UG124: ZigBee® Contact Sensor Reference Design (RD-0030-0201) Kit User's Guide

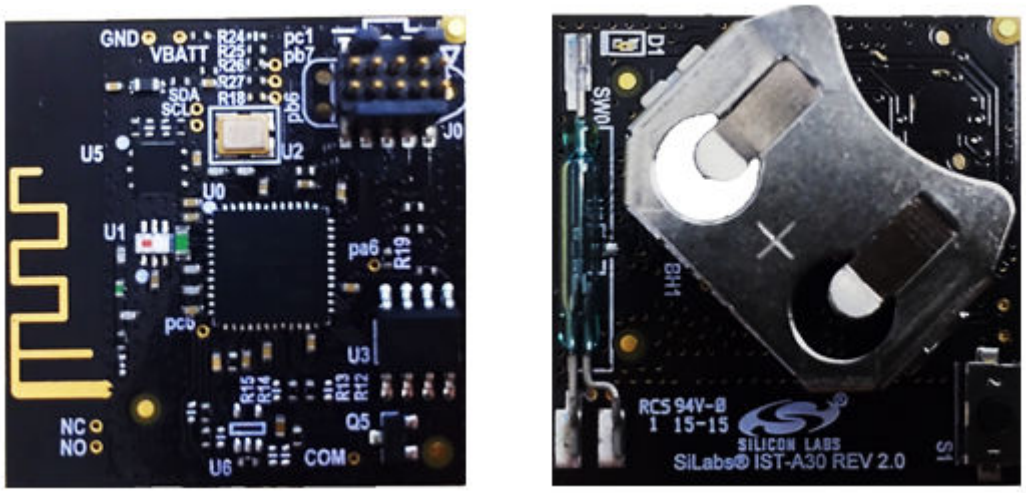
Silicon Labs' ultra-low power, small, and cost-effective complete reference design based on ZigBee HA (Home Automation) 1.2 standard focuses on contact sensors that can be used for window or door sensing. This ZigBee contact sensor reference design kit features Silicon Labs' EM3587 ZigBee Pro Wireless Microcontroller (MCU) and the Si7053 temperature sensor. This document contains instructions and guidelines for the following: a quick-start demonstration and next steps, system overview and operations, hardware and firmware considerations, and engineering and manufacturing testing.

KEY POINTS

- ZigBee Door/Window Sensor
- HA 1.2 and FCC Certifiable
- Hardware and Firmware Considerations
- Engineering and Manufacturing Testing

1. Introduction

There is an increasing desire in the market for a standards-driven, low-cost, and low-power wireless home automation system. Silicon Labs has released an ultra-low power, small, and cost-effective complete reference design based on ZigBee HA 1.2 standard that focuses on contact sensors that can be used for window or door sensing (Figure 1.1 ZigBee Contact Sensor Reference Design on page 1). This ZigBee contact sensor reference design kit features Silicon Labs' EM3587 ZigBee Pro Wireless Microcontroller (MCU) and the Si7053 temperature sensor. The reference design can be directly integrated into a connected ZigBee home automation application as shown in Figure 1.2 ZigBee Home Automation Application with Contact Sensors on page 1. The contact sensor boards come pre-programmed and fully functional out of the box. All hardware design files and firmware application source code are available.



Front **Back**

Figure 1.1. ZigBee Contact Sensor Reference Design

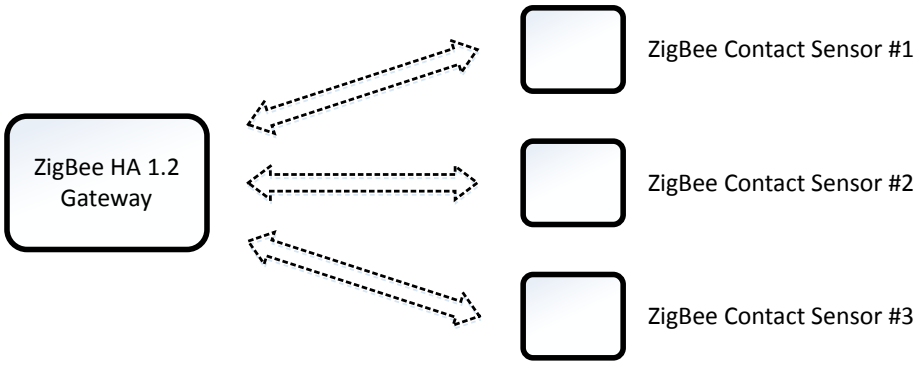


Figure 1.2. ZigBee Home Automation Application with Contact Sensors

2. Quick Start Demonstration

A video showing the quick-start demonstration is available at http://www.silabs.com/zigbeecontactsensor.

1. Setup an HA 1.2 ZigBee gateway.

   To test the contact sensor in a ZigBee network, it needs to connect to a gateway. Silicon Labs offers an RD-0002-0201 ZigBee Wi-Fi/Ethernet gateway (sold separately) for the purpose of evaluating the ZigBee contact sensor reference design. A commercially available Home Automation (HA) 1.2 compliant gateway that supports an IAS zone sensor with device profile ID = 0x0402 will also work for this purpose. Depending on the commercially available gateway, the contact sensor can also display its temperature sensor reading. The RD-0002-0201 supports the contact sensor's temperature sensor feature.

2. Supply power to the ZigBee Contact Sensor.
   a. Remove the white battery tab that separates the battery from its battery connector.
   b. The contact sensor is powered when red LED D1 momentarily flashes at least once.

