![Silicon Labs logo](SILICON LABS)

UG250: Thunderboard Sense User's Guide

The Thunderboard™ Sense is the ultimate multi-sensor, multi-protocol cloud inspiration kit.

The board is a small and cost effective, feature rich, prototype and development platform based on the EFR32™ Mighty Gecko Wireless System-on-Chip. The Thunderboard Sense is an ideal platform for developing energy-friendly connected IoT devices. This is a true multi-protocol capable kit, supporting proprietary stacks and standard protocols such as Zigbee, Thread and Bluetooth® low energy.

The Thunderboard Sense ships with a ready to use Bluetooth demo that works with a cloud connected smartphone app, showcasing easy collection of environmental and motion sensor data.

A built in SEGGER J-Link debugger ensures easy customization and development.
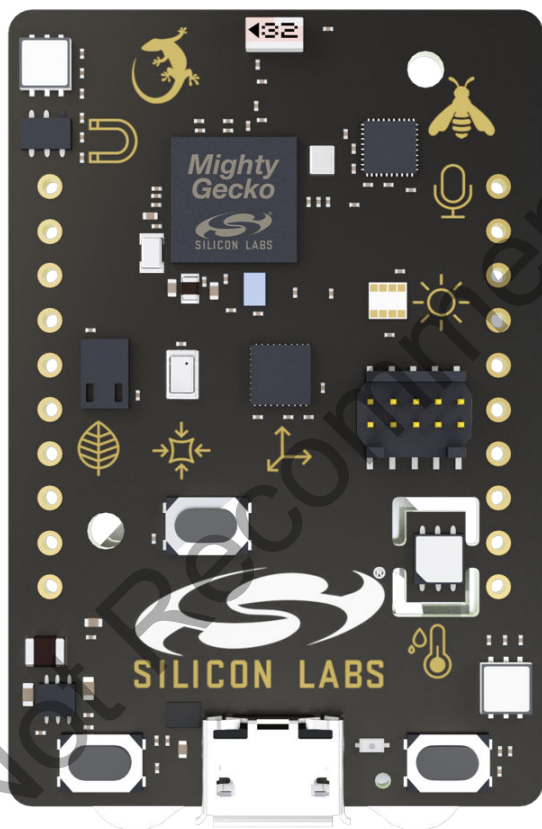
KEY POINTS

- EFR32 Mighty Gecko Wireless SoC
- Fine grained power-control for ultra low power operation
- 2.4 GHz ceramic chip antenna
- Six sensors and four high brightness controllable RGB LEDs
- User LEDs/pushbuttons
- 8-Mbit Flash for OTA programming
- SEGGER J-Link on-board debugger
- Virtual COM Port
- Mini Simplicity connector for AEM and packet trace using external Silicon Labs debugger
- 20-pin 2.54 mm breakout pads
- Power sources include USB, coin cell and external batteries

ON-BOARD SENSORS

- Relative humidity and temperature sensor
- UV index and ambient light sensor
- Indoor air quality gas sensor
- 6-axis inertial sensor
- Barometric pressure sensor
- MEMS microphone

SOFTWARE SUPPORT

- Simplicity Studio™
- Energy Profiler
- Network Analyzer

Table of Contents

1. Introduction

The Thunderboard Sense (OPN: SLTB001A) has been designed to inspire customers to make battery operated IoT devices with the Silicon Labs EFR32 Mighty Gecko Wireless System-on-Chip. The highlights of the board include six different environmental sensors and four high brightness RGB LEDs accessible to the EFR32 wireless MCU. The sensors and LEDs have been grouped into power domains that can be turned on and off by the application code as needed. By default, the board starts up in the lowest power operating mode, with all sensors disabled.

Programming the Thunderboard Sense is easily done using a USB Micro-B cable and the on-board J-Link debugger. A USB virtual COM port provides a serial connection to the target application. Included on the board is an 8 Mbit serial flash that can be used for Over-The-Air (OTA) firmware upgrade, or as a general purpose non-volatile memory. The Thunderboard Sense is supported in Simplicity Studio™, and a Board Support Package (BSP) is provided to give application developers a flying start.

Energy profiling and advanced wireless network analysis and debugging tools are available through the provided Mini Simplicity Connector using an external Silicon Labs debugger. See AN958 for more information about debugging and programming interfaces that can be used with Silicon Labs' starter kits.

Connecting external hardware to the Thunderboard Sense can be done using the 20 breakout pads which present peripherals from the EFR32 Mighty Gecko such as I^{2}C, SPI, UART and GPIOs. The breakout pads follow the same pinout as the expansion headers (EXP) on other Silicon Labs Starter Kits.
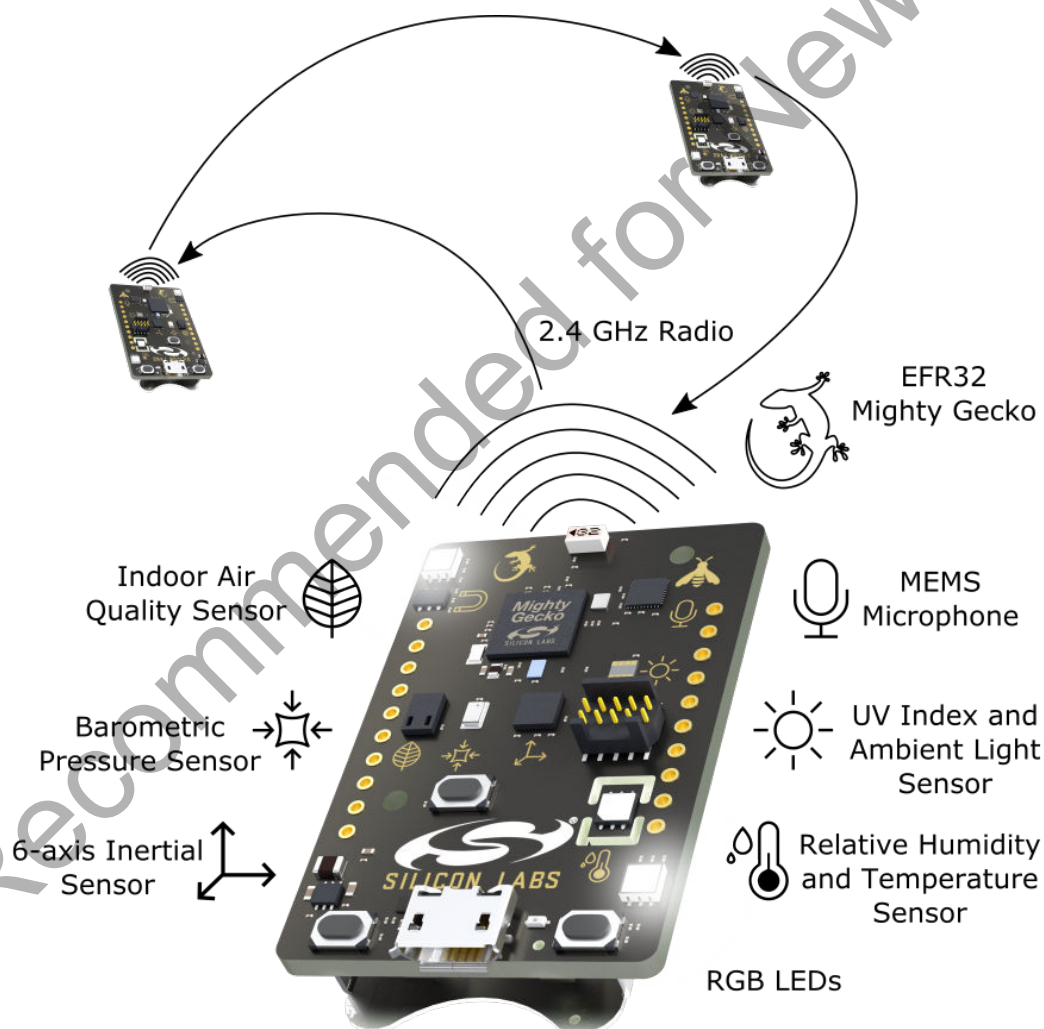
Figure 1.1. Thunderboard Sense

1.1 Kit Contents

The following items are included in the box:
• 1x Thunderboard Sense board (BRD4160A)

1.2 Hardware Content

The following key hardware elements are included on the Thunderboard Sense:
• EFR32 Mighty Gecko Wireless SoC with a 2.4 GHz ceramic antenna for wireless transmission
• Power and interrupt controller for fine grained power-control based on a Silicon Labs EFM8 Sleepy Bee microcontroller
• Silicon Labs Si7021 Relative Humidity and Temperature Sensor
• Silicon Labs Si1133 UV Index and Ambient Light Sensor
• Bosch Sensortec BMP280 Barometric Pressure Sensor
• Cambridge CMOS Sensors CCS811 Indoor Air Quality Gas Sensor
• InvenSense ICM-20648 6-Axis Inertial Sensor
• Knowles SPV1840 MEMS Microphone
• Four high brightness RGB LEDs, one bi-color LED and two push buttons
• Macronix Ultra Low Power 8-Mbit SPI Flash (MX25R8035F)
• On-board SEGGER J-Link debugger for easy programming and debugging, and with a virtual COM port through the USB Micro-B connector
• Mini Simplicity connector for access to energy profiling and advanced wireless network debugging
• Breakout pads for connection to external hardware
• Reset button and automatic switchover between USB and battery power
• CR2032 coin cell connector and external battery connector

1.3 Kit Hardware Layout

The layout of the Thunderboard Sense is shown below.
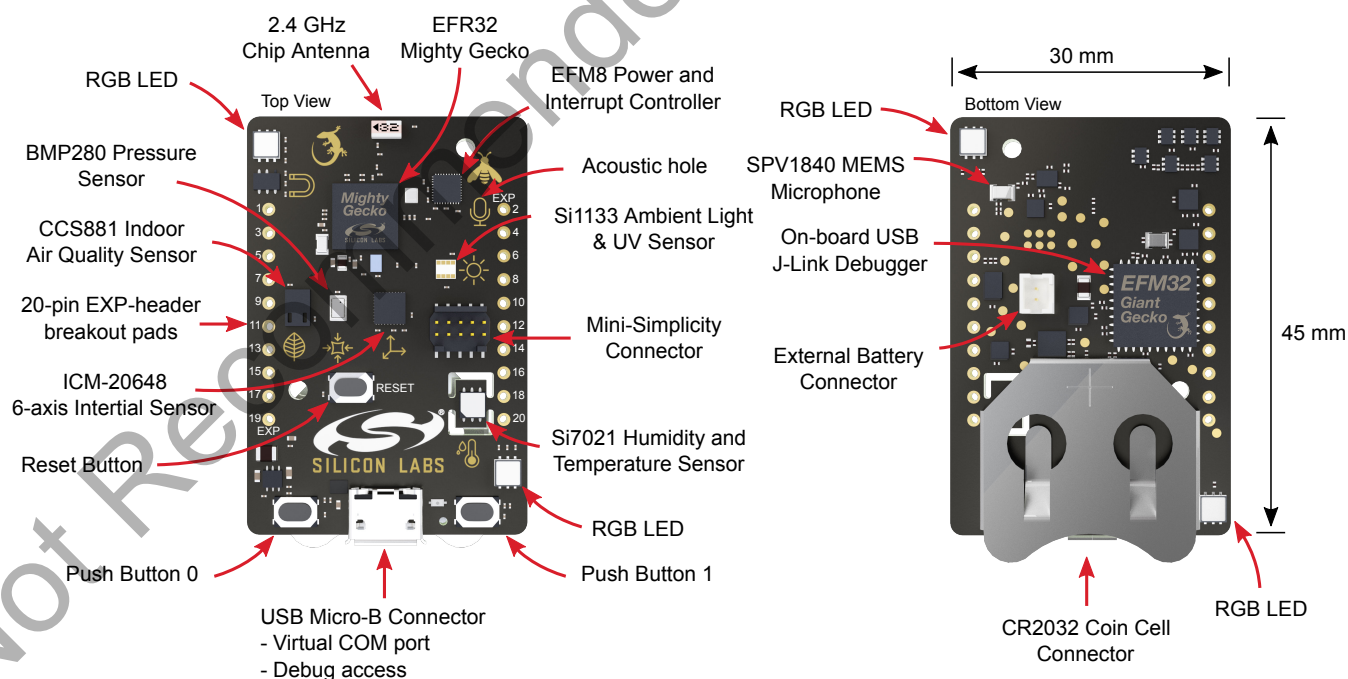
Figure 1.2. Thunderboard Sense Hardware Layout

2. Specifications

2.1 Absolute Maximum Ratings

Parameter	Symbol	Min	Typ	Max	Unit
USB Input Voltage	$V_{USB-MAX}$	0		+5.5	V
Supply Voltage VMCU	V_{VDDMAX}	0		+3.8	V
LDO output current	$I_{VREG-LOAD}$			300	mA
Voltage on any I/O pin	V_{DIGPIN}	-0.3		VMCU+0.3	V
Current per I/O pin (sink)	I_{IOMAX}			50	mA
Current per I/O pin (source)	I_{IOMAX}			50	mA
Current for all I/O pins (sink)	$I_{IOALLMAX}$			200	mA
Current for all I/O pins (source)	$I_{IOALLMAX}$			200	mA
Storage Temperature	T_{stg}	-40		+85	˚C
ESD Susceptibility HBM (Human Body Model)	V_{ESD}			2	kV

2.2 Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
Supply Input Voltage	V_{USB}	+4.5	+5.0	+5.5	V
Supply Input Voltage	V_{VBAT}	+2.0		+3.8	V
Supply Input Voltage (VMCU supplied externally)	V_{VMCU}	+2.0		+3.8	V
LDO Output Voltage	V_{REG}	+3.0	+3.3	+3.6	V
Operating Temperature	T_{OP}	0		70	˚C

2.3 Current Consumption

The operating current of the board greatly depends on the application. The number of enabled sensors, how often they are sampled and how often the radio is transmitting or receiving are examples of factors that influence the operating current. The table below attempts to give some indication of how different features of the board contribute to the overall power consumption.

