UG120: Zigbee® Capacitive Sense Dimmer Switch Reference Design (RD-0039-0201) Kit User's Guide

The Silicon Labs Zigbee HA (Home Automation) 1.2-based capacitive sense dimmer switch reference design uses the EM3587 wireless microcontroller (MCU), which reduces development costs and enables faster time to market for customers. 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 On-Off Dimmer Switch
- HA 1.2 and FCC Certifiable
- Hardware and Firmware Considerations
- Engineering and Manufacturing Testing

1. Introduction

This document describes the Silicon Labs Zigee HA 1.2-based capacitive sense dimmer switch reference design (Figure 1.1 Zigbee Capacitive Sense Dimmer Switch Reference Design on page 2) using the EM3587 wireless microcontroller (MCU) which reduces development costs and enables faster time to market for customers. This reference design can be directly integrated into a connected zigbee home automation lighting application shown in Figure 1.2 Connected Capacitive Sense Dimmer Switch Application Example on page 2. The capacitive sense dimmer switch comes preprogrammed and ready to demonstrate out of the box. All hardware design files and firmware application source code are available.

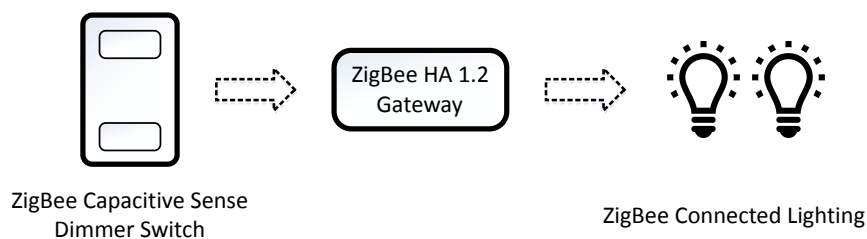**Figure 1.1. Zigbee Capacitive Sense Dimmer Switch Reference Design**

ZigBee Capacitive Sense
Dimmer Switch

ZigBee HA 1.2
Gateway

ZigBee Connected Lighting

Figure 1.2. Connected Capacitive Sense Dimmer Switch Application Example

2. Quick Start Demonstration

A video showing the quick start demonstration is available at https://www.silabs.com/zigbeedimmer.

1. Setup an HA 1.2 zigbee gateway.

   To use the dimmer switch in a zigbee network, it needs to connect to a zigbee coordinator (gateway). Silicon Labs offers the RD-0002-0201 Zigbee Wi-Fi/Ethernet Gateway (sold separately) for the purpose of evaluating the zigbee capacitive sense dimmer switch reference design. A commercially available Home Automation (HA) 1.2 compliant gateway that supports a level control switch with device profile ID = 0x0001 will also work for this purpose.

2. Supply power to the zigbee capacitive sense dimmer switch.
   a. If present, remove the white battery tab that separates the battery from its battery connector.
   b. Verify switch SW1 is set to BAT.

3. Connect the zigbee capacitive sense dimmer switch to the zigbee network.
   a. Follow the directions provided with the zigbee gateway to enable the capacitive sense dimmer switch reference design to join its zigbee network.
   b. Depress and hold S3 join button for two seconds to begin the network join procedure.
   c. The demo board has joined the zigbee network when the green LED, D2, blinks six times.
   d. The gateway should connect with a zigbee lightbulb.
   e. The gateway should have a rule to bind the dimmer to the lightbulb.

4. Demonstrate zigbee capacitive sense dimmer switch functionality.
   a. To turn ON a light, tap the top capacitive sense pad outlined in black.
   b. To turn OFF a light, tap the bottom capacitive sense pad outlined in black.
   c. While the light is on, hold the bottom capacitive sense pad to decrease light intensity.
   d. To increase light intensity, hold the top capacitive sense pad.
   e. To demonstrate color hue and temperature control with a connected color bulb, refer to Section 5.2 Capacitive Sense Behavior.

3. Recommended Next Steps

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

3.1 Evaluate the Dimmer Switch

The ZigBee capacitive sense dimmer switch reference design has been developed to support most capacitive sense dimmer switch application requirements. Typical areas for evaluation include:

1. ZigBee network behavior, such as network join and leave.
2. User control of lighting behavior.
3. 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. EM3587 ZigBee Firmware of this document to learn how to easily modify features, such as LED behavior and RF power levels.

3.3 Build a Proof of Concept

Out of the box, the capacitive sense dimmer switch reference design can be used for a rapid proof of concept. The front graphic is merely a clear sticker and can easily be replaced with any sort of company logo/design. The sticker dimensions are shown in the figure below. Refer to Section 7. EM3587 ZigBee Firmware to change behavior of the capacitive sense functionality.
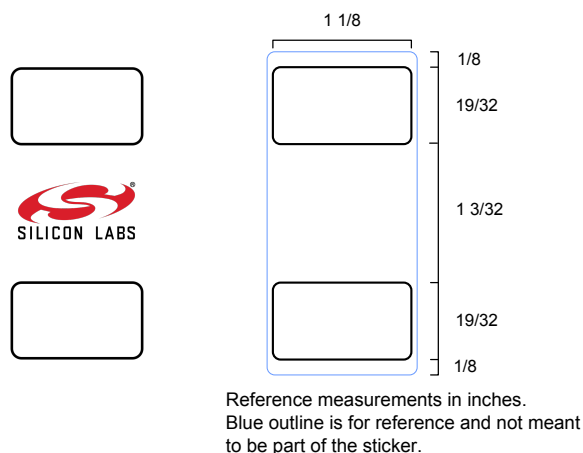

Figure 3.1. Sticker Dimensions

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 Test

Section 9. Engineering Tests of this document provide engineering test results, such as FCC and HA 1.2.

Section 10. 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 call out the reference design number (i.e., RD-XXXX) when describing the complete design and the reference design component (i.e., RD-XXXX-YYYY) when describing a specific component.

The table below 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-0039-0201	N/A	ZigBee Capacitive Sense Dimmer Switch Reference Design Kit with EM3587, EFM8SB1, and PCB Antenna.
RD-0039-0101	IST-A39 Rev 2.0	ZigBee Capacitive Sense Dimmer Switch Reference Design Evaluation Board with EM3587, EFM8SB1, and PCB Antenna.

4.2 ZigBee Capacitive Sense Dimmer Switch Reference Design Kit

Kit Contents:

• ZigBee Capacitive Sense Dimmer Switch Reference Design with CR2032 battery and battery tab.
• Quick start card to obtain the latest reference design collateral.

