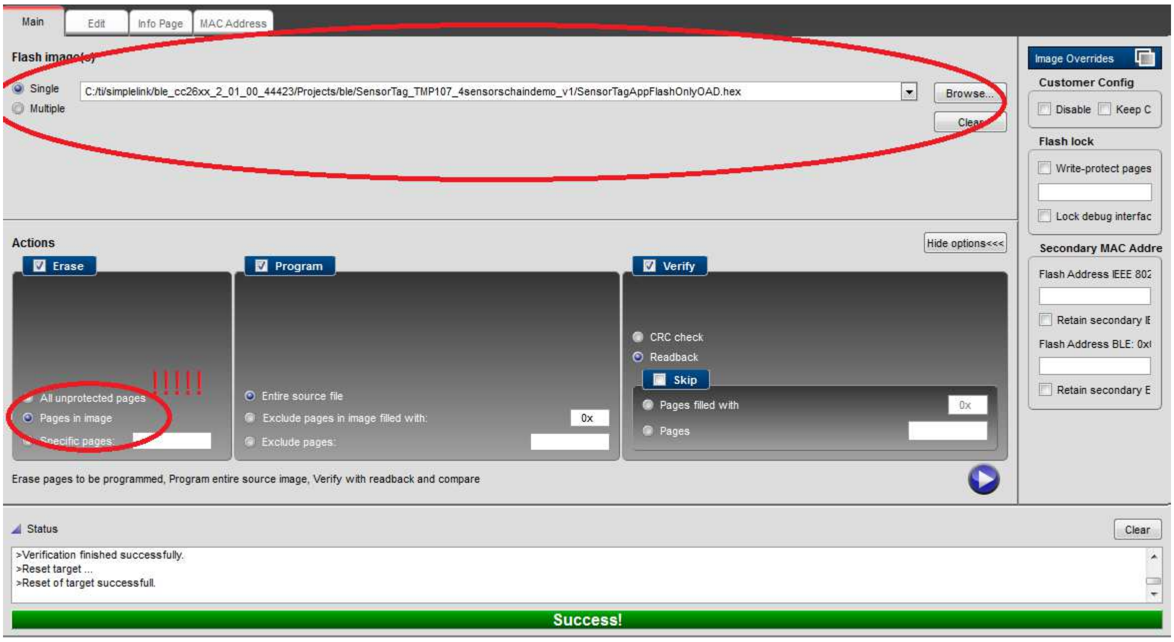


Figure 7: SmartRF Flash Programmer 2 interface

5.3 SensorTag source code:

Source code and project configuration are available for CCS v6 and IAR platforms

a. Download and install **TI BLE STACK V2.1**.
b. Copy the provided project file SensorTag_TMP107_ProjectFile_v1.zip to the following location: C:\ti\simplelink\ble_cc26xx_2_01_00_44423\Projects\ble in your computer.
c. Extract the zip file in the same location.
d. Two project configurations are available, one for the IAR and the other for CCS. Both have been tested. For more details on how to develop CC2650 using either IAR or CCS v6, please refer to the following document (SWRU393).

5.4 Running the android application:

1) Using USB cable copy the BleSensorTag-TMP107.apk file (available in the TMP107_Sensotag_androidapp folder) into your mobile phone mass storage location.
2) Using your file explorer on your device search for the apk and click on it, it should suggest install option. Device may ask you to check Unknown sources in settings -> Security-> Device administration. (some phones don't have native file explorer I recommend then installing ES file explorer)
3) After installing the application and running it, click on scan after powering on the SensorTag as shown in Figure 8:

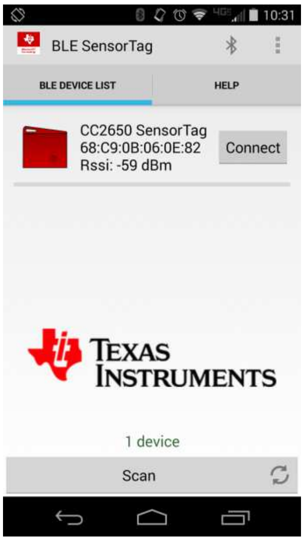


Figure 8: Android application scan interface

4) Click on connect , all sensors should appear , scroll down to find the TMP107 sensors:

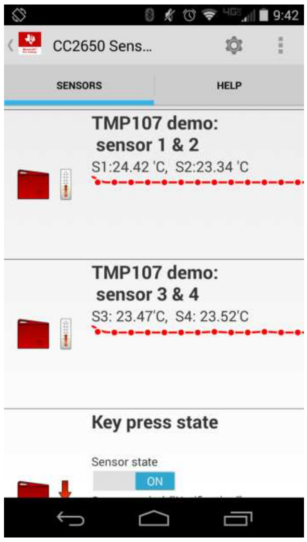


Figure 9: Android application sensors data interface

5) Optional: the unit of temperature can be changed by clicking on settings (in the app) and checking imperial units as described in figure 10:

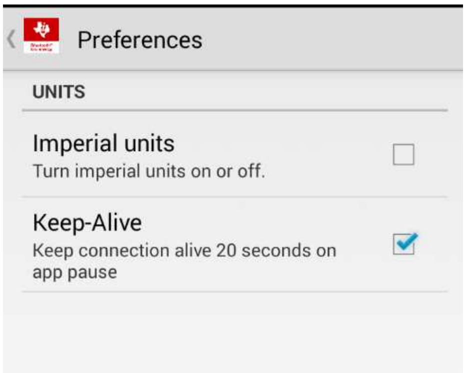


Figure 10: Android application preferences interface

6 Getting Started Firmware

6.1 High level embedded application overview

Upon power up, the CC2650 starts performing Bluetooth advertising, and when an Android device requests pairing, the BLE link is set and the two devices are connected. The CC2650 can starts sending data to the android device. For more information about the process, refer to the Software Developer's Guide for BLE-Stack ™ (SWRU393)

Once the two devices are connected, the CC2650 performs internally registers configurations of the TMP107s to prepare proper data reading. After reading the different data, the CC2650 transmits them through the BLE link to the Android device and enter into a periodic sleep mode. For more details about TMP107 configuration refer to next subsection.

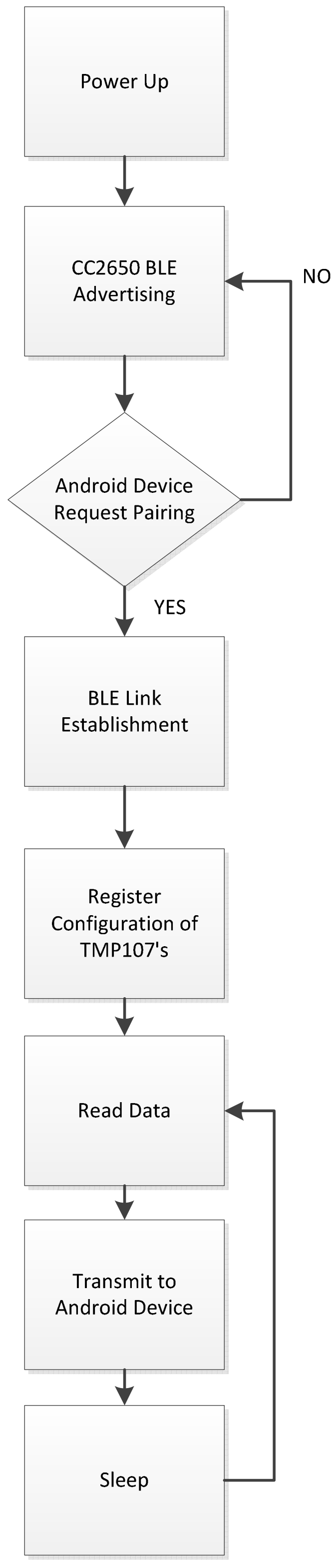


Figure 11: Application flow chart

6.2 TMP107 configuration and data reading

The application is battery operated, so for power savings considerations the data from the temperature sensors is read in one-shot mode, which means that conversion happens only on demand and the sensors are in shut down mode the rest of the time.

