# UG591: EFR32xG22E Energy Harvesting Explorer Kit

EFR32xG22E Energy Harvesting Explorer Kit is an excellent starting point to explore and evaluate different Energy Harvesting solutions with Silicon Labs' Multiprotocol Wireless Systems on Chip (SoC).

This unique Energy Harvesting kit selection includes a lightweight board with one of Silicon Labs most popular Multi-protocol Wireless SoCs, based on the Explorer Kit platform, and different shields and adapters which, combined with the Explorer Kit's features enable evaluation of multiple solutions for Energy Harvesting, making use of energy sources like photovoltaic cells, inductive or piezoelectric sources, Thermoelectric Generators (TEG), in different applications, for example pulsed or continuous supply, single or dual source.

- The Dual Harvester Shield is the most flexible shield, that can be used to harvest energy from one or two sources at the same time. Typical use case scenarios are complimentary photovoltaic cells, one photovoltaic cell and one piezoelectric source taking energy from vibrations, etc. Adapters, for interfacing AC and DC sources to the Dual Harvester Shield, are also provided
- The Kinetic Button Shield is engineered to demonstrate a specific application, using an inductive switch, aka kinetic switch, to temporarily power the Wireless SoC and transmit a sequence of packages, typically for interacting with a light bulb or coordinator
- A supplementary Battery Shield is provided for debugging for example stand-alone operation scenarios or evaluating battery lifetime
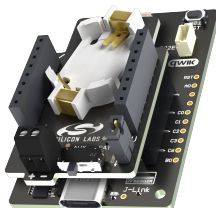
When connected to the Explorer Kit, the shield supplies exclusively the Wireless SoC, while the debugger is left powered off, allowing stand-alone operation and true real-time current measurements.
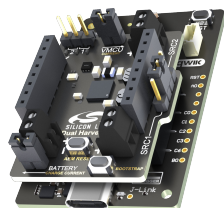
BRD8201A
Dual Harvester Shield
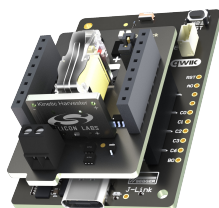
BRD8202A
Kinetic Button Shield

BRD8203A
Battery Shield

FEATURES

- Energy Harvesting
- Self-powered operation
- Flexible PMIC
- Hardware and Software configurable registers
- AC and DC sources
- Automatic power selection (self-powered or debugger)
- Test Points for current and voltage measurements
- Single or Dual source

ITEMS INCLUDED IN THIS KIT:

- BRD8201A Dual Harvester Shield
- BRD8202A Kinetic Button Shield, equipped with the BRD8206A Kinetic Switch Adapter
- BRD8203A Battery Shield
- BRD8204A AC Input Adapter
- BRD8205A DC Input Adapter
- BRD2710A EFR32xG22E Explorer Board
- 1x photovoltaic cell
- 1x lithium capacitor

ORDER INFORMATION:

- xG22-EK8200A

Table of Contents

1. Introduction

This document explains hardware and usage of the Energy Harvesting Shields for Explorer Kits with the xG22E Explorer Kit (xG22-EK2710A). Users are encouraged to download the user guide for the xG22E Explorer Kit (UG582) to have a complete documentation about the Energy Harvesting Kit as a whole.

Note: Check the orientation marks on Explorer Kit and Shield before powering the board stack. They should both point the same way. Refer to the example in for more details.

1.1 Kit Contents

The Energy Harvesting Shields for Explorer Kits contains the following shields:
* 1x BRD8201A - Dual Harvester Shield
* 1x BRD8202A - Kinetic Button Shield equipped with BRD8206A - Kinetic button
* 1x BRD8203A - Battery Shield

The shields are designed to mate the EFR32xG22E Multi-protocol Wireless SoC, also included:
* 1x BRD2710A - EFR32xG22E Explorer Board

Furthermore, the kit contains various hardware to set up some use cases with popular energy sources
* 1x BRD8204A AC Input Adapter
* 1x BRD8205A DC Input Adapter
* 1x AM-1417CA-DGK-E photovoltaic cell for indoor use
* 1x TPLC-3R8/10MR8X14 lithium capacitor

CR2032 batteries and USB-C cable are not included.

1.2 Compatibility and Prerequisites

Compatibility

While the Energy Harvesting Shields for Explorer Kits are electrically compatible with all Silicon Labs' Explorer Kits, we recommend to use the shields with the BRD2710A board, that comes with the EFR32xG22E Energy Harvesting Explorer Kit itself, or with other Explorer Kits optimized for Energy Harvesting. Orderable Part Numbers for such kits carry a trailing -E in the device family name, for example xG22-EK2710A EFR32xG22E Explorer Kit.

Prerequisites

While the Dual Harvester Shield and the Kinetic Button Shield work with the materials provided in this kit, the Battery Shield require the user to purchase a CR2032 coin cell battery or any other compatible battery for powering the Battery Shield through the auxiliary input.

Refer to for selecting appropriate components.

User will need to complement the kit with a USB type C cable, needed to flash and debug the application.

Important: All users are encouraged to read section 1.4 Safety Notes before using the Energy Harvesting Shields for Explorer Kits.

1.3 Intended Use

This section gives a brief overview of the different shields, the use they were designed for and the purposes they serve:

- The Energy Harvesting Shields for Explorer Kits always need to be connected to an Explorer Kit to operate. The shields are designed to provide power to the Multi-protocol Wireless SoC located on the Explorer Kit boards.
- The Dual Harvester Shield is designed to operate with one or two energy sources, a storage element, with or without Input Adapters. To add peripherals, a mikroBUS Click Board[TM] might optionally be added to the board stack with the Dual Harvester Shield[1].
- The Kinetic Button Shield provides everything needed to power the Wireless SoC with no need of additional components. Once connected to a compatible Explorer Kit board, with the designed firmware application, it will just work out of the box. This board does not allow further stacking with other Click Boards[TM]
- The Battery Shield is intended to provide power to the Explorer Kit board, alternatively to the debug cable, in such a way to allow stand alone (battery) operation and easily measuring current with external instruments. The Battery Shield does not accepts LiPo batteries or other batteries with higher voltage than 3.6 V. As for the Dual Harvester Shield, the Battery Shield offers the possibility to add one Click Board[TM] to the board stack[1]

Note: 1. provided that the selected Click Board[TM] operates at lower voltage than 3.3 V. Max output voltage for the Dual Harvester Shield is bound to the AEM13920 specifications and limited to 2.5 V. The voltage of a coin cell is normally between 2 and 3 V.

1.4 Safety Notes

Users are responsible to purchase batteries compliant to the specifications provided in section 2. Recommended Operating Conditions and understand the limitations with regard to charge and discharge rates, in order to ensure safe operation of the kit at any time.

Only rechargeable batteries or super-capacitors can be used as storage element with the Dual Harvester Shield. The hardware comes configured to operate with lithium capacitors.

If using other storage elements than lithium capacitors in conjunction with the Dual Harvester Shield, the Energy Harvesting PMIC must be configured accordingly, to provide the correct charge voltages and thresholds. The Energy Harvesting PMIC can be configured either by hardware or software. More details about storage settings for the Energy Harvesting PMIC are found in section 3.1.3 Dual Harvester Shield: Default Configuration or in the AEM13920 data sheet.

The Dual Harvester Shield comes with a jumper, determining the charge rate of the storage element while fast charging (13 mA, 74 mA or 135 mA), i.e. while the USB cable is connected. However, this jumper does not affect the charge rate during normal operation, when energy is being sourced from the harvester inputs. Make sure the selected harvesters can not produce current levels that exceed the rated values for the selected storage element, specially when using Lithium devices. Charging current beyond the designed limits imply safety and health hazards. For instance, **fumes from overheated lithium capacitors or batteries are toxic.** More details about setting charge rate are found in section 3.1.3 Dual Harvester Shield: Default Configuration.

When connecting external hardware, specially batteries or wired energy sources, always pay attention to the polarity markings provided on the board in proximity of the connector and make sure the external hardware is connected with the correct polarity.

Always pay attention to orientation marks on host board and Shield before powering the board stack. They should both point the same way. The following picture shows where the orientation marks are located on the BRD2710A and on the Dual Harvester Shield. All the included shields have orientation marks at the same location.
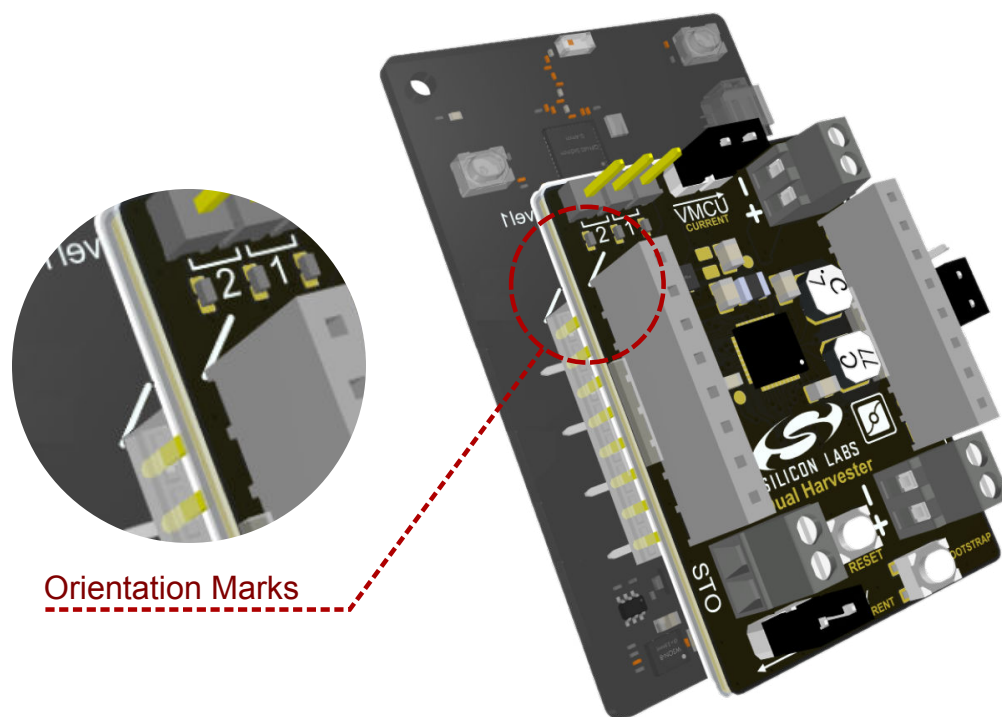
Orientation Marks

Figure 1.1. Example of Orientation Marks on BRD8201A Dual Harvester Shield

Note: Do not leave any battery operated shield unattended. This applies to the Dual Harvester Shield and Battery Shield. These are sold as development kits and not finished products. The software application plays a role in safety, with regard to charge voltages and discharge rates which might exceed the specified values for a given battery.

1.5 Getting Started

Detailed instructions for how to get started with your new EFR32xG22E Energy Harvesting Explorer Kit can be found on the Silicon Labs web page: https://www.silabs.com/development-tools/wireless/efr32xg22e-energy-harvesting-explorer-kit.html

2. Recommended Operating Conditions

The following table is intended to serve as guideline for a correct use of the Energy Harvesting Shields for Explorer Kits. Exceeding maximum values can cause permanent damage to the hardware.