3. Connect the ZigBee Contact Sensor to the ZigBee network.
   a. Follow the directions provided with the ZigBee gateway to enable the Contact Sensor reference design to join its ZigBee network.
   b. Depress and hold S1 button for more than one second, then release to begin the network join procedure.
   c. The demo board has joined the ZigBee network when the red LED D1 blinks six times.

4. Demonstrate ZigBee Contact Sensor functionality.
   a. To send a "close" command to the gateway, ensure the supplied magnet from the kit is less than 7 mm from the SW0 reed.
   b. To send an "open" command to the gateway, ensure the supplied magnet from the kit is more than 15 mm from the SW0 reed.
   c. The contact sensor will send temperature sensor updates to the gateway every thirty minutes by default if this parameter is not configured differently by the gateway.

3. Recommended Next Steps

A video showing the recommended next steps is available at http://www.silabs.com/zigbeecontactsensor.

3.1 Evaluate the Contact Sensor

The ZigBee contact sensor reference design can support most contact sensor application requirements. Typical areas of evaluation include:

1. ZigBee network behavior, such as network join and leave.
2. Monitoring open/close events.
3. Monitoring ambient temperature.
4. RF performance, such as range.

3.2 Evaluate the Firmware

If firmware modification is needed to support your application:

1. Visit the ZigBee Getting Started page and order a development kit.
2. Refer to Section 7. Firmware of this document.

3.3 Build Proof of Concept

Out of the box, the contact sensor reference design can be used for a rapid proof of concept. By simply adding a plastic housing (such as one that is 3D printed) to the reference design, one can demonstrate the look, feel, and function of a final product. Refer to Section 7. Firmware to change functional behavior, such as LED blinking or button functionality.

3.4 System Integration

Section 6. Hardware of this document describes the considerations for integrating the reference design into a typical application. Often the reference design can be designed into a system without modification. In cases where a change is required, the hardware section of this document also offers modification guidelines.

3.5 Engineering and Manufacturing Tests

Section 8. Engineering Tests of this document provide engineering test results, such as FCC and HA 1.2.

Section 9. Manufacturing Tests of this document offers considerations for simplified manufacturing tests.

3.6 Manufacturing

Please contact Silicon Labs if you would like access to our manufacturing partner network for the reference design, or a modified version of the design.

4. Overview

4.1 Part Numbers

The part number convention is RD-XXXX-YYYY, where:

RD	Reference Design
XXXX	Reference Design Number
YYYY	Reference Design Component

This document will use the reference design number (RD-XXXX) when describing the complete design, and the reference design component (RD-XXXX-YYYY) when describing a specific component.

The following table provides a description and PCB marking for each part number.

Note: Some cases lack sufficient space on the PCB, and an internal “IST” marking appears on the PCB instead of the “RD” part number.

Table 4.1. Part Numbers and Description

Part Number	PCB Marking	Description
RD-0030-0201	N/A	ZigBee Contact Sensor Reference Design Kit with EM3587, Si7053, and PCB Antenna.
RD-0030-0101	IST-A30 Rev 2.0	ZigBee Contact Sensor Reference Design Evaluation Board with EM3587, Si7053, and PCB Antenna.

4.2 ZigBee Contact Sensor Reference Design Kit

Kit Contents:

- ZigBee Contact Sensor Reference Design with CR2032 battery and battery tab.
- Standex / Meder M13 magnet enclosed in plastics with screw holes.
- Quick start card to obtain the latest reference design collateral.

4.3 ZigBee Contact Sensor Reference Design

This reference design contains many features for the evaluation of a contact sensor, including:

Table 4.2. ZigBee Contact Sensor Reference Design Features

Reference Design Features	Benefit
Form C reed switch, with footprint options for Form A reed switch or SOT23 hall-effect sensor	Senses open and close events with support for various magnetic sensor options.
Si7053 I2C temperature sensor with thermistor footprint option	Senses ambient temperature to aid home automation systems.
Status LED	Provides feedback such as network status.
10-pin ISA3 compatible connector	Facilitates ZigBee packet debugging.
User button	Eases network commissioning (join/leave) and tamper detection.
Test points	Simplifies hardware-level debugging.
CR2032 battery holder	Supports low-cost, small footprint battery.