Table 2.1. Current Consumption, all values at 25°C and VMCU = 3.3 V

Parameter	Symbol	Condition	Min	Typ	Max	Unit
EFR32 Current Consumption [1]	I_{EFR32}	EFR32 in EM0 Active mode		3.4		mA
		Radio in receive mode		8.7		mA
		Radio transmitter active @ 8 dBm		23.3		mA
		EFR32 in EM4S, all power domains disabled [2]		0.25		µA
Environmental Sensor Group Current Consumption	I_{ENV}	Turned off and isolated (leakage) [3]		0.3	15	nA
		Enabled, all sensors in standby [4]		0.29	1.2	µA
UV/ALS Current Consumption [5]	I_{Si1133}	Standby		0.125		µA
		ADC Conversion in Progress		0.525		µA
		Responding to commands and calculating results		4.25		mA
RH/Temp Sensor Current Consumption [6]	I_{Si7021}	Standby, -40 to +85°C		0.06	0.62	µA
		RH conversion in progress		150	180	µA
		Temperature conversion in progress		90	120	µA
		Peak I_{DD} during I^2C operations		3.5	4.0	mA
Barometric Pressure Sensor Current Consumption [7]	I_{BMP280}	Sleep current		0.1	0.3	µA
		1 Hz forced mode, pressure & temperature, lowest power		2.8	4.2	µA
		Peak current during pressure measurement		0.72	1.12	mA
		Current at temperature measurement		0.33		mA
Microphone Current Consumption	I_{MIC}	Turned off			50	nA
		Enabled, not sampling [8]		0.20	0.37	mA
		Sampling @ 1 kHz with EFR32 in EM2 [2]		0.28		mA
		Sampling @ 16 kHz with EFR32 in EM2 [2]		1.44		mA
CCS811 Current Consumption [9]	I_{CCS811}	Turned off and isolated (leakage) [3]		0.3	15	nA
		Enabled, sleep mode		3		µA
		During measurement		20		mA
		Average for a measurement every 60 seconds		0.67		mA

Parameter	Symbol	Condition	Min	Typ	Max	Unit
IMU Current Consumption [10]	I_{IMU}	Turned off and isolated (leakage) [3]		0.5	25	nA
		Full-chip sleep mode		8		µA
		Gyroscope Only, 102.3 Hz update rate		1.23		mA
		Accelerometer only, 102.3 Hz update rate		68.9		µA
		Gyroscope + Accelerometer, 102.3 Hz update rate		1.27		mA
RGB LED Current Consumption	I_{RGB}	Turned off		0.1	0.3	µA
		Power Enabled, all LEDs off		65		µA
		Additional current for each enabled LED		10		µA
		Current per LED, all colors 100% duty cycle		29.9		mA
Power and Interrupt Controller [2]	I_{PIC}	Idle		80		nA
		Awake, responding to I²C commands		0.54		mA
On-board Debugger Current Consumption	I_{DBG}	USB cable inserted, current sourced from USB 5V		29		mA
		USB cable removed, current sourced from VMCU rail.		20		nA

1   From EFR32 Mighty Gecko SoC datasheet
2   Measured with advanced energy monitor (AEM) using a Wireless Starter Kit (WSTK)
3   From TS3A4751 datasheet
4   Combination of UV/ALS, RH/Temp and BMP sensors' sleep currents
5   From Si1133 datasheet
6   From Si7021-A20 datasheet
7   From BMP280 datasheet
8   Based on microphone, OP-AMP and LDO datasheets
9   From CCS811 datasheet
10   From ICM-20648 datasheet

3. Hardware

The core of the Thunderboard Sense is the EFR32 Mighty Gecko Wireless System-on-Chip. The board also contains a multitude of sensors, including various environmental sensors and a motion sensor, all connected to the EFR32. The user interface components include push buttons, a bi-colour LED and four high brightness RGB LEDs.

The key aspects of the hardware will be explained in this chapter, while in-depth information on the EFR32 Mighty Gecko SoC can be found in the EFR32MG datasheet and reference manual. For placement and layout of the hardware components the reader is referred to 1.3 Kit Hardware Layout.

3.1 Block Diagram

An overview of the Thunderboard Sense is illustrated in the figure below.
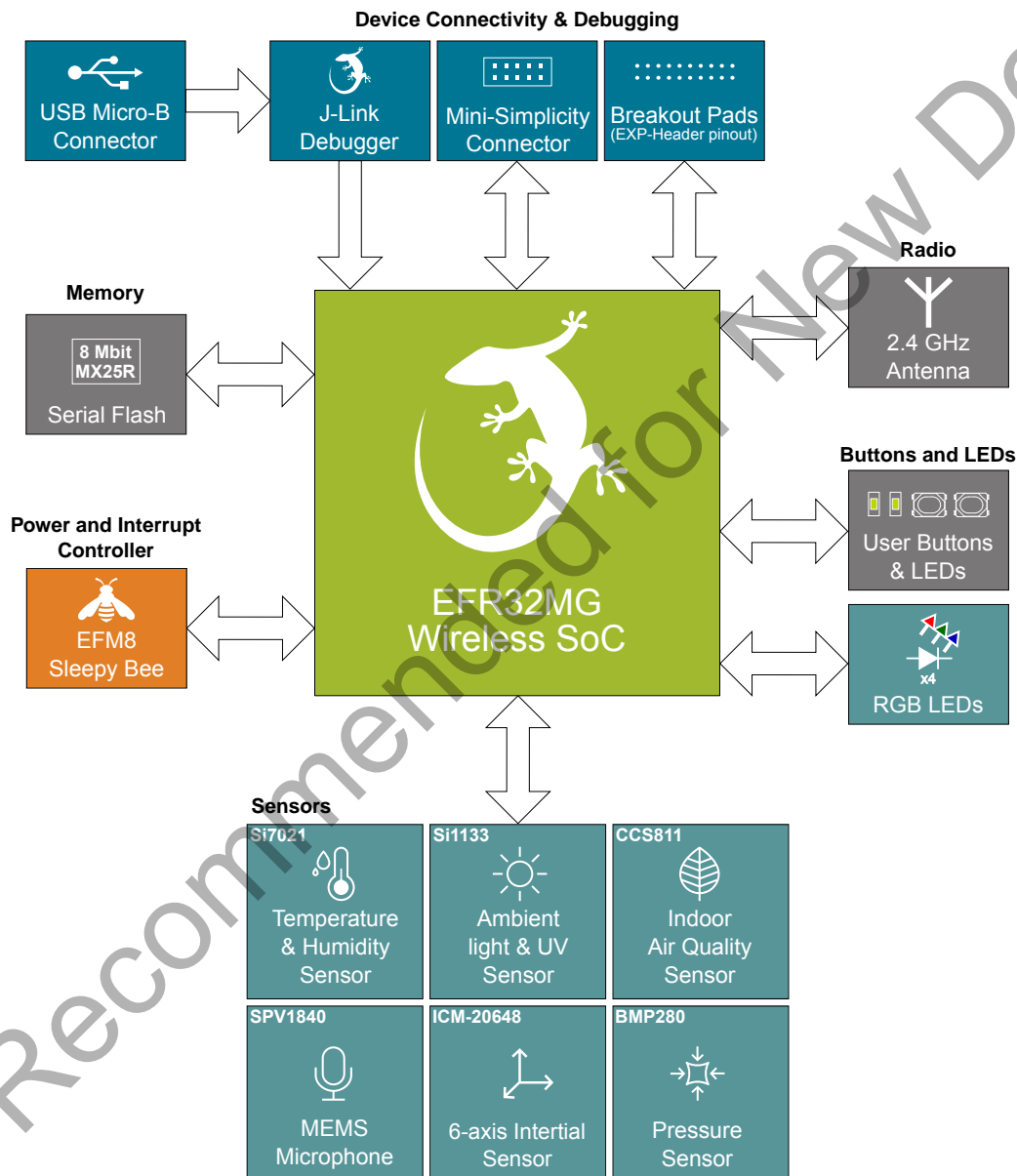

Figure 3.1. Kit Block Diagram

3.2 Power Supply

There are several ways to power the kit. The options include battery, on-board LDO from USB and the Mini Simplicity connector. Figure 3.2 Thunderboard Sense Power Options on page 10 shows the power options available on the kit and illustrates the main system power architecture.
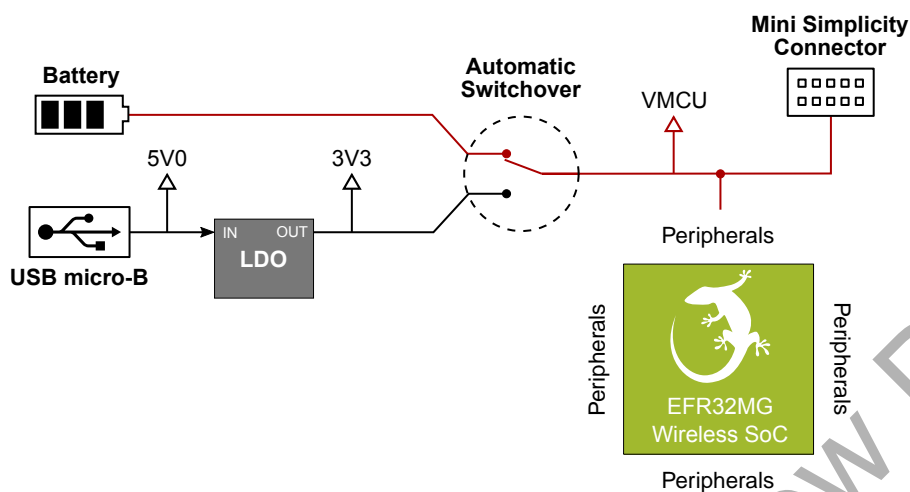

Figure 3.2. Thunderboard Sense Power Options

In normal operation, power can be applied using either a USB cable connected to a power source, or a battery connected to one of the battery connectors. The 5 volt power net on the USB bus is regulated down to 3.3 volt using a low-dropout regulator. An automatic switchover circuit switches the main system power from battery power to USB power when the USB cable is inserted, and prevents charging of the battery.

Batteries can be connected to the Thunderboard Sense using either the CR2032 coin cell connector or the external battery connector. A CR2032 coin cell is sufficient for low power operation that does not require high peak current. More demanding applications, such as enabling the RGB LEDs at high intensities, might need a higher capacity external battery or USB power.

Note: Do not connect batteries to both the CR2032 coin cell connector and the external battery connector at the same time.

A third option for powering the Thunderboard Sense exists through the Mini Simplicity connector. This option requires that no other power sources are present on the kit, as the power is injected directly to the VMCU power net. Powering the Thunderboard Sense through the Mini Simplicity connector with an external Silicon Labs debugger allows accurate current measurements using the Advanced Energy Monitoring (AEM) feature of the external debugger. For more information about using the Mini Simplicity connector, please refer to 4.3 Mini Simplicity Connector.

Note: When powering the board through the Mini Simplicity connector, the USB and battery power sources must be removed.

The power supply options are summarized in Table 3.1 Thunderboard Sense Power Options on page 10. For placement of the USB and battery connectors the reader is referred to 1.3 Kit Hardware Layout.

Table 3.1. Thunderboard Sense Power Options

Supply mode	VIN	VMCU	3V3	5V0
USB power	4.5 - 5.5 V	On-board regulator	On-board regulator	USB VBUS
CR2032 battery	2.0 - 3.8 V	Battery voltage	Turned off and isolated	No voltage present
External battery	2.0 - 3.8 V	Battery voltage	Turned off and isolated	No voltage present
Mini Simplicity	2.0 - 3.8 V	Debugger dependent	Turned off and isolated	No voltage present

3.3 EFR32 Reset

The EFR32 Wireless SoC can be reset by a few different sources:
- A user pressing the RESET button.
- The on-board debugger pulling the #RESET pin low.
- An external debugger pulling the #RESET pin low.

In addition to the reset sources mentioned above, the debugger will also issue a reset to the EFR32 when starting up. This means that removing power to the debugger (unplugging the USB Micro-B cable) will not generate a reset, but plugging the cable back in will cause a reset as the debugger starts up.

3.4 Peripheral Power Domains

The sensors that make up most of the peripheral set of the Thunderboard Sense are grouped into power domains that are turned off when not in use. This allows for the lowest possible power consumption in every application. To help out with controlling the separate power domains, a Silicon Labs EFM8 Sleepy Bee microcontroller is used as an on-board Power and Interrupt Controller. By default, all sensors are disabled when the board powers up.

The EFM8 Sleepy Bee comes pre-programmed with a simple register interface accessible over the I^2C bus, which is used to enable and disable power to the different sensors and the RGB LEDs on the board. It also contains a simple interrupt controller that aggregates interrupts from the sensors and notifies the host in case of interrupt events.

The EFM8 Sleepy Bee itself spends most of the time in sleep mode, and consumes very little power when doing so. In order for it to respond to I^2C commands, the device must first be woken up. The INT/WAKE pin (PD10) functions as a dual role interrupt/wake-up pin. The EFR32 pulses this pin low to wake up the EFM8, and the EFM8 pulses the pin low to notify the host of interrupt events.

More details on communication between the EFR32 and the power controller, as well as register map and information related to the interrupt controller, can be found in 5. Power and Interrupt Controller.

The different power connections are illustrated in the figure below.
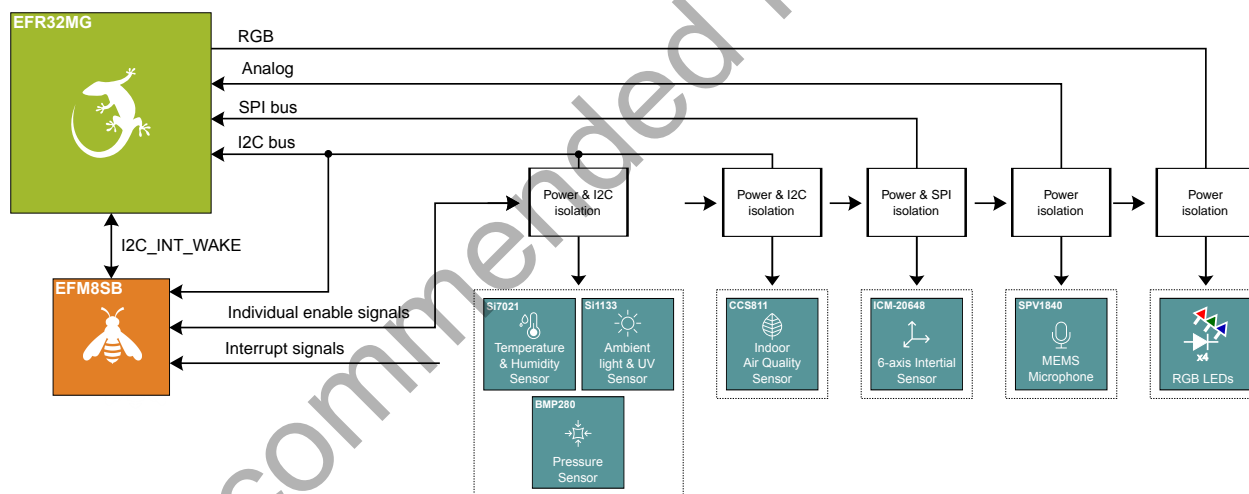
Figure 3.3. Power Domain Architecture

3.5 Sensors

The Thunderboard Sense contains six different sensors which can be accessed from the EFR32 over the I^2C and SPI interfaces.