4.3 ZigBee Capacitive Sense Dimmer Switch Reference Design

This reference design contains many features for the evaluation of the capacitive sense dimmer switch, including:

Table 4.2. ZigBee Capacitive Sense Dimmer Switch Reference Design Features

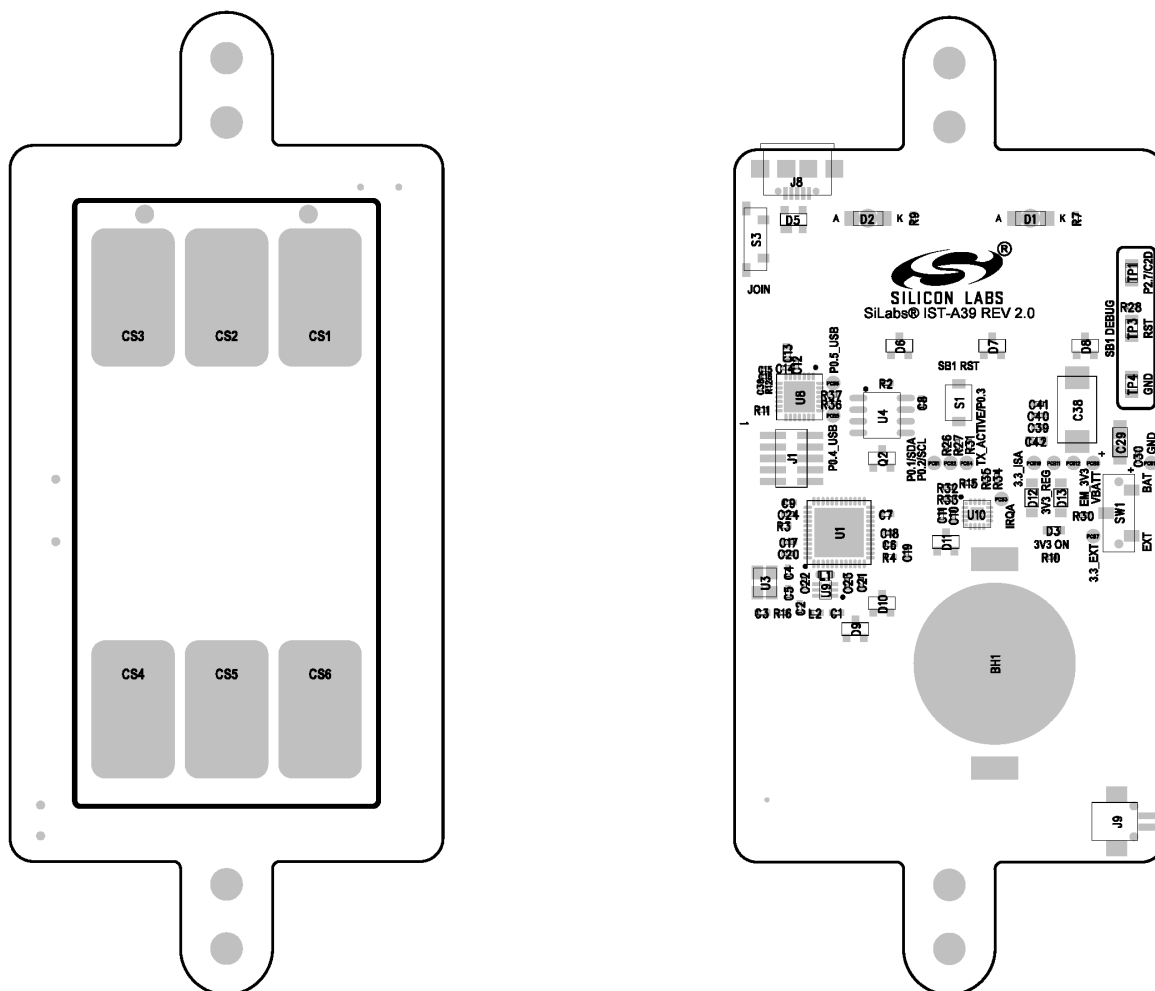| Reference Design Features	Benefit
Six capacitive sense pads	Senses user taps, holds and lateral swipes.
Two status LEDs	Provides capacitive sense feedback and dimmer status.
10-pin ISA3 compatible connector	Facilitates ZigBee wireless packet trace debugging.
Join button	Eases network commissioning (join/leave).
Test points	Simplifies hardware-level debugging.
CR2032 battery holder	Supports low-cost, small footprint battery.
Micro-USB connector	Connects to the capacitive sense profiler in Simplicity Studio.
EFM8SB1 Programming Pins	Used for capacitive sense development with Simplicity Studio.

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

4.4 Feature List

Microcontroller and Transceiver Features:
- EM3587 with 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/TWI serial communications, and general purpose timers.
- Highly efficient Thumb-2 instruction set.
- EFM8SB1 capacitive sense MCU.

ZigBee Capacitive Sense Dimmer Switch Reference Design Hardware Features:
- Integrated PCB antenna.
- Pushbutton for network join.
- Network/status and capacitive sense feedback LEDs.
- Full packet trace port for RF communications debugging.
- 2.1 V to 3.6 V operation.
- Fully qualified BOM for 0 to 55 ºC operation.
- Up to +8dBm TX power.
- 512 kB user programmable flash with 64 kB RAM.
- Pre-certified FCC Part 15.

ZigBee Capacitive Sense Dimmer Switch Reference Design Firmware Features:
- Precompiled and source application firmware.
- Over-the-Air (OTA) upgradable.
- ZigBee HA 1.2 pre-certifiable clusters: basic, power configuration, identify, on/off, level control, OTA upgrade, diagnostics.
- Application firmware (source code) available in the EmberZNet™ PRO stack library.
- Application firmware (source code) available for EFM8SB1 capacitive sense available in Simplicity Studio.