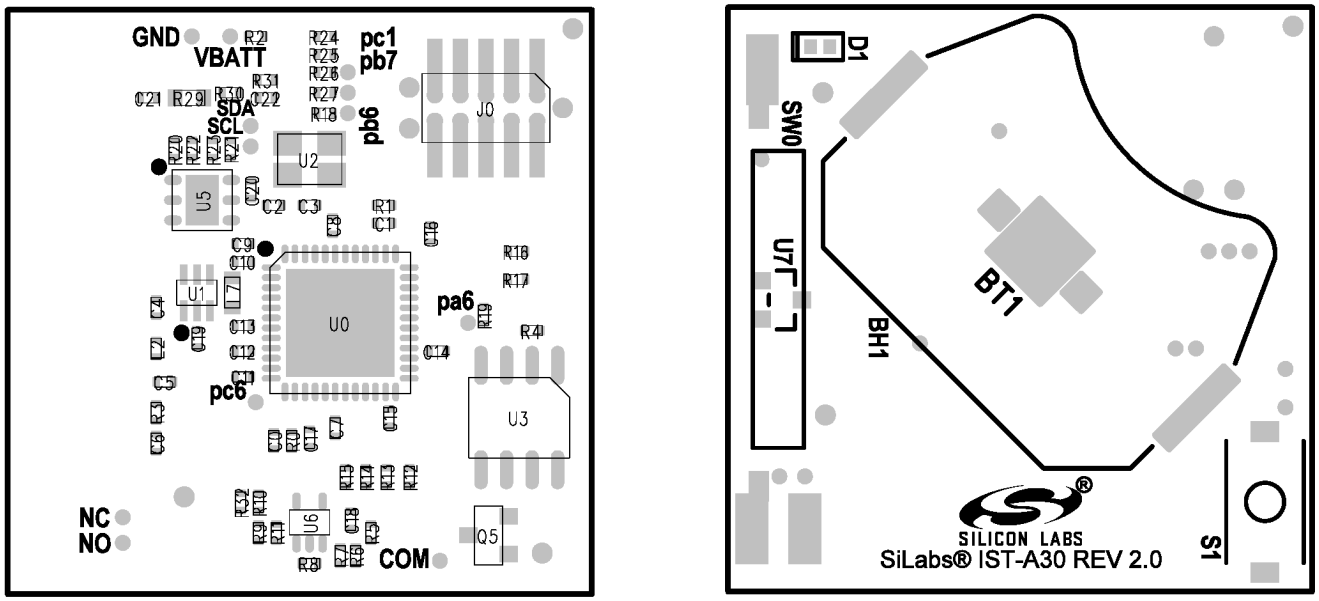


Figure 4.1. Reference Design Printed Circuit Board Diagram (Front and Back)

4.4 Feature List

EM3587 Device Features:

- 32-bit ARM® Cortex®-M3 processor.
- 2.4-GHz IEEE 802.15.4-2003 transceiver & lower MAC.
- AES-128 encryption accelerator.
- Flexible ADC, UART/SPI/I2C serial communications, and general purpose timers.
- Highly efficient Thumb-2 instruction set.

ZigBee Contact Sensor Reference Design Hardware Features:

- Integrated PCB antenna.
- Form C reed switch with PCB footprint options for form A and SOT-23 sensors.
- Silicon Labs Si7053 temperature sensor with ±0.3 ºC maximum accuracy.
- Pushbutton for network join.
- Network/status LED.
- Full packet trace port for RF communications debugging.
- Supports up to five years of operation on a CR2032 coin cell battery.
- 2.1 V to 3.6 V operation.
- Fully qualified BOM for 0 to 55 ºC operation.
- Up to +8 dBm TX power.
- 512 kB user programmable flash with 64 kB RAM.
- Pre-certified FCC Part 15.

ZigBee Contact Sensor Reference Design Firmware Features:

- Pre-compiled and source application firmware.
- Over-the-Air (OTA) upgradable.
- ZigBee HA 1.2 pre-certifiable clusters: basic, power configuration, identify, OTA upgrade, temperature measurement, IAS zone, diagnostics.
- Application firmware (source code) available in the EmberZNet™ PRO stack library.

5. Operation

5.1 ZigBee Network Behavior

This section describes the various operational states a powered contact sensor reference design is able to occupy as it joins and leaves a ZigBee network. The input mechanism for operation utilizes a join button, S1. The red LED operates as output signaling information as the reference design traverses or occupies a functional state. Refer to the figure below for a pictorial representation of this process.