- Silicon Labs Si7021 Relative Humidity & Temperature Sensor
- Silicon Labs Si1133 UV Index & Ambient Light Sensor
- Bosch BMP280 Barometric Pressure Sensor
- Cambridge CMOS Sensors CCS811 Indoor Air Quality Gas Sensor
- InvenSense ICM-20648 6-axis Inertial Measurement Sensor
- Knowles SPV1840LR5H-B MEMS Microphone

3.5.1 Si7021 Relative Humidity and Temperature Sensor

The Si7021 I^{2}C relative humidity and temperature sensor is a monolithic CMOS IC integrating humidity and temperature sensor elements, an analog-to-digital converter, signal processing, calibration data, and an I^{2}C Interface. The patented use of industry-standard, low-K polymeric dielectrics for sensing humidity enables the construction of low-power, monolithic CMOS Sensor ICs with low drift and hysteresis, and excellent long term stability.

The Si7021 offers an accurate, low-power, factory-calibrated digital solution ideal for measuring humidity, dew-point, and temperature, in applications ranging from HVAC/R and asset tracking to industrial and consumer platforms.

On the Thunderboard Sense, the Si7021 is powered down and isolated by default. To use the sensor, 0x01 must be written to the ENV_SENSOR_CTRL register in the Power and Interrupt Controller, as described in 5. Power and Interrupt Controller. Doing so enables power to the Si7021 and connects the I^{2}C lines used for the sensor to the main I^{2}C bus. The Si7021 shares power and I^{2}C bus isolation switch with the Si1133 and BMP280 sensor, and hence, all these sensors are powered and connected to the main I^{2}C bus once 0x01 has been written to the ENV_SENSOR_CTRL register. The hardware connection is illustrated in Figure 3.3 Power Domain Architecture on page 11 and Figure 3.4 Si7021 Relative Humidity and Temperature Sensor on page 12
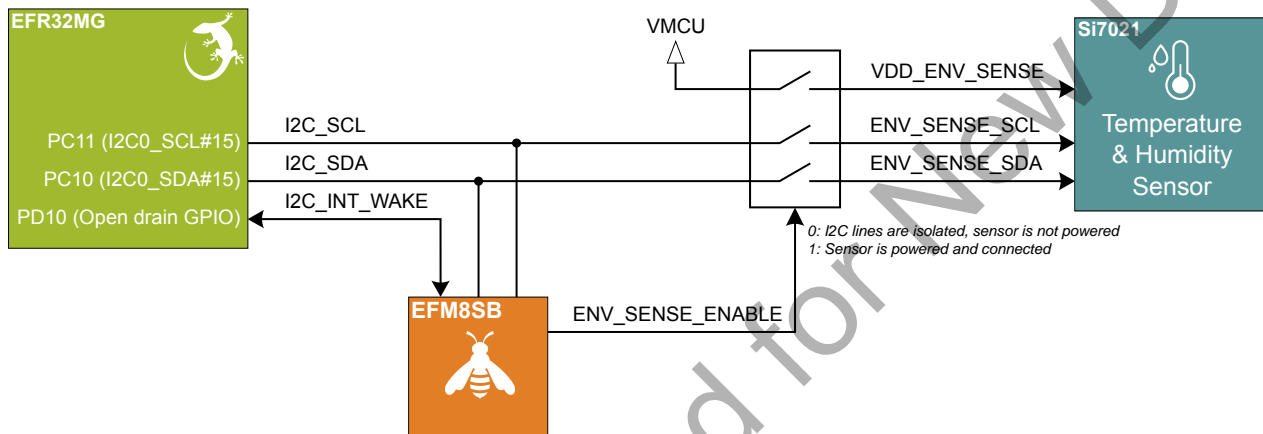

Figure 3.4. Si7021 Relative Humidity and Temperature Sensor

Note: Due to self-heating from the on-board LDO, temperature measurements are slightly off when running off USB power. More accurate temperature measurements are achieved when powering the board with a battery or through the Mini Simplicity connector.

3.5.2 Si1133 UV Index and Ambient Light Sensor

The Si1133 is a UV index and ambient light sensor with I^2C digital interface and programmable event interrupt output. This sensor IC includes dual 23-bit analog-to-digital converters, integrated high-sensitivity array of UV, visible and infrared photodiodes, and digital signal processor.

On the Thunderboard Sense, the Si1133 is powered down and isolated by default. To use the sensor, 0x01 must be written to the ENV_SENSOR_CTRL register in the Power and Interrupt Controller, as described in 5. Power and Interrupt Controller. Doing so enables power to the Si1133 and connects the I^2C lines used for the sensor to the main I^2C bus. The Si1133 shares power and I^2C bus isolation switch with the Si7021 and BMP280 sensor, and hence, all these sensors are powered and connected to the main I^2C bus once 0x01 has been written to the ENV_SENSOR_CTRL register. The Si1133 has furthermore an interrupt pin that can generate an interrupt signal whenever a new sample is ready. There are several settings for handling the interrupt signal in the Power and Interrupt Controller as explained in 5.3 Interrupt Controller. The hardware connection is illustrated in Figure 3.3 Power Domain Architecture on page 11 and Figure 3.5 Si1133 UV and Ambient Light Sensor on page 13

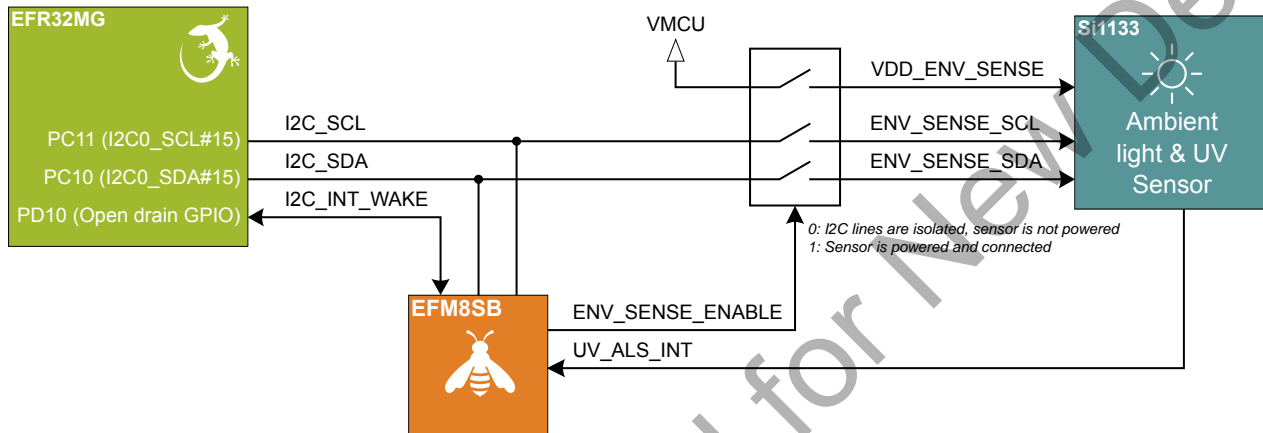**Figure 3.5. Si1133 UV and Ambient Light Sensor**

3.5.3 BMP280 Barometric Pressure Sensor

The BMP280 is a combined absolute barometric pressure sensor and temperature sensor with a digital interface supporting both SPI and I^2C. No external sensing elements are needed, and the device has an integrated ADC and ASIC with built-in configurable IIR filter to suppress noise. Selectable oversampling rates provides trade off between low power and high resolution, and an option to skip either temperature or pressure measurement is available in case one or the other is unnecessary.

On the Thunderboard Sense, the BMP280 is powered down and isolated by default. To use the sensor, 0x01 must be written to the ENV_SENSOR_CTRL register in the Power and Interrupt Controller, as described in 5. Power and Interrupt Controller. Doing so enables power to the BMP280 and connects the I^2C lines used for the sensor to the main I^2C bus. The BMP280 shares power and I^2C bus isolation switch with the Si7021 and Si1133 sensor, and hence, all these sensors are powered and connected to the main I^2C bus once 0x01 has been written to the ENV_SENSOR_CTRL register. The hardware connection is illustrated in Figure 3.3 Power Domain Architecture on page 11 and Figure 3.6 BMP280 Absolute Pressure Sensor on page 14.

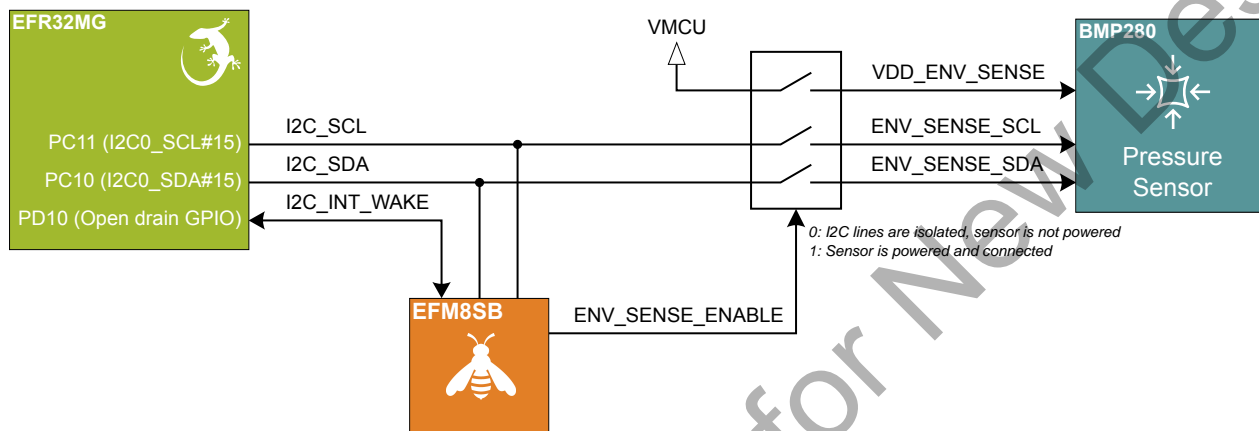**Figure 3.6. BMP280 Absolute Pressure Sensor**

3.5.4 CCS811 Indoor Air Quality Gas Sensor

The CCS811 is a digital gas sensor solution for indoor air quality monitoring over the I^{2}C interface. Gases that can be detected by the CCS811 includes ethanol and hazardous gases such as carbon monoxide and a wide range of volatile organic compounds (VOCs).

On the Thunderboard Sense, the CCS811 is powered down and isolated by default. To use the sensor, power must be enabled to the sensor, and it has to be woken up from sleep using the sensor's dedicated "wake" pin. Both are done by setting bits in the CCS_CTRL register in the Power and Interrupt Controller. See 5. Power and Interrupt Controller for details.

The CCS811 has furthermore an interrupt pin that can generate an interrupt signal whenever a new sample is ready. There are several settings for handling the interrupt signal in the Power and Interrupt Controller as explained in 5.3 Interrupt Controller. The hardware connection is illustrated in Figure 3.3 Power Domain Architecture on page 11 and Figure 3.7 CCS811 Indoor Air Quality and Gas Sensor on page 15.
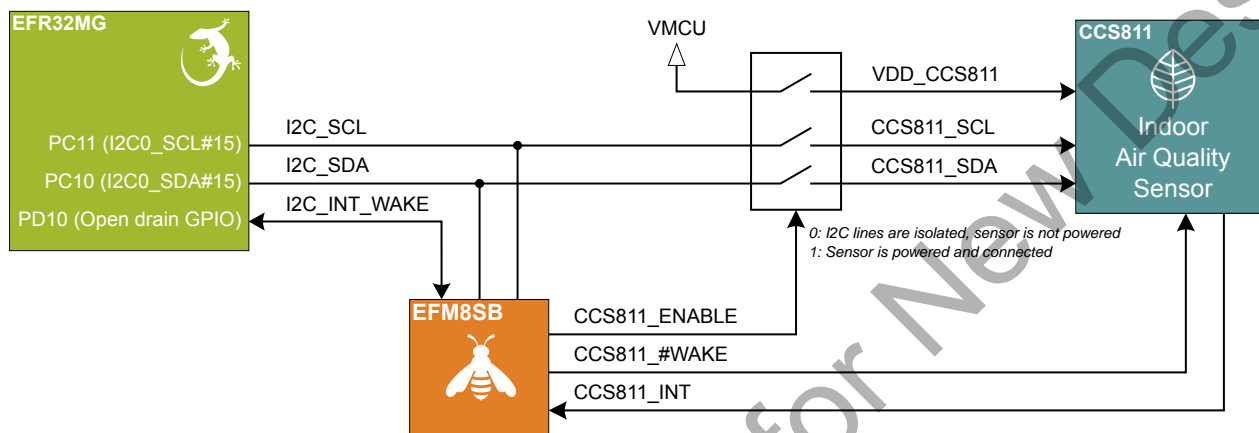

Figure 3.7. CCS811 Indoor Air Quality and Gas Sensor

3.5.5 ICM-20648 6-Axis Inertial Sensor

The ICM-20648 is a 6-axis inertial sensor consisting of a 3-axis gyroscope and a 3-axis accelerometer. Acceleration is detected independently along the X-, Y-, and Z- axes with 16-bit ADCs, in addition to the angular rates around the same axes. An integrated processor computes motion processing algorithms for ease of use and improved system power performance. The device supports both the SPI and I^{2}C interface.

