

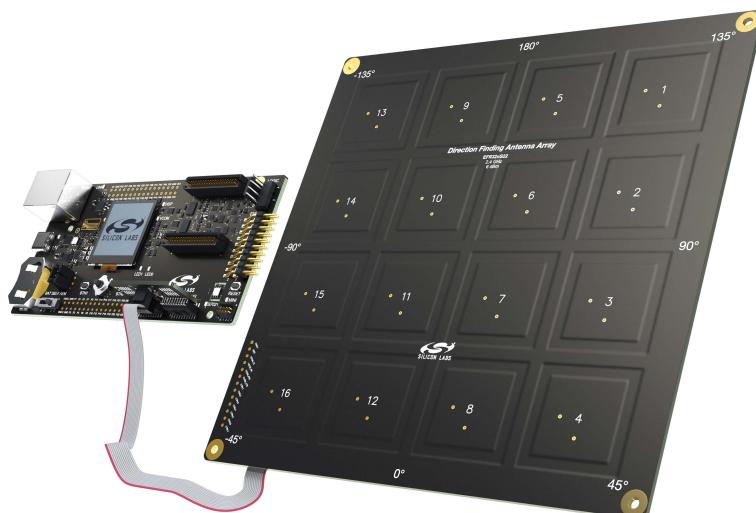
UG531: BRD4191A BG22 Direction Finding Radio Board User's Guide

A Wireless Pro Kit with the BRD4191A BG22 Direction Finding Radio Board enables developers to develop RF-based Real-Time Locationing Systems and applications, utilizing the protocol level support of Angle of Arrival (AoA) and Angle of Departure (AoD) in Bluetooth 5. The board contains a 2.4 GHz EFR32BG22 Wireless Gecko System-on-Chip, and an antenna array optimized for accurate direction finding performance.

The BRD4191A can be connected to the Wireless Starter Kit Mainboard (BRD4001A) and the Wireless Pro Kit Mainboard (BRD4002A) through a BRD8010B STK/WSTK Debug Adapter board, and a Mini Simplicity+ cable. It is a complete HW design for the EFR32BG22 Wireless SoC, with matching network, UFL connector and an antenna array for 6 dBm output power in the 2.4 GHz band.

The mainboards contain an on-board J-Link debugger with a Packet Trace Interface and a Virtual COM port, enabling application development and debugging of the connected radio board as well as external hardware. The mainboard also contains sensors and peripherals for easy demonstration of some of the EFR32's many capabilities, but due to the limited connectivity options of the Mini Simplicity+ interface, utilizing those peripherals with the BRD4191A is not supported.

This document describes how to use the BRD4191A BG22 Direction Finding Radio Board together with a Wireless Starter Kit Mainboard or a Wireless Pro Kit Mainboard.



BRD4191A RADIO BOARD FEATURES

- EFR32 Wireless Gecko SoC with 512 kB Flash and 32 kB RAM (EFR32BG22C224F512IM40).
- Direction Finding Antenna Array (2.4 GHz band)
- Mini Simplicity+ connector
- UFL connector (optional)

WIRELESS STK MAINBOARD FEATURES

- Advanced Energy Monitor
- Packet Trace Interface
- Virtual COM port
- SEGGER J-Link on-board debugger
- External device debugging
- Ethernet and USB connectivity
- Silicon Labs Si7021 relative humidity and temperature sensor (not connected to BRD4191A)
- Low power 128x128 pixel Memory LCD-TFT (not connected to BRD4191A)
- User LEDs / pushbuttons (not connected to BRD4191A)
- 20-pin 2.54 mm EXP header (not connected to BRD4191A)
- Breakout pads for SoC I/O (not connected to BRD4191A)
- CR2032 coin cell battery support

SOFTWARE SUPPORT

- Simplicity Studio™
- Energy Profiler
- Network Analyzer

ORDERING INFORMATION

- BG22-RB4191A

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1. Introduction

The EFR32BG22 Wireless Gecko System-on-Chip is featured on the that plugs into a Wireless Pro Kit (WPK) Mainboard. The mainboard features several tools for easy evaluation and development of wireless applications. An on-board J-Link debugger enables programming and debugging on the target device over USB or Ethernet. The Advanced Energy Monitor (AEM) offers real-time current and voltage monitoring. A virtual COM port interface (VCOM) provides an easy-to-use serial port connection over USB or Ethernet. The Packet Trace Interface (PTI) offers invaluable debug information about transmitted and received packets in wireless links.

All debug functionality, including AEM, VCOM, and PTI, can also be used towards external target hardware instead of a radio board attached directly to the mainboard through the 2x40-pin connectors.

To further enhance its usability, the mainboard contains sensors and peripherals that demonstrate some of the many capabilities of the EFR32BG22. The mainboard also has a 20-pin EXP header which can be used for connecting EXP boards to the kit or for easy connection to I/Os on the target IC on the radio board.

1.1 Radio Boards

A Wireless Pro Kit consists of one or more mainboards and radio boards that plug into the mainboard. Different radio boards are available, each featuring different Silicon Labs devices with different operating frequency bands. Because the mainboards are designed to work with different radio boards, the actual pin mapping from a device pin to a mainboard feature is done on the radio board. This means that each radio board has its own pin mapping to the Wireless Pro Kit features, such as buttons, LEDs, the display, the EXP header and the breakout pads. Because this pin mapping is different for every radio board, it is important to consult the correct document, which shows the kit features in context of the radio board plugged in.

1.2 Mainboards

The BG22 Direction Finding Radio Board (BRD4191A) can be used with either a Wireless Starter Kit Mainboard (BRD4001A) or a Wireless Pro Kit Mainboard (BRD4002A). The Wireless Pro Kit Mainboard is the successor to the Wireless Starter Kit Mainboard, which comes with some improvements and added features including increased AEM measurement range and sample rate, variable VMCU voltage, joystick, and a Mini Simplicity Connector. Kit features, such as the Si7021 sensor and the EXP header, are available on the same EFR32 pins regardless of the mainboard being used, but the pinout to the breakout pads differs. The combination of the BG22 Direction Finding Radio Board with either one of these mainboards is hereby referred to as a Wireless Pro Kit as the figure below illustrates.

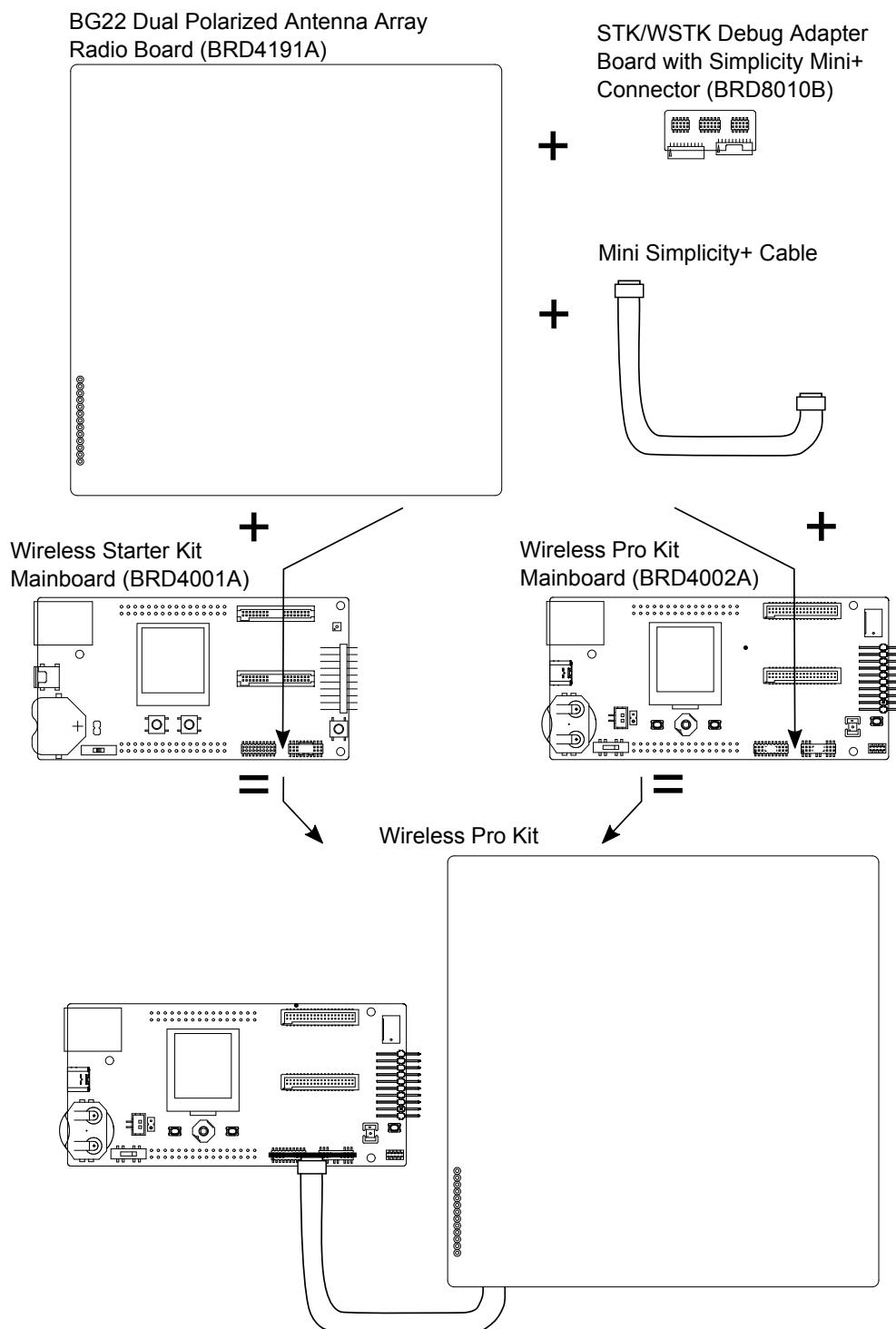


Figure 1.1. Wireless Pro Kit Combinations

Note: This document explains how to use the Wireless Pro Kit when the BG22 Direction Finding Radio Board (BRD4191A) is combined with either a Wireless Starter Kit Mainboard (BRD4001A) or a Wireless Pro Kit Mainboard (BRD4002A). Since some of the functionality

of the kit depends on the type of mainboard used, it is important to consult the right information in the user guide whenever there are discrepancies.

1.3 Ordering Information

BRD4191A can be obtained as a separate radio board, BG22-RB4191A.

Table 1.1. Ordering Information

| Part Number | Description | Contents |
|--------------|------------------------------------|---|
| BG22-RB4191A | BG22 Direction Finding Radio Board | 1x BRD4191A BG22 Direction Finding Radio Board 1x BRD8010B STK/WSTK Debug Adapter Board with Simplicity Mini+ Connector 1x 12-pin Mini Simplicity+ Ribbon Cable |
| BG22-PK6022A | BG22 Direction Finding Pro Kit | 1x BRD4191A BG22 Direction Finding Radio Board 1x BRD8010B STK/WSTK Debug Adapter Board with Simplicity Mini+ Connector 1x 12-pin Mini Simplicity+ Ribbon Cable 1x BRD4002A Wireless Pro Kit Mainboard |

1.4 Getting Started

Detailed instructions for how to get started can be found on the Silicon Labs web pages: silabs.com/development-tools.