To set the sensors into this mode, the configuration register has to be set properly by setting to 1 the SD (shutdown) bit. To perform a single temperature conversion, the OS (one-shot) bit has to be set in the configuration register. After waiting for the conversion to finish the data can be read.

7 Test Data

7.1 Temperature Characterization

Figure 12 shows the test setup for temperature testing. For this test, the cable that has the 3 sensors is placed in Delta 9064 Environmental Test Chamber. The SensorTag and its add on board are left outside the test chamber.

Figure 12: Delta 9064 Environmental Test Chamber and Test Setup

The test chamber was programmed to do temperature steps every 10°C, from 0°C to 60°C. Figure 13 shows the data readings from the Android application from the two tests for every TMP107 sensor in the chain. These readings confirm the accuracy of TMP107 in this design is around +/- 0.078 °C (typ), +/- 0.26°C (max) without calibration.

Oven Temperature (°C)	TMP107 #1 Temperature (°C)	TMP107 #2 Temperature (°C)	TMP107 #3 Temperature (°C)
0.0	0.24	0.03	0.16
10.0	9.7	9.91	9.97
20.0	19.8	20.01	19.98
30.0	29.9	30.14	30.12
40.0	39.6	39.92	39.84
50.0	49.75	49.92	49.81
60.0	59.74	59.95	59.88

Figure 13: TMP107 Temperature reading results

8 Design Files

8.1 Schematics

To download the Schematics for each board, see the design files at
http://www.ti.com/tool/TIDA-00800