Table 2.1. Recommended Operating Conditions

Parameter	Hardware	Symbol	Min	Typ	Max	Unit
USB Supply Input Voltage, Explorer Board	All	V_{USB}	4.4	5.0	5.25	V
Source Voltage, Dual Harvester Shield	BRD8201A	SRC_X	0.275	−	5.0	V
Battery Voltage Dual Harvester Shield	BRD8201A	V_{STO}	V_{LOAD}	3.8	5	V
Auxiliary Input Voltage Battery Shield	BRD8203A	V_{AUX_IN}	1.8	−	3.6	V
Battery Input Voltage Battery Shield	BRD8203A	V_{BAT_IN}	2.0	−	3.0	V
Load Current Battery Shield	BRD8203A	I_{LOAD}, I_{VMCU}	−	−	0.3	A
Operating Temperature	All	T_{OP}	0	20	40	˚C

3. Hardware

This section illustrates the hardware architecture and features of each of the shields included in the Energy Harvesting Shields for Explorer Kits.
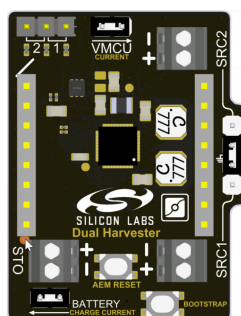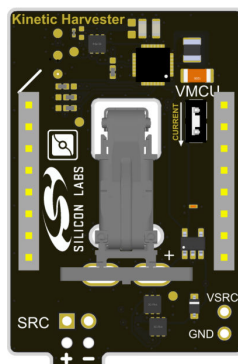

Figure 3.1.   BRD8201A Dual Harvester Shield

Figure 3.2.   BRD8202A Kinetic Button Shield
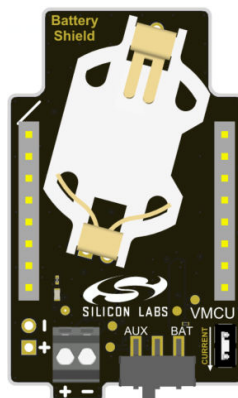
Figure 3.3.   BRD8203A Battery Shield
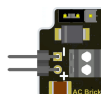
Figure 3.4.   BRD8204A AC Input Adapter
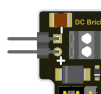
Figure 3.5.   BRD8205A DC Input Adapter

3.1 Dual Harvester Shield: Hardware Description

3.1.1 Dual Harvester Shield: Block Diagram

The following diagram illustrates the hardware architecture of the Dual Harvester Shield in connection with the Explorer Kit:
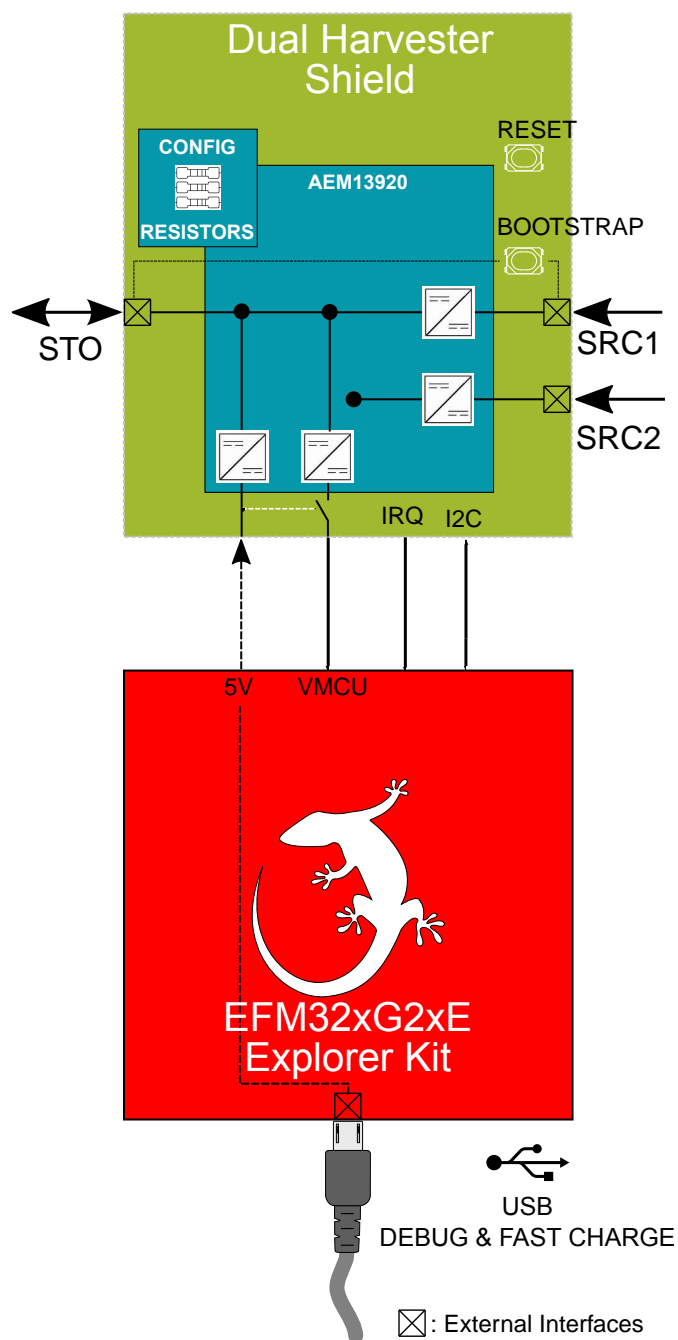
Figure 3.6. BRD8201A Dual Harvester Shield: Block Diagram

The Dual Harvester Shield is based on the AEM13920 Power Management Integrated Circuit (PMIC). The PMIC can seamlessly harvest energy from one or two sources at the same time. The blue box in the diagram represents the main blocks internal to the PMIC, needed to understand the energy flow in this kit. The AEM13920 can use the energy from these two sources (SRC1 and SRC2) to power the explorer kit and to charge a storage element (STO). If none of the two sources is able to deliver enough energy, the PMIC will try to draw current from the storage element.

There is a thermistor (NTC) on the board, directly connected to the PMIC, which can cause it to trip if the temperature is above or below certain thresholds. These thresholds are defined by hardware (see section 3.1.3 Dual Harvester Shield: Default Configuration) but can also be configured by software.

When a USB cable is inserted, the Explorer Kit provides 5V to the PMIC through the stacking interface, so the storage element can be quickly charged from the USB BUS voltage. Note that in this condition the SoC supply voltage, V_{MCU}, is derived from the USB BUS voltage too, so the Wireless SoC is supplied from the on-board debugger (3.3 V) and not from the Shield, that typically operates at a lower voltage.

The PMIC output voltage is gated (turned off) by the presence of the USB BUS voltage. When the Energy Harvesting Kit is self-powered, i.e. no USB cable is attached, a switch is closed and the PMIC powers directly the Wireless SoC on the Explorer Kit, and the on-board debugger is disconnected, drawing no current from the circuitry.

A resistor network allow users to configure the AEM13920 by hardware, adding or removing some shunt resistors. More details about this will be given in the following section.

More than power, the stacking interface also routes a few digital signals between the Wireless SoC and the PMIC:

- one I^{2}C bus, to access the PMIC configuration register and override the configuration otherwise imposed by the configuration resistors
- one interrupt signal from the PMIC

Users are encouraged to download the AEM13920 data sheet to read more about the interrupt functionality and software configuration using I^{2}C.

There are two buttons on this shields:

- BOOTSTRAP: connects the storage element (STO) to input source 1 (SRC1). This is meant to start the PMIC when the source input voltage is below the cold start voltage (refer to the minimum input voltage in table 2. Recommended Operating Conditions)
- AEM RESET: drains the decoupling capacitor of the PMIC supply voltage to force reset of the PMIC

3.1.2 Dual Harvester Shield: Board Layout and Interfaces

Components of major interest for the user, such as connectors, jumpers, placeholder footprints and configuration resistors are marked on the board's silkscreen, here shown in grey text. Reference Designators in red.
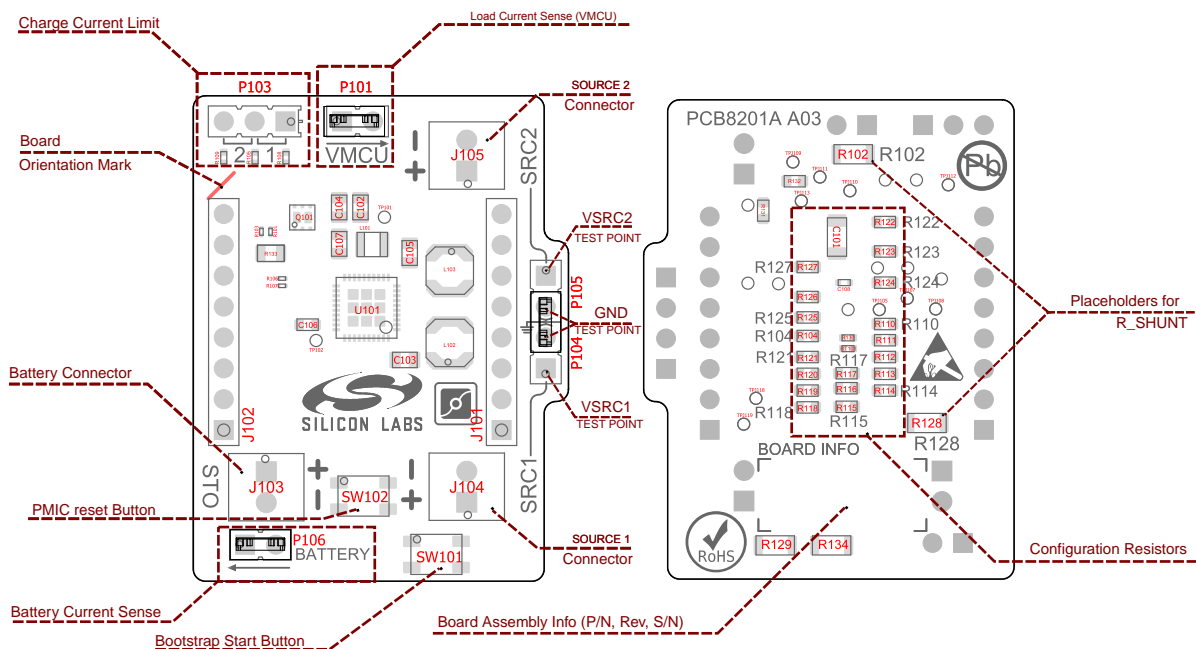
Figure 3.7. BRD8201A Dual Harvester Shield Assembly Drawings, Top Side to the Left and Bottom Side to the Right

When mounted on the Explorer Kit, the Dual Harvester Shield is placed with its bottom side down and top side remains accessible.

Note: Check the orientation marks on Explorer Kit and Shield before powering the board stack. They should both point the same way. Refer to the example in Figure 1.1 Example of Orientation Marks on BRD8201A Dual Harvester Shield on page 6 for more details.

3.1.3 Dual Harvester Shield: Default Configuration

The AEM13920 PMIC is configured in hardware by a series of resistors located on the bottom side of the board (see section 3.1.2 Dual Harvester Shield: Board Layout and Interfaces for more details). The resulting configuration at power up is:

- Source 1 regulation mode: Constant Voltage
- Source 1 level: 0.6 V
- Source 2 regulation mode: Maximum Power Point Tracking (MPPT)
- Source 2 level: 75 %
- MPPT Sampling Period: 8/512 ms
- Storage Element: lithium capacitor(determines Overcharge and Undercharge Threshold Voltages)
- Output voltage: 2.2 V (determines V_{MCU})
- Fast charge current: 13 mA
- On-board temperature range: -25°C … 70°C

The **source, storage and output settings**, i.e. the first 7 items of the list above, are governed by the configuration resistors at positions **R110:R127**. The PMIC has internal pull-up resistors. The corresponding register bit is HIGH when the pin is left unconnected, otherwise LOW if externally pulled to GND. Note that these input pins are polled at a such low frequency that the current consumption through the pull networks is negligible. The following table provides an overview of resistors and corresponding register bits.

Table 3.1. Configuration resistors on BRD8201A and configuration registers in AEM13920

Designator	Register Bit	Default
R110	SRC1_MODE	LOW
R111	SRC1_CFG[0]	LOW
R112	SRC1_CFG[1]	HIGH (NC)
R113	SRC1_CFG[2]	LOW
R114	SRC1_CFG[3]	HIGH (NC)
R115	SRC1_CFG[4]	LOW
R116	SRC2_MODE	HIGH (NC)
R117	SRC2_CFG[0]	LOW
R118	SRC2_CFG[1]	LOW
R119	SRC2_CFG[2]	HIGH (NC)
R120	SRC2_CFG[3]	HIGH (NC)
R121	SRC2_CFG[4]	LOW
R122	STO_CFG[0]	LOW
R123	STO_CFG[1]	LOW
R124	STO_CFG[2]	LOW
R125	LOAD_CFG[0]	LOW
R126	LOAD_CFG[1]	HIGH (NC)
R127	LOAD_CFG[2]	HIGH (NC)

Please refer to the AEM13920 data sheet before modifying register configuration.