2. Hardware Overview

2.1 Hardware Layout

The layout of the BG22 Direction Finding Wireless Pro Kit when the radio board is combined with a Wireless Pro Kit Mainboard (BRD4002A) or a Wireless STK Mainboard (BRD4001A) is shown below.

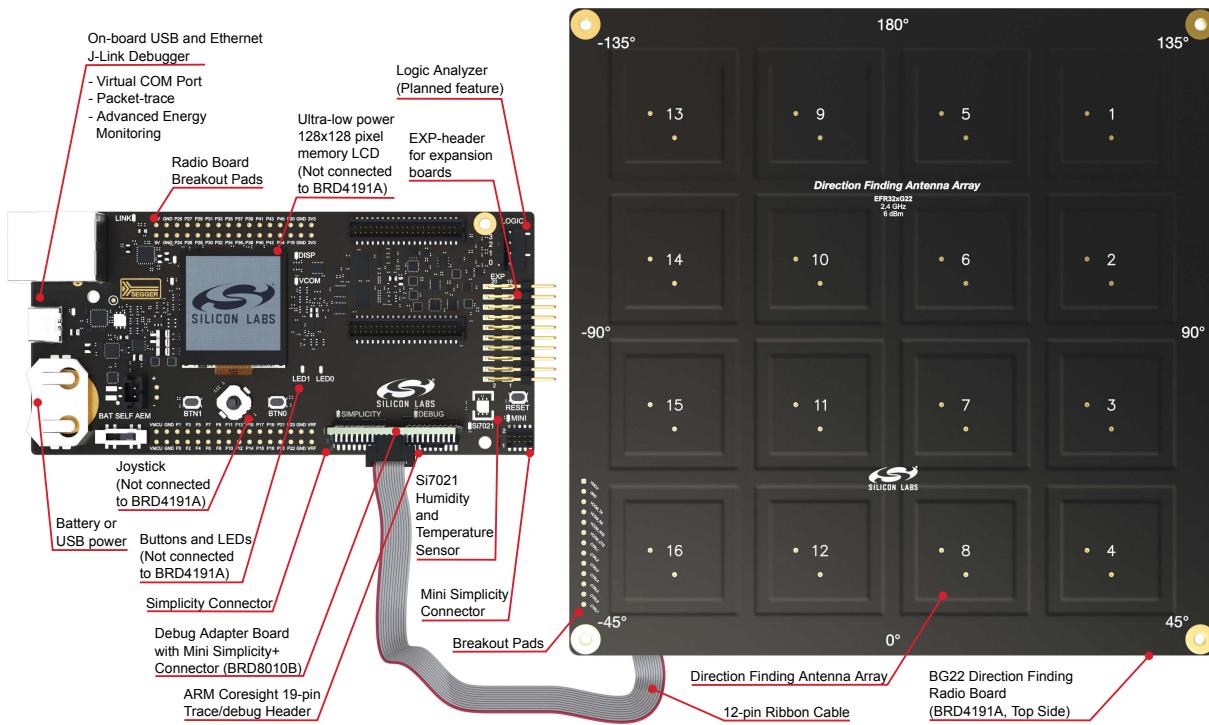


Figure 2.1. Hardware Layout With A Wireless Pro Kit Mainboard (BRD4002A)

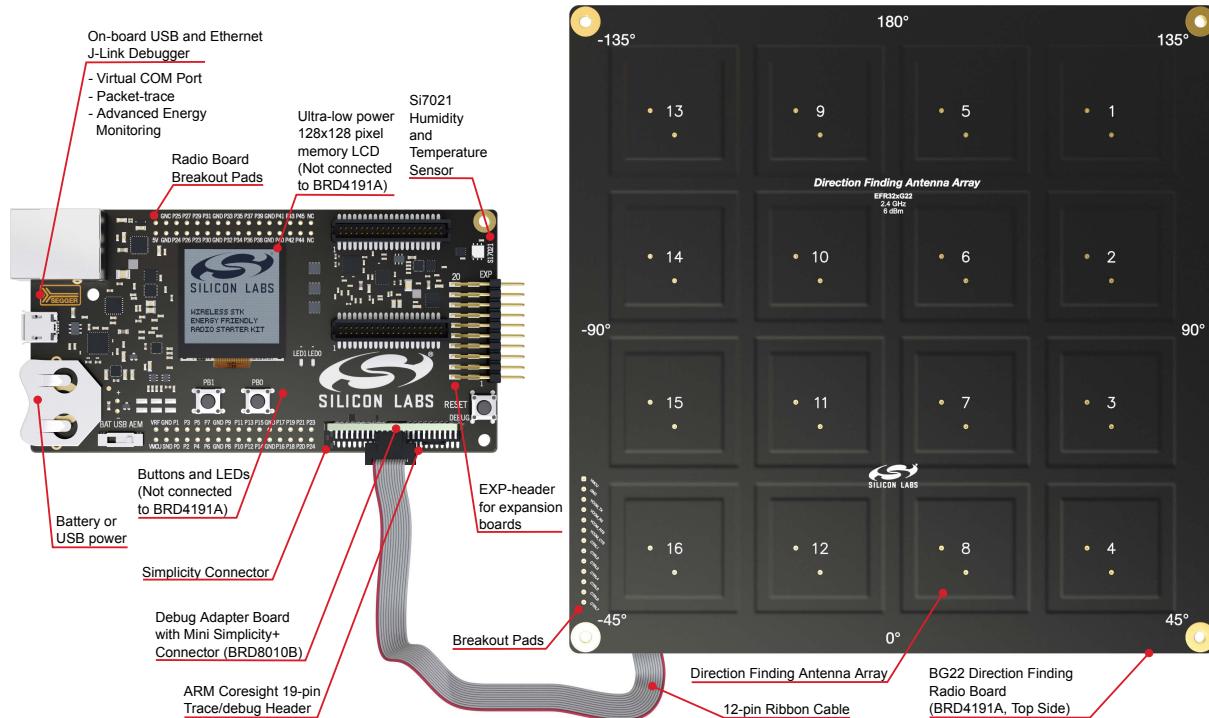


Figure 2.2. Hardware Layout With A Wireless STK Mainboard (BRD4001A)

2.2 Block Diagram

An overview of the BG22 Direction Finding Wireless Pro Kit is shown in the figure below.

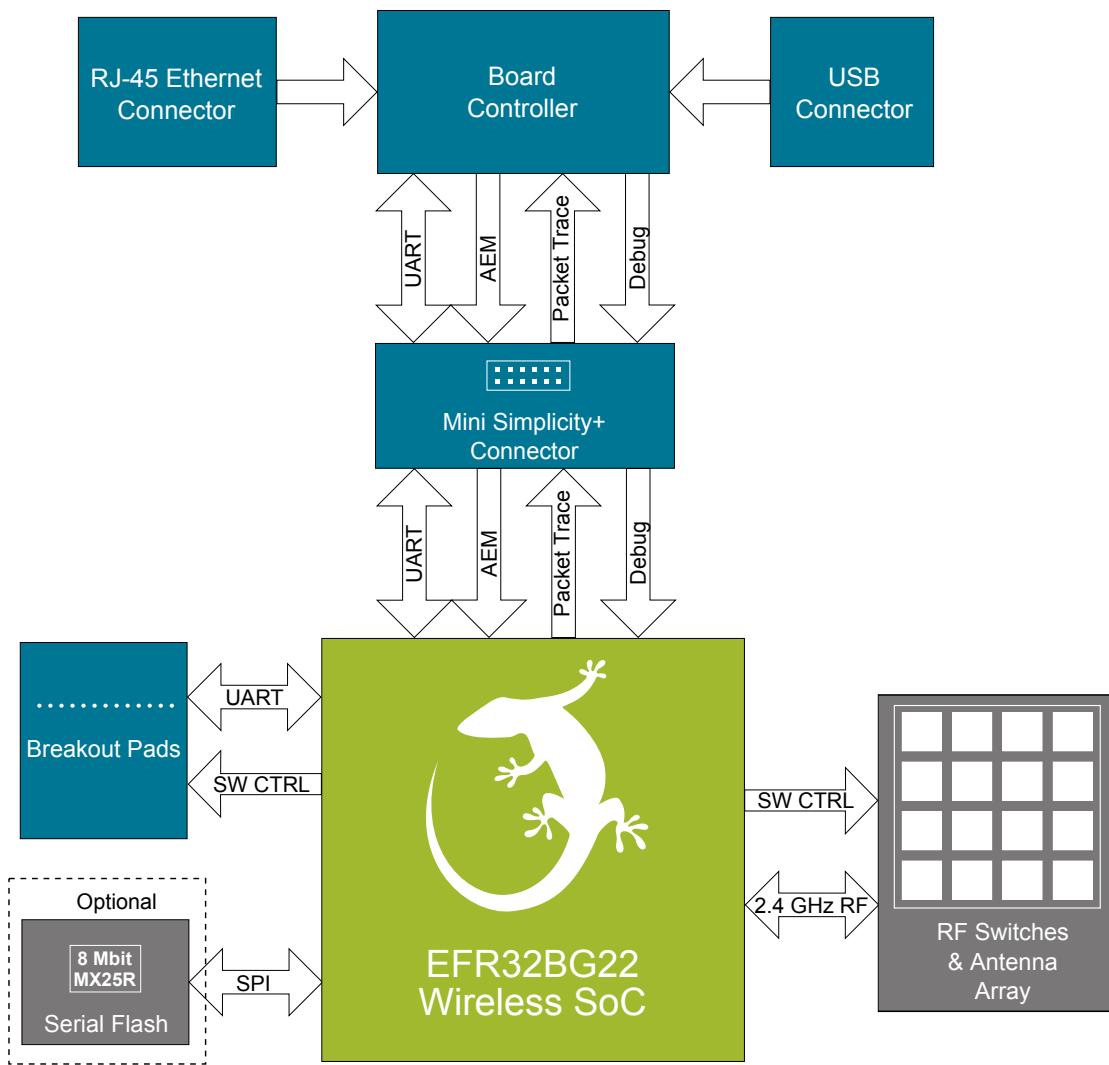


Figure 2.3. Kit Block Diagram

3. Mainboard Connectors

This chapter gives you an overview of the mainboard connectivity. The placement of the connectors on the Wireless Pro Kit Mainboard (BRD4002A) and the Wireless STK Mainboard (BRD4001A) is shown below.