5. Operation

5.1 ZigBee Network Behavior

This section will describe the various operational states a powered capacitive sense dimmer switch reference design is able to occupy as it joins and leaves a ZigBee network. The input mechanism for operation utilizes a join button, S3. A button assertion for at least a second and releasing equates to an input button press. The green LEDs operate 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.
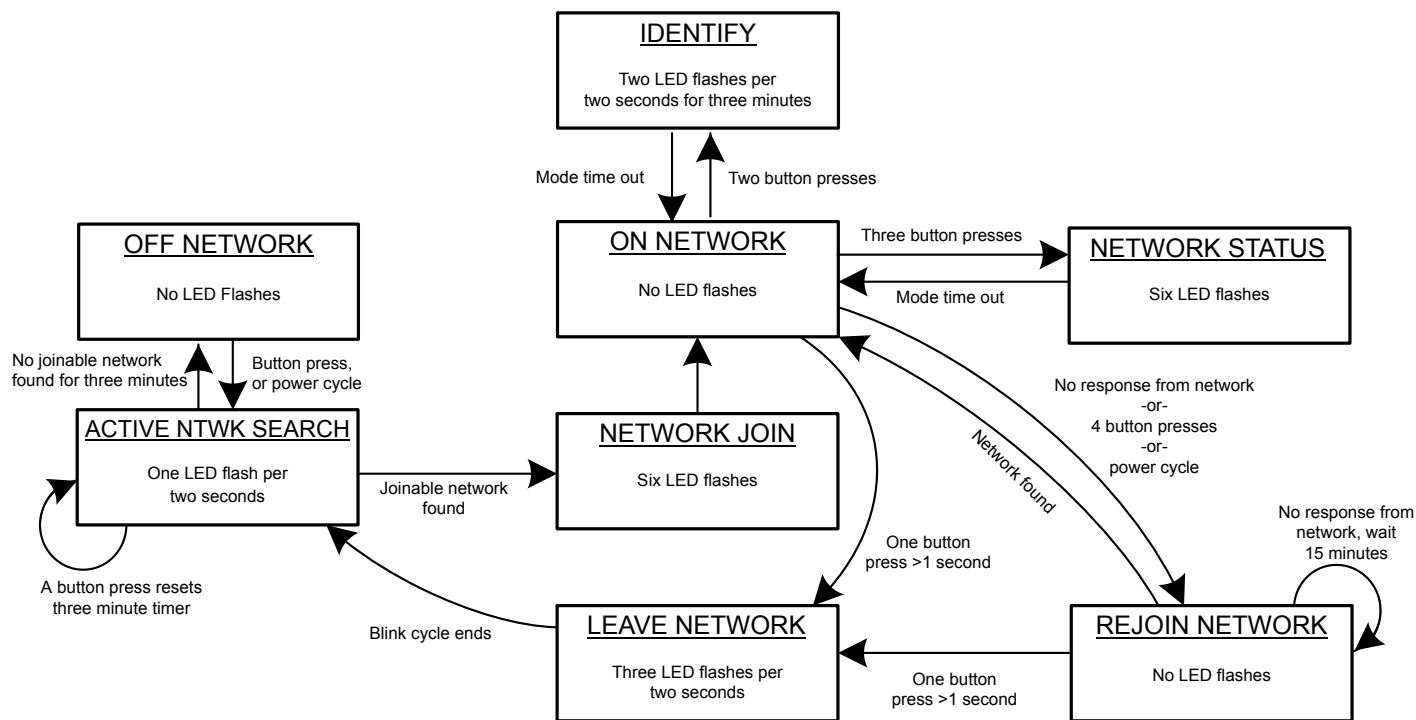
Figure 5.1. Device Operation State Diagram

5.1.1 First Time Demo Board 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 and 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 S3 button once.

5.1.3 ACTIVE NTWK SEARCH State

This state is a condition where the dimmer switch is actively searching for a network but has not joined a network. While in this mode, the D2 LED will flash once per two seconds. This operation of actively searching for a network will remain for up to three minutes. If no network is found by that time limit, the dimmer switch will enter the OFF NETWORK state. Power-cycling or an S3 button press in this state will reset the three minute timer, while keeping the reference design 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 dimmer switch leaves the ACTIVE NTWK SEARCH state and enters this state, the D2 LED will flash six times to indicate successfully finding and joining a network. This state is temporary and will place the dimmer switch into the ON NETWORK state once the LEDs complete their flash sequence.

5.1.5 ON-NETWORK State

This state is a condition where the dimmer switch is connected to a ZigBee HA 1.2 network and is not searching for another network. While in this state, the green LEDs on the dimmer switch will not be illuminated unless in a color tab mode. This state contains multiple entry and exit paths depending on various factors, such as the number of S3 button presses that are within 0.5 second of each consecutive press.

If the power to the dimmer switch is removed and later restored, the reference design will enter the REJOIN NETWORK state and will not seek other networks unless the user forces the design to leave its joined network (as will be described later within this section).

If S3 is pressed once for longer than one second, the reference design will enter the LEAVE NETWORK state.

If S3 is pressed two times, the reference design will temporarily enter the IDENTIFY state while remaining on its joined network.

If S3 is pressed three times, the reference design will temporarily enter the NETWORK STATUS state while remaining on its joined network.

If S3 is pressed four times, the reference design will enter the REJOIN NETWORK state.

5.1.6 IDENTIFY State

The purpose of this state is to help an installer (or user) identify which device is being communicated to by visually flashing the D2 LED in a specified pattern to locate the targeted device. After a dimmer switch leaves the ON-NETWORK state and enters this state, the D2 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 will return the reference design into the ON NETWORK state once the state's timer reaches its time limit, or if one of the capacitve sense pads is pressed at least once.

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

This state helps an installer (or user) to identify if a device is successfully connected to a network. After a dimmer switch leaves the ON-NETWORK state and enters this state, the D2 LED will flash six times if on a network. This state is temporary and will return the dimmer switch into the ON-NETWORK state once the state's timer reaches its time limit, or if one of the capacitive sense pads is pressed at least once.

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 S3 is pressed once for longer than one second, the reference design will enter the LEAVE NETWORK state.

5.1.9 LEAVE NETWORK State

Upon entering this state, the dimmer switch will leave the joined network and will indicate this process is in action by flashing the D2 LED three times within a two second period. This state is temporary and will place the dimmer switch into the ACTIVE NTWK SEARCH state once the LEDs complete their flash sequence.

5.2 Capacitive Sense Behavior

ZigBee Capacitive Sense Dimmer Switch Reference Design utilizes capacitive sense points and LEDs to guide a user through controlling a ZigBee lightbulb that is bound to the switch.

5.2.1 Capacitive Sense Features

The inputs are based on a user depressing capacitive sense areas on the reference design. This design has six capacitive sense points (CS1, CS2, CS3, CS4, CS5, CS6). CS1, CS2, and CS3 are grouped and located along the top area of the PCB design next to the two LEDS. CS4, CS5, and CS6 are grouped and located on the bottom area of the PCB design.