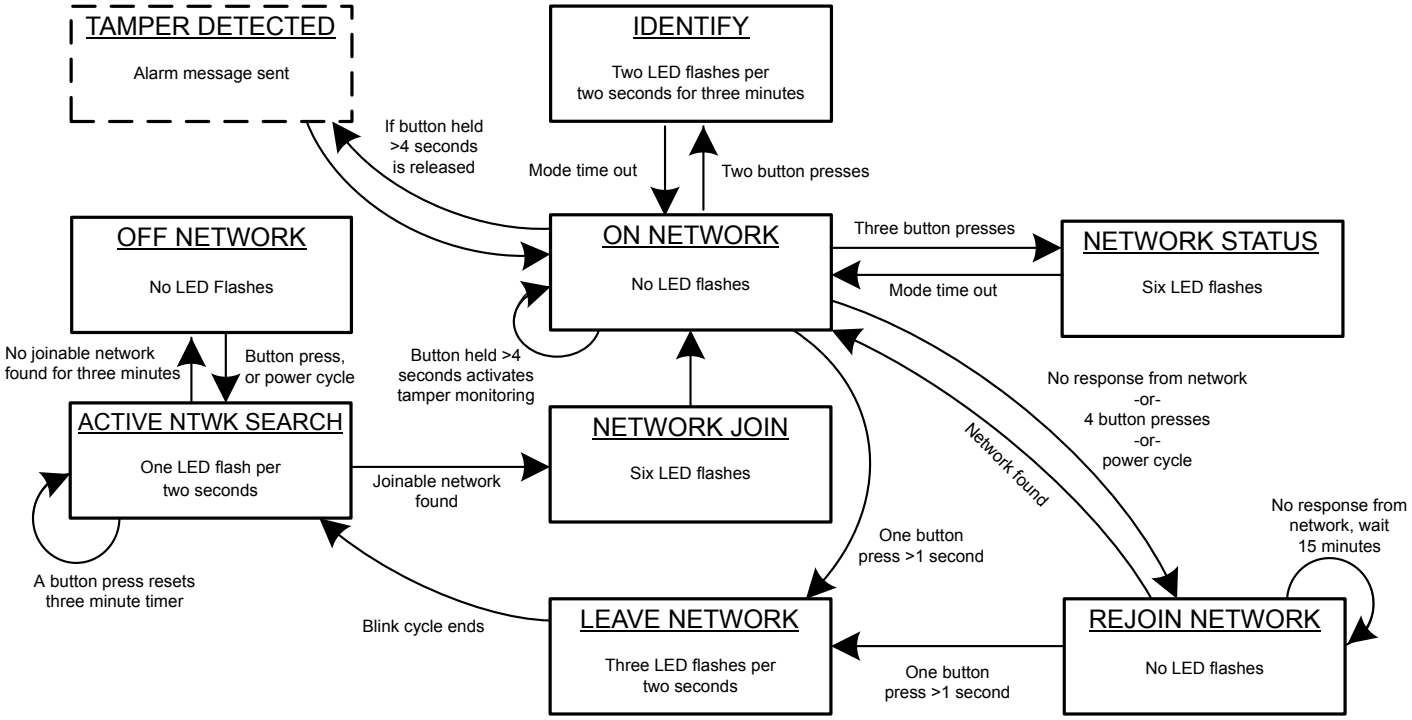


Figure 5.1. Device Operation State Diagram

5.1.1 First Time Contact Sensor Power-up

After the hardware has been powered for the first time, the device will be in a factory default mode and will be placed in the ACTIVE NTWK SEARCH state. If the dimmer switch successfully joins a network is powered off at a later time, upon re-powering, it will enter the REJOIN NETWORK state instead of the ACTIVE NTWK SEARCH state.

5.1.2 OFF NETWORK State

This state is a condition where the design is not connected to a network and is not searching for a network. To leave this state and enter the ACTIVE NTWK SEARCH state, press the S1 button one time.

5.1.3 ACTIVE NTWK SEARCH State

This state is a condition where the contact sensor is actively searching for a network but has not yet joined a network. While in this mode, the D1 LED will flash once every two seconds. This operation of actively searching for a network will remain for up to three minutes. If no network is found by the three minute time limit, the contact sensor will enter into the OFF NETWORK state. Power-cycling or a button press while in this state will reset the three minute timer, while keeping the contact sensor in this state. If a network is found it will leave this state and enter the NETWORK JOIN state.

5.1.4 NETWORK JOIN State

After a contact sensor leaves the ACTIVE NTWK SEARCH state and enters this state, the D1 LED will flash six times to indicate successfully finding and joining a network. This state is temporary and will place the contact sensor into the ON NETWORK state once the LEDs complete their flash sequence. Power cycling will only impair the LED flashes, and will not prevent entry into the ON NETWORK STATE once the power is reapplied.

5.1.5 ON-NETWORK State

The ON-NETWORK state is a condition where the contact sensor is connected to a ZigBee HA 1.2 network and is not searching for another network. This state contains multiple entry and exit paths depending on various factors, such as the number of S1 button presses that are within 0.5 second of each consecutive press.

If power to the contact sensor is removed and later restored, the reference design will not seek other networks unless the user forces it to leave its joined network (as will be described within this section).

If S1 is pressed once for more than one second, the reference design will enter the LEAVE NETWORK state.

If S1 is pressed two times, the reference design will temporarily enter the IDENTIFY state while remaining on its joined network.

If S1 is pressed three times, the reference design will temporarily enter the NETWORK STATUS state while remaining on its joined network.

If S1 is pressed four times, the reference design will enter the REJOIN NETWORK state.

If S1 is pressed and held for greater than four seconds, the reference design will activate its tamper monitoring algorithm while remaining on its joined network. Tamper monitoring is used when a reference design is contained inside a housing and the opening of the housing will release the S1 button. If tamper monitoring is activated and the S1 button is released, it will temporarily enter into the TAMPER DETECTED state.

5.1.6 IDENTIFY State

The purpose of this state is to help an installer (or user) identify which device is communicated to by visually flashing the D1 LED in a specified pattern to locate the targeted device. After a contact sensor leaves the ON-NETWORK state and enters this state, the D1 LED will flash twice per second if on a network then pause for a full second, repeating the pattern for up to three minutes. This state is temporary, and the contact sensor will return to the ON-NETWORK state once the state's timer reaches its time limit. While in this state, the device will report any change in open/close state or any change in tamper alarm state (if tamper monitoring is enabled).

If not on a network, it will enter the ACTIVE NTWK SEARCH state.

If power cycled while in this state, the design will enter the REJOIN NETWORK state.

5.1.7 NETWORK STATUS State

The purpose of this state is to help an installer (or user) to identify if a device is successfully connected to a network. After a contact sensor leaves the ON-NETWORK state and enters this state, the D1 LED will flash six times if on a network. This state is temporary, and the contact sensor will return to the ON-NETWORK state once the state's timer reaches its time limit. While in this state, the device will report any change in open/close state or any change in tamper alarm state (if tamper monitoring is enabled).

If not on a network, it will enter the ACTIVE NTWK SEARCH state.

If power cycled while in this state, the design will enter the REJOIN NETWORK state.

5.1.8 REJOIN NETWORK State

The purpose of this state is to ensure the design can successfully rejoin a previously joined network with little user intervention, while minimizing battery drain when searching for the network on both its original connected channel as well as searching on all channels for the network. Upon locating its original joined network, the design will enter the ON NETWORK state where it will rejoin the network. No LED flashes will occur during this transition.

For battery savings, if it receives no response from the network, the device will wait 15 minutes before attempting to search for the network.

If S1 is pressed once for longer than one second, the reference design will enter the LEAVE NETWORK state.