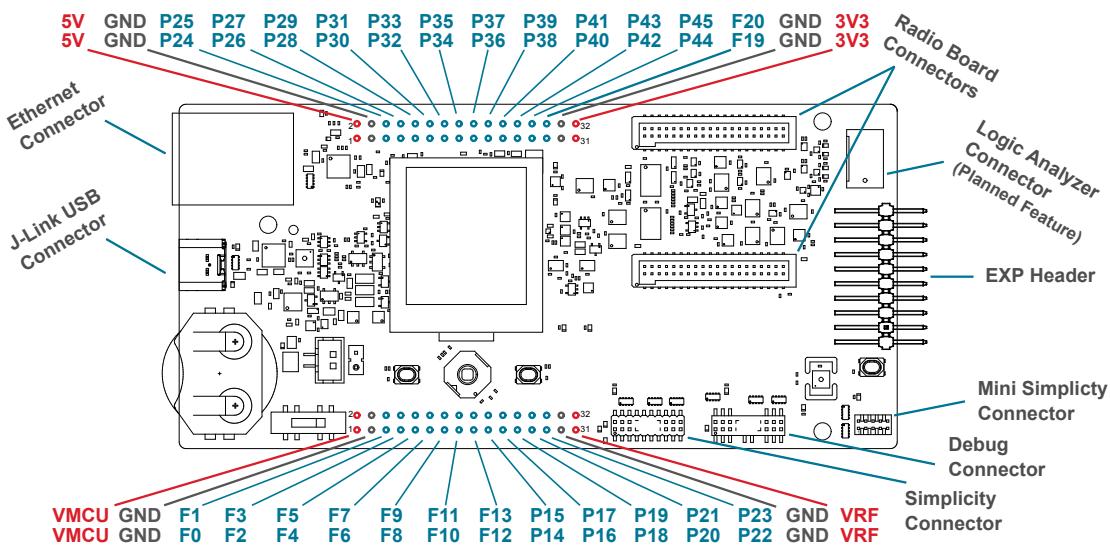


Figure 3.1. Wireless Pro Kit Mainboard (BRD4002A) Connector Layout

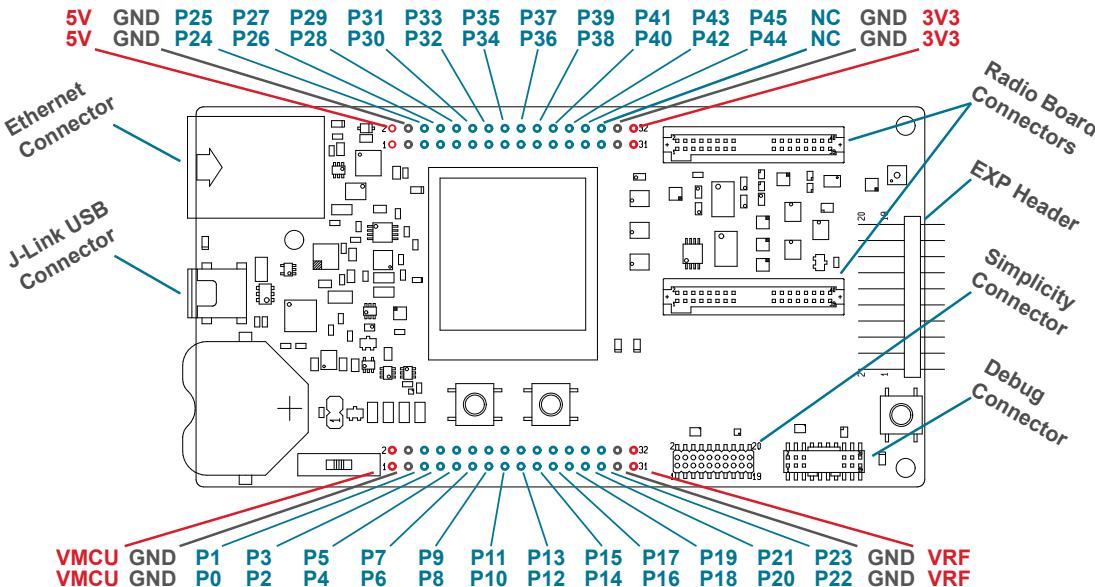


Figure 3.2. Wireless STK Mainboard (BRD4001A) Connector Layout

3.1 J-Link USB Connector

The J-Link USB connector is situated on the left side of the Wireless STK Mainboard. Most of the kit's development features are supported through this USB interface when connected to a host computer. Such features include:

- Debugging and programming of the target device using the on-board J-Link debugger
- Communication with the target device over the virtual COM port using USB-CDC
- Accurate current profiling using the AEM

In addition to providing access to development features of the kit, this USB connector is also the main power source for the kit. USB 5V from this connector powers the board controller and the AEM. It is recommended that the USB host be able to supply at least 500 mA to this connector, although the actual current required will vary depending on the application.

3.2 Ethernet Connector

The Ethernet connector provides access to all of the Wireless STK's development features over TCP/IP. The Ethernet interface provides some additional development features to the user. Supported features include:

- Debugging and programming of the target device using the on-board J-Link debugger
- Communication with the target device over the virtual COM port using TCP/IP socket 4901
- "VUART" communication with the target device over the debug SWD/SWO interface using TCP/IP socket 4900
- Accurate current profiling using the AEM
- Real-time radio packet and network analysis using the Packet Trace Interface
- Access to advanced configuration options using the admin console over TCP/IP socket 4902

Note: The Wireless STK cannot be powered using the Ethernet connector, so to use this interface, the USB connector must be used to provide power to the board.

3.3 Debug Adapter

The BRD8010B STK/WSTK Debug Adapter is an adapter board which plugs directly into the debug connector and the Simplicity Connector on the mainboard. It combines selected functionality from the two connectors to smaller footprint 10 and 12-pin connectors, which are more suitable for space-constrained designs.

For versatility, the debug adapter features three different debug connectors:

- 12-pin Silicon Labs Mini Simplicity+ Connector
- 10-pin ARM Cortex 10-pin Debug Connector (not mounted)
- 10-pin Silicon Labs ISA3 Packet Trace (not mounted)

The ARM Cortex 10-pin Debug Connector follows the standard Cortex pinout defined by ARM and allows the Wireless Pro Kit to be used to debug hardware designs that use this connector.

The ISA3 connector follows the same pinout as the Packet Trace connector found on the Silicon Labs Ember Debug Adapter (ISA3). This enables using the Wireless Pro Kit to debug hardware designs that use this connector.

The Mini Simplicity+ Connector is designed to offer advanced debug features from the kit on a 12-pin connector. The connector has the same pinout and functionality as described in [4.2 Mini Simplicity+ Connector](#).

4. Radio Board Connectors

The Wireless Pro Kit features a Mini Simplicity+ connector, and 13 breakout pads. The Mini Simplicity+ connector is placed on the bottom side of the board, the placements and the breakout pads pinout are shown in the figure below. For additional information on the connectors, see the following sub chapters.

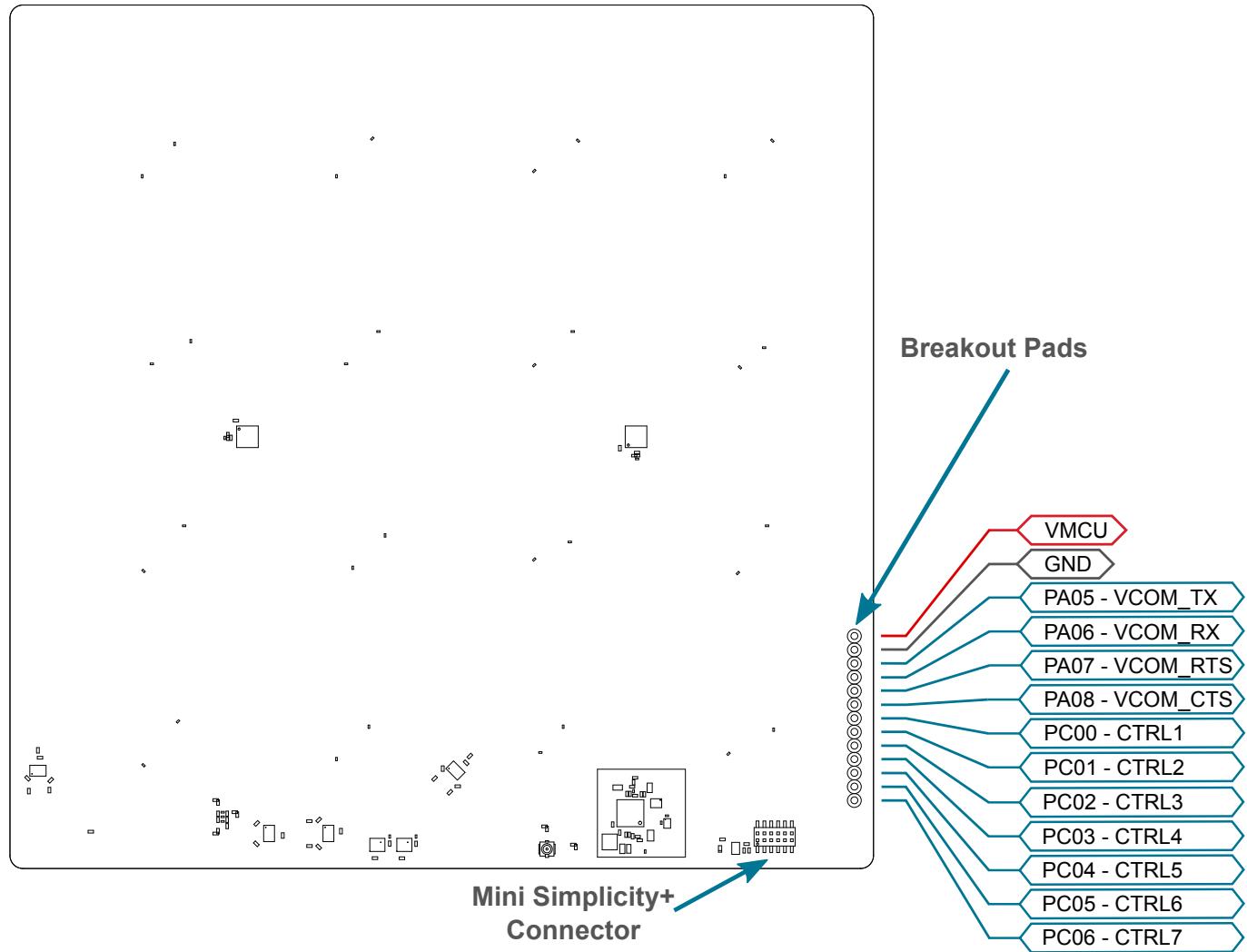


Figure 4.1. Wireless Pro Kit Connectors (Bottom Side)

4.1 Breakout Pads

Twenty breakout pads are provided and allow connection of external peripherals. There are 10 pads on the left side of the board, and 10 pads on the right. The breakout pads contain a number of I/O pins that can be used with most of the EFR32BG22 Wireless Gecko's features. Additionally, the VMCU (main board power rail), 3V3 (LDO regulator output), and 5V power rails are also exposed on the pads.

The pin-routing on the Wireless Gecko is very flexible, so most peripherals can be routed to any pin. However, pins may be shared between the breakout pads and other functions on the Wireless Pro Kit. The table below includes an overview of the breakout pads and functionality that is shared with the kit.

Table 4.1. Breakout Pads Pinout

| Pin | Connection | Shared Feature |
|-----|------------|---|
| 1 | VMCU | Target voltage on the debugged application. Supplied and monitored by the AEM when powered by a Wireless STK with its power selection switch in the "AEM" position. |
| 2 | GND | Ground |
| 3 | PA05 | Virtual COM TX |
| 4 | PA06 | Virtual COM RX |
| 5 | PA07 | Virtual COM RTS |
| 6 | PA08 | Virtual COM Port CTS |
| 7 | PC00 | RF Switch Control Signal 1 |
| 8 | PC01 | RF Switch Control Signal 2 |
| 9 | PC02 | RF Switch Control Signal 3 |
| 10 | PC03 | RF Switch Control Signal 4 |
| 11 | PC04 | RF Switch Control Signal 5 |
| 12 | PC05 | RF Switch Control Signal 6 |
| 12 | PC06 | RF Switch Control Signal 7 |

4.2 Mini Simplicity+ Connector

The Mini Simplicity+ connector featured on the Wireless Pro Kit is a 12-pin 1.27 mm pitch connector that allows the use of an external debugger such as the one found on a Silicon Labs Wireless Pro Kit (WPK) Mainboard. In addition to providing serial wiredebug (SWD) and virtual COM port functionality with flow control, the WPK can also support advanced energy profiling, wireless network analysis and debugging tools.