The Dual Harvester Shield offers the possibility to limit charge currents during fast charge, when supplied by USB power.
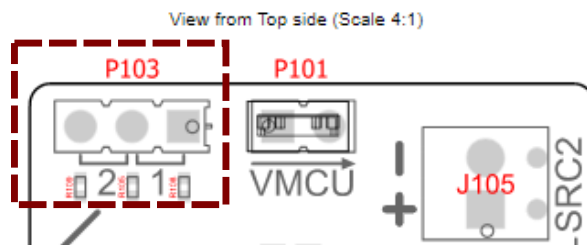
Figure 3.8. Charge Current Selector

Default configuration for the current selector is 13 mA, with the jumper not being fitted.

Fitting a jumper at P103 will provide two quick alternate settings for the charge current, as follows:

Table 3.2. Charge current quick configuration

Jumper position	Connector Pins	Current limit
1	1,2	135 mA
2	2,3	74 mA
NC	–	13 mA

Note: this setting only affect currents coming from the USB cable

An extra jumper is normally fit at P104-P105. Its removal has no impact on the function and can be moved to P103 instead. Leaving P103 open, it is also possible to select other limits by replacing the resistor at R105. Please refer to the AEM13920 data sheet before modifying register configuration.

Please refer to section 3.1.2 Dual Harvester Shield: Board Layout and Interfaces to see component locations.

3.1.4 Dual Harvester Shield: Connectors

The Dual Harvester Shield is equipped with the following connectors:

Table 3.3. Connectors: Overview

Description	Designator	Label	Type	Positions
Source 1, Source 2	J104, J105	SRC1, SRC2	Screw terminal	2
VSRC1, VSRC2	P104, P105	–	Pin Header	2
Storage Element	J103	STO	Screw terminal	2
Load Current Sense	P101	VMCU CURRENT	Pin Header, Jumper	2
Battery Current Sense	P106	BATTERY CHARGE CURRENT	Pin Header, Jumper	2
Charge Current Limit Selector	P103	1, 2	Pin Header, Jumper	3
Stacking Interface	J101, J102	–	Pass-thru socket	2x8

Please refer to the drawings in section 3.1.2 Dual Harvester Shield: Board Layout and Interfaces to look up designators, connector names and silk screen labels.

Input Source Connectors and test points

The Input Source Connectors (SRCx) are screw terminals requiring a flat screw driver to secure the wires. They are labeled with "+" (positive sign) and "-" (negative sign), where the negative input is directly connected to the circuit ground (GND). The positive input is connected to the PMIC input pins, with no additional ESD protection. Caution must be used when connecting flying leads to these inputs. If ESD protection is needed, it can be provided by connecting the AC Input Adapter or the DC Input Adapter in series to these input terminals.

Test points, connected in parallel to the screw terminals, are provided to easily hook up probes. The two test point groups are placed in a row, with the GND pins facing each other. Out of the box, the two GND pins are used to carry a spare jumper.

Storage Element

The Storage Element connector is a screw terminal similar to the Input Source Connectors, with the same type of labels and connections for positive and negative inputs. The positive terminal is connected to an intermediate node of the PMIC, the STO pin, that normally receives current from the input boost converters and is discharged by the output buck converter.

Current Measurement Test Points

The shield provide a means of easily measuring currents, by inserting a current meter between two test points. The arrow labelled on the board shows the normal current flow with passive sign convention, starting from the positive terminal and ending (pointing to) the negative terminal. The test points are normally shortened by a jumper. To start measuring current, remove the jumper and connect a current meter.

The Battery Charge Current arrow is directed as for charging, giving positive currents while charging and negative while discharging, i.e. while supplying the Wireless SoC located on the Explorer Kit board.

Fast Charge Current Limit Selector

This 3-pins header can be used to quickly set the charge current to two discrete values, by connecting the center pin to either the one in position 1 or position 2, as indicated on the silk screen. See section 3.1.3 Dual Harvester Shield: Default Configuration for detailed instructions for how to change current limits.

Stacking Interface

The stacking interface of the Dual Harvester Shield utilizes a subgroup of the mikroBUS™ interface, matching the Explorer Kit's socket. While Figure 3.6 BRD8201A Dual Harvester Shield: Block Diagram on page 9 gives a functional overview, the following table gives the exact pin-out:

Table 3.4. mikroBUS Socket Pin-out

mikro-BUS Pin Name	mikroBUS Pin Definition	Connection	Shared Feature	Usage in Dual Harvester Shield
AN	Analog	PB00	BREAKOUT_RIGHT10	–
RST	Reset	PC06	BREAKOUT_RIGHT9	–
CS	SPI Chip Select	PC03	BREAKOUT_RIGHT8	–
SCK	SPI Clock	PC02	BREAKOUT_RIGHT7	–
MISO	SPI Master Input Slave Output	PC01	BREAKOUT_RIGHT6	–
MOSI	SPI Master Output Slave Input	PC00	BREAKOUT_RIGHT5	–
PWM	PWM output	PB04	BREAKOUT_LEFT10	–
INT	Hardware Interrupt	PB03	BREAKOUT_LEFT9	IRQ: Interrupt from PMIC
RX	UART Receive	PB02	BREAKOUT_LEFT8	–
TX	UART Transmit	PB01	BREAKOUT_LEFT7	–
SCL	I2C Clock	PD02	QWIIC_I2C_SCL, BREAKOUT_LEFT6	PMIC programming and monitoring, address: 0x41
SDA	I2C Data	PD03	QWIIC_I2C_SDA, BREAKOUT_LEFT5	PMIC programming and monitoring, address: 0x41
3V3	VCC 3.3V power	VMCU	V_{MCU}	PMIC output voltage
5V	VCC 5V power	5V	Board USB voltage	Fast Charge
GND	Reference Ground	GND	Ground	–

Note: Check the orientation marks on Explorer Kit and Shield before powering the board stack. They should both point the same way. Refer to the example in Figure 1.1 Example of Orientation Marks on BRD8201A Dual Harvester Shield on page 6 for more details.

Note: It is possible to stack other mikroBUS™ Click Boards on top of the shield. The working voltage of the shield is lower than the mikroBUS standard 3.3 V. Make sure the selected shield supports the operation voltage specific for your application.

3.2 Kinetic Button Shield: Hardware Description

3.2.1 Kinetic Button Shield: Block Diagram

The following diagram illustrates the hardware architecture of the Kinetic Button Shield in connection with the Explorer Kit:
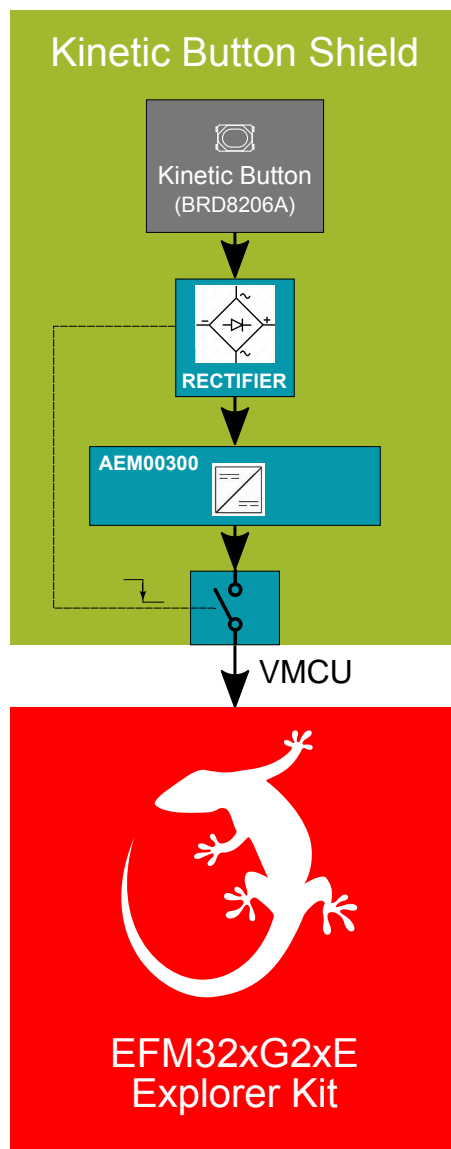

Figure 3.9. BRD8202A Kinetic Button Shield: Block Diagram

The Kinetic Button Shield is based on the AEM00300 PMIC. The PMIC can harvest energy from an AC source, in this case a kinetic button.

The kinetic button has a special rod made of magnetic material, that induces electric currents in the button windings when it moves, in both directions.

This energy is conveyed to a rectifier, so the rectified pulses are fed to the PMIC input. The PMIC then converts these pulses into a regulated voltage, that is used to power the Wireless SoC on the Explorer Kit. This conversion only involves one stage, transferring energy stored in an input capacitor, directly connected to the input rectifier, to an output capacitor. No other energy storage elements than ceramic capacitors are involved.

The output capacitor bank stores the energy generated by one activation, enough to execute the short boot sequence of the EFR32xG22E and a few more instructions, for example to transmit packets.

Power Output Gate: a switch connects the output capacitor bank of the PMIC to the SoC supply rail, when a negative pulse comes to the input node of the PMIC. This prevents the SoC from starting up when not all energy has been harvested from a single activation. Purpose of this circuit is to wait to gather enough energy to complete the boot sequence with good margins. The Power Output Gate is

kept closed (latched) until the output voltage falls below 0.9 V (typ). A discharge time in the order of a few seconds must be considered to allow the Power Output Gate to open the circuit again.

When a USB cable is inserted, the SoC supply voltage, V_{MCU}, is derived from the USB BUS voltage, so the Wireless SoC is supplied from the on-board debugger and not from the Shield. When no USB cable is attached, a switch is closed and the PMIC powers directly the Wireless SoC on the Explorer Kit, the on-board debugger is disconnected, drawing no current from the circuitry.

Unlike the Dual Harvester Shield, the Kinetic Button Shield is designed to showcase one specific application and there is no need nor energy to read or write the PMIC registers, so no signals are routed through the stacking interface. The stacking interface only carries power and ground.

3.2.2 Kinetic Button Shield: Board Layout and Interfaces

Components of major interest for the user, such as connectors, jumpers, placeholder footprints and configuration resistors are marked on the board's silkscreen, here shown in grey text. Reference Designators in red.

Users who want to try out other kinetic buttons, will need to refer to these drawings in this section to locate the placeholder to mount the input terminal and shunt resistors, to disconnect the on-board switch. Reference Designators in red.
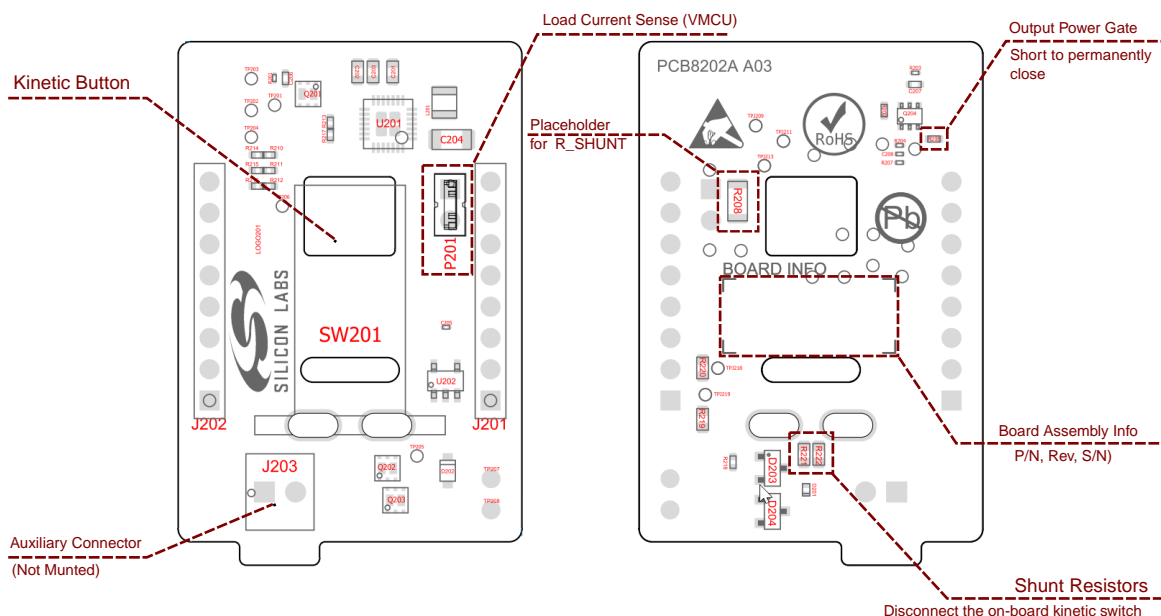

Figure 3.10. BRD8202A Kinetic Button Shield Assembly Drawings, Top Side to the Left and Bottom Side to the Right

When mounted on the Explorer Kit, the Kinetic Button Shield is placed with its bottom side down and top side remains accessible.