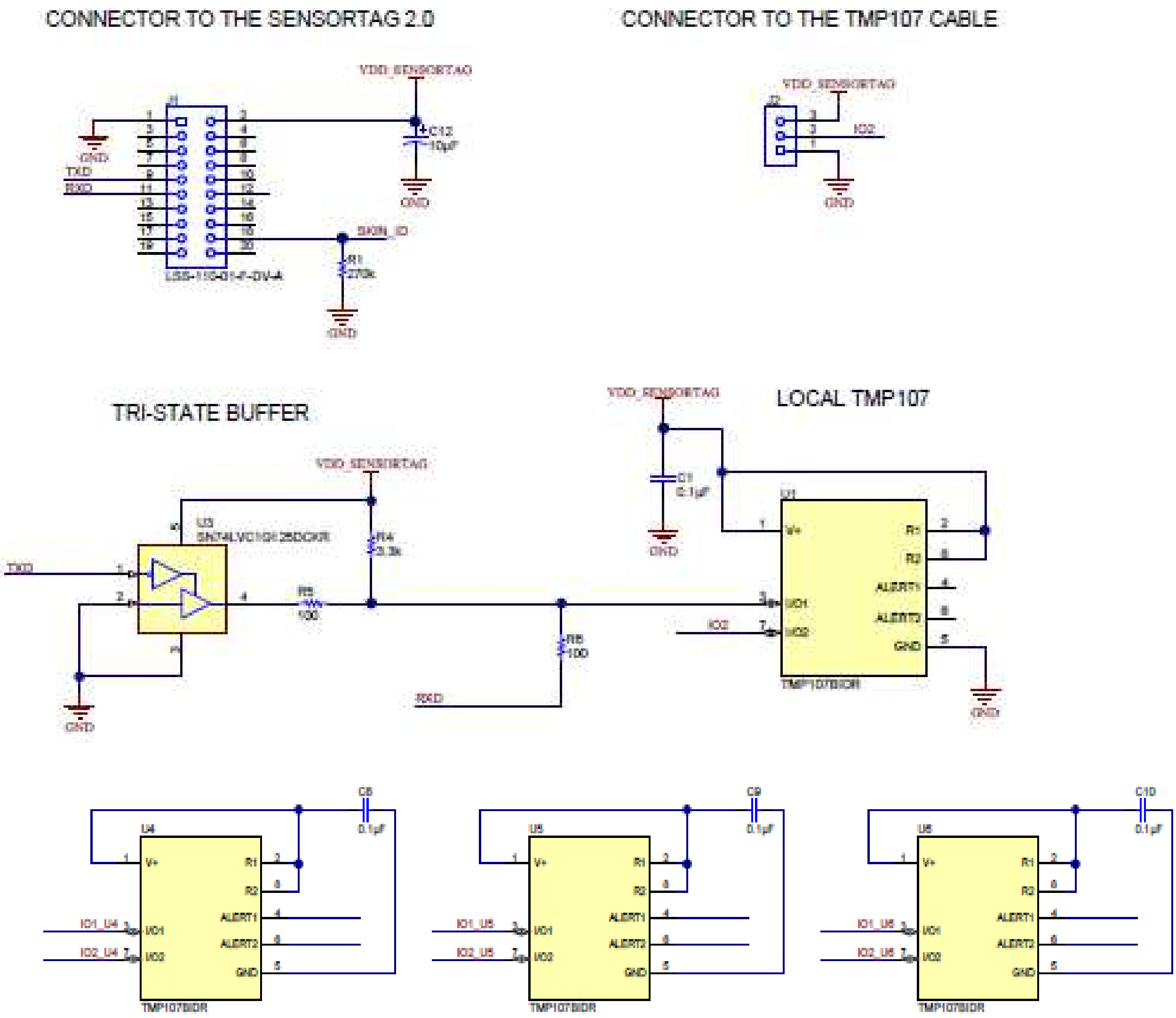


Figure 12: TI design schematics

8.2 Bill of Materials

To download the Bill of Materials for each board, see the design files at http://www.ti.com/tool/TIDA-00800

8.3 PCB Layout Recommendations

This section covers mechanical needs for SensorTag and layout considerations for the design.

The designed board has to be mechanically stacked with the SensorTag board. In this sense, the dimension of the board and the position of the skin connector play a crucial role.

In order to connect the two boards properly, it is important that the bottom layer of the designated board is without components apart from the skin connector. Also, all the components placed on the top layer have to be SMD because the through-hole ones could cause connectivity problems due to their leads that protrude through a PCB.

For all the TI products used in this TI design, ensure that care is taken to adhere to the layout guidelines given in the respective datasheets.

8.4 Layout Prints

To download the Layout Prints for each board, see the design files at http://www.ti.com/tool/TIDA-00800

8.5 Altium Project

To download the Altium project files for each board, see the design files at http://www.ti.com/tool/TIDA-00800

8.6 Gerber files

To download the Gerber files for each board, see the design files at http://www.ti.com/tool/TIDA-00800

8.7 Assembly Drawings

To download the Assembly Drawings for each board, see the design files at http://www.ti.com/tool/TIDA-00800

9 Software Files

To download the software files for this reference design, please see the link at http://www.ti.com/tool/TIDA-00800

10 References

For additional references, see the following:

1. TMP107 Datasheet, Digital Temperature Sensor with Bidirectional UART One-Wire Interface and EEPROM (www.ti.com/tmp107)
2. CC2650 Datasheet, Simplelink™ Multistandard Wireless MCU (SWRS158)
3. Simplelink™ Bluetooth®low energy CC2640 wireless MCU, Developer's Guide (SWRU393)

11 About the Author

AMJAD EL HILALI is a field application engineer at Texas Instruments where he is responsible for technical support for industrial customers. Amjad brings to this role his experience in both hardware design (sensing and power management) and software design (RTOS, RF protocols and signal processing). Amjad earned his master in electrical engineering from INSA de Lyon University in France.

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