The Mini Simplicity+ connector pinout is illustrated in the figure below.

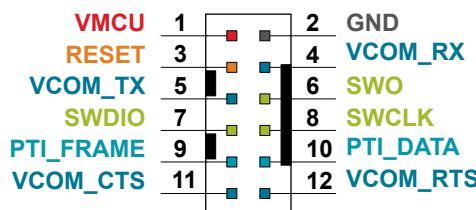


Figure 4.2. Mini Simplicity+ Connector

Note: Current drawn from the VMCU voltage pin is included in the AEM measurements. When monitoring the current consumption of the Wireless Pro Kit with the AEM, unplug any radio board from the WPK Mainboard to avoid adding the radio board's current consumption to the measurements.

Table 4.2. Mini Simplicity+ Connector Pin Descriptions

| Pin Number(s) | Function | Connection | Description |
|---------------|-----------|------------|---|
| 1 | AEM | VMCU | Target voltage on the debugged application. May be supplied and monitored by the AEM on an external debugger. |
| 2 | GND | GND | Ground |
| 3 | RST | RESET | EFR32BG22 reset |
| 4 | VCOM_RX | PA06 | Virtual COM Rx |
| 5 | VCOM_TX | PA05 | Virtual COM Tx |
| 6 | SWO | PA03 | Serial Wire Output |
| 7 | SWDIO | PA02 | Serial Wire Data |
| 8 | SWCLK | PA01 | Serial Wire Clock |
| 9 | PTI_FRAME | PD03 | Packet Trace Frame |
| 10 | PTI_DATA | PD02 | Packet Trace Data |
| 11 | VCOM_CTS | PA08 | Virtual COM Port CTS |
| 12 | VCOM_RTS | PA07 | Virtual COM Port RTS |

Note: Mini Simplicity+ Connector pin-out is referenced from the device target side.

5. Power Supply and Reset

5.1 Radio Board Power Selection

The EFR32BG22 on a Wireless Pro Kit can be powered by one of these sources:

- The debug USB cable
- A 3 V coin cell battery
- A USB regulator on the radio board (for devices with USB support only)

The power source for the radio board is selected with the slide switch in the lower left corner of the Wireless STK Mainboard or the Wireless Pro Kit Mainboard. The figure below shows how the different power sources can be selected with the slide switch.

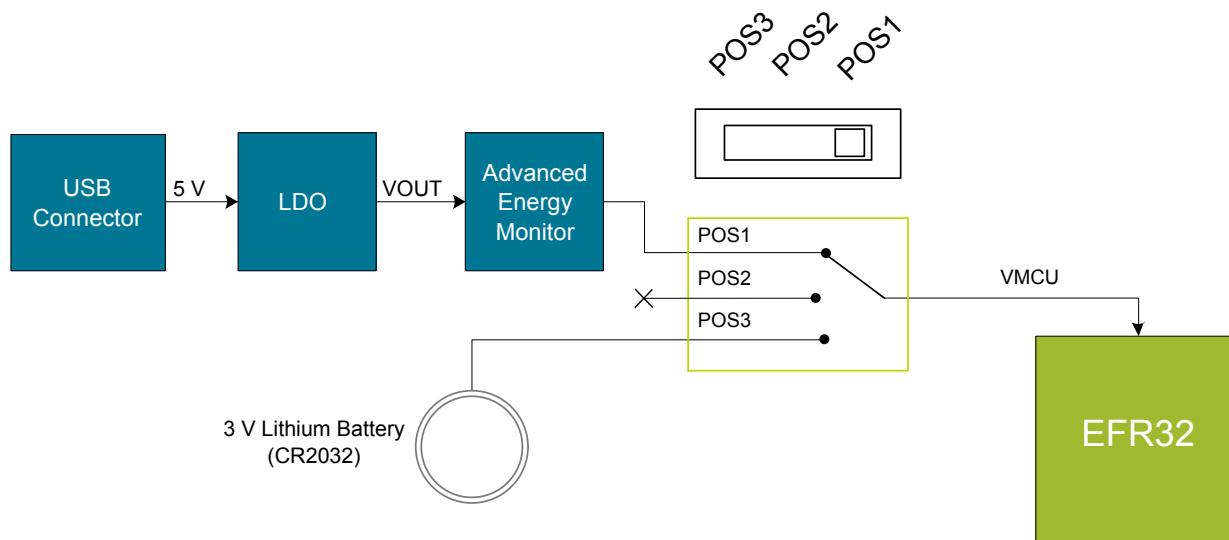


Figure 5.1. Power Switch

Note: The middle position is denoted by "USB" on the Wireless STK Mainboard, while it is denoted by "SELF" on the Wireless Pro Kit Mainboard. The slide switch functions the same on both mainboards.

Note: The AEM can only measure the current consumption of the EFR32BG22 when the power selection switch is in the **AEM** position.

AEM position: With the switch in the AEM position, a low noise LDO on the mainboard is used to power the radio board. This LDO is again powered from the debug USB cable. The AEM is now also connected in series, allowing accurate high speed current measurements and energy debugging/profiling.

USB position: With the switch in the USB position, radio boards with USB-support can be powered by a regulator on the radio board itself. BRD4191A does not contain a USB regulator, and setting the switch in the **USB** position will cause the EFR32BG22 to be unpowered.

BAT position: With the switch in the BAT position, a 20 mm coin cell battery in the CR2032 socket can be used to power the device. With the switch in this position, no current measurements are active. This is the switch position that should be used when the radio board is powered with an external power source. The Wireless Pro Kit Mainboard (BRD4002A) features an additional 2-pin JST connector connected in parallel to the CR2032 socket that can be used with an external power source between 1.8 V and 3.6 V instead of a coin cell. The coin cell battery is not protected from reverse current, and it is therefore important to remove the coin cell battery from the CR2032 socket if applying external power.

Note: The current sourcing capabilities of a coin cell battery might be too low to supply certain wireless applications.

5.2 Kit Power

There are normally two main contributions to the power consumption from the mainboard USB connector, i.e., two main current paths:

- One being monitored by the AEM that goes to the target power domain (VMCU)
- One that goes to the board controller power domain

While the current consumption of the board controller section is fairly deterministic and stable, the current consumption connected to the target's power domain (VMCU) varies widely depending on the application and the slide switch position. Typically, the board controller power domain draws 200 mA on the Wireless Starter Kit Mainboard (BRD4001A) and 250 mA on the Wireless Pro Kit Mainboard (BRD4002A). The mainboards use linear regulators, and the recommended input voltage is 4.4 - 5.25 V. Use a USB host or power supply and cables that can deliver at least the total amount of current required by the kit.

The 5V net exposed on the breakout pads, EXP header and radio board is also sourced from the mainboard USB connector when the power select switch is in the AEM position. The 3V3 net exposed on the same peripherals is always sourced from the mainboard USB connector. The current consumption of these nets must be included in the total current consumption of the kit if these are utilized.

5.2.1 Board Controller Power

The board controller is responsible for important features, such as the debugger and the AEM, and is powered exclusively through the USB port in the top left corner of the board. This part of the kit resides on a separate power domain, so a different power source can be selected for the target device while retaining debugging functionality. This power domain is also isolated to prevent current leakage from the target power domain when power to the board controller is removed.

The board controller power domain is not influenced by the position of the power switch.

The kit has been carefully designed to keep the board controller and the target power domains isolated from each other as one of them powers down. This ensures that the target EFR32BG22 device will continue to operate in the **BAT** mode.

5.2.2 AEM Power

The supply for the target power domain (VMCU) is a linear regulator integrated with the AEM described in Section when the power select switch is in the AEM position. The output voltage of the regulator is fixed to 3.3 V on the Wireless STK Mainboard (BRD4001A), while it can be adjusted between 1.8 V and 3.6 V on the Wireless Pro Kit Mainboard (BRD4002A) using the .

The output current on the Wireless Pro Kit Mainboard (BRD4002A) is limited by an overcurrent protection (OCP) function, which depends on the programmed VMCU voltage: $OCP(A) \approx VMCU_{SET}(V) \times 0.2 \text{ (A/V)}$. Approaching or exceeding the OCP limit is not recommended as the output voltage will be pulled low, which causes loss of function.

The maximum recommended output current on the Wireless STK Mainboard (BRD4001A) is 300 mA.

5.3 EFR32BG22 Reset

The EFR32BG22 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, a reset to the EFR32BG22 will also be issued during board controller boot-up. This means that removing power to the board controller (unplugging the J-Link USB cable) will not generate a reset but plugging the cable back in will as the board controller boots up.

6. Peripherals

The Wireless Pro Kit has a set of peripherals that showcase some of the EFR32BG22 features.

6.1 Serial Flash (Not Mounted)

The BRD4191A Radio Board has an option to mount an 8 Mbit Macronix MX25R SPI flash that is connected directly to the EFR32BG22. The figure below shows how the serial flash is connected to the EFR32BG22.

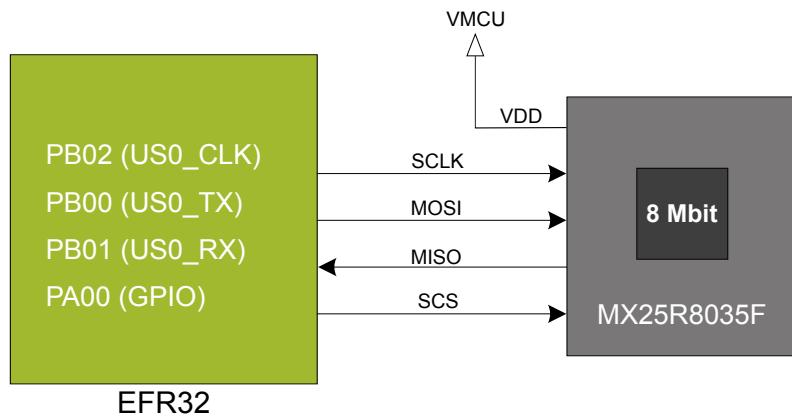


Figure 6.1. Radio Board Serial Flash

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 radio board current consumption.

6.2 Virtual COM Port

An asynchronous serial connection to the board controller is provided for application data transfer between a host PC and the target EFR32BG22. This eliminates the need for an external serial port adapter.