Note: Check the orientation marks on Explorer Kit and Shield before powering the board stack. They should both point the same way. Refer to the example in Figure 1.1 Example of Orientation Marks on BRD8201A Dual Harvester Shield on page 6 for more details.

3.2.3 Kinetic Button Shield: Connectors

The Kinetic Button Shield is equipped with the following connectors:

Table 3.5. Connectors: Overview

Description	Designator	Label	Type	Positions
Alternate Source (Not Mounted)	J203	SRC	Screw terminal	2
Load Current Sense	P201	VMCU CURRENT	Pin Header, Jumper	2
Stacking Interface	J201, J202	–	Pass-thru socket	2x8

Please refer to the drawings in section 3.2.2 Kinetic Button Shield: Board Layout and Interfaces to look up designators, connector names and silk screen labels.

Input Source Connector (optional)

The Input Source Connector (SRC) is not mounted. Users interested in evaluating alternate harvesters with this shield, need to purchase either a screw terminal (Phoenix 1725656) or a 2-pins, 0.1" header (e.g. Sullins PBC02SAAN), to mount at pos. J203. SRC is labeled with "+" (positive sign) and "-" (negative sign), where the negative input plays a role gating the output voltage.

Current Measurement Test Points

The shield provide a means of easily measuring currents, by inserting a current meter between two test points. The arrow labelled on the board shows the normal current flow with passive sign convention, starting from the positive terminal and ending (pointing to) the negative terminal. The test points are normally shortened by a jumper. To start measuring current, remove the jumper and connect a current meter.

Stacking Interface

The stacking interface of the Kinetic Button Shield utilizes only power pins to supply the Wireless SoC.

Note: Check the orientation marks on Explorer Kit and Shield before powering the board stack. They should both point the same way. Refer to the example in Figure 1.1 Example of Orientation Marks on BRD8201A Dual Harvester Shield on page 6 for more details.

3.3 Battery Shield: Hardware Description

3.3.1 Battery Shield: Block Diagram

The following diagram illustrates the hardware architecture of the Battery Shield in connection with the Explorer Kit:
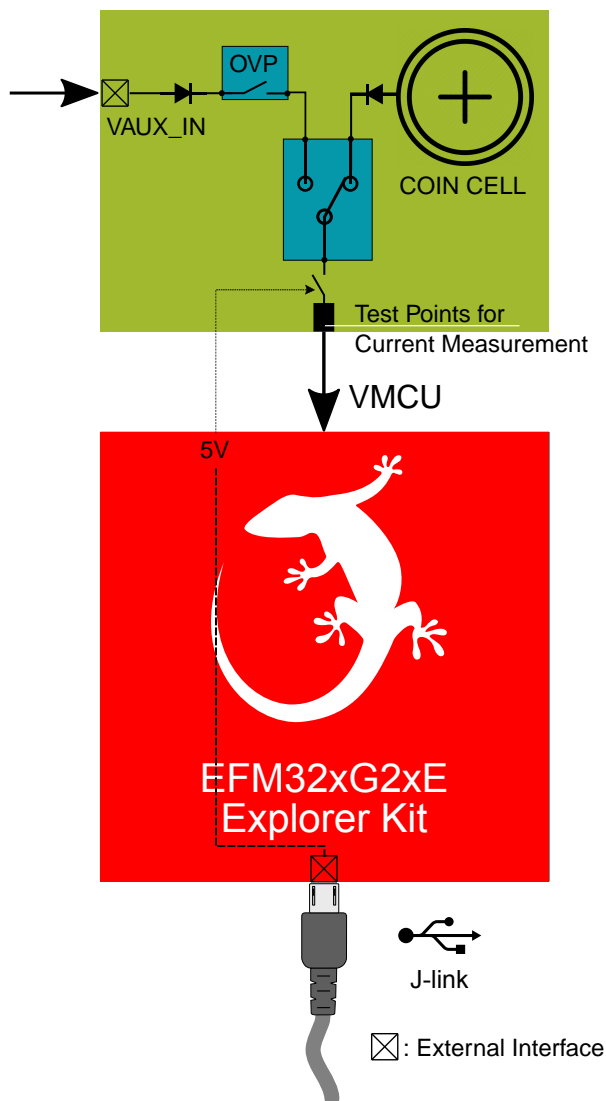

Figure 3.11. BRD8203A Battery Shield: Block Diagram

The Battery Shield is designed to supply the Explorer Kit from a CR2032 coin cell or an auxiliary power source, which could be a battery in a different format. Input voltage range is 1.8 V to 3.6 V, so Lithium battery will not work with this shield.
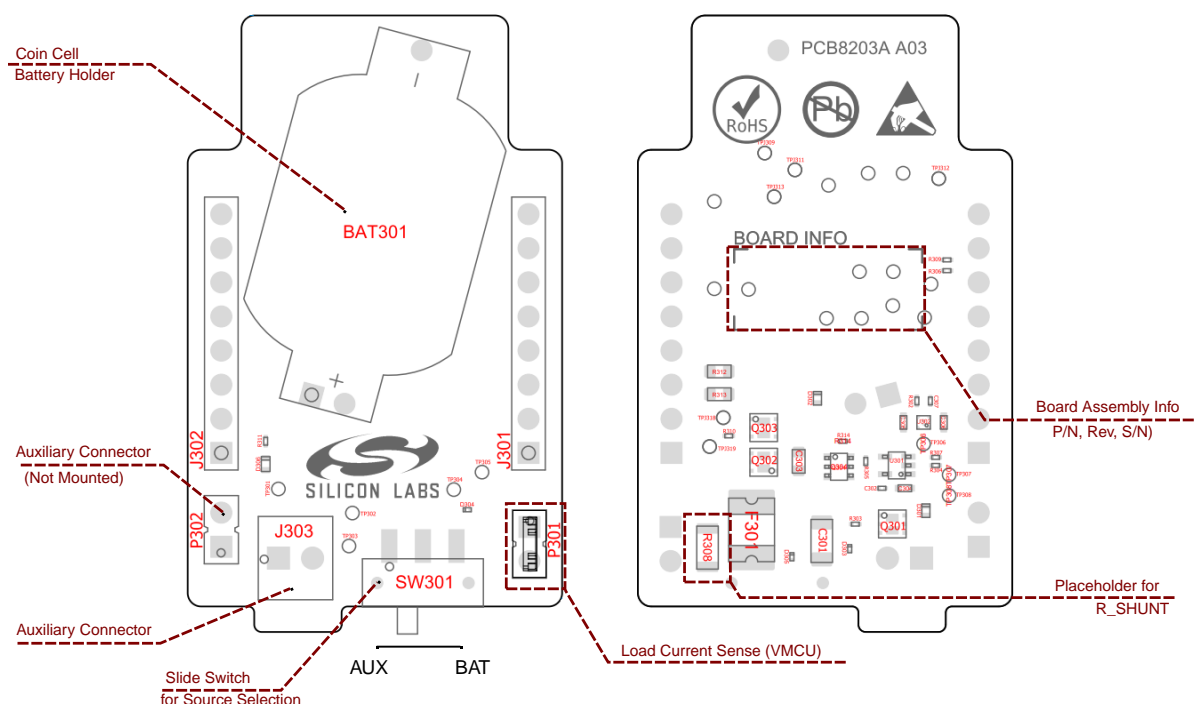
Both input are protected against reverse polarity. In addition, the auxiliary input features an Over Voltage Protection (OVP), which consumes about 2 µA during normal operation. However, the test points for measuring current are placed downstream so the current drawn by the OVP circuit does not affect current measurements, as long as they are taken at the suggested test points.

The two power inputs are multiplexed by a single pole dual throw slide switch, which is connected to the output switch. As for the other shields, the output switch is a solid-state switch gated by the presence of the USB BUS voltage from the Explorer Board, preventing accidental back biasing of the coin cell or auxiliary power source.

When a USB cable is inserted, the SoC supply voltage, V_{MCU}, is derived from the USB BUS voltage too, so the Wireless SoC is supplied from the on-board debugger and not from the Shield.

3.3.2 Battery Shield: Board Layout and Interfaces

Components of major interest for the user, such as connectors, jumpers, placeholder footprints and configuration resistors are marked on the board's silkscreen, here shown in grey text. Reference Designators in red.

Figure 3.12. BRD8203A Battery Shield Assembly Drawings, Top Side to the Left and Bottom Side to the Right

When mounted on the Explorer Kit, the Battery Shield is placed with its bottom side down and top side remains accessible.

Note: Check the orientation marks on Explorer Kit and Shield before powering the board stack. They should both point the same way. Refer to the example in Figure 1.1 Example of Orientation Marks on BRD8201A Dual Harvester Shield on page 6 for more details.

3.3.3 Battery Shield: Connectors

The Battery Shield is equipped with the following connectors:

Table 3.6. Connectors: Overview

Description	Designator	Type	Positions
Battery Holder	BAT301	Electromechanical	2
Auxiliary Input Connector	J303	Screw terminal	2
Alternate Aux Input Connector (Not Mounted)	P302	Pin Header	2
Load Current Sense	P301	Pin Header, Jumper	2
Stacking Interface	J301, J302	Pass-thru socket	2x8

Please refer to the drawings in section 3.3.2 Battery Shield: Board Layout and Interfaces to look up designators, connector names and silk screen labels.

Battery Holder

The battery holder is designed for CR2032 coin cells and is connected to the input selection switch, BAT input.

Auxiliary Input Connector

The Auxiliary Input Connector is a screw terminal, with positive and negative labels for positive and negative inputs. The Auxiliary Input Connector is connected to the input selection switch, AUX input.

Alternate Auxiliary Input Connector

The shield features a place holder for a 0.1" pin header (not mounted), provided as alternate means of connection for auxiliary power input sources. If mounted, this connector is connected in parallel to the Auxiliary Input Connector (Screw terminal), offering the possibility of wiring this input to a 0.1" socket, but also opening for possible conflicts. Never connect both J303 and P302 at the same time. The Alternate Auxiliary Input Connector is labeled with positive and negative labels for positive and negative inputs, and also connected to the input selection switch, AUX input.

Current Measurement Test Points

The shield provide a means of easily measuring currents, by inserting a current meter between two test points. The arrow labelled on the board shows the normal current flow with passive sign convention, starting from the positive terminal and ending (pointing to) the negative terminal. The test points are normally shortened by a jumper. To start measuring current, remove the jumper and connect a current meter.

Stacking Interface

The stacking interface of the Battery Shield utilizes only power pins to supply the Wireless SoC.

Note: Check the orientation marks on Explorer Kit and Shield before powering the board stack. They should both point the same way. Refer to the example in Figure 1.1 Example of Orientation Marks on BRD8201A Dual Harvester Shield on page 6 for more details.