In the basic functionality of this design, if the switch is bound to a ZigBee light, tapping any of the CS1, CS2, or CS3 sense points will turn a light on. Tapping any CS4, CS5, or CS6 sense points will turn a light off. A static hold on C1, C2, or C3 will increase the intensity of an already lit light bulb. A static hold on C4, C5, or C6 will decrease the intensity on an already lit light bulb.

Note: If a dimmed bulb reaches a visually off state, use hold on C1, C2, or C3 to reactivate the light.

To access advanced features, swiping across sense points CS1 to CS3 (or in reverse) or CS4 to CS6 (or in reverse) will set the dimmer into new tab states with the LEDs providing visual feedback to a user on which mode they are in.

Swiping across the three sense points should occur for a duration of at least 500 milliseconds, and will ensure the swipe is validated by the reference design.
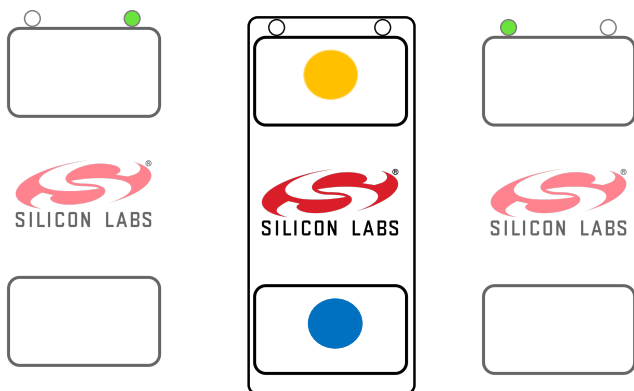
User features are visually shown in the figure below.

Switch Pages
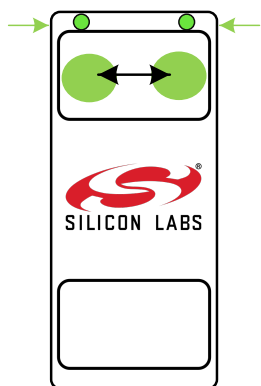
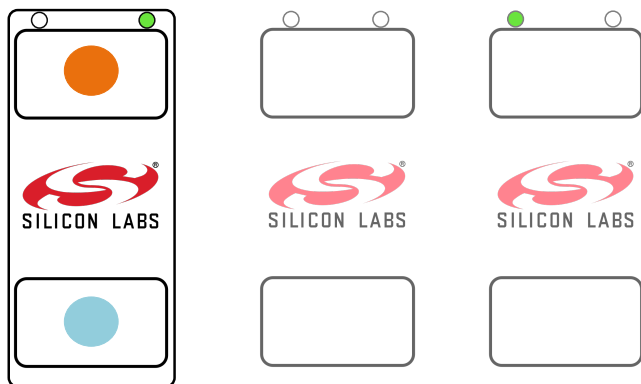**Swipe left or right** to change page.

Page selection is indicated by LEDs.

Normal Page (Default)
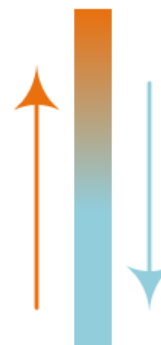
Tap to turn on.
Hold to dim up.

Tap to turn off.
Hold to dim down.

Color Temperature Page (Swipe Right-to-Left)
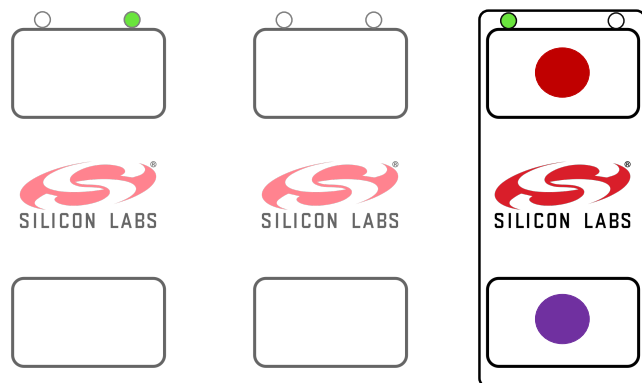
Hold to move color temp down.

Hold to move color temp up.

Hue Page (Swipe Left-to-Right)

Hold to cycle color to the right.
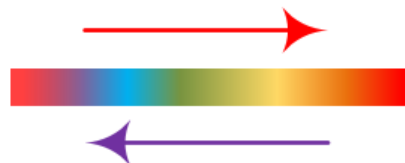
Hold to cycle color to the left.

Figure 5.2. ZigBee Capacitive Sense Dimmer Switch Advanced Features

The two LEDs provide network status, indicate valid capacitive sense command from a user was received, and which tab mode the sense points are current set.

Table 5.1. LED Features

	State	LED D1	LED D2
No Network	Active Network Scan	OFF	Slow Blink
	Network Join	OFF	Rapid Blink
Network Connected	Normal Tab	OFF	Blink = valid capacitive sense OFF = no valid capacitive sense
	Color Temperature Tab	Static ON	Blink = valid capacitive sense OFF = no valid capacitive sense
	Color Hue Tab	Blink = valid capacitive sense OFF = no valid capacitive sense	Static ON

6. Hardware

This section describes the key aspects of the reference design.

6.1 ZigBee Capacitive Sense Dimmer Switch Reference Design RD-0039

This section describes the key hardware specifics of the RD-0039 module.