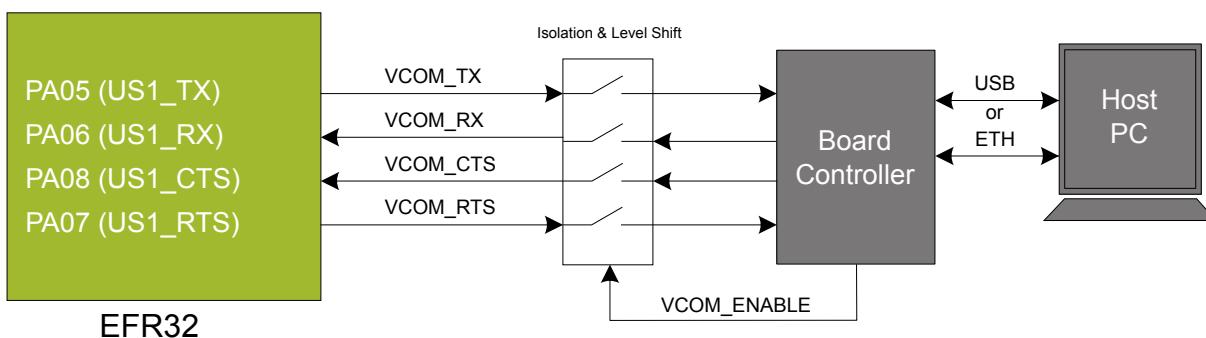


Figure 6.2. Virtual COM Port Interface

The virtual COM port consists of a physical UART between the target device and the board controller and a logical function in the board controller that makes the serial port available to the host PC over USB or Ethernet. The UART interface consists of four pins and an enable signal.

Table 6.1. Virtual COM Port Interface Pins

| Signal | Description |
|-------------|---|
| VCOM_TX | Transmit data from the EFR32BG22 to the board controller |
| VCOM_RX | Receive data from the board controller to the EFR32BG22 |
| VCOM_CTS | Clear to Send hardware flow control input, asserted by the board controller when it is ready to receive more data |
| VCOM_RTS | Request to Send hardware flow control output, asserted by the EFR32BG22 when it is ready to receive more data |
| VCOM_ENABLE | Enables the VCOM interface, allowing data to pass through to the board controller |

The parameters of the serial port, such as baud rate or flow control, can be configured using the . The default settings depend on which radio board is used with the mainboard.

Note: The VCOM port is only available when the board controller is powered, which requires the J-Link USB cable to be inserted.

Note: There may be slight differences on the terminal prompt and settings between the Wireless Starter Kit Mainboard and the Wireless Pro Kit Mainboard.

6.2.1 Host Interfaces

Data can be exchanged between the board controller and the target device through the VCOM interface, which is then available to the user in two different ways:

- Virtual COM port using a standard USB-CDC driver
- TCP/IP by connecting to the Wireless STK on TCP/IP port 4901 with a Telnet client

When connecting via USB, the device should automatically show up as a COM port. The actual device name that is associated with the kit depends on the operating system and how many devices are or have been connected previously. The following are examples of what the device might show up as:

- JLink CDC UART Port (COM5) on Windows hosts
- /dev/cu.usbmodem1411 on macOS
- /dev/ttyACM0 on Linux

Data sent by the target device into the VCOM interface can be read from the COM port, and data written to the port is transmitted to the target device. Connecting to the Wireless STK on port 4901 gives access to the same data over TCP/IP. Data written into the VCOM interface by the target device can be read from the socket, and data written into the socket is transmitted to the target device.

Note: Only one of these interfaces can be used at the same time, with the TCP/IP socket taking priority. This means that if a socket is connected to port 4901, no data can be sent or received on the USB COM port.

6.2.2 Serial Configuration

By default, the VCOM serial port is configured to use 115200 8N1 (115.2 kbit/s, 8 data bits, 1 stop bit), with flow control disabled/ignored. The configuration can be changed using the admin console:

```
WPK> serial vcom config
Usage: serial vcom config [--nostore] [handshake <rts/cts/rtscts/disable/auto>] [speed <9600,921600>]
```

Using this command, the baud rate can be configured between 9600 and 921600 bit/s, and hardware handshake can be enabled or disabled on either or both flow control pins.

6.2.3 Hardware Handshake

The VCOM peripheral supports basic RTS/CTS flow control.

VCOM_CTS (target clear to send) is a signal that is output from the board controller and input to the target device. The board controller de-asserts this pin whenever its input buffer is full and it is unable to accept more data from the target device. If hardware handshake is enabled in the target firmware, its UART peripheral will halt when data is not being consumed by the host. This implements end-to-end flow control for data moving from the target device to the host.

VCOM_CTS is connected to the RTS pin on the board controller and is enabled by setting handshake to either RTS or RTSCTS using the "serial vcom config" command.

VCOM_RTS (target request to send) is a signal that is output from the target device and input to the board controller. The board controller will halt transmission of data towards the target if the target device de-asserts this signal. This gives the target firmware a means to hold off incoming data until it can be processed. Note that de-asserting RTS will not abort the byte currently being transmitted, so the target firmware must be able to accept at least one more character after RTS is de-asserted.

VCOM_RTS is connected to the CTS pin of the board controller. It is enabled by setting handshake to either CTS or RTSCTS using the "serial vcom config" command in the admin console. If CTS flow control is disabled, the state of VCOM_RTS will be ignored and data will be transmitted to the target device anyway.

Table 6.2. Hardware Handshake Configuration

| Mode | Description |
|----------|--|
| disabled | RTS (VCOM_CTS) is not driven by the board controller and CTS (VCOM_RTS) is ignored. |
| rts | RTS (VCOM_CTS) is driven by the board controller to halt target from transmitting when input buffer is full. CTS (VCOM_RTS) is ignored. |
| cts | RTS (VCOM_CTS) is not driven by the board controller. Data is transmitted to the target device if CTS (VCOM_RTS) is asserted and halted when de-asserted. |
| rtscts | RTS (VCOM_CTS) is driven by the board controller to halt target when buffers are full. Data is transmitted to the target device if CTS (VCOM_RTS) is asserted and halted when de-asserted. |

Note: Enabling CTS flow control without configuring the VCOM_RTS pin can result in no data being transmitted from the host to the target device.

7. Board Controller

The Wireless STK Mainboard contains a dedicated microcontroller for some of the advanced kit features provided. This microcontroller is referred to as the board controller and is not programmable by the user. The board controller acts as an interface between the host PC and the target device on the radio board, as well as handling some housekeeping functions on the board.

Some of the kit features actively managed by the board controller are

- The [on-board debugger](#), which can flash and debug both on-board and external targets.
- The [Advanced Energy Monitor](#), which provides real-time energy profiling of the user application.
- The Packet Trace Interface, which is used in conjunction with PC software to provide detailed insight into an active radio network.
- The [Virtual COM Port](#) and interfaces, which provide ways to transfer application data between the host PC and the target processor.
- The [admin console](#), which provides configuration of the various board features.

Silicon Labs publishes updates to the board controller firmware in the form of firmware upgrade packages. These updates may enable new features or fix issues. See Section for details on firmware upgrade.

7.1 Introduction

The Wireless STK Mainboard and the Wireless Pro Kit Mainboard contain a dedicated microcontroller for some of the advanced kit features provided. This microcontroller is referred to as the board controller and is not programmable by the user. The board controller acts as an interface between the host PC and the target device on the radio board, as well as handling some housekeeping functions on the board.

Note: This chapter describes the board controller on both the Wireless Starter Kit Mainboard and the Wireless Pro Kit Mainboard. There might be slight differences between these two boards, such as the exact menu and format on the admin console, not highlighted in this chapter.

Some of the kit features actively managed by the board controller are:

- The [on-board debugger](#), which can flash and debug both on-board and external targets.
- The [Advanced Energy Monitor](#), which provides real-time energy profiling of the user application.
- The Packet Trace Interface, which is used in conjunction with PC software to provide detailed insight into an active radio network.
- The [Virtual COM Port](#) and interfaces, which provide ways to transfer application data between the host PC and the target processor.
- The [admin console](#), which provides configuration of the various board features.

Silicon Labs publishes updates to the board controller firmware in the form of firmware upgrade packages. These updates may enable new features or fix issues. See Section for details on firmware upgrade.

7.2 Admin Console

The admin console is a command line interface to the board controller on the kit. It provides functionality for configuring the kit behavior and retrieving configuration and operational parameters.

7.2.1 Connecting

The Wireless STK must be connected to Ethernet using the Ethernet connector in the top left corner of the mainboard for the admin console to be available. See Section [9.1.2 Ethernet Interface](#) for details on the Ethernet connectivity.

Connect to the admin console by opening a telnet connection to the kit's IP address, port number 4902.

When successfully connected, a `wstk>` prompt is displayed.

7.2.2 Built-in Help

The admin console has a built-in help system which is accessed by the `help` command. The `help` command will print a list of all top level commands:

```
WPK> help
***** Root commands *****
aem          AEM Configuration and Information Commands  [ avg, calibrate, calinfo ]
boardid      Commands for board ID probe.  [ list, probe ]
dbg          Debug interface status and control  [ info, mode ]
dch          Datachannel control and info commands  [ info, message ]
discovery    Discovery service commands.  [ key ]
net          Network commands.  [ dnslookup, ip, mac ]
pti          Packet trace interface status and control  [ config, disable, dump, ... ]
quit         Exit from shell
serial       Serial channel commands  [ vcom ]
sys          System commands  [ crashlog, nickname, reset, ... ]
target       Target commands.  [ button, go, halt, ... ]
time         Time Sync Service commands  [ client, disable, info, ... ]
user         User management functions  [ login, ]
```

The `help` command can be used in conjunction with any top level command to get a list of sub-commands with descriptions. For example, `pti help` will print a list of all available sub-commands of `pti`:

```
WPK> pti help
***** pti commands *****
config      Configure packet trace
disable     Disable packet trace
dump        Dump PTI packets to the console as they come
enable      Enable packet trace
info        Packet trace state information
```

This means that running `pti enable` will enable packet trace.

7.2.3 Command Examples

PTI Configuration

```
pti config 0 efruart 1600000
```

Configures PTI to use the "EFRUART" mode at 1.6 Mb/s.

Serial Port Configuration

```
serial config vcom handshake enable
```

Enables hardware handshake on the VCOM UART connection.

7.3 Virtual UART

The Virtual UART (VUART) interface provides a high-performance application data interface that does not require additional I/O pins apart from the debug interface.

The Wireless STK makes the VUART interface available on TCP/IP port 4900.

7.3.1 Target to Host

Target to host communication utilizes the SWO-pin of the debug interface through the ITM debug peripheral. This approach allows a sleepy target device to enter all energy modes and still wake up intermittently to send debug information. The baud rate of the SWO data is locked to 875 kHz.

VUART utilizes ITM stimulus port 0 for general purpose printing. Silicon Labs' networking stacks utilize ITM stimulus port 8 for debug printing. The data on port 8 is encapsulated in additional framing and will also appear in the Simplicity Studio Network Analyzer.

7.3.2 Host to Target

Host to target communication utilizes SEGGER's Real Time Transfer (RTT) technology. A full explanation of how this works can be found in *J-Link/J-Trace User Guide (UM08001)*. Briefly summarized, RTT consists of a structure called the RTT Control Block, which is located in RAM. This control block points to circular buffers that the debugger can write data into. The target application can then read data out of this circular buffer.

The board controller will start searching for the RTT Control Block upon receiving data on TCP/IP port 4900. If the board controller is unable to locate the RTT Control Block, it will return an error message on the same connection. For the board controller to be able to locate the RTT Control Block, it has to be aligned on a 1024-byte boundary in RAM.

After initializing the RTT connection, the target will only enter emulated EM2 and EM3 where the power consumption remains similar to EM1. This is because RTT utilizes the debug interface which requires use of high-frequency oscillators. Energy modes EM4S and EM4H will work as normal. When debugging energy consumption, it is therefore important to not send data on TCP/IP port 4900 as not to instantiate the RTT connection.