5.1.9 TAMPER DETECTED State

As described in the ON NETWORK state, this state provides a method to act once tampering is detected with this reference design upon the release of the held S1 button. Entering this state will trigger and launch an alarm message, promptly transmitting this event to the host gateway on the network. Once tamper monitoring is activated, this alarm can occur in any of the network states. To disable it, one must fully remove the CR2032 battery and re-install it.

5.1.10 LEAVE NETWORK State

Upon entering this state, the contact sensor will leave the joined network and will indicate this process is in action by flashing the D1 LED three times within a two second period. This state is temporary and will place the contact sensor into the ACTIVE NTWK SEARCH state once the LEDs complete their flash sequence.

5.2 Reed Switch Behavior

ZigBee Contact Sensor Reference Design utilizes a reed switch for magnetic sensing in conjunction with a nearby magnet to detect an entry points' open and close events. With the provided magnet, the SW0 form C reed switch will be in a closed state when the magnet is within 7 mm of proximity to it. The reed switch will be in an open state if the magnet is at least 15 mm away from it.

Alignment is critical to a predictable magnet for reed switch operation. The specifications are based on both the reed switch and magnet being on the same plane, parallel to each other and aligned from top to bottom.

6. Hardware

This section describes the key aspects of the reference design.

6.1 ZigBee Contact Sensor Reference Design RD-0030

This section describes the key hardware specifics of the RD-0030 module.

Key Highlights:

- EM3587 ZigBee Pro radio with an embedded flash.
- Si7053 temperature sensor.
- Two-layer 0.031” printed circuit board.