On the Thunderboard Sense, the inertial sensor is located in the center of the board. The coordinate system and rotation of the sensor follows the right-hand rule, and the spatial orientation of the board is shown in Figure 3.8 Thunderboard Sense Spatial Orientation on page 16.
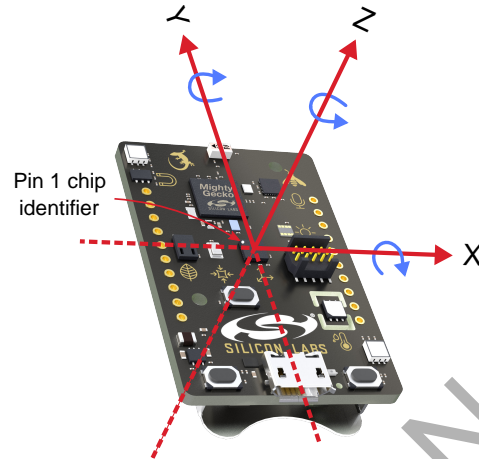
Figure 3.8. Thunderboard Sense Spatial Orientation

On the Thunderboard Sense, the ICM-20648 is powered down and isolated by default. To use the sensor, 0x01 must be written to the IMU_CTRL register in the Power and Interrupt Controller, as described in 5. Power and Interrupt Controller. Doing so enables power to the ICM-20648 and connects the SPI lines used for the sensor to the main SPI bus. The SPI interface is shared between the ICM-20648 and the SPI Flash, but uses separate chip select signals for the two devices. The ICM-20648 has an interrupt pin which, when enabled, generates an interrupt signal whenever a new sample is ready. There are several settings for handling the interrupt signal in the Power and Interrupt Controller as explained in 5.3 Interrupt Controller. The hardware connection is illustrated in Figure 3.3 Power Domain Architecture on page 11 and Figure 3.9 ICM-20648 Six-axis Inertial Sensor on page 16.

Figure 3.9. ICM-20648 Six-axis Inertial Sensor

3.5.6 SPV1840 MEMS Microphone

The SPV1840 is an omnidirectional MEMS microphone with high performance and low power consumption in a miniature 3.75 x 1.85 x 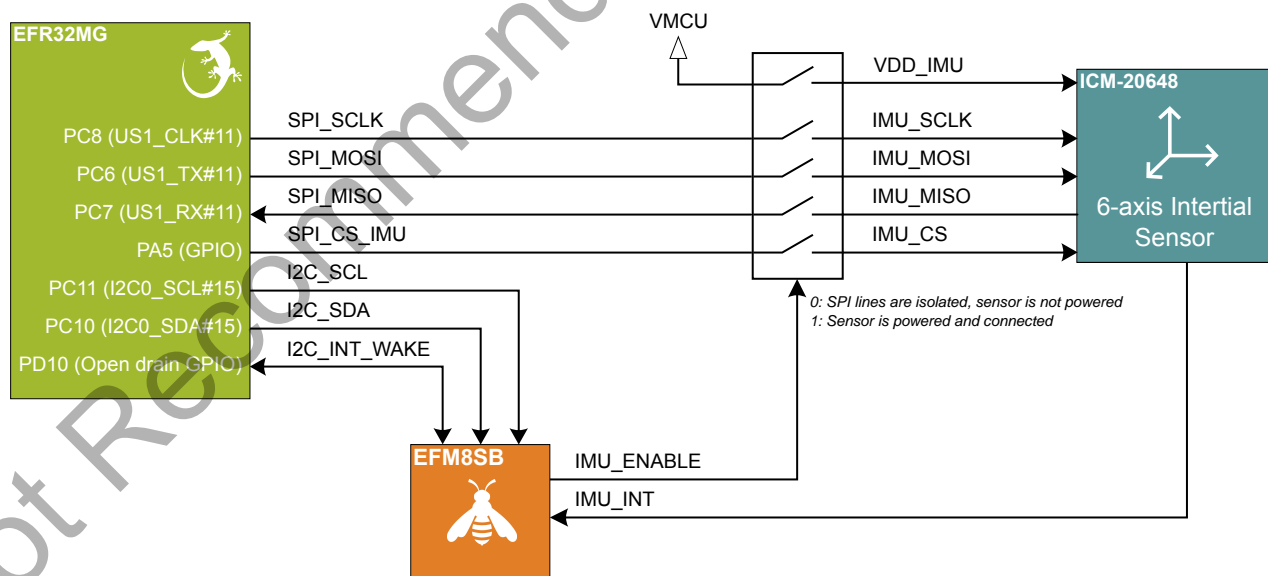0.90 mm surface mount package. Included on the SPV1840 is an acoustic sensor, a low noise input buffer and an output amplifier. The microphone is suitable in applications requiring excellent audio performance and RF immunity.

The SPV1840 is placed on the bottom side of the Thunderboard Sense with an acoustic ventilation hole going through to the top side. This hole lets sound waves travel unimpeded from the top side of the board to the acoustic port of the MEMS microphone located on the back side of the component. The top side of the board should therefore be oriented against the sound source for best possible performance. Following the microphone is a signal processing stage containing an amplifier with 32.1 dB gain (-40.2 V/V) and an active first order low pass filter with a cut-off frequency of 10 kHz.

On the Thunderboard Sense, the SPV1840 is powered down by default. To use the sensor, 0x01 must be written to the MIC_CTRL register in the Power and Interrupt Controller, as described in 5. Power and Interrupt Controller. This turns on the low-dropout regulator powering both the microphone and the signal processing stage. The analog microphone signal is transmitted to the ADC of the EFR32. The hardware connection is illustrated in Figure 3.3 Power Domain Architecture on page 11 and Figure 3.10 SPV1840 MEMS Microphone on page 17
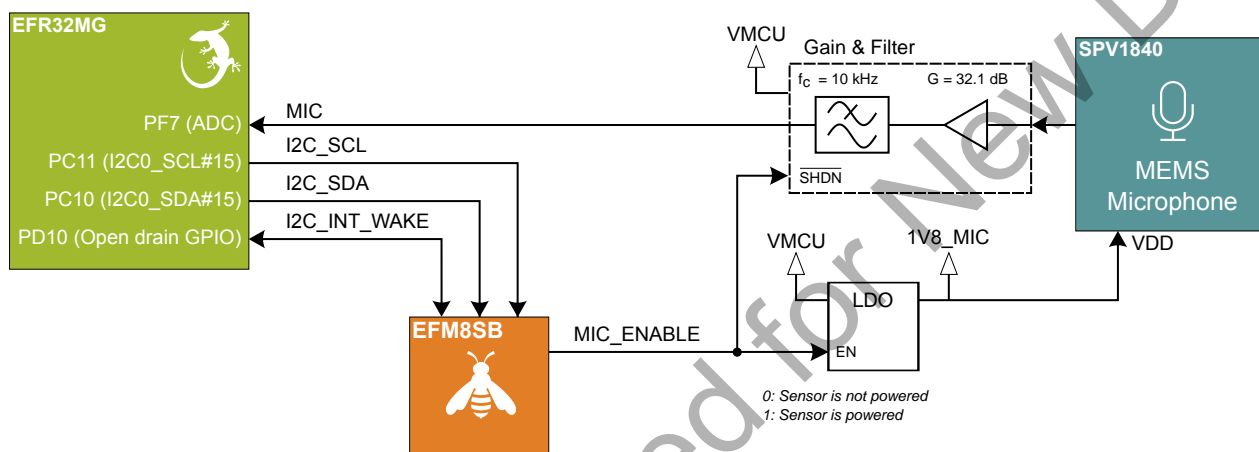

Figure 3.10. SPV1840 MEMS Microphone

3.6 LEDs

The board contains one low power bi-color LED (red/green), and four high brightness RGB LEDs. The low power LED and the RGB LEDs share the same I/O pins, but the RGB LEDs can be individually enabled/disabled through the Power and Interrupt Controller. Figure 3.11 LEDs on page 18 shows how the different LEDs are connected to the EFR32, and how power to the RGB LEDs is controlled.

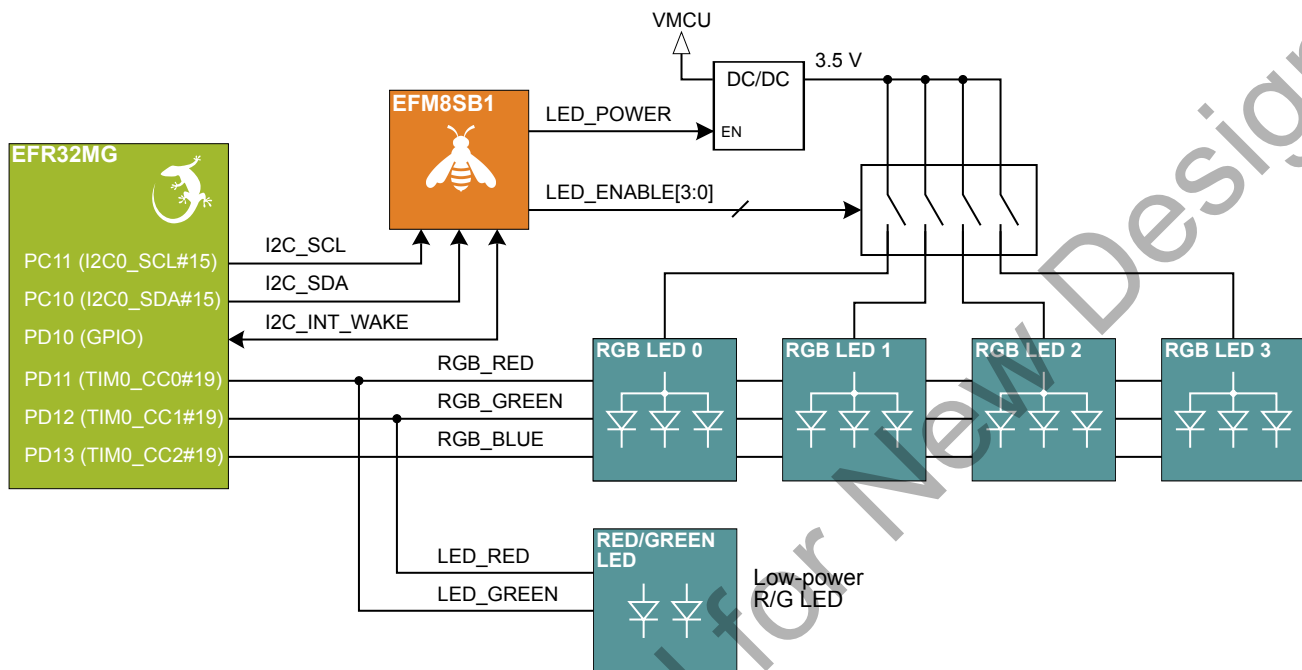The following sections contain more detailed information.

Figure 3.11. LEDs

3.6.1 RGB LEDs

The RGB LEDs are driven from a 3.5 V rail that is generated by a boost regulator. This ensures that the color representation remains constant even if the battery voltage drops below the LED forward voltage (V_f).

The boost regulator and each LED is individually enabled by writing to the LED_CTRL register in the power domain and interrupt controller. The cathodes of the same color of each LED are tied together, so that all enabled RGB LEDs will show the same color. The RGB LED hardware includes fast low-side drivers, so that any color can be created using the TIMER peripheral in the EFR32 in pulse width modulation (PWM) mode.

Because of the high current consumption, the RGB LEDs are not suitable for use in a coin cell application. Even with a low duty cycle PWM, the pulsed current can easily exceed 100 mA when all LEDs are enabled. Because of the boost regulator, the actual current drain increases slightly as the battery voltage decreases.

Table 3.2. RGB LED Typical Power Consumption at 3.3V VMCU

Color	1x LED	2x LEDs	3x LEDs	4x LEDs
Red, 100% duty cycle	13.4 mA	26.8 mA	40.2 mA	53.6 mA
Green, 100% duty cycle	8.0 mA	16.0 mA	24.0 mA	32.0 mA
Blue, 100% duty cycle	8.5 mA	17.0 mA	25.5 mA	34.0 mA
All, 100% duty cycle (white)	29.9 mA	59.8 mA	89.7 mA	119.6 mA

Turning off the boost regulator and the individual RGB LEDs reduces the quiescent current to about 100 nA typically. Turning on the boost regulator increases the quiescent current to about 65 µA, even with no LEDs enabled. Due to the high side drivers, each enabled LED adds an additional 10 µA of quiescent current even if the red, green and blue signals are all off.

3.6.2 Low power red/green LED

The board contains a small bi-color LED that is directly connected to PD11 and PD12 through current limiting resistors. Since these are directly connected, they cannot be disabled, and will always light up when these lines are driven high.

The current consumption of this LED is fairly low compared to the RGB LEDs, so the use of this LED is suitable for coin cell applications. The red LED consumes about 0.8 mA @ 3.3 V, and the green LED about 0.7 mA @ 3.3 V.

Note: The pin that drives the green line of the RGB LEDs is connected to the red low-power LED, and the red line of the RGB LEDs is connected to the green low-power LED.

3.7 Push Buttons

The kit has two user push buttons. Push button 0 is located at the bottom left corner of the board, while push button 1 is located at the bottom right corner of the board. The push buttons are connected to pin PD14 and PD15 respectively. Both push buttons are active low and de-bounced by an RC filter with a time constant of 1 ms.
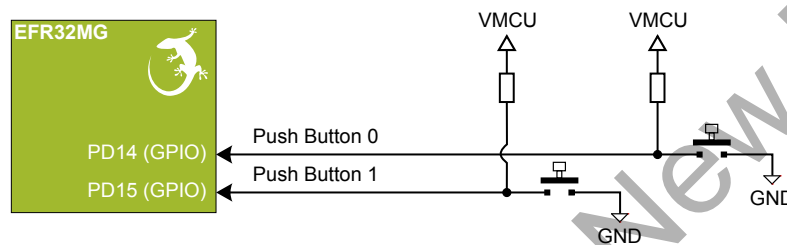
Figure 3.12. Push Buttons

3.8 Memory

The Thunderboard Sense is equipped with an 8-Mbit Macronix SPI Flash that is connected directly to the EFR32 Mighty Gecko. Figure 3.13 Serial Flash on page 19 shows how the serial flash is connected to the EFR32. The SPI bus used for the flash is shared with the ICM-20648 six-axis inertial sensor.
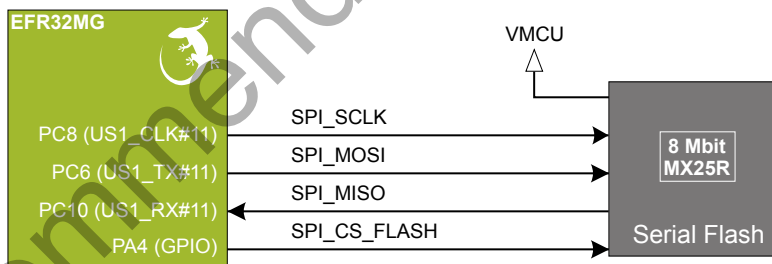
Figure 3.13. Serial Flash

The MX25R series are ultra low power serial flash devices, so there is no need for a separate enable switch to keep current consumption down. However, it is important that the flash is always put in deep power down mode when not used. This is done by issuing a command over the SPI interface. In deep power down, the MX25R typically adds approximately 100 nA to the current consumption.