3.4 AC Input Adapter brick: Hardware Description

3.4.1 AC Input Adapter: Block Diagram

The following diagram illustrates the hardware architecture of the AC Input Adapter:
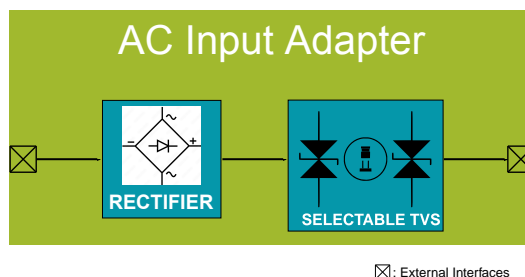

⊠: External Interfaces

Figure 3.13.   BRD8204A AC Input Adapter: Block Diagram

The AC Input Adapter features a MOSFET based rectifier bridge, which virtually tracks the AC input, rectifying it with negligible voltage drop. This stage includes also a 47 µF capacitor to smooth the rectified voltage. A placeholder allows users to add more capacitance if needed.

A Transient Voltage Suppressor (TVS) is connected to the input terminals to protect the input against ESD.

A jumper allows users to select one of two optional zener diodes (300 mW and 5 W), for lighter or heavier peak shaving, adding smaller or larger leakage current to the total consumption. Please refer to section 3.4.3 AC Input Adapter: Connectors for more details.

The rectified voltage is connected to a 0.1" right angle pin header, that can be plugged directly to any of the two SRC inputs of the BRD8201A Dual Harvester Shield.

3.4.2 AC Input Adapter: Board Layout and Interfaces

The following figure shows connectors and jumpers with their designators and functions:
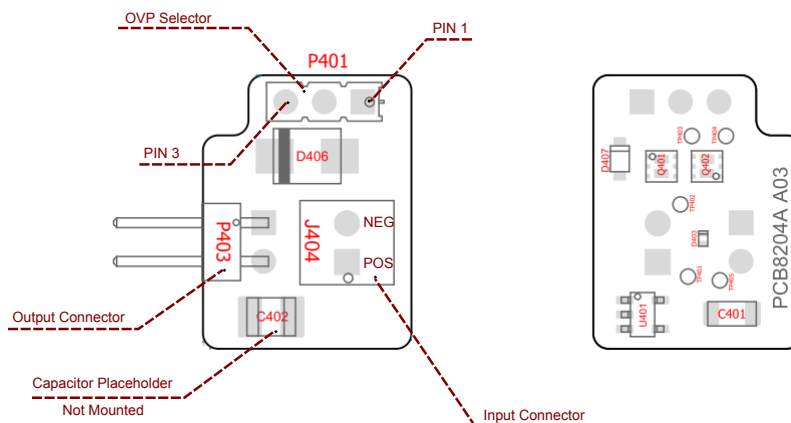

Figure 3.14. BRD8204A AC Input Adapter Assembly Drawings, Top Side to the Left and Bottom Side to the Right

OVP (Over voltage Protection) selector is a jumper used to select one of two available Zener diodes with different ratings.

3.4.3 AC Input Adapter: Connectors

The AC Input Adapter is equipped with the following connectors:

Table 3.7. Connectors: Overview

Description	Designator	Type	Positions
AC Input Source	J404	Screw terminal	2
DC Output	P403	R/A Pin Header	2
OVP Selector	P401	Pin Header, Jumper	3

Please refer to the drawings in section 3.4.2 AC Input Adapter: Board Layout and Interfaces to look up designators, connector names and silk screen labels.

AC Input Source Connector

The AC Input Source Connector is a screw terminal requiring a flat screw driver to secure the wires. There are polarity marks, "+" (positive sign) and "-" (negative sign), for respectively positive and negative input, placed between the AC Input Source and DC Output connectors, valid for both.

DC Output Connector

The DC Output connector is a 0.1" 2-pins header, right angle, intended to be plugged directly into any of the SRC Input Connectors of the Dual Harvester Shield (see section 3.1.2 Dual Harvester Shield: Board Layout and Interfaces to locate the SRC Input Connectors on BRD8201A).

Note: with the kit laying on the explorer board, connect the AC Input Adapter with its top side face up, so polarity is correct.

Over Voltage Protection - OVP Selector

This 3-pins header can be used to connect one or the two optional Zener diodes to the rectified output, i.e. to the DC Output Connector. Refer to the figure of section 3.4.2 AC Input Adapter: Board Layout and Interfaces to see connector placement and pin locations. Possible configuration are:

*   jumper between pin 1 and pin 2 (center pin): 300 mW Zener + TVS
*   jumper between pin 3 and pin 2 (center pin): 5 W Zener + TVS
*   no jumper: TVS only

3.5 DC Input Adapter brick: Hardware Description

3.5.1 DC Input Adapter: Block Diagram

The following diagram illustrates the hardware architecture of the DC Input Adapter:
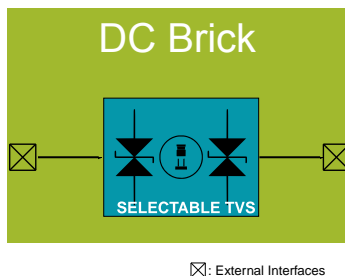

⊠: External Interfaces

Figure 3.15.   BRD8205A DC Input Adapter: Block Diagram

A part from the input voltage rectifier,the DC Input Adapter is similar to the the AC Input Adapter. It offers a placeholder for extra capacitance and extra over voltage protection to add to the Dual Harvester Shield SRC inputs, applicable for DC sources:

- a fixed Transient Voltage Suppressor (TVS), to protect the input against ESD
- provision to select one of two optional zener diodes (300 mW and 5 W), for lighter or heavier peak shaving, adding smaller or larger leakage current to the total consumption. Please refer to section 3.5.3 DC Input Adapter: Connectors for more details.

The input voltage is connected to a 0.1" right angle pin header, that can be plugged directly to any of the two SRC inputs of the BRD8201A Dual Harvester Shield.

3.5.2 DC Input Adapter: Board Layout and Interfaces

The following figure shows connectors and jumpers with their designators and functions:
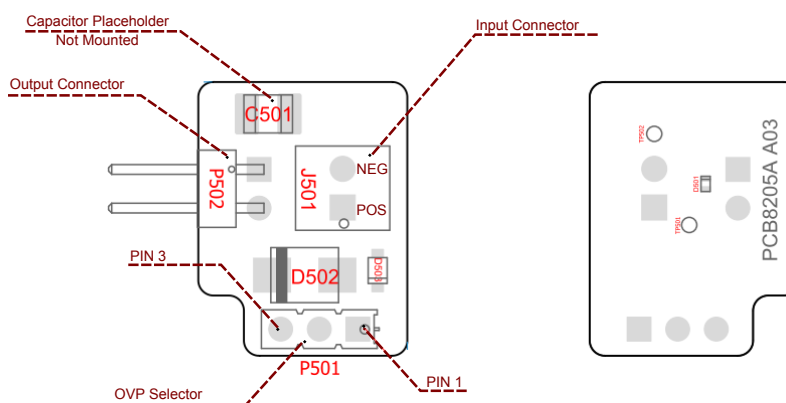

Figure 3.16.   BRD8205A DC Input Adapter Assembly Drawings, Top Side to the Left and Bottom Side to the Right

OVP (Over Voltage Protection) selector is a jumper used to select one of two available Zener diodes with different ratings.

3.5.3 DC Input Adapter: Connectors

The DC Input Adapter is equipped with the following connectors:

Table 3.8. Connectors: Overview

Description	Designator	Type	Positions
DC Input Source	J501	Screw terminal	2
DC Output	P502	R/A Pin Header	2
OVP Selector	P501	Pin Header, Jumper	3

Please refer to the drawings in section 3.5.2 DC Input Adapter: Board Layout and Interfaces to look up designators, connector names and silk screen labels.

DC Input Source Connector

The DC Input Source Connector is a screw terminal requiring a flat screw driver to secure the wires. There are polarity marks, "+" (positive sign) and "-" (negative sign), for respectively positive and negative input, placed between the DC Input Source and DC Output connectors, valid for both.

Note: Always make sure the input sources are wired with correct polarity. Reverse polarity might cause permanent damage to the PMIC.

DC Output Connector

The DC Output connector is a 0.1" 2-pins header, right angle, intended to be plugged directly into any of the SRC Input Connectors of the Dual Harvester Shield (see section 3.1.2 Dual Harvester Shield: Board Layout and Interfaces to locate the SRC Input Connectors on BRD8201A).

Note: with the kit laying on the explorer board, connect the DC Input Adapter with its top side face up, so polarity is correct.

Over Voltage Protection - OVP Selector

This 3-pins header can be used to connect one or the two optional Zener diodes to the rectified output, i.e. to the DC Output Connector. Refer to the figure of section 3.5.2 DC Input Adapter: Board Layout and Interfaces to see connector placement and pin locations. Possible configuration are:
*   jumper between pin 1 and pin 2 (center pin): 300 mW Zener + TVS
*   jumper between pin 3 and pin 2 (center pin): 5 W Zener + TVS
*   no jumper: TVS only

4. Using the Energy Harvesting Shields for Explorer Kits

4.1 Reference case: Dual Harvester Shield with photovoltaic cell

Prerequisites

The energy source (photovoltaic cell) and storage element (lithium capacitor) used in this scenario are provided with the Energy Harvesting Kit. There is no need to purchase additional parts.

Components needed:
- BRD2710A Explorer board with the EFR32xG22E SoC
- BRD8201A Dual Harvester Shield
- TPLC-3R8/10MR8X14 lithium capacitor
- AM-1417CA-DGK-E photovoltaic cell

Tools and instruments: a small flat screw driver to connect the photovoltaic cell and TPLC-3R8/10MR8X14 to the board. Current meters to monitors current flows (optional).

Assembly steps

1. Connect BRD2710A and BRD8201A together, paying attention to the board orientation mark on top of each board. Refer to figure of section 3.1.2 Dual Harvester Shield: Board Layout and Interfaces to locate the board orientation marks.
2. Remove jumpers to optionally connect current meters
3. Connect the lithium capacitor. It is important to pay attention to polarity and not to shorten the capacitor leads
4. Connect the photovoltaic cell to SRC2 (this input is optimized for the photovoltaic cell included in the kit)

When the above steps are completed, in the given sequence, the assembly should result as follows:
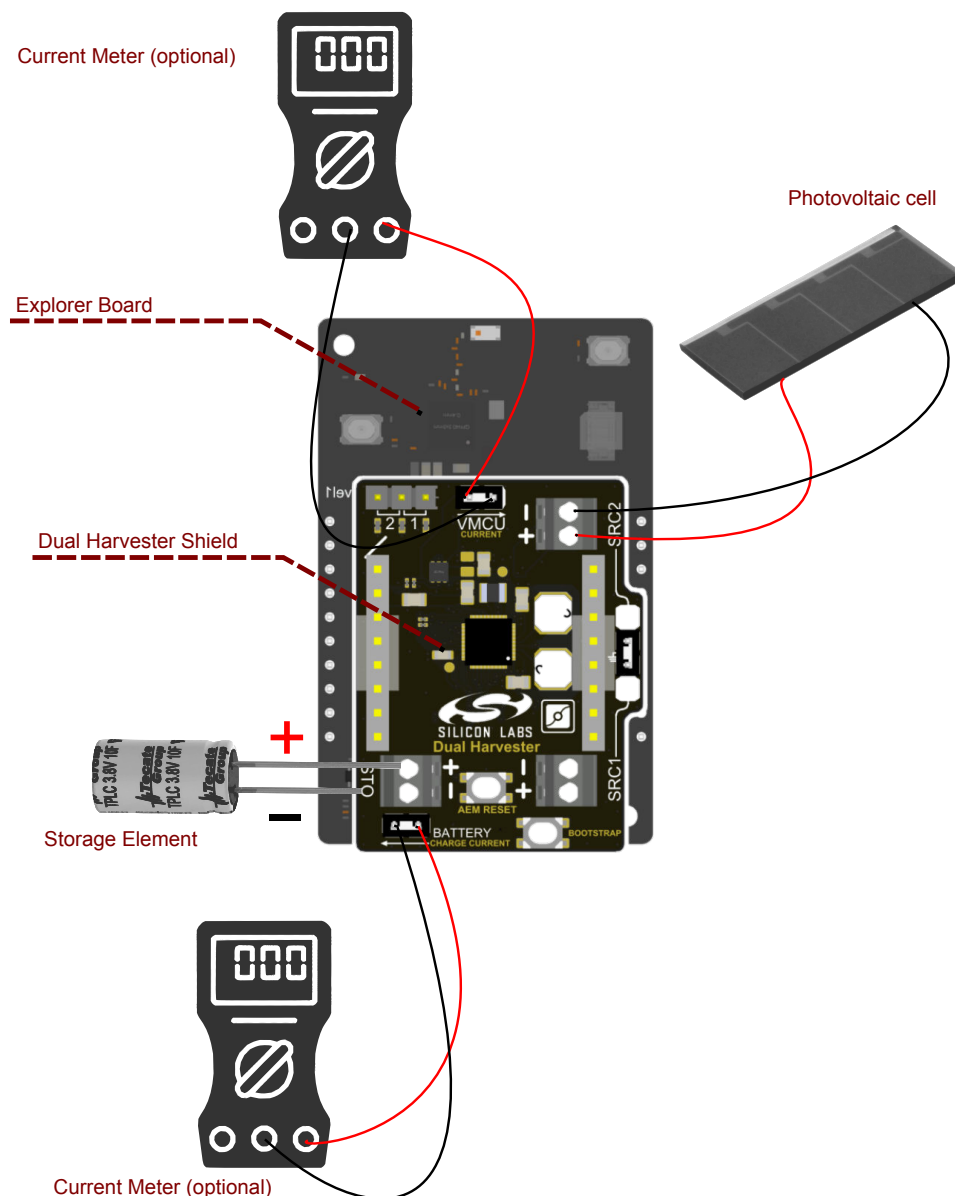
Figure 4.1. Dual Harvester Shield: basic set up with lithium capacitor and single photovoltaic cell

Important: Pay attention to capacitor polarity. Do not shorten capacitor leads.