Key Highlights:
- EM3587 ZigBee Pro radio with embedded flash.
- EFM8SB1 capacitive sense MCU.
- Two-layer 0.062" printed circuit board with all components on primary side.
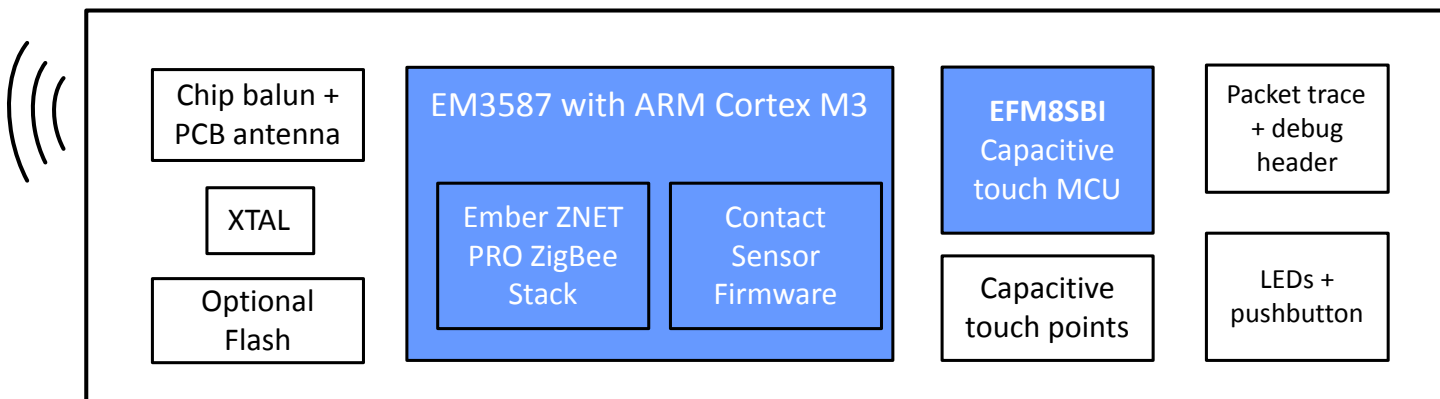- 6-pin 0.050" board header with VDD, GND and four PWM output pins.

Figure 6.1. Reference Design Block Diagram
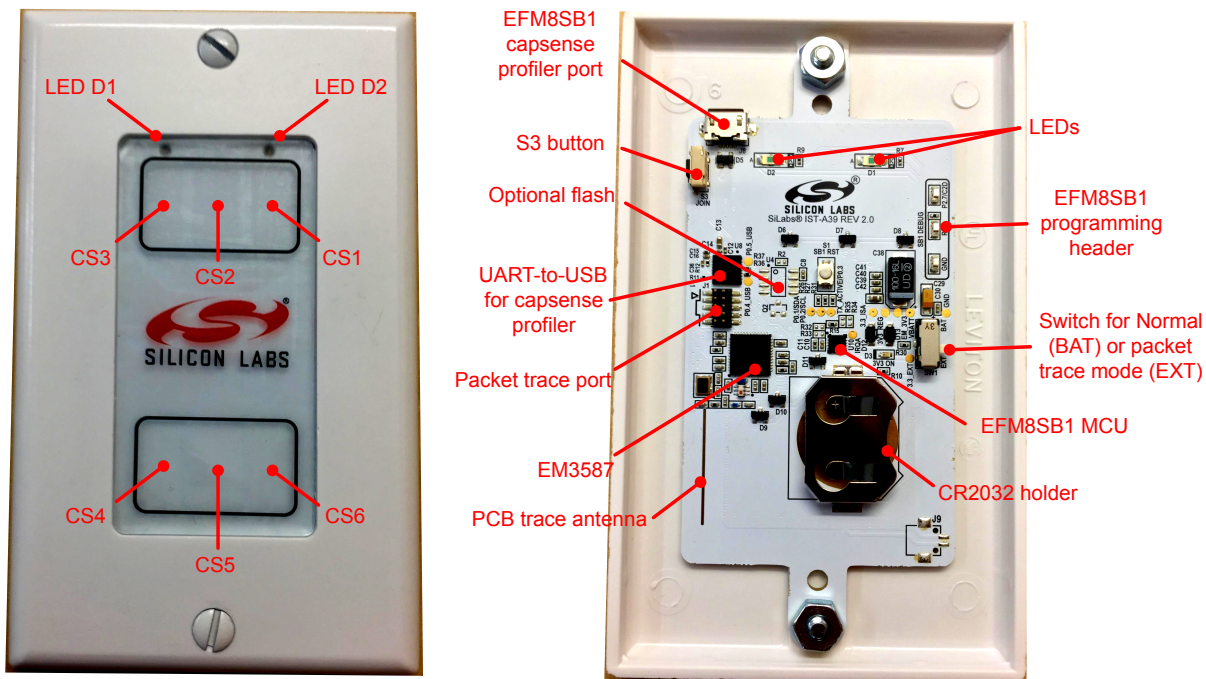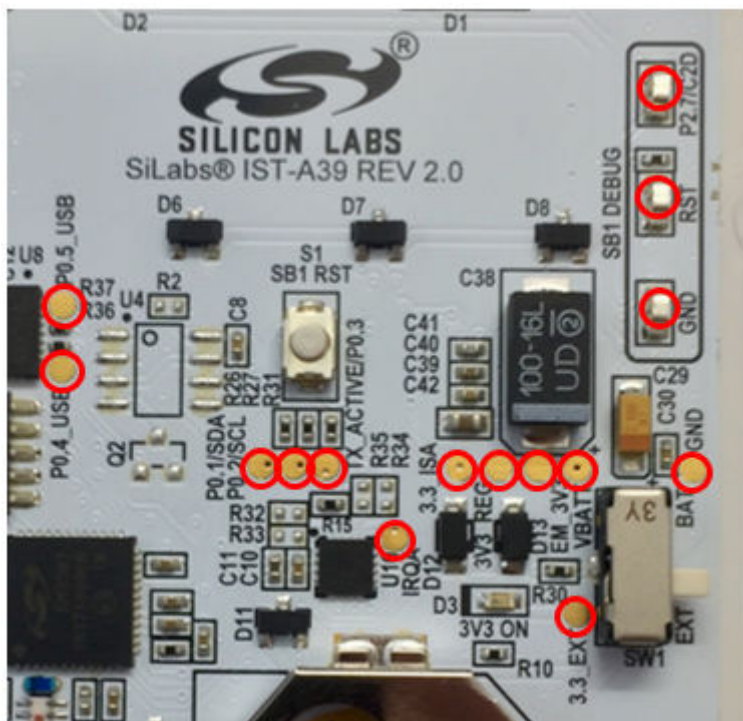

Figure 6.2. Reference Design Front and Back

Figure 6.3. PCB Test Points

Table 6.1. Connector Pin Assignments

Packet Trace Port				
Pin Number	PCB Pin Name	ISA3 Pin Name	Pin Functions	Description
1	3.3_ISA	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	PTI_EN	PA4	PTF	Packet Trace Enable
10	PTI_DATA	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.				

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

For a slightly longer battery life and only supporting ZigBee, the EM357 can be used instead of EM3587.

Note: The EM357 cannot support the upcoming Thread protocol.

6.2.2 Avoid Modification

All changes listed here may have serious impacts on performance:
*   Modifying the spacing between the EM3587 and 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 dimmer switch, see the schematic for complete information on which components can be depopulated in mass production.