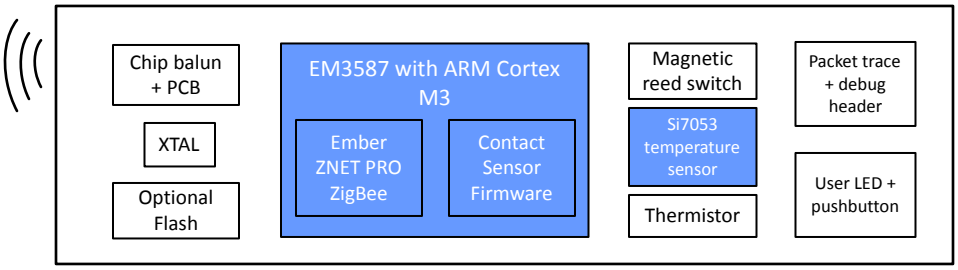


Figure 6.1. Reference Design Block Diagram

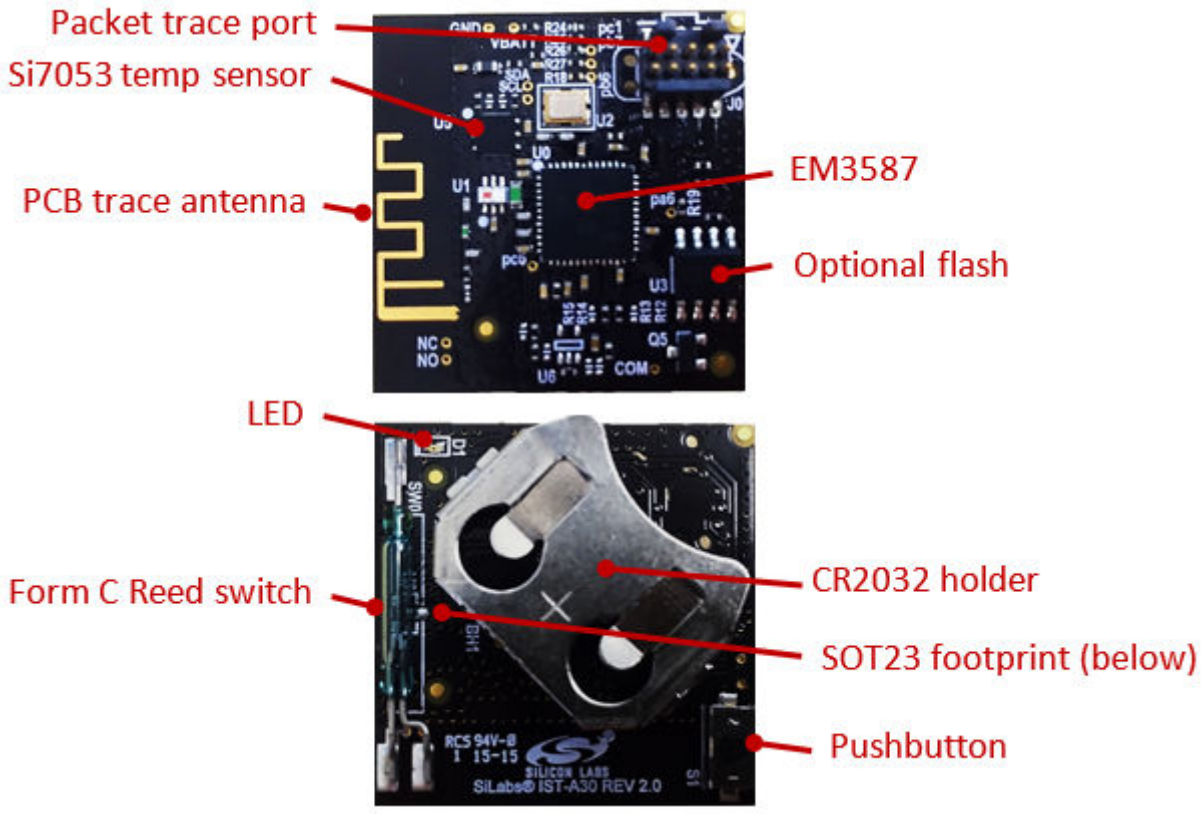


Figure 6.2. Reference Design Front and Back

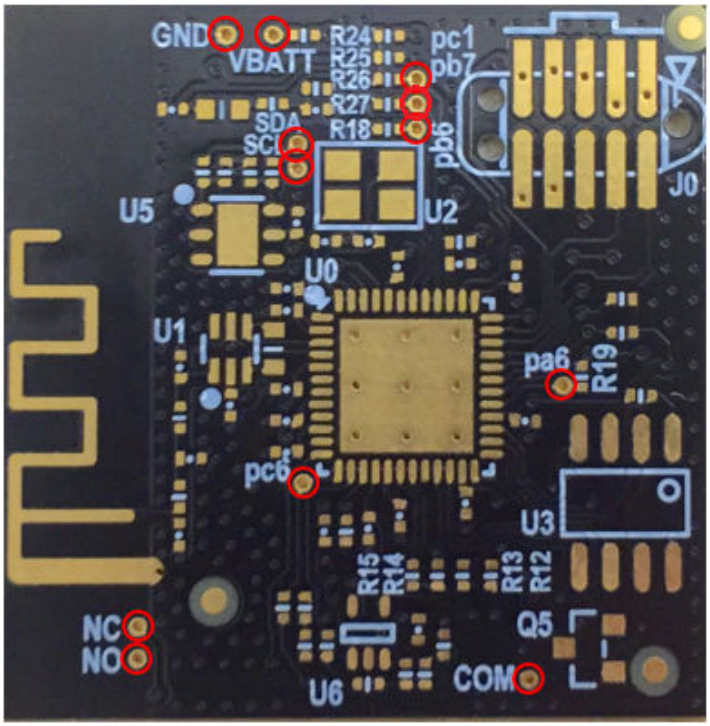


Figure 6.3. PCB Test Points

Table 6.1. Connector Pin Assignments

Packet Trace Support				
Pin Number	**PCB Pin Name**	**ISA3 Pin Name**	**Pin Functions**	**Description**
1	VMCU	VBRD		Supply Voltage
2	JTDO	PC2	JTDO/ SWO	JTAG Data Out, Serial Wire Out
3	JRST	PC0	nJRST	JTAG Reset
4	JTDI	PC3	JTDI	JTAG Data In
5	GND	GND		Ground
6	JTCK	SWCLK	JTCK/SWCLK	JTAG Clock, Serial Wire Clock
7	JTMS	PC4	JTMS/SWDIO	JTAG Mode Select, Serial Wire Data In/Out
8	nRESET	nRESET		EM3xx Reset
9	PA4_EM	PA4	PTF	Packet Trace Enable
10	PA5_EM	PA5	PTD	Packet Trace Data

Note:

1. The debug connector is compatible with the ISA3 packet trace port connector when placed on the bottom side of the PCB. J1 connector footprint also supports TagConnect (R) TC2050-IDC-NL for manufacturing programming when the 10-pin 0.050" male debug header is not populated.

6.2 Hardware Modification Guidelines

For users who wish to modify the reference design, we offer guidelines below for what to expect in the modification process.

6.2.1 Alternate Footprint Parts

- Alternate type reed switch SW-1 + support circuitry.
- U7 is a SOT23 footprint for hall-effect sensor.

6.2.2 Avoid Modificaton

All changes listed here may have serious impacts on performance:

- Modifying the spacing between the U0 EM3587 and the U1 balun.
- Changing the PCB antenna length/shape.
- Changing any part of the ground pour area.

6.2.3 Bill of Material Cost-Saving Options

To further reduce overall bill-of-material (BOM) cost of this contact sensor, the following items and their supporting circuitry can be considered for removal:

- J3 programming header.
- U3 external flash.
- U5 Si7053 temperature sensor.

7. Firmware

This section describes the Contact Sensor reference design application firmware.

7.1 Obtaining the Firmware Application

The firmware application in pre-compiled binary form is available for download from: http://www.silabs.com/zigbeecontactsensor. The firmware application source code is available as part of EmberZNet PRO, which is available to registered users of a development kit.

For more information visit the ZigBee Getting Started page.

7.2 Programming the Contact Sensor Reference Design

The reference design provides two methods to reprogram the demo board:

- Using the ISA3 header with an .s37 or .hex image file.
- Using the over-the-air (OTA) upgrade feature with an .ota image file.

7.2.1 Board Header Reprogramming

The contact sensor can be reprogrammed with an available .s37 or .hex file and an ISA3 programmer. Please refer to Silicon Labs' UG110: "Ember® EM35x Development User's Guide" for more information on how to successfully program the contact sensor with an ISA3 programmer. The ISA3 connector on the contact sensor is the J3 header. Notice the orientation of the connector, where the keyed side of the connector corresponds to the ISA3 key marking found with the silkscreen drawing surrounding the J3 header.

7.2.2 Over-the-Air Repregramming

The demo board can be reprogrammed with an available .ota file and a device that can perform OTA upgrades such as the RD-0002-0201 ZigBee USB Gateway Kit supported by Silicon Labs. Refer to the gateway documentation for more information on how to reprogram via OTA upgrade.

7.3 Build Instructions

The instructions below describe how to build the device firmware.