The connections shown, with red wires being positive leads, will yield net charge current entering the storage element and current drawn by the SoC. If the net charge current reads positive, the SoC consumes less energy than that being generated by the photovoltaic cell. If it reads negative, the application will likely deplete the storage element over time.

Further developments

Adding one more DC source, like one more photovoltaic cell with different characteristic, for example optimized for outdoor use, or a thermoelectric generator, can be done connecting it to the vacant input terminal. Consult the default settings specified in section 3.1.3 Dual Harvester Shield: Default Configuration along with the data sheet for the AEM13920 PMIC, to verify or eventually change the configuration of the input source, in this example SRC1. The input sources can be configured by hardware, as described in section 3.1.3 Dual Harvester Shield: Default Configuration, or by software, using the I^{2}C interface to write to the PMIC configuration registers.

Next section shows how to add AC sources.

Note: It is possible to stack other mikroBUS^{TM} Click Boards on top of the shield. The working voltage of the shield is lower than the mikroBUS standard 3.3 V. Make sure the selected shield supports the operation voltage specific for your application. 3.1.4 Dual Harvester Shield: Connectors

4.2 Adding an AC source to the Dual Harvester Shield

Prerequisites

The Input Adapter board used in this scenario is provided with the Energy Harvesting Kit. Users will need to select and purchase an AC source for their specific application, for example a vibration harvester, an inductive harvester, etc.

Components needed:
• BRD2710A Explorer board with the EFR32xG22E SoC
• BRD8201A Dual Harvester Shield
• BRD8204A AC Input Adapter
• AC source

Tools and instruments: a small flat screw driver to connect the photovoltaic cell and TPLC-3R8/10MR8X14 to the board. Current meters to monitors current flows (optional).

Assembly steps

The Dual Harvester Shield accepts DC source at its inputs. To connect AC sources, the BRD8204A AC Input Adapter is needed, as it provides the circuitry necessary to rectify the AC input.

1. Connect BRD2710A and BRD8201A together, paying attention to the board orientation mark on top of each board. Refer to the figure of section 3.1.2 Dual Harvester Shield: Board Layout and Interfaces to locate the board orientation marks.
2. Remove jumpers to optionally connect current meters
3. Connect the lithium capacitor. It is important to pay attention to polarity and not to shorten the capacitor leads
4. Connect the AC Input Adapter to a suitable input terminal (SRC1 in this example)
5. Connect the AC source to the AC Input Adapter. Polarity is not important for this connection

The following figure shows an example with two sources, adding an AC source is added to the previous reference case.
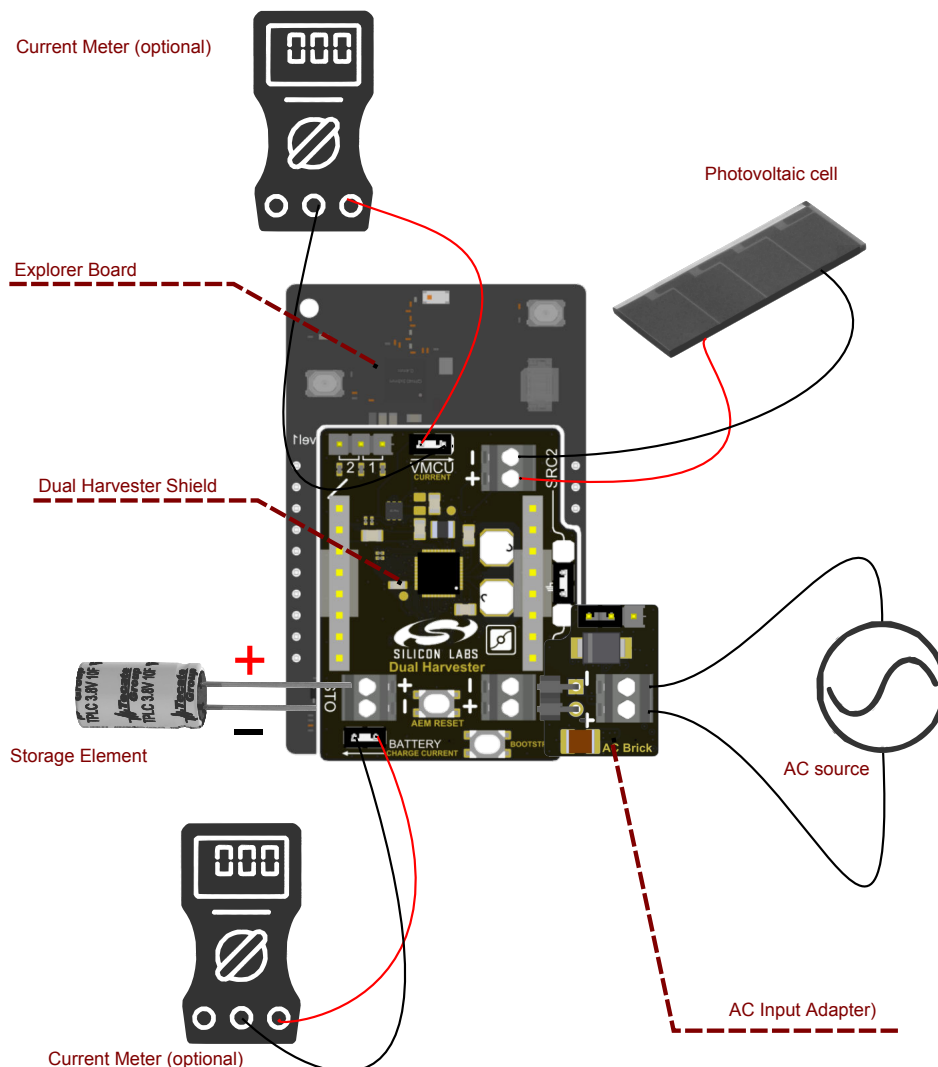
Figure 4.2. Dual Harvester Shield: adding an AC energy source with the AC Input Adapter

4.3 Using the Kinetic Button Shield

The Kinetic Button Shield works out of the box, once mounted on top of the EFR32xG22E Energy Harvesting Explorer Kit.

Connect a USB cable to flash or debug the application through the on-board debugger.

When testing the application, it is important to understand the difference between this evaluation kit and a finished product. While in a finished product, the button enclosure would conveniently keep the board in place, moving parts would be rigid and opportunely designed. Using the Kinetic Button Shield, users will operate the kinetic button actuator with their bare fingers.

For the best outcome, it's helpful to consider the following points:

- make sure the rod travels freely in both directions. Avoid touching other moving parts than the pressure point on the lever top (see next figure). Place the board bottom side on a clean surface, free or objects that might come in the way

- be determined when pressing. The amount of energy generated in the inductive device is proportional to the changes of the magnetic field generated by the rod, hence its speed of travel. A plastic actuator in a finished product would leverage stiffly enough

- release the button as soon as it is pressed. A spring in the button ensure that the rod is efficiently bounced back when pressed. However, if fingers or other objects brake the motion, slowing down the return travel, less energy will be generated
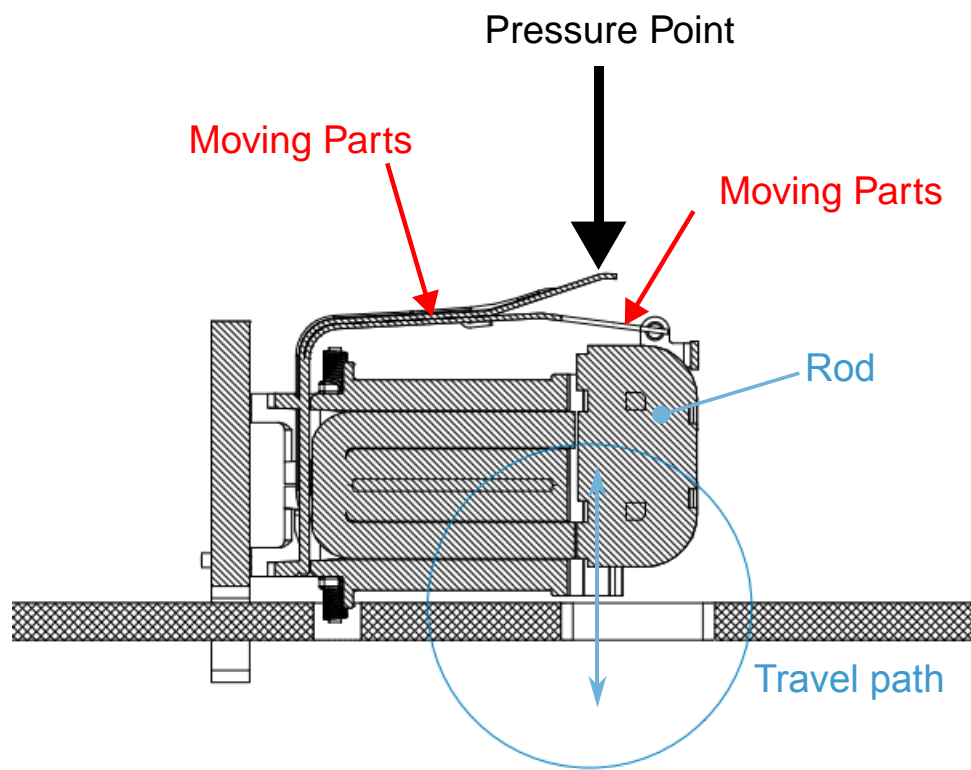
Figure 4.3. Section view: kinetic button showing travel path and pressure point

The more energy is generated, the more headroom the application has to execute the instructions needed before the supply voltage falls below the brown-out voltage, typically about 1.65 V for the EFR32xG22E SoC.

There is one jumper on this board that might be removed to connect a power analyzer or an oscilloscope to probe the SoC supply current. Using oscilloscopes, a shunt resistor will be needed to sense the current. There is a placeholder for a 1206 resistor on the board that could be used to solder a shunt resistor to the board (R206). Mind this resistor, if current meters are used, as it will shunt the meter's internal sense resistor.

If not needed, the Power Output Gate transistor can be permanently closed (permanent conduction) by mounting a single 0R 0404 resistor or short-circuiting the placeholder (R205).

Refer to the drawings in section 3.2.2 Kinetic Button Shield: Board Layout and Interfaces for more details about component locations.

Testing the application with other pulse harvesters

Selecting alternate energy harvesters, make sure that the operating specifications of section 2. Recommended Operating Conditions are met. Other inductive switches might generate too high voltages for the PMIC.