7. EM3587 ZigBee Firmware

This section describes the capacitive sense dimmer switch reference design's ZigBee application firmware.

7.1 Obtaining the Firmware Application

The firmware application in pre-compiled binary form is available for download from https://www.silabs.com/zigbeedimmer. 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 EM3587

The reference design provides two methods to reprogram the EM3587:
- 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 dimmer switch 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 on ISA3 for more information on how to successfully program the demo board with the ISA3 programmer. The ISA3 connector on the demo board is the J1 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 J1 header.

7.2.2 Over-the-Air Reprogramming

The demo board can be reprogrammed with an available .ota file and a device that can perform OTA upgrades such as the RD-0002-0101 ZigBee USB Gateway Reference Design Kit with EM3588 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 EM3587 firmware.
1. Install EmberZNet PRO™ 5.4.4.

   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, users can load the image into the capacitive sense dimmer switch reference design.

7.4 Cluster Support

This section details clusters that were developed as part of this project.
- Basic
- Power Configuration
- Identify
- On/Off
- Level Control
- OTA boot-loading
- Diagnostics

8. EFM8SB1 Firmware

This section describes the capacitive sense dimmer switch reference design application firmware. The EFM8SB1 firmware responds to valid inputs on its six capacitive sense pads. The firmware communicates the following eight types of gestures to the EM3587, which hosts the main application:

- Top Row: tap, hold, swipe-left, swipe-right.
- Bottom Row: tap, hold, swipe-left, swipe-right.

These gestures allow for application flexibility. If more complex gesture recognition is needed, the EFM8SB1 firmware can be modified.

8.1 Obtaining the Firmware Application

The firmware application in pre-compiled binary form is available for download from: http://www.silabs.com/zigbeedimmer. The firmware application source code is available as part of Simplicity Studio's v3.1 or higher. For more information, visit the Simplicity Studio page: http://www.silabs.com/simplicity-studio.

8.2 Programming the EFM8SB1

The reference design provides board headers to re-program the EFM8SB1 with an available .hex file and a USB Debug Adapter for EFM8 MCUs. Information regarding the USB Debug Adapter can be found here: http://www.silabs.com/products/mcu/Pages/USBDebug.aspx. In addition, a micro-USB to USB cable will be needed as both a power source and for using the Capacitive Sense Profiler tool found in Simplicity Studio. Two connectors on the reference design are used to program the EFM8SB1 (shown in the figure below):

- J8 micro USB power port, which is also used for the EFM8SB1 Capacitive Sense Profiler.
- The GND, RST, and P2.7/C2D metallic hooks labeled SB1 DEBUG.
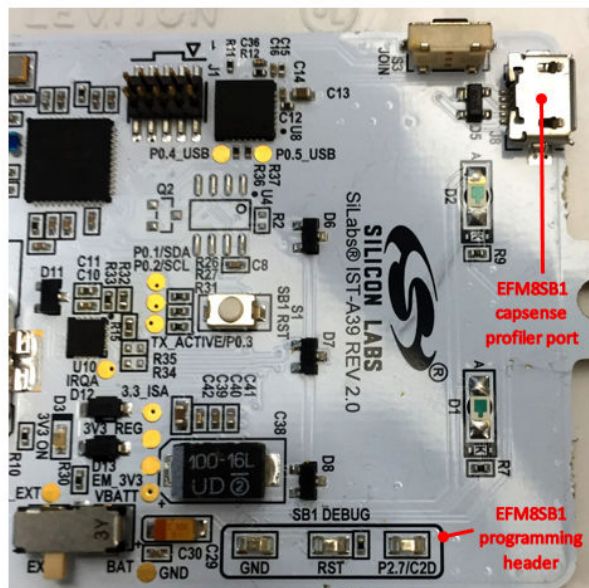
Figure 8.1. EM3587 Programming Headers

The USB Debug Adapter and SB1 DEBUG hooks will require individual wiring connectors to complete the connection. To mate these signals, refer to the table below:

Table 8.1. EFM8SB1 Programming Connection

USB Debug Adapter	SB1 DEBUG
Pin 4	P2.7/C2D
Pin 7	RST
Pin 9	GND

The programming steps are listed below:

1. Attach the USB Debug Adapter to the GND, RST, and P2.7/C2D test hooks.
2. Plug the micro USB cable into J8, and the other end of this cable to a USB power source. When using the Capacitive Sense Profiler this USB connection should be connected to the computer with Simplicity Studio.
3. Once all cables are connected to the reference design, open Simplicity Studio.
4. In the "Enter Product Name" box on the left panel, type: "EFM8SB10F8G" and select it in the pop-up window.
5. "EFM8SB10F8G" should be listed in the favorites and expanded.
6. Click the "Flash Programmer" tile.
7. If the "Device Detection" menu appears, click the entry for "EFM8SB10F8G-QFN20 (EC30001D236)" and click "OK". If this entry is not available, hold one of the cap sense pads and press the refresh button, which will prevent the EFM8SB1 from entering a sleep state, and thus ensure that it is detected by Simplicity Studio.
8. Click the "Browse" button, then browse to the location of the .hex binary.
9. Click the "Program button.

8.3 Build Instructions

The instructions below describe how to build the EFM8SB1 firmware:

1. Once downloaded as found in Section 8.1 Obtaining the Firmware Application, open Simplicity Studio.

2. In the "Enter Product Name" box on the left panel, type: "EFM8SB10F8G" and select it in the pop-up window. "EFM8SB10F8G" should be listed in the favorites and expanded.

3. On the right panel, select the "Application Notes" tile.

4. Scroll to UG120: "Zigbee Capacitive Sense Dimmer Switch Reference Design (RD-0039-0201)" and click on it.

5. Click on the "Import Project .." button on the lower portion of the visible window.

6. In the "Choose a Project" window, select the "EFM8SB1_RD0039.slsproj" project and click "OK".

7. This will open the "Development Project Explorer".

    a. From here either select various files in the left panel, which will open in the right panel.

    b. Edits to files can be made in the right panel on selected files.

8. To build the project, in the menu select "Project" → "Build Project".

At this point, users can load the image into the capacitive sense dimmer switch reference design.

8.4 Source Code Description

The following sections describe the CapTouchGestureDetect and CapTouchProfiler directory source files and how it relates to specific capacitive sense functional behavior within the reference design. The CapTouchGestureDetect are the files associated with the reference design application. The CapTouchProfiler is used in conjunction with the Capacitive Sense Profiler to optimize the responsiveness of the reference design's capacitive sense pads and power use.