3.9 On-board Debugger

The Thunderboard Sense contains a microcontroller separate from the EFR32 Mighty Gecko that provides the user with a on-board J-Link debugger through the USB micro-B port. This microcontroller is referred to as the "On-board Debugger", and is not programmable by the user.

In addition to providing code download and debug features, the on-board debugger also presents a virtual COM port for general purpose application serial data transfer.

Figure 3.14 On-Board Debugger Connections on page 20 shows the connections between the target EFR32 device and the on-board debugger. The figure also shows the presence of the Mini Simplicity Connector, and how this is connected to the same I/O pins. Please refer to chapter 4. Debugging for more details on debugging.
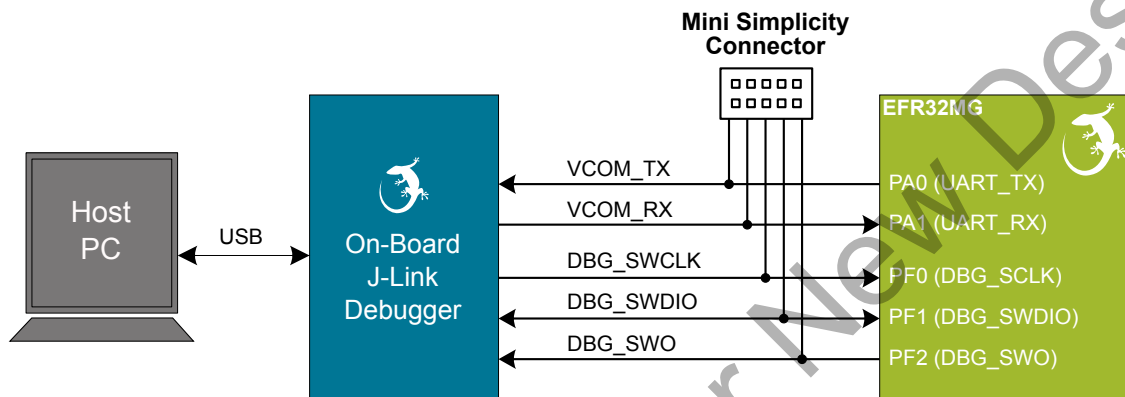
Figure 3.14. On-Board Debugger Connections

3.10 Connectors

Featured on the Thunderboard Sense is a Mini Simplicity connector, a USB Micro-B connector and 20 breakout pads that follow the expansion header pinout. The connectors are placed on the top side of the board, and their placement and pinout can be seen in Figure 3.15 Thunderboard Sense Connectors on page 20. For additional information on the connectors see the following sub chapters.

Figure 3.15. Thunderboard Sense Connectors

3.10.1 Breakout Pads

20 breakout pads, which follow the expansion header pinout, are provided and allow connection of peripherals or add-on boards. Ten of the pads are located along the left side of the board while the remaining ten are located on the right side of the board. The breakout pads contain a number of I/O pins that can be used with most of the EFR32 Mighty Gecko's features. Additionally, the VMCU (main board power rail), 3.3V (LDO regulator output) and 5V power rails are also exported.

The breakout pads are pinned out similar to the expansion header found on other Silicon Labs Starter Kits, which ensures that commonly used peripherals such as SPI, UART and I^{2}C buses are available on fixed locations. The rest of the pins are used for general purpose IO. This allows the definition of expansion boards that can plug into a number of different Silicon Labs starter kits.

The pin-routing on the EFR32 is very flexible, so most peripherals can be routed to any pin. However, some pins are shared between the breakout pads and other functions on the Thunderb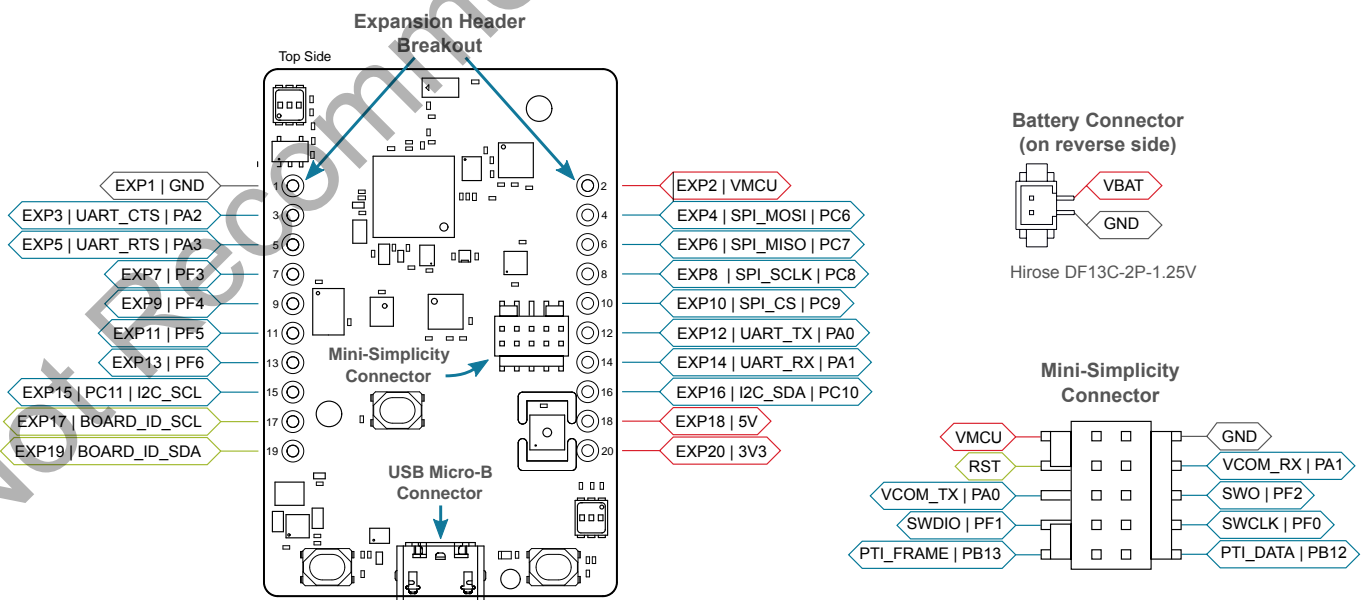oard Sense. Table 3.3 Expansion Header Pinout on page 21 includes an overview of the expansion header and functionality that is shared with the kit.

Table 3.3. Expansion Header Pinout

Pin	Connection	EXP Header Function	Shared Feature	Peripheral Mapping
		Right Side Breakout Pins		
2	VMCU	EFR32 voltage domain, included in AEM measurements.		
4	PC6	SPI_MOSI	IMU/SPI Flash	USART1_TX #11
6	PC7	SPI_MISO	IMU/SPI Flash	USART1_RX #11
8	PC8	SPI_SCLK	IMU/SPI Flash	USART1_CLK #11
10	PC9	SPI_CS		USART1_CS #11
12	PA0	UART_TX	Virtual COM Port	USART0_TX #0
14	PA1	UART_RX	Virtual COM Port	USART0_RX #0
16	PC10	I2C_SDA	Sensors/Power & Int. Controller	I2C0_SDA #15
18	5V	Board USB voltage		
20	3V3	Board controller supply		
		Left Side Breakout Pins		
1	GND	Ground		
3	PA2	GPIO		
5	PA3	GPIO		
7	PF3	GPIO		
9	PF4	GPIO		
11	PF5	GPIO		
13	PF6	GPIO		
15	PC11	I2C_SCL	Sensors/Power & Int. Controller	I2C0_SCL #15
17	BOARD_ID_SCL	Connected to Board Controller for identification of add-on boards.		
19	BOARD_ID_SDA	Connected to Board Controller for identification of add-on boards.		

3.10.2 Mini Simplicity Connector

The Mini Simplicity connector featured on the Thunderboard Sense allows the use of an external debugger such as a Silicon Labs Wireless Starter Kit (WSTK) with the board. In addition to providing serial wire debug (SWD) and virtual COM port functionality, the WSTK can also support advanced energy profiling and wireless network analysis and debugging tools. The pinout is described in 3.10.2 Mini Simplicity Connector.

Table 3.4. Mini Simplicity Connector Pin Descriptions

Pin number	Connection	Function	Description
1	VMCU	VAEM	Target voltage on the debugged application. Supplied and monitored by the AEM when power selection switch is in the "AEM" position.
2	GND	GND	
3	EFR32 reset pin	DBG_RST	Reset
4	PA1	VCOM_RX	Virtual COM Rx
5	PA0	VCOM_TX	Virtual COM Tx
6	PF2	DBG_SWO	Serial Wire Output
7	PF1	DBG_SWDIO	Serial Wire Data
8	PF0	DBG_SWCLK	Serial Wire Clock
9	PB13	PTI_FRAME	Packet Trace Frame Signal
10	PB12	PTI_DATA	Packet Trace Data Signal

3.10.3 USB Micro-B Connector

The USB port can be used for uploading code, debugging and as Virtual COM port, as described in 4. Debugging.

3.10.4 Battery Connector

A small battery connector can be found on the secondary side of the board, above the CR2032 coin cell holder. This is a 1.25 mm pitch miniature crimping connector from Hirose (P/N: DF13C-2P-1.25V).

The positive supply input pin on this connector (VBAT) is directly connected to the coin cell holder +terminal, so only one battery should be used at a time to prevent current flow between batteries. The Thunderboard Sense contains a small transistor switch circuit that protects the board from reverse polarity on VBAT. When the USB cable is inserted, the transistor is turned off to prevent the on-board LDO from charging the battery connected either to the battery connector or to the coin cell holder.

P/N for mating products:
- Single row socket, 2 pos: Hirose DF13-2S-1.25C
- Crimping contact: Hirose DF13-2630SCFA

It is also possible to source pre-crimped cables from catalog distributors such as Digi-Key.

4. Debugging

The Thunderboard Sense contains an on-board fully functional SEGGER J-Link Debugger that interfaces to the target EFR32 using the Serial Wire Debug (SWD) interface. The debugger allows the user to download code and debug applications running in the target EFR32. Additionally, it also provides a virtual COM port (VCOM) to the host computer that is directly connected to the target device's serial port, for general purpose communication between the running application and the host computer.

An external Silicon Labs debugger can also be used with the board by connecting it to the Mini Simplicity connector. This allows advanced debugging features as described in 4.3 Mini Simplicity Connector. A Silicon Labs Wireless Starter Kit (WSTK) is a good example of a debugger that can be used with the Thunderboard Sense when connected through a debug adapter.

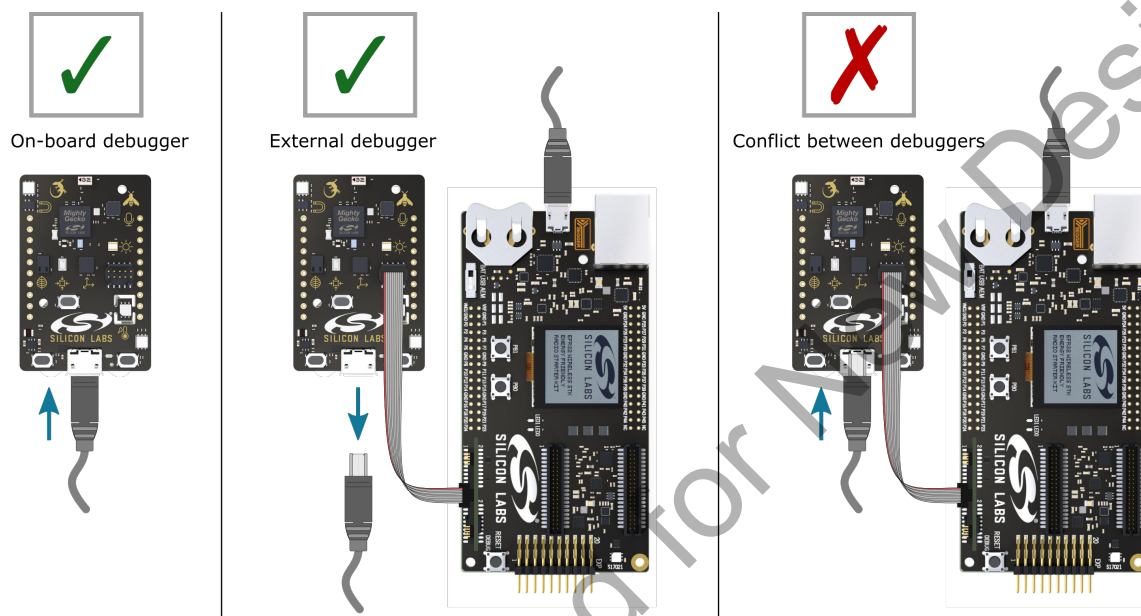Figure 4.1 Thunderboard Sense Debugging Possibilities on page 23 show the possible debug options.

On-board debugger External debugger Conflict between debuggers

Figure 4.1. Thunderboard Sense Debugging Possibilities

4.1 On-board Debugger

The on-board debugger is a SEGGER J-Link debugger running on an EFM32 Giant Gecko. The debugger is directly connected to the SWD and VCOM pins of the target EFR32.

When the USB cable is inserted, the on-board debugger is automatically active, and takes control of the SWD and VCOM interfaces. This means that serial wire debug and communication will *not* work with an external WSTK connected through the Mini Simplicity Connector at the same time. The on-board LDO is also activated which then powers the board.

When the USB cable is removed, the on-board debugger goes into a very low power shutoff mode (EM4S), consuming around 20 nA typically. This means that an application running off batteries does not need to worry about the power consumption of the on-board debugger. Since the I/O voltage rail of the debugger remains powered in the battery operated mode, the pins connected to the SWD and VCOM interfaces maintain proper isolation and prevent leakage currents.

4.2 Virtual COM Port

The virtual COM port is a connection to a USART of the target EFR32, and allows serial data to be sent and received from the device. The on-board debugger presents this as a virtual COM port on the host computer that shows up when the USB cable is inserted. Alternatively, the VCOM port can also be used through the Mini Simplicity Connector with an external WSTK.

Data is transferred between the host computer and the debugger through the USB connection, which emulates a serial port using the USB Communication Device Class (CDC). From the debugger the data is passed on to the target device through a physical UART connection.

The serial format is 115200 bps, 8 bits, no parity and 1 stop bit. Flow control signals RTS and CTS are provided, but not supported by the current firmware implementation. The current firmware also does not support changing the baud rate.

Using the VCOM port through the Mini Simplicity Connector with an external WSTK works in a similar way, but requires that the on-board debugger is unplugged. The board controller on the WSTK then makes the data available over USB (CDC) or an IP socket.