There is provision to mount an optional screw terminal (Phoenix 1725656), a 0.1" pin header (e.g. Sullins PBC02SAAN) or to solder leads directly onto the board and connect an alternate harvester for evaluation purposes. The connector place holder (SRC) is routed to the PMIC input.

Because of its low output impedance, it will be necessary to disconnect the on-board switch, by removing the two shunt resistors, shown in the layout overview of section 3.2.2 Kinetic Button Shield: Board Layout and Interfaces. Removing these two resistors, it is not needed to remove the on-board switch, which might conveniently remain in place to easily switch back to the original application.

4.4 Using the Battery Shield

Using the Battery Shield is straight forward. Connect it on top of the EFR32xG22E Energy Harvesting Explorer Kit. This set up allows users to run the Wireless SoC EFR32xG22E Energy Harvesting Explorer Kit on a coin cell battery or an alternate portable power source, which could be useful to carry out range tests or similar use cases where isolating the Wireless SoC might help troubleshooting, detaching the complex dynamics of any energy harvester from the system.

Connect a USB cable to flash or debug the application through the on-board debugger. It is not necessary to remove the battery or disconnect the alternate power source. A solid state switch automatically disconnects the Wireless SoC power domain when a USB cable is connected to the kit.

Note: It is possible to stack other mikroBUS^{TM} Click Boards on top of the shield. The working voltage of the shield is lower than the mikroBUS standard 3.3 V. Make sure the selected shield supports the operation voltage specific for your application. 3.3.3 Battery Shield: Connectors

4.5 Using the Input Adapters

Input Adapters are optional pieces of hardware included in the EFR32xG22E Energy Harvesting Explorer Kit, that are designed to be paired with the Dual Harvester Shield.

Both Input Adapters are designed to be connected in series to any of the SRC inputs on the Dual Harvester Shield. When Input Adapters are connected to any SRC input, the energy source is connected to its extended input terminals. It is recommended to let the Input Adapters and shield overlap, to ensure mechanical stability while connecting and disconnecting sources at the screw terminals.
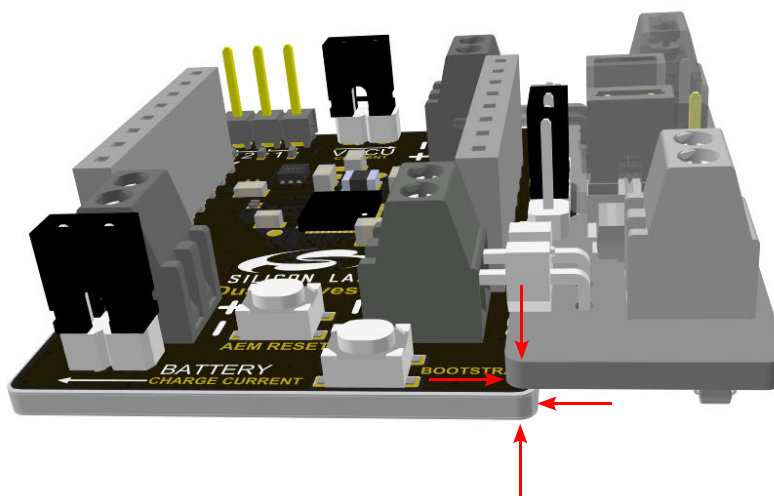
Figure 4.4. Securing the Input Adapters to the shield

AC sources

The BRD8204A AC Input Adapter becomes necessary whenever interfacing the Dual Harvester Shield with AC sources. Please refer to section 4.2 Adding an AC source to the Dual Harvester Shield. The MOSFET-based AC rectifier does not subtract a relevant portion of the input voltage, but it requires some additional current to work, adding to the total current consumption. While the AC Input Adapter is mandatory when interfacing to AC sources, it is recommended to disconnect it if DC sources are being used, to avoid unnecessary current consumption.

Providing additional protection at SRC inputs

The BRD8205A DC Input Adapter is optional and offers some extra protection against over voltages at the source inputs of the Dual Harvester Shield. The optional protection devices add current leakages at the input nodes, adding to the total current consumption, but they might be useful for experiments with unqualified energy sources that might output too high voltage peaks, or test set ups that are particularly exposed to over voltage transients or surges.

Similarly, the AC Input Adapter offers the same optional Over Voltage Protection (OVP) options as the DC Input Adapter.

Both Input Adapters provide the following additional protection:

- 130 mW TVS, fixed: these are tiny diodes that can absorb fast over voltage transients of relatively low energy, typical of Electrostatic Discharge (ESD) events. Not suitable for slow voltage fluctuations. These device add leakage current in nA range when the bias voltage approaches 5V. The actual leakage during normal operation will depend on how close to 5V the input voltage comes.
- 300 mW Zener diode, optional: the Zener diode is intended to do some peak shaving of the input waveforms exceeding the limit for the input voltage for a relatively small power, according to its power rating. This device is level sensitive and relatively accurate if compared to a TVS, hence suitable for slower voltage fluctuations. This device adds leakage current in µA range when the bias voltage approaches 5V. The actual leakage during normal operation will depend on how close to 5V the input voltage comes
- 5 W Zener diode, optional: same scope as the other zener diode described above, but able to absorb significantly more power. Suitable for uncharacterised sources with a high degree of uncertainty. This device adds leakage current in mA range when the bias voltage approaches 5V. The actual leakage during normal operation will depend on how close to 5V the input voltage comes

Summarizing, ESD protection comes automatically with both Input Adapters adding some current consumption that is in most cases negligible (less than 10 nA).

In addition, both Input Adapters are equipped with two optional Zener diodes, mutually exclusive, with different ratings and leakage currents. If not sure about the voltage waveforms of an energy harvester, it is recommended to start experimenting with the larger Zener diode and possibly switch to the smaller one or none, once the energy source behaviour is mapped in realistic use case scenarios. The Zener diodes are selectable by means of a jumper. For more details about the jumpers and how to configure these, please refer to sections 3.4.3 AC Input Adapter: Connectors and 3.5.3 DC Input Adapter: Connectors.

Note: Over Voltage Protection does not act against reverse polarity. Always make sure the input sources are wired with correct polarity. Reverse polarity might cause permanent damage to the PMIC.

Optional Capacitance

Both Input Adapters feature a placeholder to mount an extra capacitor (size 1210, not included), which might be turn useful in some applications. However, the input capacitance provided with the Dual Harvester Shield will in most cases be enough to stabilize the input of the PMIC.

5. Current Measurements with the Energy Harvesting Shields for Explorer Kits

This section provides some general considerations about measurement techniques and methods that are relevant to the Energy Harvesting Shields for Explorer Kits. Then it goes deeper into techniques that are suggested for each of the Energy Harvesting shields, providing examples and connection schemes.

In low energy systems, current consumption is usually measured by reading a voltage drop across a Shunt Resistor (R_{SHUNT}). Such Shunt Resistor can be internal to the measuring instruments, like current meters, or external to the meter, like voltmeters or oscilloscopes. To further complicate the scenario, current measurements can be performed passivly, without changing the overall supply scheme of the system, or by supplying the system with auxiliary power and measuring it at the source. The latter is usually done by instruments called Source Meters (SM). With the Dual Harvester Shield and Kinetic Button Shield, the Wireless SoC is supplied by a PMIC which harvests energy from a source. To avoid altering normal operation, we recommend passive measurements with in-line Shunt Resistors.

Many intruments have automatic range selection, meaning that the instrument optimizes the signal strength, by adjusting its internal Shunt Resistor, while keepin the voltage drop across it reasonably small. Excessive voltage drop might result in incorrect function or even temporary loss of function (Brown-out reset). Other instruments have manual range selection, so users shall make sure the Shunt Resistor always allows correct operation at run time. When working with external Shunt Resistors, the same basic criteria apply. External resistors might be cumbersome to connect, exposing the system for more noise, but they offer the advantage of full control of the voltage drop, hence operating conditions. There is provision for conveniently soldering a permanent Shunt Resistor on each shield.

Sampling rate and precision are important parameters of any instrument of measure. With a few exceptions for expensive top-end equipment, these two parameters are often a trade off. Depending on the purpose of a measurement, it might be more important to have a high sample rate, like during debugging, to observe the dynamic behaviour of the system, or higher precision, when measuring constant currents, for example while the system is constantly kept in low energy mode (sleep).

While measuring constant currents might be useful to determine sleep currents or battery lifetime, dynamic measurements provide information about code execution and might be used for debugging, optimizing the software in active state, detect spurious wake events, etc. The following paragraphs will focus on dynamic measurements.

Sampling rate should always be higher than the maximum signal frequency, to correctly record transients like fast wake/sleep cycles, either intentional or unintentional. How fast transients can be, depends on the input capacitance of the load, in this case the total capacitance of the VMCU node on the Explorer Kit (C_{LOAD}) and the Shunt Resistor (R_{SHUNT}), forming a low pass filter. These two elements, forming a low-pass filter, are highlighted in next figure.
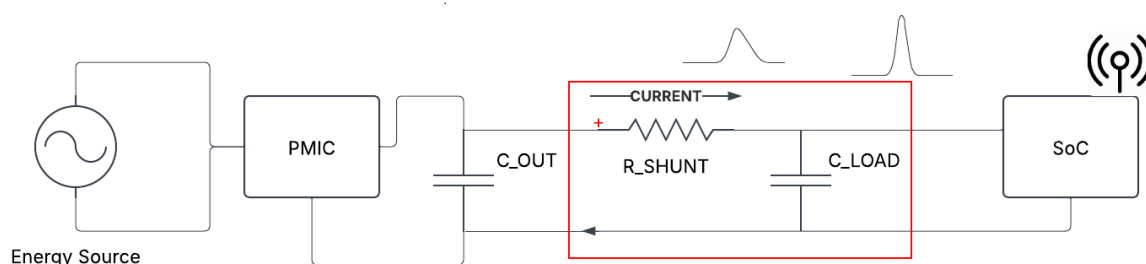

Figure 5.1. Low-pass filter governing in-line current measurements in Energy Harvesting Shields for Explorer Kits

Note that the output capacitance of the PMIC does not contribute to filter current signals. Choosing a Shunt Resistor is often a trade-off. Larger Shunt Resistors (higher resistance)

- increase the signal strength, hence its ratio to noise (SNR), but
- reduce the signal bandwidth, hence insight in code execution, and
- increase the risk of afftecting or even disrupting operation, if the supply voltage becomes too low

An example of affecting normal operation is when a low supply voltage triggers a machine state for power save when it is not supposed to, alterning the outcome of current measurements. Such measurement-induced errors are more difficult to notice than complete loss of function, e.g. brown-out reset.

In Explorer Kits, typical values for the C_{LOAD} are in the range 10 µF to 20 µF. With a R_{SHUNT} of 10 Ω, for example, the cut frequency of the low-pass filter can not exceed 1/(2π x 10 µF x 10 Ω) < 1.6 kHz,

Selecting instruments with the necessary bandwidth / sampling rate is important to avoid aliasing or loss of information in dynamic measurements and calculating correct average current values. While most oscilloscopes usually offer large bandwidths, well above the example above, current meters and digital multimeters with LCD display will typically not be appropriate instruments for dynamic measurements.

Knowing the time constant governing the measurements is also useful to precisely filter current traces in oscilloscopes or other instruments with much higher bandwidth and digital filters, so electrical noise can be conveniently filtered.

All boards in the Energy Harvesting Shields for Explorer Kits are equipped with:

- a jumper, which can be removed, leaving an open circuit in the power supply path from the PMICto the Wireless SoC input, suitable for passive in-line measurements. Probes can be connected directly to the pin headers supporting this jumper. The arrow on the board's silk screen shows the normal current flow with passive sign convention, so to have positive reading for currents absorbed by the Wireless SoC, the meter's leads shall be connected accordingly. The following sections give clear indications to connect a meter to each Energy Harvesting shield in particular

- a placeholder for an SMD resistor (1206 Imperial), to permanently mount a Shunt Resistor between the two pins of the header supporting the jumper. The Shunt Resistor can be used by removing the jumper and connecting probes to the header, or bypassed (disengaged) by fitting the jumper back to its original position. This shunt resistor is intended to minimize current loops, hence induced noise, for users who use exclusively voltage probes. If used with any instrument with embedded Shunt Resistor, this resistor will produce invalid results

5.1 Current Measurements with the Dual Harvester Shield

The Dual Harvester Shield is designed to demonstrate low energy wireless applications, such as sleepy IoT sensor applications, sustained by energy harvesters of various nature, mainly battery-less. Expected normal operation, where users will typically measure currents, could include various wake/sleep cycles, TRX events, NVM writing cycles and interactions with the PMIC. To achieve realistic measurements, it is important not to alter the power supply scheme and voltages. For example, measuring the current consumption of the Explorer Kit alone, one would overlook events connected to PMIC interactions or supply voltage monitoring, and in the worst case ending with invalid machine states. This is why Silicon Labs recommends in-line, passive methods, as described in the previous section.