8.4.1 Low Power Management

`lib/efm8sb1/cslib/device_layer/hardware_routines.c`

- Function `executeConversion()` should contain an `if` statement, checking if `disableSleepandStall` is set or not. This makes sure that the SB1 stays awake during an I2C send.

- Function `executeConversion()` also contains: CS0THH = 0 and CS0THL = 0. This sets the SB1 to enter suspend mode during a conversion, so that the SB1 is not awake and consuming 3 mA during the entire 600 μs conversion while it checks for a touch every several hundred milliseconds.

`src/device_init.c`

- This sets CLKSEL = 0x04, which specifies using the low power oscillator.

8.4.2 Adjusting Sensitivity

`Inc/config/cslib_config.h`

DEF_AVERAGE_TOUCH_DELTA	This sets the expected delta change on a capacitive sense pad. If the expected delta is significantly smaller than the actual average, then the device will try to compensate for noise which consumes more power. If this needs to be modified, use the cap sense profiler to help choose an appropriate modified value.
DEF_ACTIVE_SENSOR_DELTA	Sets the threshold for an active touch. Currently set to 200 to improve sensitivity, which is reasonably low even with the 1/16th inch overlay included within the hardware reference design.
DEF_INACTIVE_SENSOR_DELTA	Sets the threshold for an inactive touch. Currently set at a high threshold to ensure the device quickly returns to a low power state.
DEF_BUTTON_DEBOUNCE	Sets the number of readings which must be above the active threshold to count as an active touch. Currently set to two readings, which is ideal for picking up fast or light touches.
DEF_ACTIVE_MODE_PERIOD	Active mode sleep time is the amount of time between each read while at least one of the buttons is active. It is currently set to 30, which is very low, making it more likely that an entire swipe will be caught. This can be lowered to lower power consumption, but the risks fast swipes not being registered.
DEF_SLEEP_MODE_PERIOD	Sleep mode time is 400 which corresponds to the SB1 checking if any buttons are being touched approximately every 90 milliseconds. This setting is the lowest that sleep mode period that can be set to achieve approximately three years life time on the reference design. This frequent checking for touches is necessary to pick up light, fast swipes and taps. If it becomes okay to respond to only the most deliberate swipes and require slightly slower taps, then increasing sleep mode period is the best way to gain additional lower power savings.
DEF_COUNTS_BEFORE_SLEEP	Number of inactive reads before the part returns to sleep. Set low to preserve power.
DEF_FREE_RUN_SETTING	Free run mode collects data quickly during active mode and directly affects gesture timing and device power consumption.
DEF_SLEEP_MODE_ENABLE	Set to 1 to allow the device to enter sleep mode when not active.

`Inc/config/cslib_hwconfig.h`

GAIN_VALUE_ARRAY	All values currently set to 7's. Gain controls the magnitude of an active touch on a button.

8.4.3 I2C

This section describes changing I2C interface behaviors.

`i2c/I2CRoutines.c`

InterruptPin	Changes Interrupt GPIO.
SMB_FREQUENCY	Changes clock speed.

`src/device_init.c`
- `PORT_init()` edit P0SKIP to change SDA and SCL pins on the cross bar. Refer to the EFM8SB1 datasheet for more information.

8.5 Capacitive Sense State Behavior

This section describes the state functional behavior on how it interprets capacitive sense readings found in the "main.c" source file.
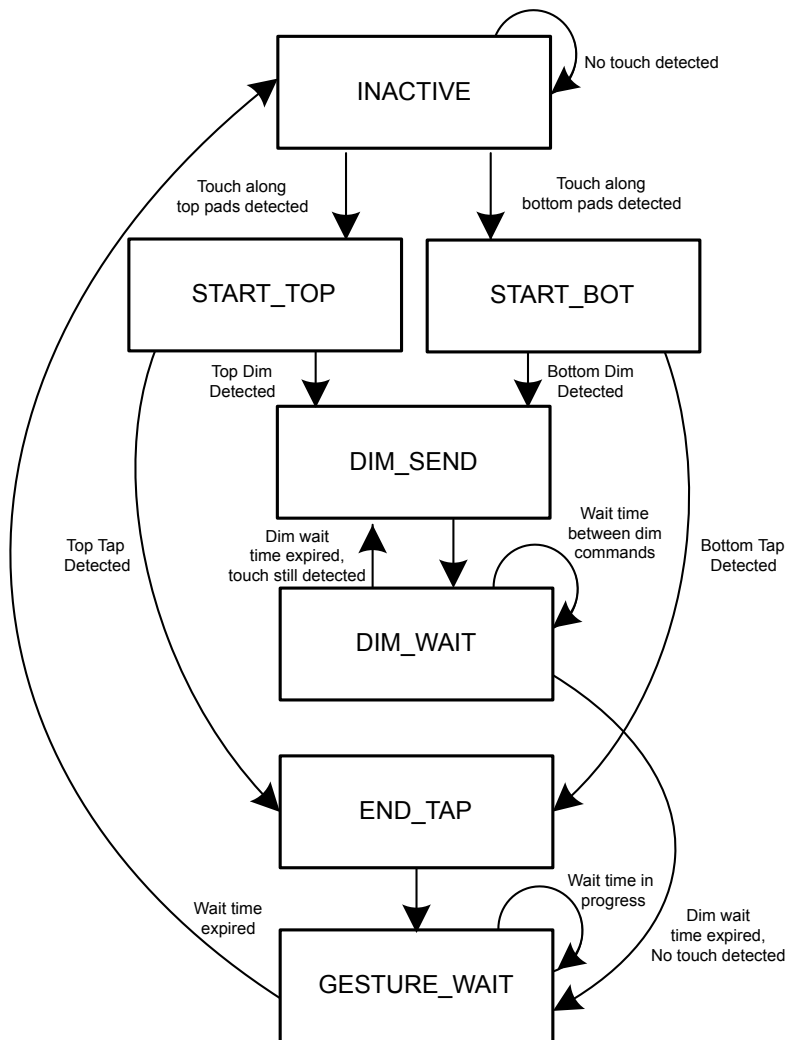

Figure 8.2. Capacitive Sense State Diagram

8.5.1 INACTIVE

This state is a condition when no touch has been detected. If a touch is detected on the top capacitive sense pads, the device will enter the START_TOP state. If a touch is detected on the bottom, the device will enter the START_BOT state. If a gesture is being recognized, it will save the state of which buttons are currently active as it transitions to the next state.