Note: Changing the baud rate for the COM port on the PC side does not influence the UART baud rate between the debugger and the target device.

4.3 Mini Simplicity Connector

The Mini Simplicity connector is a 10-pin 1.27 mm pitch connector that gives access to advanced debugging features. Debugging with an external WSTK allows:

• Debugging of the target device through SWD
• Communication using the VCOM port
• Packet Trace Interface
• Advanced Energy Monitor

Please note that the Mini Simplicity Connector *cannot* be used at the same time as the on-board debugger is active (USB cable is plugged in). For information on how to correctly connect to the kit, see Figure 4.1 Thunderboard Sense Debugging Possibilities on page 23. The recommended way to power the board when using the Mini Simplicity Connector is to use the AEM voltage supply of the WSTK. Power-cycling of the board, if necessary, can easily be done by flipping the power switch on the WSTK to "BAT" and back to "AEM".

It is also possible to have the Thunderboard Sense powered by a battery, and still use the the Mini Simplicity Connector for debugging and communication. In this case the power switch on the WSTK must be set to the "BAT" position, to prevent a power conflict. In this case level shifters on the WSTK itself takes care of interfacing to different voltage levels on the Thunderboard Sense.

5. Power and Interrupt Controller

This chapter contains reference information about how to interface with the Power and Interrupt Controller implemented in the EFM8 Sleepy Bee on the Thunderboard Sense.

The software examples available for the Thunderboard Sense provide a board support package (BSP) that handles enabling and interfacing to the different peripherals on the board. The BSP has supporting code to enable the different power domains, control the RGB LEDs and enable interrupts in the interrupt controller. It is recommended to use the provided BSP to get up and running as quick as possible with the kit.

5.1 Communication

Controlling the power domains and using the interrupt controller is done with commands over the I^{2}C bus. The EFM8 firmware presents a register interface that can be read and written by the EFR32.

Before the Power and Interrupt Controller will respond to I^{2}C commands, it must first be woken up. The EFM8 wakes up and enables its I^{2}C peripheral on the falling edge of the int/wake pin (PD10). It remains awake as long as this line is low, and for about 1 ms after the line goes high again. If there is activity on the I^{2}C bus lines while it is awake, the timeout is extended until 1 ms after the activity stops.

This means that the device can be woken up with just a short pulse on the int/wake pin. Please note that the minimum pulse width is about 4 μs to ensure that the device properly wakes up. Several consecutive commands can be issued without re-asserting the wake-up pin as long as each transfer follows within 1 ms of the last.

Since the int/wake pin is used for both wake-up and interrupt signaling, it is recommended to configure the int/wake pin to an open drain (wired AND) configuration to ensure that both devices can change the pin state.

Writing to the registers is done by transmitting the 7-bit bus address 0x90 with the R/W bit cleared, followed by the register address and the data to be written. Reading a register first requires the address pointer to be set up using an I^{2}C write, followed by a new start and the address with the R/W bit set. Reading can be done with a repeated start, or can be a simple one byte write followed by a read.
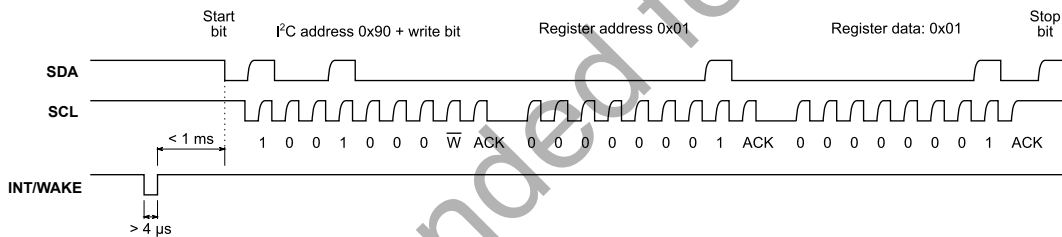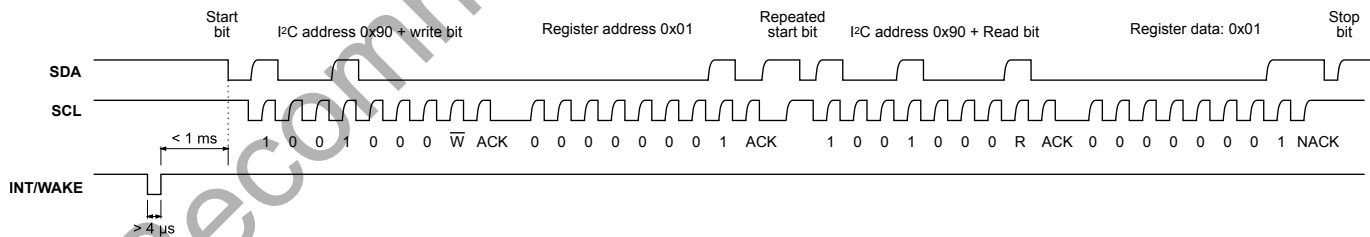

Figure 5.1. I^{2}C Register Write Example

Figure 5.2. I^{2}C Register Read Example

5.2 Register Map

The register map of the power and interrupt controller is outlined below. Power to sensors are enabled by writing a single bit to the control register for each sensor or sensor group. The CCS811 indoor air quality sensor has an additional "wake" bit that controls the sensor's WAKE line. Control of the RGB LEDs consists of an enable bit for the on board regulator, and one bit for each of the four RGB LEDs located on the board.

Table 5.1. Register Map

Addr	Name	Type	Description	Reset
0x00	IMU_CTRL	RW	**Control register for the inertial sensor** • Bits 7:1 - Reserved • Bit 0 - Write 1 to this bit to enable power and SPI access	0x00
0x01	ENV_SENSOR_CTRL	RW	**Environmental sensor group control register** • Bits 7:1 - Reserved • Bit 0 - Write 1 to this bit to enable power and I^2C access to the environmental sensor group	0x00
0x02	MIC_CTRL	RW	**Microphone control register** • Bits 7:1 - Reserved • Bit 0 - Write 1 to this bit to enable power to the microphone and microphone gain/filter circuit	0x00
0x03	CCS_CTRL	RW	**Indoor air quality sensor control register** • Bits 7:2 - Reserved • Bit 1 - Write 1 to this bit to wake up the indoor air quality sensor • Bit 0 - Write 1 to this to enable power and I^2C access to the indoor air quality sensor	0x00
0x04	LED_CTRL	RW	**Control register for the RGB LEDs** • Bits 7:4 - Individual enable bit for each RGB LED • Bits 3:1 - Reserved • Bit 0 - Write 1 to this bit to enable the RGB LED voltage regulator	0x00
0x05	INT_ENABLE	RW	**Interrupt enable register** • Bits 7:3 - Reserved • Bit 2 - UV_ALS interrupt enable • Bit 1 - IMU interrupt enable • Bit 0 - CCS811 interrupt enable	0x00
0x06	INT_CLEAR	W	**Interrupt clear register** • Bits 7:3 - Reserved • Bit 2 - Clears UV_ALS interrupt status flag • Bit 1 - Clears IMU interrupt status flag • Bit 0 - Clears CCS811 interrupt status flag	0x00
0x07	INT_STATUS	R	**Interrupt status register** • Bits 7:3 - Reserved • Bit 2 - UV_ALS interrupt status flag • Bit 1 - IMU interrupt status flag • Bit 0 - CCS811 interrupt status flag	0x00

Addr	Name	Type	Description	Reset
0x08	INT_CTRL	RW	**Interrupt controller settings register** • Bits 7:6 - Reserved • Bit 5 - Latched interrupt pin mode. If this bit is set the device will keep the int/wake signal low as long as an enabled interrupt flag is set. • Bit 4 - Periodic interrupt pulse enable. If this bit is set the device will produce continuous pulses on the int/wake signal as long as an enabled interrupt flag is set. • Bits 3:0 - Periodic interrupt pulse timer value. This bit field controls the frequency of the periodic interrupt pulses.	0x00
0xF0	SYS_CMD	W	System command register	0x00
0xF1	VER_MAJOR	R	Firmware revision major	0
0xF2	VER_MINOR	R	Firmware revision minor	4
0xF3	VER_PATCH	R	Firmware revision patch	0
0xF4	SCRATCH0	RW	Scratch register 0	0
0xF5	SCRATCH1	RW	Scratch register 1	0
0xF6	SCRATCH2	RW	Scratch register 2	0
0xF7	SCRATCH3	RW	Scratch register 3	0
0xF8	DEVICE_ID0	RW	Device identification register 0	0x49
0xF9	DEVICE_ID1	RW	Device identification register 1	0x4F
0xFA	DEVICE_ID2	RW	Device identification register 2	0x58
0xFB	DEVICE_ID3	R	Device identification register 3	0x50

5.3 Interrupt Controller

A simple interrupt controller has been implemented in the EFM8 Sleepy Bee firmware to collect interrupt signals from several sources and notify the host if something happens.

The three different interrupt sources available are

- The inertial sensor (ICM-20648) interrupt
- The UV/ALS sensor (Si1133) interrupt
- The indoor air quality sensor (CCS811) interrupt

The interrupt controller always registers the falling edges of these three interrupt signals, and sets corresponding interrupt status flags in the INT_STATUS register. If the corresponding enable bit is set in INT_ENABLE, the controller pulls INT/WAKE low for about 400 ns.

If the int/wake line happens to be pulled low by the EFR32 at the time an interrupt arrives, the interrupt controller defers generating the pulse until a few µs after INT/WAKE goes high. This ensures that no interrupts are missed when the host is asserting the int/wake line in order to communicate with the EFM8.

The recommended procedure for asserting the int/wake pin when using interrupts is:

1. Disable falling edge interrupt on the int/wake pin (PD10)
2. Set the int/wake pin low
3. Wait minimum 4 µs (required to wake up the EFM8)
4. Enable falling edge interrupt on the int/wake pin
5. Release INT/WAKE so it gets pulled high externally

Re-enabling the interrupt before releasing the INT/WAKE allows any interrupts signalled by the interrupt controller right afterwards to be caught.

Figure 5.3 Interrupt Controller Example on page 28 shows an example of how the external interrupt events cause pulses on the int/wake line when enabled.
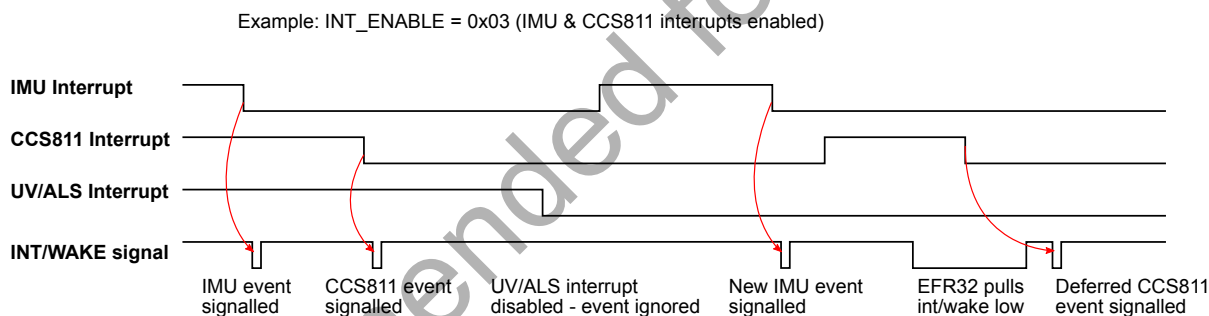

Example: INT_ENABLE = 0x03 (IMU & CCS811 interrupts enabled)

Figure 5.3. Interrupt Controller Example

5.3.1 Clearing Interrupts

Clearing the interrupt status flags is done by writing 1 to the corresponding bits in the INT_CLEAR register, but interrupt flags can only be cleared if they have been read from the INT_STATUS register. This ensures that no interrupt flags can be accidentally cleared without the host knowing they were set, if for example the interrupt occurs between reading the status register and clearing the flags.

Note that interrupt status flags can only be cleared by writing to the INT_CLEAR register after reading INT_STATUS. If the external interrupt line goes high again, the flag remains set until cleared. If another falling edge arrives, another interrupt pulse to the host will be generated if the interrupt is enabled, regardless of the status flag value.

5.3.2 Periodic Event Signalling

In some systems it could be possible that the interrupt pulse from the interrupt controller is missed, which can be critical to the application in some cases. As a possible work-around, there is a possibility to let the interrupt controller continuously signal pulses as long as an interrupt that is enabled has its flag set. The idea being that if an interrupt is missed for some reason, one of the consecutive pulses will be registered.

Because this is very system and application dependent, it is necessary to choose an appropriate frequency for the interrupt pulses. Slow systems expecting interrupts infrequently might need a longer repeat time than applications where the interrupt must be serviced immediately. Since the application have to wait for the next pulse if an interrupt has been missed, this timing will influence the time it takes for the application to respond to the event.

The periodic pulses are enabled by setting bit 4 of the INT_CTRL register. The time between interrupt pulses is controlled by bits 3:0 of the INT_CTRL register, with the formula shown below:

$$t_{pulse} = \begin{cases} \dfrac{2}{32.8 \text{ kHz}}, & \text{if INT\_CTRL}[3:0] = 0 \\[2ex] \dfrac{4+2^{\text{INT\_CTRL}[3:0]}}{32.8 \text{ kHz}}, & \text{otherwise} \end{cases}$$

For example, INT_CTRL[3:0] = 8 gives a pulse period of about 7.9 ms (about 126 Hz), while the lowest frequency is achieved with INT_CTRL[3:0] = 15, which gives about 1 second (1 Hz). The shortest period is achieved by setting INT_CTRL[3:0] = 0, which gives an interrupt period of 61 μs (about 16.4 kHz).

Figure 5.5 Periodic Event Signalling Example on page 29 shows an example of the interrupt pulse generation.

INT_ENABLE = 0x02 (IMU interrupt enabled)
INT_CTRL = 0x18 (periodic interrupt pulses enabled, t_{pulse} = 7.9 ms)

IMU Interrupt

INT_STATUS   0x00   0x02   0x00   0x02

INT/WAKE signal

t_{pulse} Periodic event pulses signalled   EFR32 reads and clears interrupt status flags   New IMU interrupt
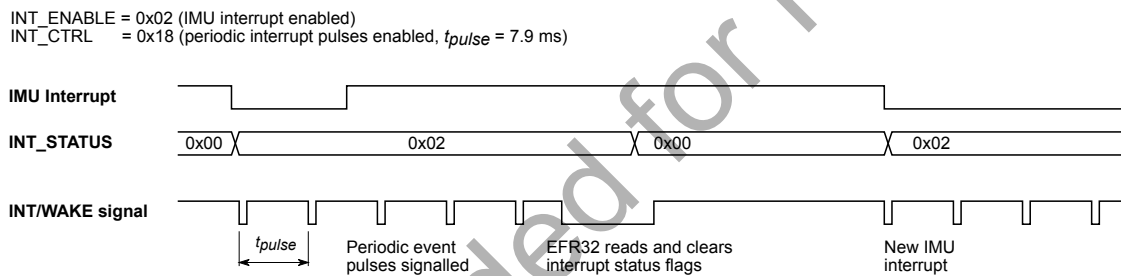
Figure 5.5. Periodic Event Signalling Example

6. Radio

6.1 RF Section

This section gives a short introduction to the RF section of the BRD4160A board.