7.3.3 Limitations

- Because the SWO-connection can be disabled by the debugger at will, it is important for the target application to verify that SWO is enabled and configured before each transmission on the interface.
- After initializing host to target communication over RTT by sending data on TCP/IP port 4900, the target application will be unable to enter EM2 and EM3. This is because RTT utilizes the debug connection of the target.
- VUART might not work reliably during an active debugging session. This is because there is contention over the target's debug interface. The board controller will defer accessing the target until it is made available by the host debugger.
- VUART is designed with the assumption that only the board controller will access the RTT control block. If the target application uses RTT for other purposes, such as Segger SystemView, refrain from using VUART.

7.3.4 Troubleshooting

| Problem | Solution |
|--|--|
| No data received after ending a debug session. | After certain debugger operations, the host computer manually disables SWO on the target in order to conserve power. This might cause SWO data to not appear if the target application initialized SWO before the debugger has disconnected. Either press the RESET-button on the Wireless Starter Kit to reset the target application or make sure that the target application verifies that SWO is enabled and configured before sending any data. |
| No data received after flashing a new application. | |
| Other issues | Disconnect from TCP port 4900, press the RESET-button on the kit, then reconnect to 4900. If this does not fix the issue, try to restart the kit by unplugging and replugging the USB cable. |

8. Advanced Energy Monitor

8.1 Introduction

Any embedded developer seeking to make their embedded code spend as little energy as the underlying architecture supports needs tools to easily and quickly discover inefficiencies in the running application. This is what the Simplicity Energy Profiler is designed to do. In real-time, the Energy Profiler will graph and log current as a function of time while correlating this to the actual target application code running on the EFR32BG22. There are multiple features in the profiler software that allow for easy analysis, such as markers and statistics on selected regions of the current graph or aggregate energy usage by different parts of the application. The Energy Profiler is available through Simplicity Studio.

8.2 Code Correlation

By using the Energy Profiler, current consumption and voltage can be measured and linked to the actual code running on the EFR32BG22 in realtime. The Energy Profiler gets its data from the board controller on the mainboard through the Advanced Energy Monitor (AEM). The current signal is combined with the target processor's Program Counter (PC) sampling by utilizing a feature of the ARM CoreSight debug architecture, and the Instrumentation Trace Macrocell (ITM) block can be programmed to sample the MCU's PC at periodic intervals and output these over SWO pin ARM devices. When these two data streams are fused and correlated with the running application's memory map, an accurate statistical profile can be built that shows the energy profile of the running application in real-time.

8.3 AEM Circuit

The AEM circuit on the Wireless Pro Kit Mainboard (BRD4002A) and the Wireless STK Mainboard (BRD4001A) measures the current through a sense resistor inside the feedback loop of a low-dropout regulator (LDO). The output voltage of this LDO powers the EFR32BG22 when the power slide switch is in the AEM position. AEM usage on both mainboards is similar, but the implementation and performance on the Wireless Pro Kit Mainboard (BRD4002A) has some key differences including the utilization of two sense resistors instead of one and a different LDO, which is explained in Section 8.3.1 AEM Details. The AEM implementation on the Wireless Pro Kit Mainboard (BRD4002A) is shown in the figure below.

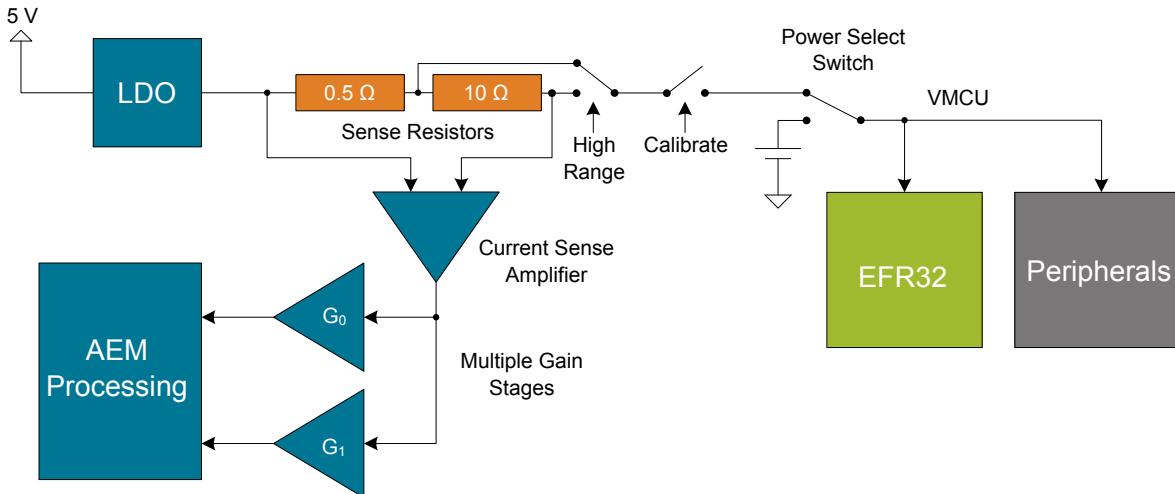


Figure 8.1. Advanced Energy Monitor On The Wireless Pro Kit Mainboard (BRD4002A)

Note: The VMCU regulator feedback point is after the sense resistor to ensure that the VMCU voltage is kept constant when the output current changes. Series resistances in the current path will, however, cause some IR drop on VMCU.

Note: The AEM circuit only works when the kit is powered and the power switch is in the AEM position.

8.3.1 AEM Details

The main differences between the AEM on the Wireless Pro Kit Mainboard (BRD4002A) and the Wireless STK Mainboard (BRD4001A) is summarized in the table below with more in-depth information given in the text to follow.

Table 8.1. Advanced Energy Monitor Parameters

| Parameter | BRD4002A | BRD4001A |
|--------------------------------|------------------------------|---------------|
| Voltage | 1.8 - 3.6 V | 3.3 V |
| Sample Rate | 100 kHz | 10 kHz |
| Sense Resistor | 10.5 Ω / 0.5 Ω | 2.35 Ω |
| Measurement Range ¹ | 0 - 495 mA | 0 - 95 mA |

Note:

1. The current sourcing capabilities of the LDO may be different than the measurement range.

Wireless Pro Kit Mainboard (BRD4002A) AEM Design Details

The AEM circuitry on the Wireless Pro Kit Mainboard is capable of measuring current signals in the range of approximately 0.1 μ A to 495 mA. This is accomplished through a combination of a highly capable current sense amplifier, multiple sense resistors and gain stages, and signal processing within the kit's board controller before the current sense signal is read by a host computer with 100 kHz sample rate for display and/or storage. Averaging on the output data may be required to achieve sufficient accuracy in some situations, such as low currents, which can be traded for lower bandwidth. High current applications require that the regulator is able to supply enough current as described in Section [5.2 Kit Power](#).

At low currents the current sense amplifier measures the voltage drop over a 10.5 Ω resistive path. The gain stage further amplifies this voltage with two different parallel gain settings to obtain two current ranges. The transition between these two ranges occurs around 150 μ A. When the current exceeds a threshold, which is typically between 10 and 30 mA, the AEM circuitry switches from the 10.5 Ω resistive path to a 0.5 Ω sense resistor and is now capable of measuring currents up to approximately 495 mA. Should the current drop below the threshold again, the sense resistor is changed back to the 10.5 Ω resistive path and the AEM is back to using two different gain stages depending on whether the current is above or below 150 μ A.

The expected typical accuracy of the AEM on the Wireless Pro Kit Mainboard is within 1 %, except for currents in the low tens of microamps where offset errors start to dominate. In this low current region, the expected typical accuracy is some hundred nanoamps. At kit power-up or on a power-cycle, an automatic AEM calibration is performed which compensates for offset errors in the current sense amplifiers. To achieve the stated accuracy, averaging of the AEM output data is required in certain situations (typically at low currents and close to the bottom of the measurement ranges) to reduce noise. Averaging can be applied in Energy Profiler to suit different requirements during or after the acquisition. The analog bandwidth of the measurement circuit depends on multiple factors, such as output current and capacitance on the VMCU net, and may be lower than the output data rate. Generally, higher output current and lower capacitance on VMCU gives a higher analog bandwidth.

Wireless STK Mainboard (BRD4001A) AEM Design Details

The AEM circuitry on the Wireless STK Mainboard works conceptually in a similar way to the implementation on the Wireless Pro Kit Mainboard except for two key differences: it uses only one 2.35 Ω sense resistor and the low-dropout regulator (LDO) is different. For details about the two implementations, the reader is encouraged to see the schematics.

The AEM on the Wireless STK Mainboard is capable of measuring currents in the range of 0.1 μ A to 95 mA. The second stage amplifier amplifies the signal with two different gain settings with the transition occurring around 250 μ A. For currents above 250 μ A, the AEM is accurate within 0.1 mA. When measuring currents below 250 μ A, the accuracy increases to 1 μ A. Even though the absolute accuracy is 1 μ A in the sub 250 μ A range, the AEM can detect changes in the current consumption as small as 0.1 μ A. It is possible to source currents above the measurement range as described in Section [5.2 Kit Power](#). The board controller outputs the AEM data with 10 kHz sample rate.

9. On-Board Debugger

The Wireless Pro Kit Mainboard and the Wireless STK Mainboard contain an integrated debugger, which can be used to download code and debug the EFR32BG22. In addition to programming a target on a plug-in radio board, the debugger can also be used to program and debug external Silicon Labs EFM32, EFM8, EZR32, and EFR32 devices connected through the debug connector.

The debugger supports three different debug interfaces for Silicon Labs devices:

- Serial Wire Debug is supported by all EFM32, EFR32, and EZR32 devices
- JTAG is supported by EFR32 and some EFM32 devices
- C2 Debug is supported by EFM8 devices

For debugging to work properly, make sure the selected debug interface is supported by the target device. The debug connector on the board supports all three of these modes.

9.1 Host Interfaces

The Wireless STK supports connecting to the on-board debugger using either Ethernet or USB.

Many tools support connecting to a debugger using either USB or Ethernet. When connected over USB, the kit is identified by its J-Link serial number. When connected over Ethernet, the kit is normally identified by its IP address. Some tools also support using the serial number when connecting over Ethernet; however, this typically requires the computer and the kit to be on the same subnet for the discovery protocol (using UDP broadcast packets) to work.

9.1.1 USB Interface

The USB interface is available whenever the USB connector on the left-hand side of the mainboard is connected to a computer.

9.1.2 Ethernet Interface

The Ethernet interface is available when the mainboard Ethernet connector in the top left corner is connected to a network. Normally, the kit will receive an IP address from a local DHCP server, and the IP address is printed on the LCD display. If your network does not have a DHCP server, you need to connect to the kit via USB and set the IP address manually using Simplicity Studio, Simplicity Commander, or J-Link Configurator.

For the Ethernet connectivity to work, the kit must still be powered through the USB Mini-B connector. See Section [5.2.1 Board Controller Power](#) for details.

9.1.3 Serial Number Identification

All Silicon Labs kits have a unique J-Link serial number which identifies the kit to PC applications. This number is 9 digits and is normally on the form 44xxxxxxxx.

The J-Link serial number is normally printed at the bottom of the kit LCD display.

9.2 Debug Mode

The on-board debugger can be used to debug the EFR32BG22 on the BG22 Direction Finding Radio Board through the debug connector and a BRD8010B STK/WSTK Debug Adapter. To use this mode, set the debug mode to **[Out]**.