1. Install EmberZNet PRO.

   Note: You must have installed Ember Desktop version 3.3 build 1913 or later for this stack release to work.

2. Create a new Application Framework Configuration in AppBuilder and select the 5.4.4 stack release.
3. Create a project using HaContactSensor sample application.
4. In AppBuilder, under the “hal configuration tab”, select the EM3587 chip.
5. Generate and note the directory in which the project files were created.
6. Save the Ember Desktop project file into the directory you just created.
7. Compile in IAR version 7.30.1 or later.

At this point you can load the image onto the Contact Sensor reference design.

7.4 Cluster Support

This section details clusters that were implemented as part of this project.

- Basic
- Power Configuration
- Identify
- OTA Boot-loading
- Poll Control
- Temperature Measurement
- IAS Zone
- Diagnostics

8. Engineering Tests

This reference design completed the following product testing for pre-certification purposes:

- ZigBee Home Automation (HA) v1.2
- FCC Emissions
- Antenna Radiation Patterns

8.1 ZigBee Home Automation HA v1.2

The contact sensor went through a preliminary HA 1.2 testing to verify compliance with the ZigBee standard.

8.2 FCC Emissions Testing

This design went through a preliminary FCC pre-scan testing to verify compliance with FCC Part 15 restrictions. Such testing is done to ensure customers are given a design that can pass FCC. FCC compliance does not transfer to modules built according to this reference design, even if the design is copied exactly.

9. Manufacturing Tests

This section describes how a user can develop a low-cost manufacturing test methodology in order to test products that utilize this reference design. Recommended test equipment and test procedures will also be outlined in this section.

9.1 Test Coverage

By following these guidelines, the following items will be tested and verified for functionality:

- RF TX/RX performance
- Current consumption
- Magnetic sense functionality
- Common ZigBee operations
- Frequency offset (with optional spectrum analyzer)

9.2 Test Equipment List

The test system is composed of the following components:

- Desktop PC
- RF Shielded Box
- Power Supply (Agilent E3646A + Ammeter)
- PoE Hub (Netgear Prosafe 108P)
- 2x ISA3 programming/packet trace adapters (Silicon Labs ISA3)
- Golden Node (Silicon Labs ZigBee coordinator device)
- Spectrum Analyzer (Agilent E4407B)
- Device Under Test (DUT)

9.3 Test System Diagram

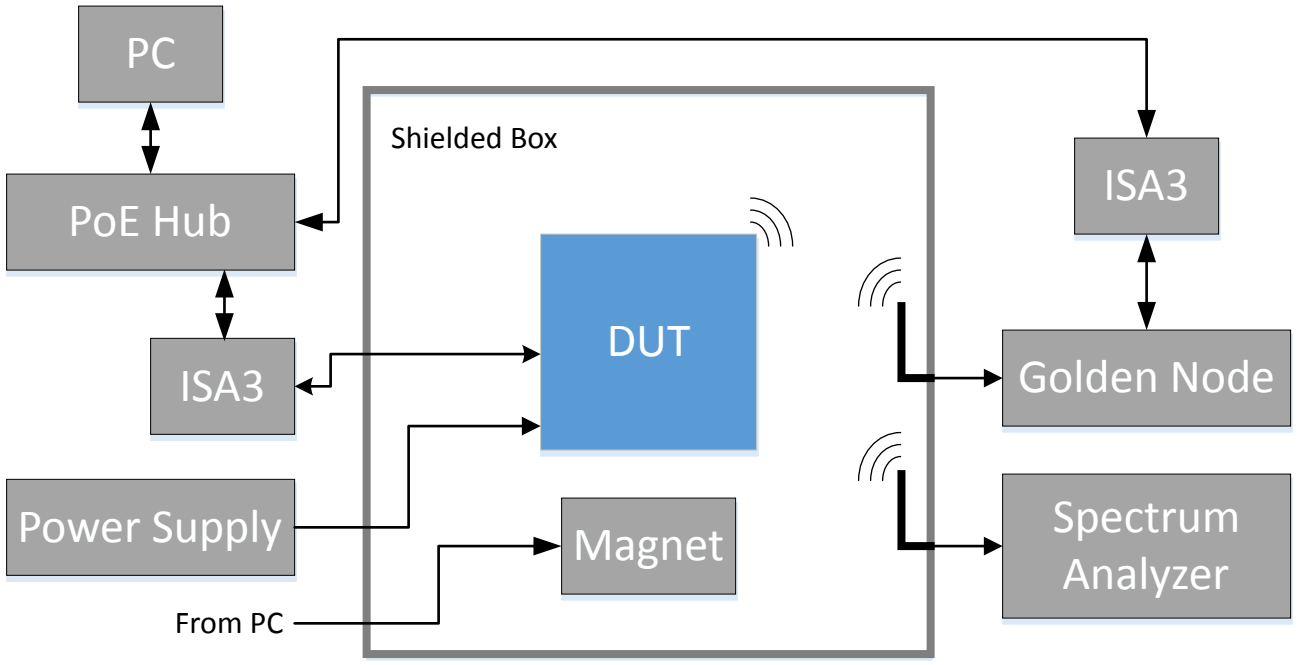


Figure 9.1. Test System Diagram

9.4 Test System Connection Procedure

Wire the system as indicated above. Both ISA3 adapters and the PC will be connected to the PoE hub. One ISA3 adapter will connect to the DUT, to both reprogram and interact with the DUT, whereas the second ISA3 adapter will connect to the Golden Node for testing network functionality. The ISA3 Adapters connected to the DUT should never be turned off. Instead, the DUT will be powered from the Power Supply for live current measurements.