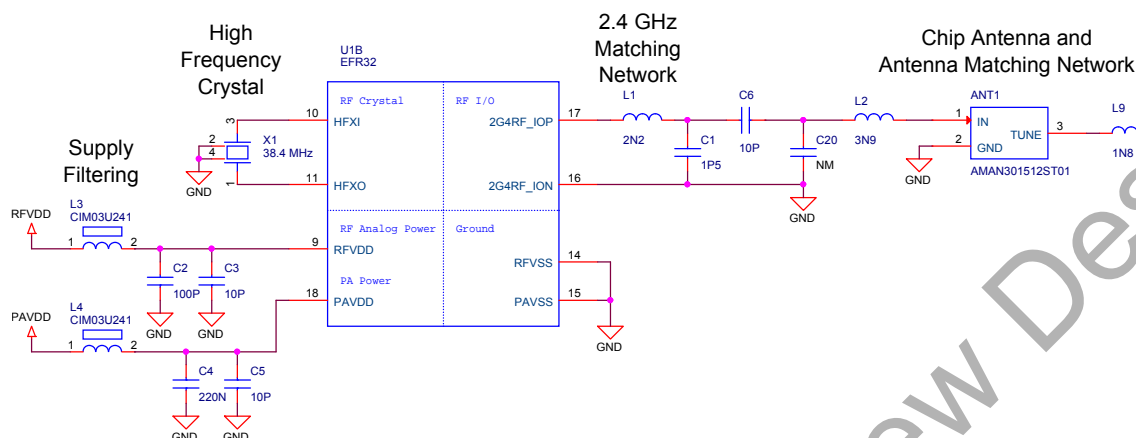The schematic of the RF section is shown in the figue below.

Figure 6.1. Schematic of the RF section

6.1.1 Description of the RF Matching

The impedance of the RF port of the EFR32 is matched to 50 Ohm: the 2G4RF_ION pin is connected to ground while the 2G4RF_IOP pin is connected to a two-element impedance matching circuitry. The on-board ceramic antenna is also matched to 50 Ohm by its impedance matching components and connected to the EFR32 through an optional bypass capacitor.

6.1.2 RF Section Power Supply

On the BRD4160A the supply for the radio (RFVDD) and the power amplifier (PAVDD) is connected to the on-chip DC-DC converter. By default, the DC-DC converter provides 1.8 V for the entire RF section (for details, see the schematic of the BRD4160A).

6.1.3 RF Matching Bill of Materials

The Bill of Materials of the BRD4160A RF matching network is shown in the following table.

Table 6.1. Bill of Materials of the BRD4160A RF Matching Network

Component name	Value	Manufacturer	Part Number
L1	2.2 nH	Murata	LQP03TN2N2B02D
C1	1.5 pF	Murata	GRM0335C1E1R5CD01
C6 (optional)	10 pF	Murata	GRM0335C1E100JA01

6.1.4 Antenna

The BRD4160A has an on-board ceramic antenna.

The land pattern for the antenna on the PCB layout was designed based on the recommendations of the antenna datasheet. Due to the fact that there is significant difference between the layout (practically the board size) of the BRD4160A and the antenna evaluation board the applied antenna matching network deviates from the recommendation.

The values of the antenna matching network were fine tuned to match the antenna impedance close to 50 Ohm on the BRD4160A PCB. The resulting antenna impedance and reflection are shown in the figure below.
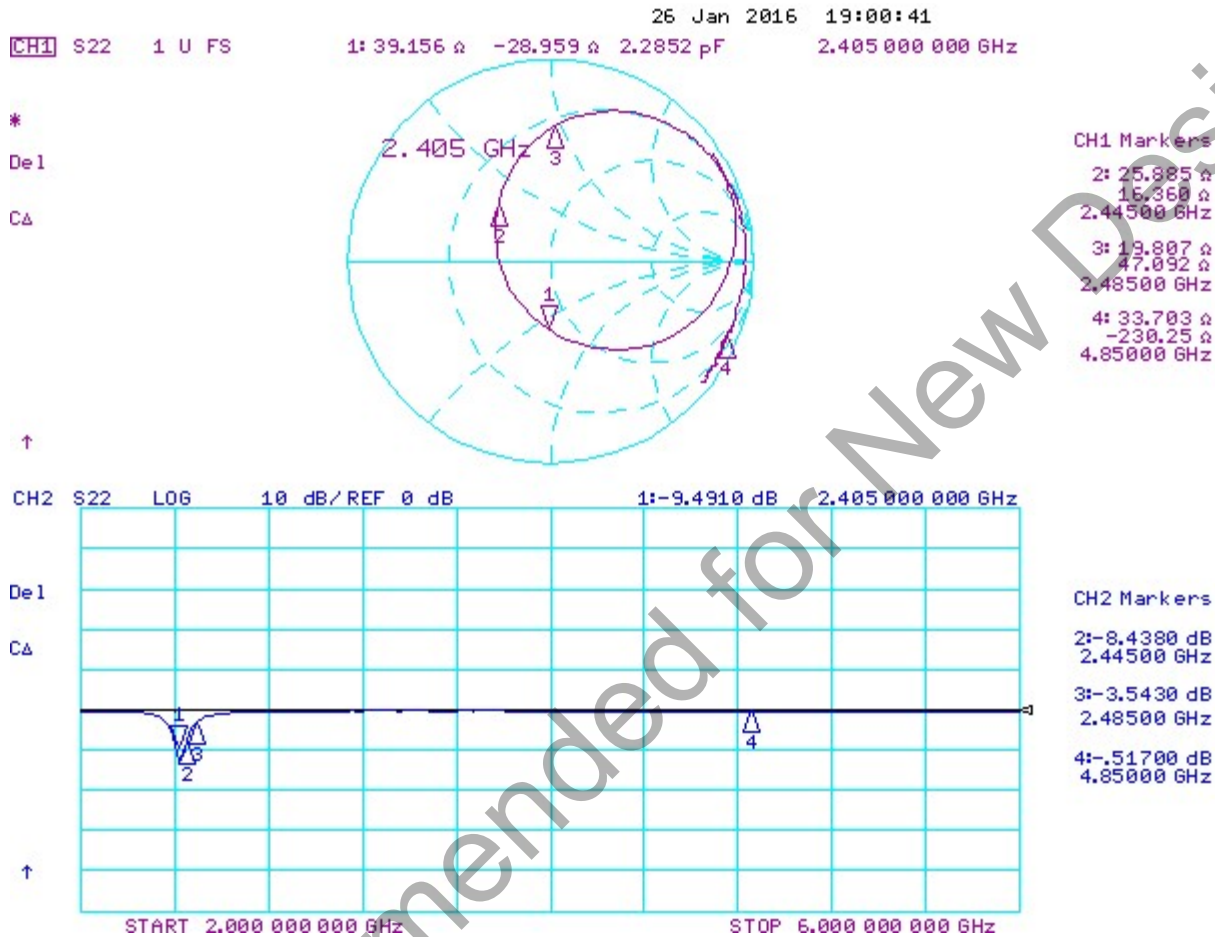

Figure 6.2.   Fine Tuned Antenna Impedance and Reflection

6.1.5 Antenna Matching Bill of Materials

The Bill of Materials of the BRD4160A antenna matching network is shown in the following table.

Table 6.2. Bill of Materials of the BRD4160A Antenna Matching Network

Component name	Value	Manufacturer	Part Number
ANT1	-	Amotech	AMAN301512ST01
L2	3.9 nH	Murata	LQP03TN3N9B02D
L9	1.8 nH	Murata	LQP03TN1N8C02D
C20	Not Populated	-	-

6.2 EMC Regulations for 2.4 GHz

6.2.1 ETSI EN 300-328 Emission Limits for the 2400-2483.5 MHz Band

Based on ETSI EN 300-328 the allowed maximum fundamental power for the 2400-2483.5 MHz band is 20 dBm EIRP. For the unwanted emissions in the 1 GHz to 12.75 GHz domain the specified limit is -30 dBm EIRP.

6.2.2 FCC15.247 Emission Limits for the 2400-2483.5 MHz Band

FCC 15.247 allows conducted output power up to 1 Watt (30 dBm) in the 2400-2483.5 MHz band. For spurious emmissions the limit is -20 dBc based on either conducted or radiated measurement, if the emission is not in a restricted band. The restricted bands are specified in FCC 15.205. In these bands the spurious emission levels must meet the levels set out in FCC 15.209. In the range from 960 MHz to the frequency of the 5th harmonic it is defined as 0.5 mV/m at 3 m distance (equals to -41.2 dBm in EIRP).

In case of operating in the 2400-2483.5 MHz band the 2nd, 3rd and 5th harmonics can fall into restricted bands so for those the -41.2 dBm limit should be applied. For the 4th harmonic the -20 dBc limit should be applied.

6.2.3 Applied Emission Limits

The FCC restricted band limits are radiated limits only. Besides that, Silicon Labs applies those to the conducted spectrum i.e. it is assumed that in case of a custom board an antenna is used which has 0 dB gain at the fundamental and the harmonic frequencies. In that theoretical case, based on the conducted measurement, the compliance with the radiated limits can be estimated.

The overall applied limits are shown in the table below.

Table 6.3. Applied Limits for Spurious Emissions

Harmonic	Frequency	Limit
2nd	4800~4967 MHz	-41.2 dBm
3rd	7200~7450.5 MHz	-41.2 dBm
4th	9600~9934 MHz	-30 dBm
5th	12000~12417.5 MHz	-41.2 dBm

6.3 Radiated Power Measurements

The output power of the EFR32 was set to 10 dBm. The board was supplied through its USB connector by connecting to a PC through a USB cable.

During the measurements the board was rotated in three cuts, see the reference plane illustration in the figure below. The radiated powers of the fundamental and the harmonics were measured with horizontal and vertical reference antenna polarizations.
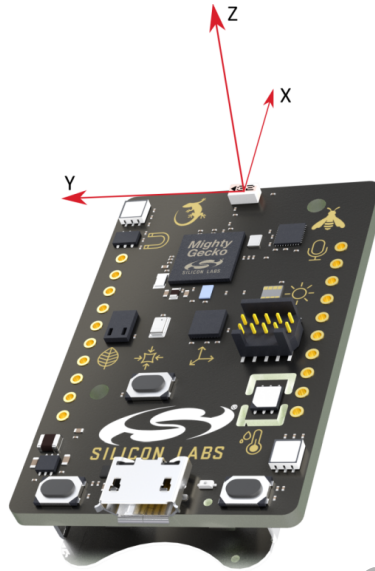

Figure 6.3. DUT Reference Planes

6.3.1 Maximum Radiated Power Measurement

The measured maximums of the fundamental and the harmonics are shown in the table below.

Table 6.4. Maximums of the Measured Radiated Powers of BRD4160A

2.405 GHz	EIRP [dBm]	Orientation	Margin [dB]	Limit in EIRP [dBm]
Fundamental	9.1	XY/H	20.9	30
2nd harmonic	-55.4	XZ/H	14.2	-41.2
3rd harmonic	<-50*	-/-	>10	-41.2
4th harmonic	<-50*	-/-	>20	-30
5th harmonic	<-50*	-/-	>10	-41.2
* Signal level is below the Spectrum Analyzer noise floor.				

As it can be observed the levels of the harmonics are far below the applied limit.