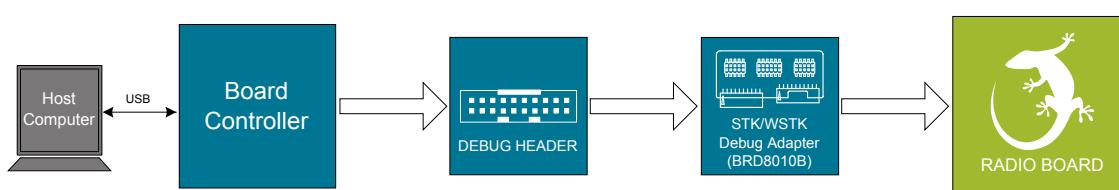


Figure 9.1. Debug OUT

9.3 Debugging During Battery Operation

When the EFR32BG22 is battery-powered and the J-Link USB is still connected, the on-board debug functionality is available. If the USB power is disconnected, the Debug IN mode will stop working.

If debug access is required when the target is running off another energy source, such as a battery, and the board controller is powered down, make direct connections to the GPIOs used for debugging, which are exposed on the breakout pads.

10. Radio

10.1 RF Section

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

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

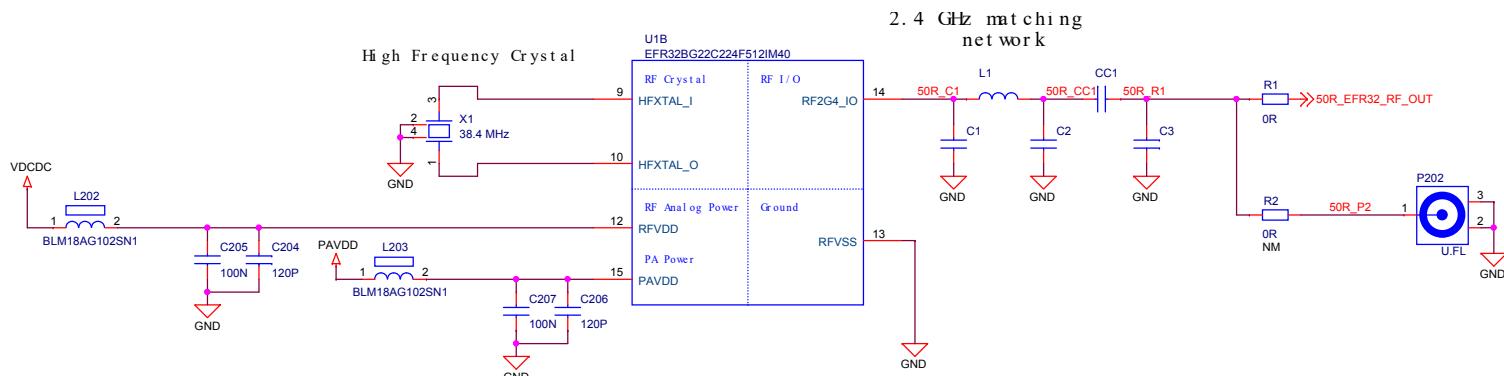


Figure 10.1. Schematic of the RF Section

10.1.1 Description of the RF Matching

The impedance of the RF port of the EFR32BG22 is matched to 50 Ohm: the RF2G4_IO pin is connected to a three-element impedance matching and harmonic filter circuitry, and a dc blocking capacitor. The output of the matching circuit is connected to the Direction Finding Antenna Array.

10.1.2 RF Section Power Supply

On the BRD4191A, 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 BRD4191A schematic).

10.1.3 RF Matching Bill of Materials

The BRD4191A RF matching network bill of materials is shown in the following table.

Table 10.1. BRD4191A RF Matching Network Bill of Materials

| Component name | Value | Manufacturer | Part Number |
|----------------|-------------|--------------|--------------------|
| L1 | 2.6 nH | Murata | LQP03HQ2N6B02 |
| C1 | 1.2 pF | Murata | GRM0335C1H1R2BA01D |
| C2 | 1.3 pF | Murata | GRM0335C1H1R3BA01D |
| C3 | Not Mounted | - | - |
| CC1 | 18 pF | Murata | GJM0335C1E180GB01D |

10.1.4 Antenna

The BRD4191A has 16 patch antennas optimized for direction finding applications.

For detailed description of the antennas, design guidelines, antenna switching concept, refer to [AN1195: Antenna Array Design Guidelines for Direction Finding](#).

10.3 Conducted Power Measurements

During measurements, the BRD4191A BG22 Direction Finding Radio Board was attached to a Wireless Pro Kit Mainboard (BRD4002A) which was supplied by USB. The voltage supply for the radio board (VMCU) was 3.3 V and for the power amplifier (PAVDD), it was 1.8 V.

10.3.1 Conducted Power Measurements with Unmodulated Carrier

The transceiver was operated in unmodulated carrier transmission mode. The output power of the radio was set to 6 dBm. The typical output spectrum is shown in the following figure.

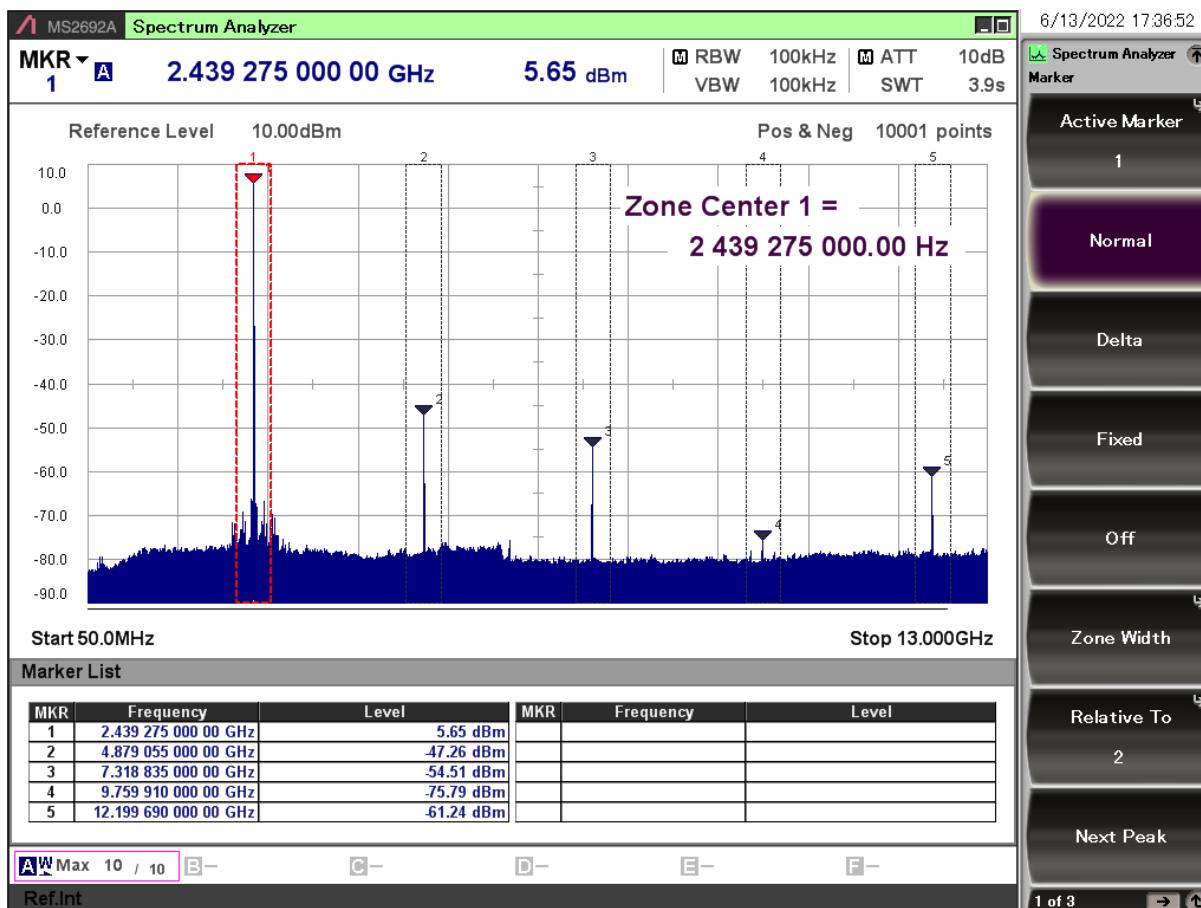


Figure 10.2. Typical Output Spectrum of the BRD4191A; PAVDD = 1.8 V

As it is shown in the figure, the fundamental is a bit below 6 dBm, the harmonics are under their corresponding limits.

Note: The conducted measurement is performed by connecting the on-board UFL connector to a spectrum analyzer through an SMA conversion adapter (P/N: HRMJ-U.FLP(40)). This connection itself introduces approximately 0.3 dB insertion loss.

10.3.2 Relaxation with Modulated Carrier

Depending on the applied modulation scheme and the Spectrum Analyzer settings specified by the relevant EMC regulations, the measured power levels are usually lower compared to the results with unmodulated carrier. These differences have been measured and used as relaxation factors on the results of the radiated measurement performed with unmodulated carrier. This way, the radiated compliance with modulated transmission can be evaluated.

In this case, both the ETSI EN 300-328 and the FCC 15.247 regulations define the following Spectrum Analyzer settings for measuring the unwanted emissions above 1 GHz:

- Detector: Average
- RBW: 1 MHz

The table below shows the relative levels of the measured modulated signals compared to the unmodulated levels with the above Spectrum Analyzer settings in case of the supported modulation schemes.

Table 10.2. Measured Relaxation Factors for the Supported Modulation Schemes

| Applied Modulation (Packet Length: 255 bytes) | BLE Coded PHY: 125 Kb/s (PRBS9) [dB] | BLE Coded PHY: 500 Kb/s (PRBS9) [dB] | BLE 1M PHY: 1 Mb/s (PRBS9) [dB] | BLE 2M PHY: 2 Mb/s (PRBS9) [dB] |
|---|---|---|------------------------------------|------------------------------------|
| 2nd harmonic | -2.7 | -3.1 | -3.3 | -9.1 |
| 3rd harmonic | -4.8 | -5.2 | -5.2 | -10.7 |
| 4th harmonic | -5.5 | -6.5 | -6.7 | -11.9 |
| 5th harmonic | -6.3 | -6.5 | -6.7 | -11.4 |

As it can be observed, the BLE 125 Kb/s coded modulation scheme has the lowest relaxation factors. These values will be used as the worst case relaxation factors for the radiated measurements.

10.4 Radiated Power Measurements

The output power of the EFR32BG22 was set to 6 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.