8.5.2 START_TOP/STOP_BOT

Upon entry, these two states will increment a timer to determine the duration of a valid capacitive sense touch. When a touch ends, it will enter the END_TAP state. If timer exceeds its threshold of 25 milliseconds, the gesture is determined to be a hold and thereby a dimming command, causing the device to enter the DIM_SEND state. Depending on whether the state is START_TOP or STOP_BOT, the SB1 will emit the corresponding commands based on those states as described in Section 5.2.1 Capacitive Sense Features.

8.5.3 END_TAP

This state is entered once a touch has ended. If this is determined to be a gesture, the SB1 will register the action as a swipe gesture. If it does not meet the requirements for a swipe, then the action is counted as a tap. Once completed, it will enter the GESTURE_WAIT state.

8.5.4 DIM_SEND/DIM_WAIT

This state is used to send a dim command when a dimming gesture is detected. If the touch is still active, it will enter the DIM_WAIT state which increments a counter. Once the counter reaches a threshold (12.5 milliseconds) it will re-enter the DIM_SEND state. This process will continue until a no touch is registered by the device. If no touch is detected, then the gesture has determined to have ended and the device will enter the GESTURE_WAIT state.

8.5.5 GESTURE_WAIT

This state is used as a wait state to add a specified time between gestures to avoid flooding a network with multiple gesture commands. Once the gesture wait time has reached 2.5 milliseconds, it will then enter the INACTIVE state.

8.6 Using the Capacitive Sense Profiler

This section describes how to use Simplicity Studio's Capacitive Sense Profiler with the reference design.

1. Connect the reference design as shown in the programming instructions in Section 8.2 Programming the EFM8SB1, which includes the USB Debug Adapter and micro-USB cable.
2. Program the design using the .hex from the CapTouchProfiler project.
3. Open Simplicity Studio, Enter Product Name "EFM8SB10F8G" and select it.
4. On the right panel, click on the "Capacitive Sense Profiler" tile to launch this tool.
5. Click the "Use Device..." button and select "EFM8SB10F8G-QFN20 (EC30001D236)" when the Device Detection window appears. Click "OK".
6. From the dropdown menu, select the COM port labeled "Silicon Labs CP210x USB to UART Bridge (COM<x>)", where <x> is the COM port allocated for the dimmer switch. Click "OK".
7. Data should now be streaming from the device. If an error is generated stating that no data has been received within five seconds, click "OK" and reset the SB1 by pressing the SB1 RST button S1 on the back of the dimmer switch.

For more information on how to use Simplicity Studio's Capacitive Sense Profiler, read: AN0829: "Capacitive Sensing Library Configuration Guide".

9. Engineering Tests

This reference design has undergone the following product testing for pre-certification purposes:
- Zigbee Home Automation (HA) v1.2
- FCC Emissions
- Antenna Radiation Patterns

9.1 Zigbee Home Automation (HA) v1.2

The dimmer switch went through a preliminary HA 1.2 testing to verify compliance with the zigbee standard.

9.2 FCC Emissions Testing

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

10. 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. It will outline recommended test equipment and test procedure.

10.1 Test Coverage

By following these guidelines, the following items will be tested and verified for functionality:
- RF TX/RX performance
- Current consumption
- Capacitive sense functionality
- Common zigbee operations
- Frequency offset (with optional spectrum analyzer)

10.2 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)

10.3 Test System Diagram
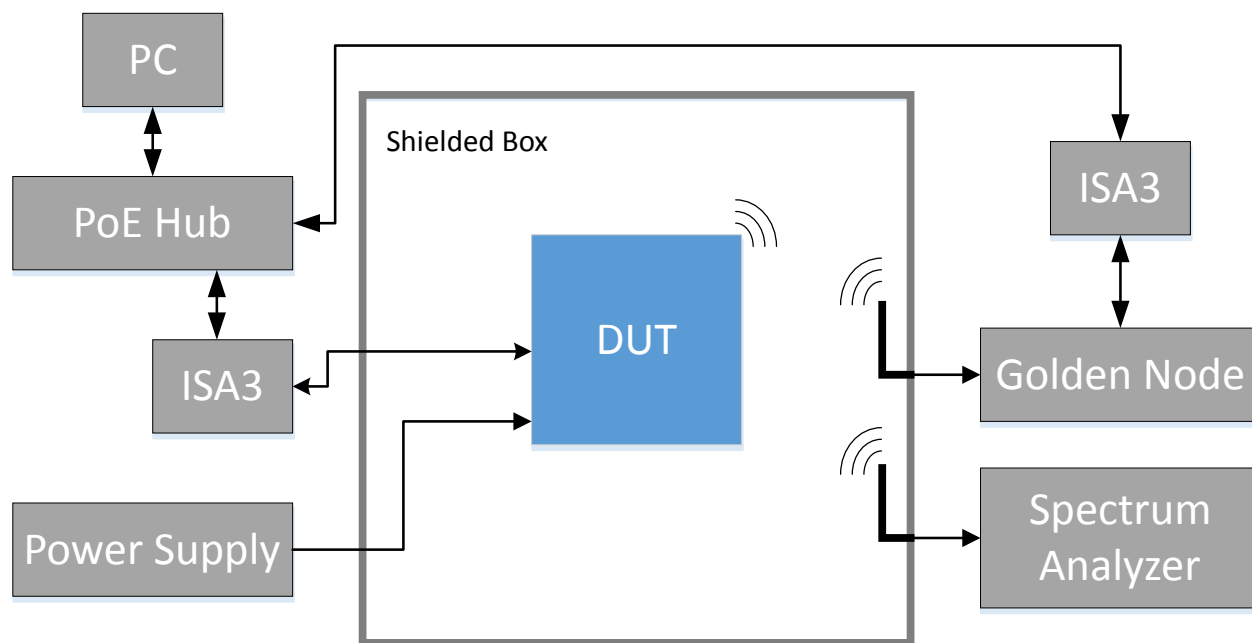
Figure 10.1. Test System Diagram

10.4 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, while 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.

The only thing in the shielded box should be connectors linked to the DUT, and connectors for 50 Ω antennas. If desired, a spectrum analyzer may be integrated into the system to measure frequency offset. Some tests, such as verification of the capacitive sense pad functionality may require operator interaction.

10.5 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. 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.

10.6 Communicating with Targets

For testing purposes, 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.

10.7 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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