To connect an in-line meter and measure the current consumption of the Wireless SoC, remove the jumper at P101 and connect the meter according to the following drawing:
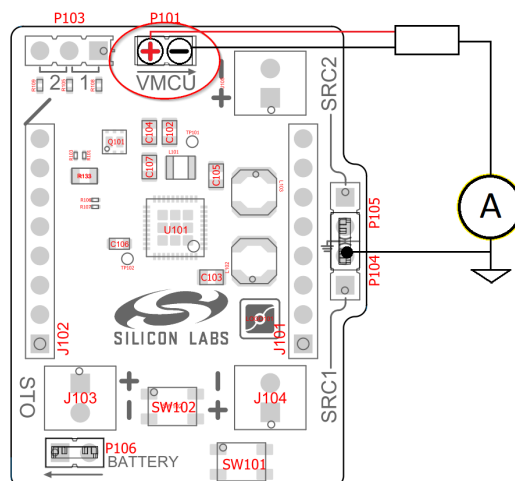

Figure 5.2.   Measuring current with BRD8201A Dual Harvester Shield: connection scheme

Some instruments might require a direct connection to the kit's ground to limit common mode voltage. The connection scheme described in section 4.1 Reference case: Dual Harvester Shield with photovoltaic cell and 4.2 Adding an AC source to the Dual Harvester Shield show the connection schemes with remaining portions of the systems.

To measure the charge currents flowing to the storage element, the connection scheme at P106 utliizes the same polarity convention. If the energy being harvested is more than the energy being consumed by the system, meaning the Wireless SoC and internal circuits of the Energy Harvesting PMIC together, the measured current will be positive. The other way around, if the system consumes more energy than the source is able to provide, it will yeld negative currents.

The first example shows a measurement that aims to estimate the average current consumption in an application, where the Wireless SoC, an EFR32MG22E on a BRD2710A, periodically wakes up from EM4, the lowest available energy mode in EFR32 Wireless SoCs, initializes peripherals and radio stack, reads the storage voltage recorded by the PMIC by means of a few I^{2}C transactions, and transmits it over the air as Bluetooth beacons. After the first packet is sent, the application enters EM2, wakes after 1s and repeat the TX twice more, thereafter enters EM4 and sleeps 25 s. For this measurement, we selected a power analyzer with one differential probe, connected between the positive and negative terminals shown in the drawing above, and the following characteristics:

- 200 kHz bandwidth

- ability to buffer up to 60 s records / 500 M readings per datalog. In this case, an entire wake/sleep period of about 27 s will fit into the buffer menory with good margins

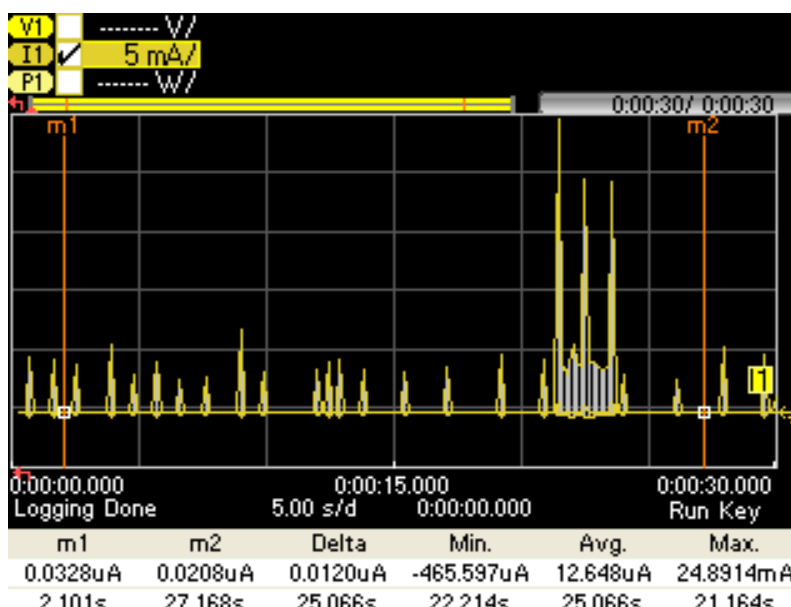- differential probe
- built-in Shunt Resistor

Figure 5.3. Example of measurement of avarage current using a Dual Harvester Shield and a DC power analyzer.

The 30 s long capture shows the overall activity during an entire cycle, clearly visible are the three TX events. Vertical cursors are used to select the period, so the instrument can calculate the average current for the given period and no longer. During EM4, the PMIC works in discontinuous mode, to refill the output capacitance when the voltage drops below a given threshold and going idle, sourcing no current for a longer period. This explains the sequence of smaller current spikes when the Wireless SoC is in EM4.

DC power analyzers or oscilloscope are suitable intruments to further investigate code execution, by focusing on smaller area with larger time scale and conveniently triggering on events of interest.

Current meters can be useful to accurately measure sleep current at steady state.

If the instrument can not buffer an entire cycle, one could combine the two methods to calculate the average current with a reasonable level of approximation.

5.2 Current Measurements with the Kinetic Button Shield

The Kinetic Button Shield is designed to demonstrate specific use cases where a Wireless SoC is momentary powered by an energy pulse, in this case generated by a kinetic switch, boots, initializes peripherals, radio stack, activate the transceiver and eventually writes to an non-voltatile memory. In this system there is no capability of storing energy in the long term, so the system consumes the entire amount of energy harvested at each cycle, before going in a de-energized state again.

With constrained power budgets, developers would typically be interested in know the cost of each instruction set in term of energy, to evaluate feasibility of the executions and take countermeasures, rather than studying average currents.

As for the Dual Harvester Shield, Silicon Labs recommends s in-line, passive methods for the Kinetic Button Shield too.

To connect an oscilloscope, remove the jumper at P201 and connect the meter according to the following drawing:
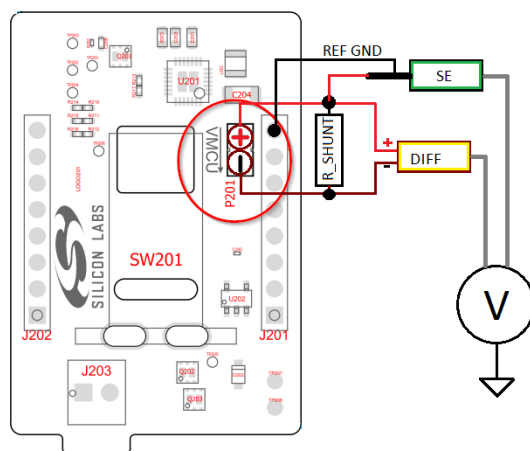
Figure 5.4. Measuring current with BRD8202A Kinetic Button Shield: connection scheme

The Shunt Resistor can be conveniently soldered to the bottom side of BRD8202A, at R208. An advantage of this approach is that oscilloscope often have more channels available to track voltages and currents a the same time. Probing voltages at input capacitors (V_{SRC}) and/or output capacitors (V_{LOAD}, (V_{MCU})) provides direct measure of the amount of energy accumulated in the different parts of the system ($E = \frac{1}{2} C \times V^2$) and gives further insight of energy transfers, timing and losses. Note that oscilloscopes must be properly connected to the system ground to work correctly.

Next example shows how to measure the instant current consumption and how to relate it to the state of charge of the output capacitor, in an application where the PMIC charges the output capacitor every time the kinetic button is pressed by the user.

For this example we selected:

- Shunt Resistor of 10 Ω, limiting the signal bandwidth to about 1 / (2π x 10 Ω x 12 µF) < 1.4 kHz,
- 2 channel oscilloscope. Almost any oscilloscope will fit the above bandwidth requirements, even the most affordable ones
- One differential probe
- One single ended probe with ground lead
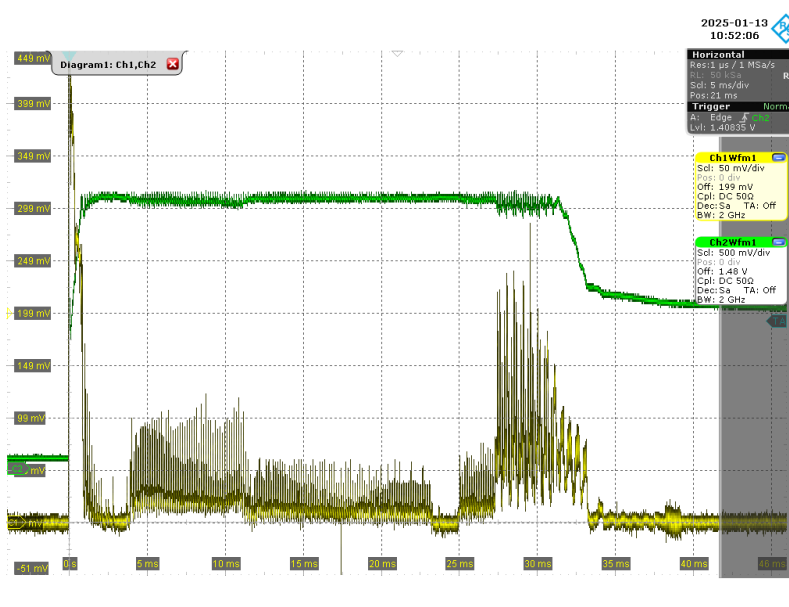
Figure 5.5. Example of transient measurement with a Kinetic Button Shield

Referring to the transient capture shown here, the yellow trace represents the current consumed by the SoC, measured across the external shunt resistor at P201, while the green trace is the V_{MCU} voltage, measured at J201:7 with reference to J201:8.

The Kinetic Button Shield features an output switch to gate power while the energy is being harvested, described in section 3.2.1 Kinetic Button Shield: Block Diagram. The first rush of current fills the C_{LOAD} capacitance as soon the output switch closes the circuit, i.e. the input capacitance of BRD2710A, previously discharged. When the V_{MCU} voltage exceeds the Power-On threshold of the EFR32MG22E

used in this example, the chip cold-starts, internal voltages needs to stabilize, then it boots and starts executing instructions. In general, the current pattern of first ~12 ms are hardware-dependent, while the following sequence, initialization of peripherals, radio stack, TRX, etc will depend on the application code. Note that in this example the Wireless SoC is actively executing instructions until the circuit runs out of charge. It is noticeable how the V_{MCU} voltage quickly drops at the end of the cycle, and then continues discharging at a lower rate. The *VMCU* voltage is sustained by the PMIC, as long it converts energy stored at the input capacitance (measuring V_{SRC} would shows this), thereafter the output capacitance is drained at certain pace by the SW activity. When the voltage drops below the brown-out voltage, the chip enters a reset state and the consumption suddenly decreases.

6. Schematics, Assembly Drawings, and BOM

Schematics, assembly drawings, and Bill of Materials (BOM) are available through Simplicity Studio after the kit documentation package is installed. These resources are also available on the applicable kit pages on the Silicon Labs website at http://www.silabs.com/dev-tools.

7. Kit Revision History

The kit revision can be found printed on the kit packaging label, as outlined in the figure below. The revision history given in this section may not list every kit revision. Revisions with minor changes may be omitted.

Figure 7.1. Kit Label

7.1 xG22-EK8200A Revision History

Kit Revision	Released	Description
A01	15 January 2025	Initial release.

8. Document Revision History

Revision 1.1

April, 2025
- Corrected register names for SRC2_CFG[x] in table 3.1

Revision 1.0

February, 2025
- Initial release

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