6.3.2 Antenna Pattern Measurement

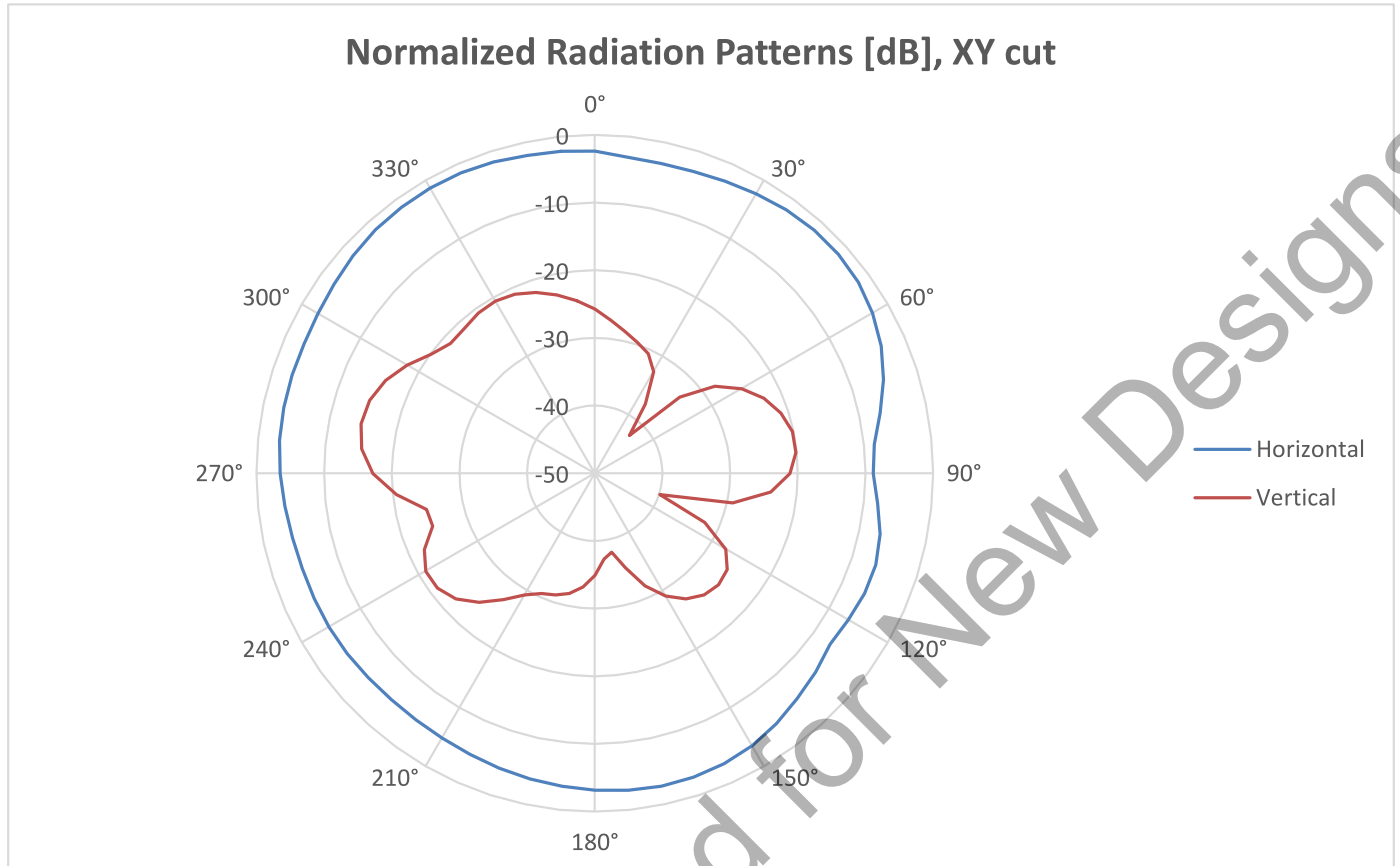The measured typical antenna patterns are shown in the figures below.
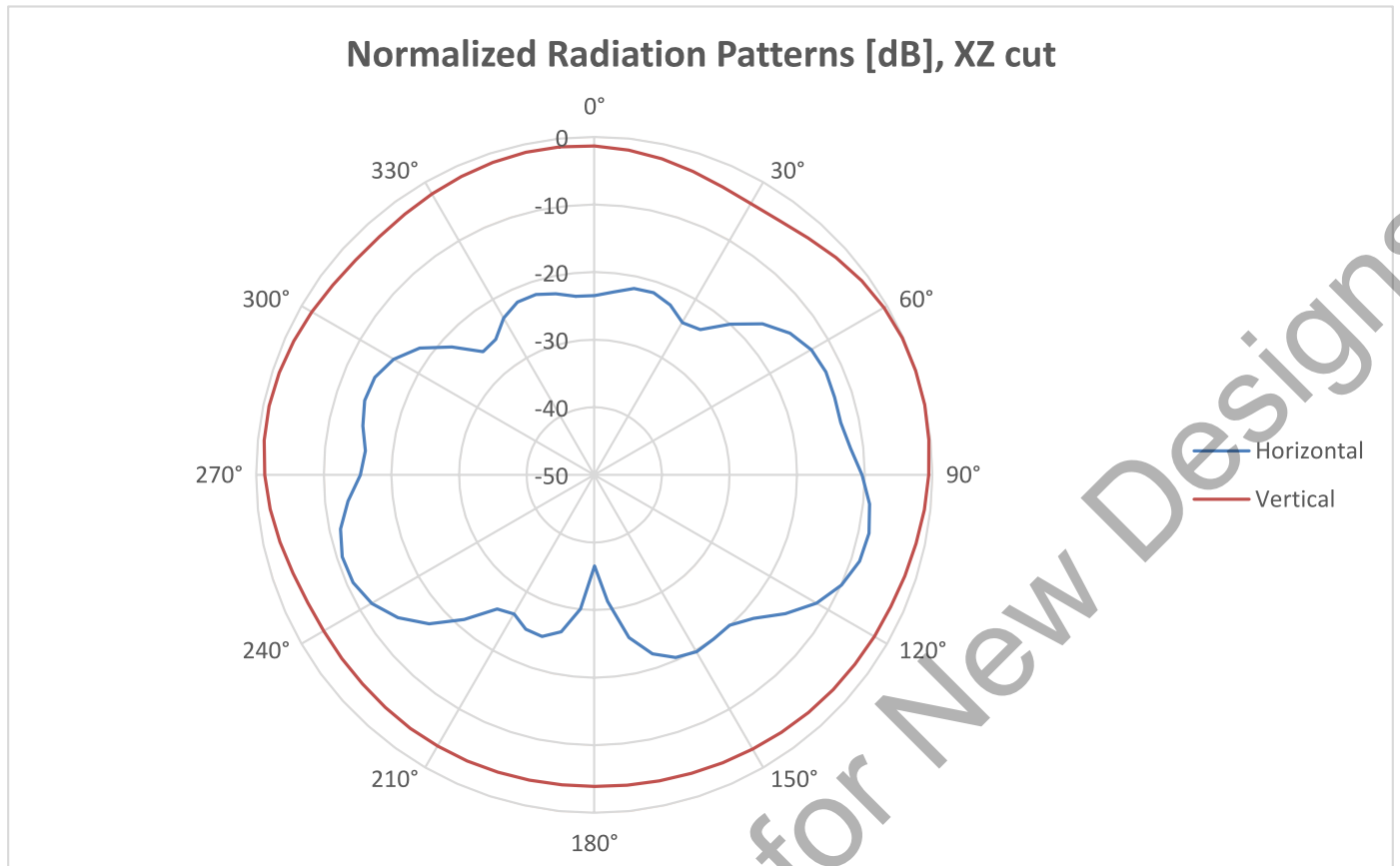

Figure 6.4.   Antenna Pattern - XY

Normalized Radiation Patterns [dB], XZ cut

Figure 6.5.   Antenna Pattern - XZ

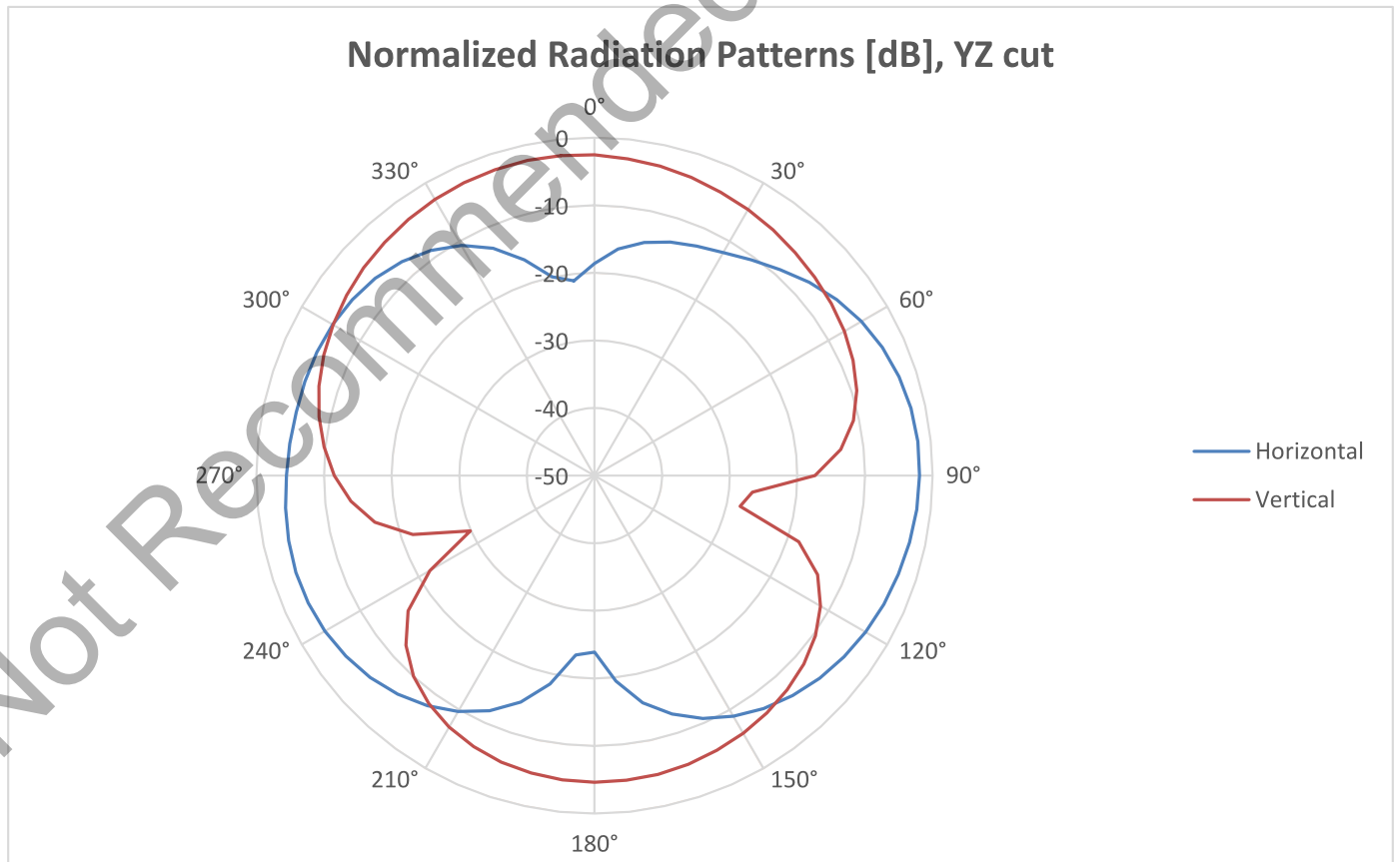## Normalized Radiation Patterns [dB], YZ cut

Figure 6.6.   Antenna Pattern - YZ

6.4 EMC Compliance Recommendations

6.4.1 Recommendations for 2.4 GHz ETSI EN 300-328 Compliance

As it was shown in the previous chapter with the EFR32 output power set to 10 dBm the radiated power of the fundamental of the BRD4160A complies with the 20 dBm limit of the ETSI EN 300-328. The harmonic emissions are under the -30 dBm limit with large margin.

6.4.2 Recommendations for 2.4 GHz FCC 15.247 Compliance

As it was shown in the previous chapter with the EFR32 output power set to 10 dBm the radiated power of the fundamental of the BRD4160A complies with the 30 dBm limit of the FCC 15.247. The harmonic emissions are under the applied limits with large margin.

7. Schematics, Assembly Drawings and BOM

The schematics, assembly drawings and bill of materials (BOM) for the hardware included on the Thunderboard Sense are available through Simplicity Studio when the kit documentation package has been installed.

8. Kit Revision History and Errata

8.1 Revision History

The kit revision can be found printed on the box label of the kit, as outlined in the figure below. The kit revision history is summarised in

Thunderboard Sense

(1P) Part: SLTB001A   (D) Date: 25-08-16

S.nr: 1632000360   (Q) Qty: 1

Rev. B01

Figure 8.1. Revision Info

Table 8.1. Kit Revision History

Kit Revision	Released	Description
C00	2017-09-28	Removed coin cell battery due to shipping restrictions.
B02	2017-04-05	Updated to BRD4160A Rev. B02.
B01	2016-08-25	Updated to BRD4160A Rev. B01.
B00	2016-08-23	Updated to BRD4160A Rev. B00.
A00	2016-06-22	Initial kit release with BRD4160A Rev A02.

8.2 Errata

There are no known errata at present.

9. Board Revision History and Errata

9.1 Revision History

The board revision can be found laser printed on the board, and the board revision history is summarised in

Table 9.1. Board Revision History

Revision	Label Outline	Released	Description
B02	BRD4160A Rev. B02 162701381	2016-11-17	Minor update to PCB.
B01	BRD4160A Rev. B01 162701381	2016-08-25	Minor update to PCB.
B00	BRD4160A Rev. 162701381 B00	2016-08-18	Removed engineering sample of Si7210 Hall-effect sensor.
A02	BRD4160A Rev. A02 162701381	2016-07-04	Initial release.

9.2 Errata

There are no known errata at present.

10. Document Revision History

Revision 1.1

2017-10-10
- Removed CR2032 battery from Section 1.1 Kit Contents
- Updated section 8.1 and section 9.1.

Revision 1.01

2016-09-26
- Minor edit.
- Corrected release dates in table 8.1.

Revision 1.00

2016-09-20
- Initial document release.

Simplicity Studio

One-click access to MCU and wireless tools, documentation, software, source code libraries & more. Available for Windows, Mac and Linux!

IoT Portfolio
www.silabs.com/IoT

SW/HW
www.silabs.com/simplicity

Quality
www.silabs.com/quality

Support and Community
community.silabs.com

Disclaimer

Silicon Labs intends to provide customers with the latest, accurate, and in-depth documentation of all peripherals and modules available for system and software implementers using or intending to use the Silicon Labs products. Characterization data, available modules and peripherals, memory sizes and memory addresses refer to each specific device, and "Typical" parameters provided can and do vary in different applications. Application examples described herein are for illustrative purposes only. Silicon Labs reserves the right to make changes without further notice and limitation to product information, specifications, and descriptions herein, and does not give warranties as to the accuracy or completeness of the included information. Silicon Labs shall have no liability for the consequences of use of the information supplied herein. This document does not imply or express copyright licenses granted hereunder to design or fabricate any integrated circuits. The products are not designed or authorized to be used within any Life Support System without the specific written consent of Silicon Labs. A "Life Support System" is any product or system intended to support or sustain life and/or health, which, if it fails, can be reasonably expected to result in significant personal injury or death. Silicon Labs products are not designed or authorized for military applications. Silicon Labs products shall under no circumstances be used in weapons of mass destruction including (but not limited to) nuclear, biological or chemical weapons, or missiles capable of delivering such weapons.

Trademark Information

Silicon Laboratories Inc.® , Silicon Laboratories®, Silicon Labs®, SiLabs® and the Silicon Labs logo®, Bluegiga®, Bluegiga Logo®, Clockbuilder®, CMEMS®, DSPLL®, EFM®, EFM32®, EFR, Ember®, Energy Micro, Energy Micro logo and combinations thereof, "the world's most energy friendly microcontrollers", Ember®, EZLink®, EZRadio®, EZRadioPRO®, Gecko®, ISOmodem®, Micrium, Precision32®, ProSLIC®, Simplicity Studio®, SiPHY®, Telegesis, the Telegesis Logo®, USBXpress®, Zentri and others are trademarks or registered trademarks of Silicon Labs. ARM, CORTEX, Cortex-M3 and THUMB are trademarks or registered trademarks of ARM Holdings. Keil is a registered trademark of ARM Limited. All other products or brand names mentioned herein are trademarks of their respective holders.

Silicon Laboratories Inc.
400 West Cesar Chavez
Austin, TX 78701
USA

http://www.silabs.com

Mouser Electronics

Authorized Distributor

Click to View Pricing, Inventory, Delivery & Lifecycle Information:

[Silicon Laboratories](#):
  [SLTB001A](#)