Within the shielded box the only items protruding inward should be the connectors linked to the DUT, the magnet and connectors for 50 Ω antennas. If desired, a spectrum analyzer may be procured and integrated into the system to measure frequency offset.

A controllable electro-magnet can be used to verify correct installation of the reed switch.

9.5 Configuring the ISA3 Adapters

For this setup, the PC will communicate to the ISA3 Adapter with an Ethernet connection over Telnet. To do this, first the ISA3 adapters need to be configured to use a static IP address. For instructions on how to setup static IPs, reference Chapter 6.3 and 6.4 in Silicon Labs' UG110: "Ember® EM35x Development User's Guide". Use the Admin interface over USB to set up the ISA3 adapters.

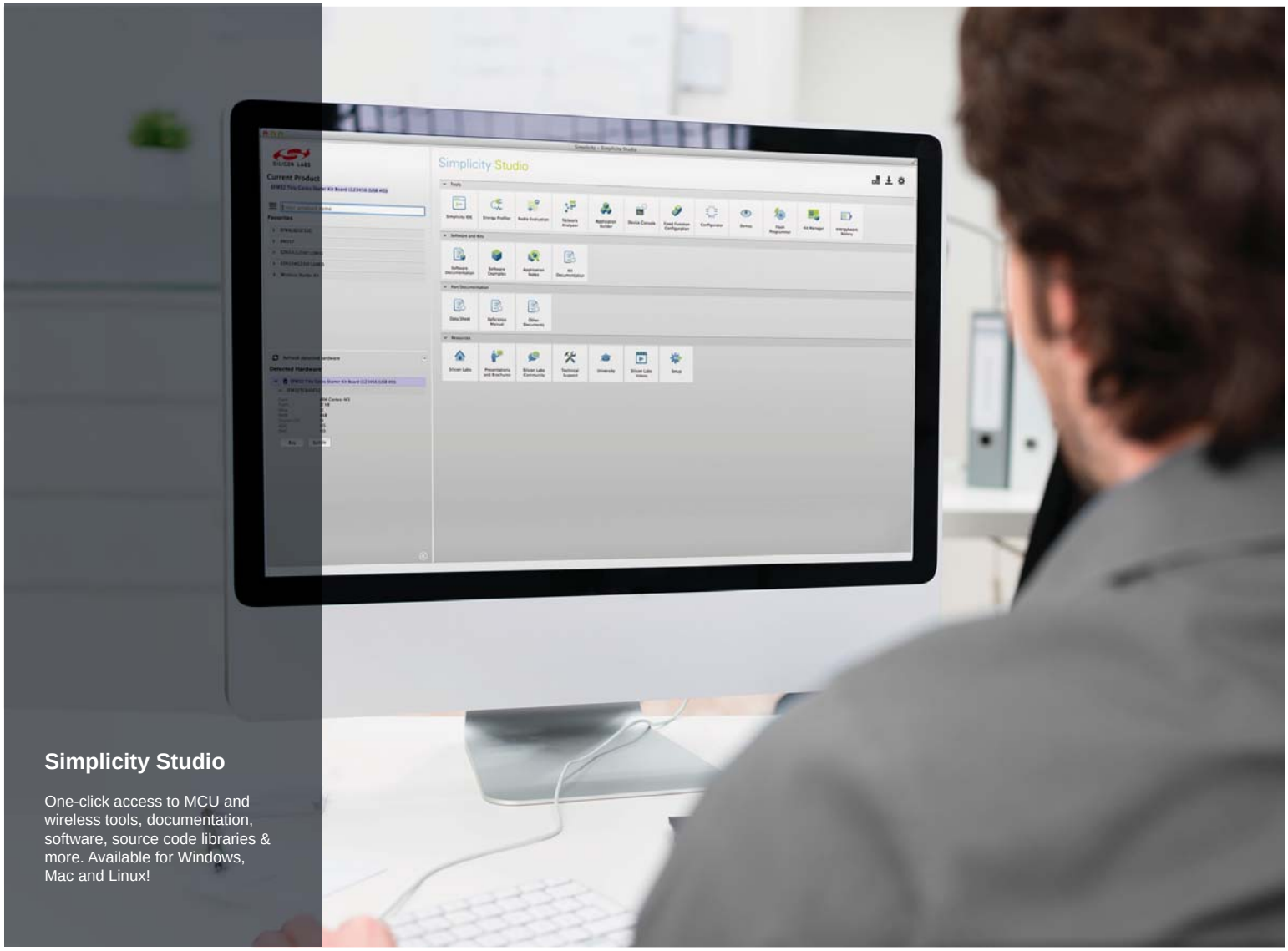
9.6 Communicating with Targets

For testing purposes, the nodetest will be used. Through the telnet interface, both the ISA3 adapters and their respective connected targets can be communicated with simultaneously. To communicate with the ISA3 adapters, a telnet session should be opened to its static IP at port 4902. To communicate with a target connected to the ISA3 adapter though virtual UART, connect to the ISA3's static IP at port 4900.

Once connected, pressing Enter, or sending a '\r\n' sequence will result in a prompt ending with a '>' character.

9.7 Additional Details

For a more thorough checklist, refer to application note, AN700: "Manufacturing Test Guidelines for the Ember EM250, EM260, and EM35x" or contact Silicon Labs (http://www.silabs.com) for additional information.



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Silicon Laboratories Inc.
400 West Cesar Chavez
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