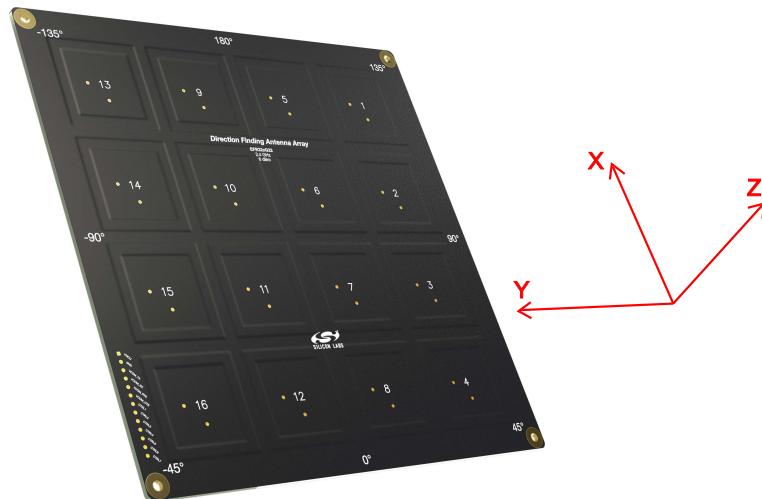


Figure 10.3. DUT Reference Planes

10.4.1 Maximum Radiated Power Measurement

The transceiver was operated in unmodulated carrier transmission mode and the output power of the radio was set to 6 dBm. Antenna #2 was used as the transmitter antenna. The results are shown in the table below.

The correction factors are applied based on the BLE 125 Kb/s coded modulation, shown in section [10.3.2 Relaxation with Modulated Carrier](#). For the rest of the supported modulation schemes the correction factors are larger, thus the related calculated margins would be higher compared to the ones shown in the table below. Thus, the below margins can be considered as worst case margins.

Table 10.3. Maximums of the Measured Radiated Powers of BRD4191A

| Frequency (2440 MHz) | Measured Un-modulated EIRP [dBm] | Orientation | BLE 125 Kb/s Coded Modulation | | | Limit in EIRP [dBm] |
|-------------------------|-------------------------------------|-------------|-------------------------------|---------------------------------|-----------------------|------------------------|
| | | | Correction Factor [dB] | Calculated Modulated EIRP [dBm] | Modulated Margin [dB] | |
| Fund | -5.6 | XZ/H | NA (0 is used) | -5.6 | 35.6 | 30.0 |
| 2nd | -60.2 | YZ/H | -2.7 | -62.9 | 21.7 | -41.2 |
| 3rd | -38.7 | XZ/H | -4.8 | -43.5 | 2.3 | -41.2 |
| 4th | <-50* | -/- | -5.5 | - | >20 | -30.0 |
| 5th | -47.7 | XZ/H | -6.3 | -54.0 | 12.8 | -41.2 |

* Signal level is below the Spectrum Analyzer noise floor

As it is shown in the table, the radiated power of the fundamental is low. This is due to the long transmission lines, the low antenna gain and the insertion loss of the switches on the board. In total, those introduce ~10dB loss.

The 3rd harmonic is above the limit with unmodulated transmission, but with the applied correction factor its level is compliant. The rest of the harmonics are under their corresponding limits with large margins.

10.5.1 Recommendations for 2.4 GHz ETSI EN 300-328 Compliance

As it was shown in the previous chapter, with the EFR32BG22 output power set to 6 dBm, the radiated power of the fundamental of the BRD4191A complies with the 20 dBm limit of the ETSI EN 300-328. With the supported modulation schemes, the harmonics are also compliant with the relevant limits. Although the BRD4191A Radio Board has an option for mounting a shielding can, it is not required for the compliance.

10.5.2 Recommendations for 2.4 GHz FCC 15.247 Compliance

As it was shown in the previous chapter, with the EFR32BG22 output power set to 6 dBm, the radiated power of the fundamental of the BRD4191A complies with the 30 dBm limit of the FCC 15.247. With the supported modulation schemes, the harmonics are also compliant with the relevant limits. Although the BRD4191A Radio Board has an option for mounting a shielding can, it is not required for the compliance.

11. Kit Configuration and Upgrades

The kit configuration dialog in Simplicity Studio allows you to change the J-Link adapter debug mode, upgrade its firmware, and change other configuration settings. To download Simplicity Studio, go to silabs.com/simplicity.

In the main window of the Simplicity Studio's Launcher perspective, the debug mode and firmware version of the selected J-Link adapter are shown. Click the **[Change]** link next to any of these settings to open the kit configuration dialog.

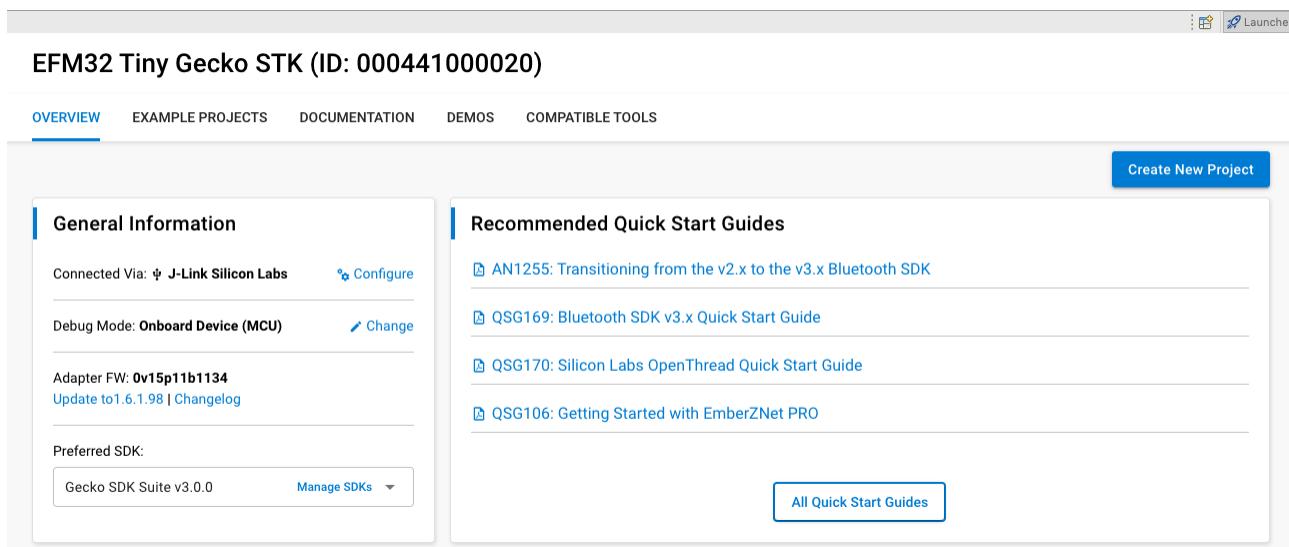


Figure 11.1. Simplicity Studio Kit Information

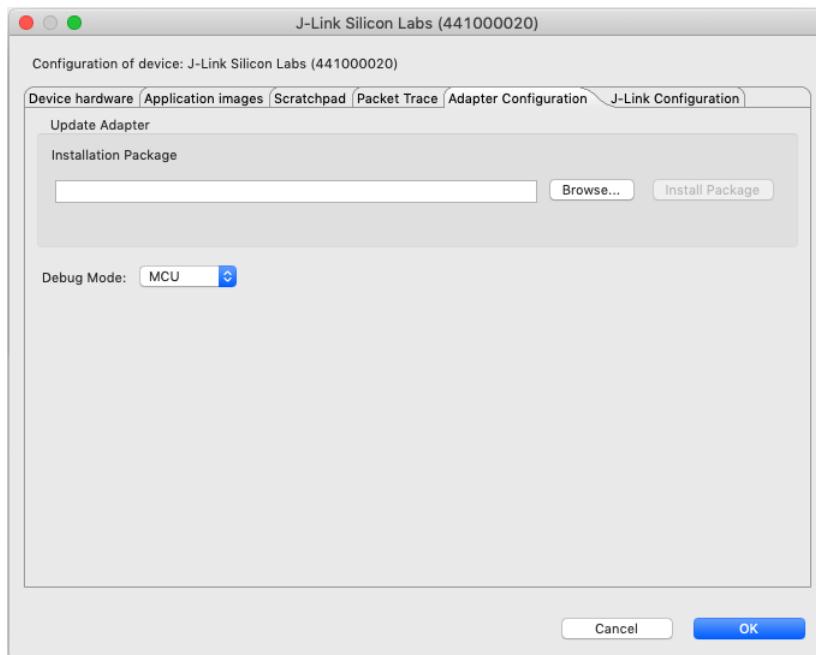


Figure 11.2. Kit Configuration Dialog

11.1 Firmware Upgrades

You can upgrade the kit firmware through Simplicity Studio. Simplicity Studio will automatically check for new updates on startup.

You can also use the kit configuration dialog for manual upgrades. Click the **[Browse]** button in the **[Update Adapter]** section to select the correct file ending in **.emz**. Then, click the **[Install Package]** button.

12. Schematics, Assembly Drawings, and BOM

Schematics, assembly drawings, and bill of materials (BOM) are available through Simplicity Studio when the kit documentation package has been installed. They are also available from the kit page on the Silicon Labs website: silabs.com.

13. Kit Revision History and Errata

13.1 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 summarized in the table below.

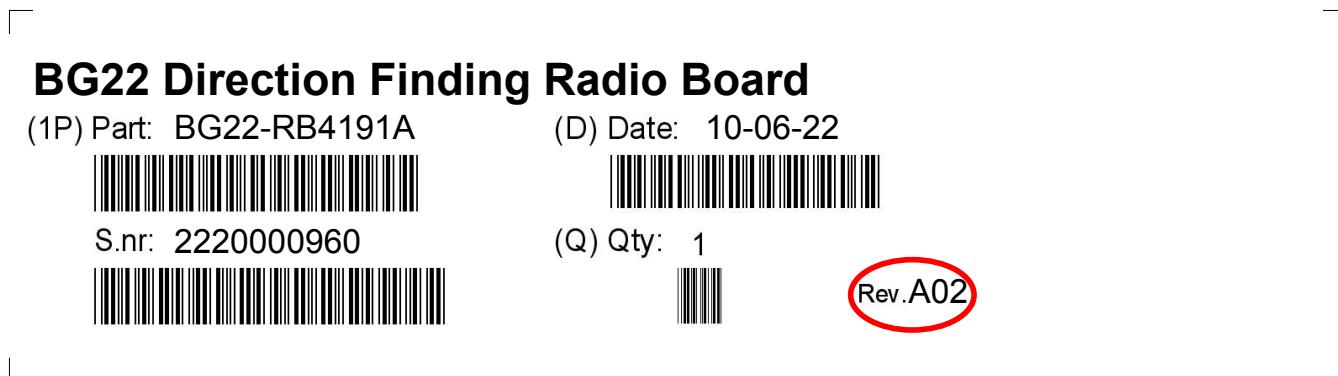


Figure 13.1. Revision Info

Table 13.1. Kit Revision History

| Kit Revision | Released | Description |
|--------------|-----------------|---------------------------------------|
| A00 | 25 January 2022 | New kit introduction of BG22-RB4191A. |

13.2 Errata

There are no known errata at present.

14. Board Revision History and Errata

14.1 Revision History

The board revision can be found laser printed on the board, and the board revision history is summarized in the following table.

Table 14.1. Board Revision History

| Revision | Released | Description |
|----------|-----------------|--|
| A03 | 3 May 2022 | Updated PCB revision. |
| A02 | 25 January 2022 | Updated PCB variant to final. Added optional parallel antenna tuning components. |
| A01 | 13 January 2022 | Updated PCB variant. No change in the components. |
| A00 | 6 August 2021 | Initial production release. |

14.2 Errata

There are no known errata at present.

15. Document Revision History

Revision 1.0

June 2022

- Initial document release.

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400 West Cesar Chavez
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