

UG296: USB Type-C Rechargeable Battery Pack Reference Design



SLRDK1000A is a reference design for a small and cost effective USB Type-C rechargeable battery pack. A Silicon Labs EFM8BB3 Busy Bee microcontroller is used for USB Type-C Power Delivery (PD) negotiation.

The USB Type-C Battery Pack Reference Design ships with a ready to use demo firmware that is capable of operating in both sink and source mode, delivering up to 15 W (3.0 A at 5 V) of output power or charging a connected Lithium battery with up to 1.8 A charge current.

An on-board SEGGER J-Link debugger enables easy customization and development.

KEY FEATURES

- EFM8BB3 Busy Bee Microcontroller
- USB Type-C Power Delivery
- 15 W output boost converter
- 1.8 A lithium-ion battery charger
- User LEDs/push buttons
- SEGGER J-Link on-board debugger
- Virtual COM Port
- 20-pin 2.54 mm breakout pads for all I/Os

SOFTWARE SUPPORT

- Simplicity Studio™
- USB PD Libraries and Kernel

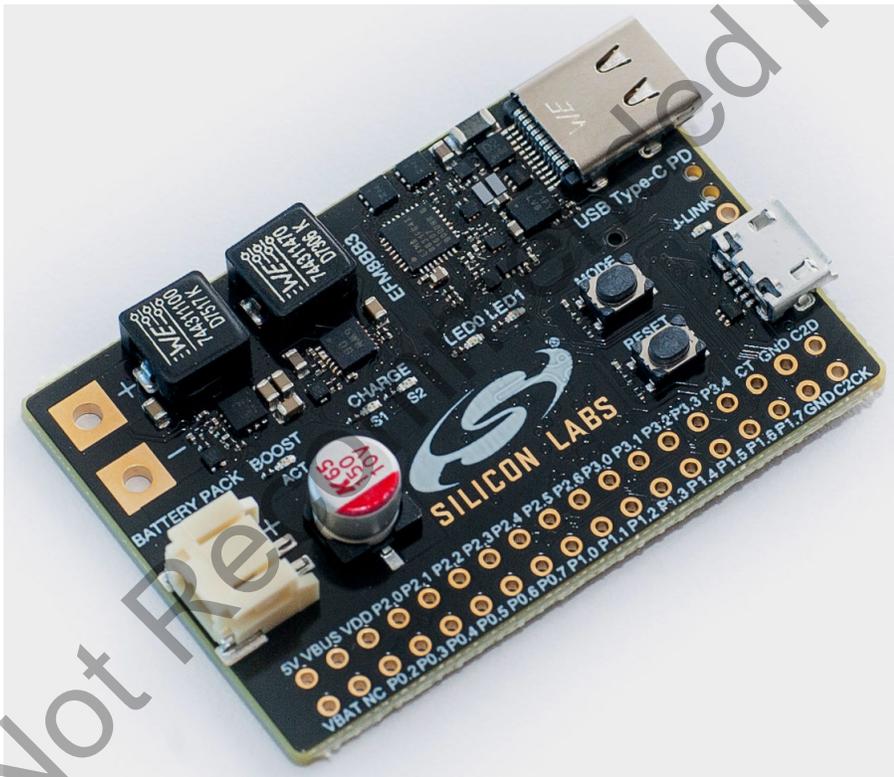


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1. Introduction

The SLRDK1000A USB Type-C battery pack reference design showcases the EFM8BB3 Busy Bee as a USB Type-C Power Delivery (PD) controller, capable of negotiating both a sink and a source contract with another USB Type-C port.

In addition to the EFM8BB3 Busy Bee microcontroller, the design features both a battery charger IC and a boost converter IC. The battery charger enables quick charging at 1.8 A of a connected lithium-ion battery. The boost converter is capable of sourcing up to 15 W of output power (3.0 A at 5 V) for powering or charging a USB Type-C device.

The board is equipped with solder pads for connecting a battery with short leads and is designed to work with a single cell lithium-ion battery (typically 3.7 V). A battery pack consisting of several cells in parallel can be used to achieve the required output current and battery capacity. A JST battery connector allows for easy connection of commonly available off-the-shelf lithium-ion batteries.

To simplify application development, the board includes an on-board SEGGER J-Link debugger running on an EFM32 Giant Gecko MCU. The debugger also features a USB virtual COM port. The entire debugger design is located on the bottom side of the board so it is easy to distinguish from the actual reference design.

The board features are:

- EFM8BB3 Busy Bee USB PD controller
- 15 W boost converter
- 1.8 A lithium-ion battery charger
- JST connector for commercial off-the shelf lithium-ion battery pack
- On-board J-Link debugger with a USB virtual COM port
- Area-effective design
- Breakout for all I/Os

Note: Batteries are not included. See [1.3 Lithium-Ion Batteries](#) for recommendations on battery specifications.

1.1 Hardware Layout

The layout of the EFM8BB3 USB Type-C Battery Pack Reference Design is shown below.

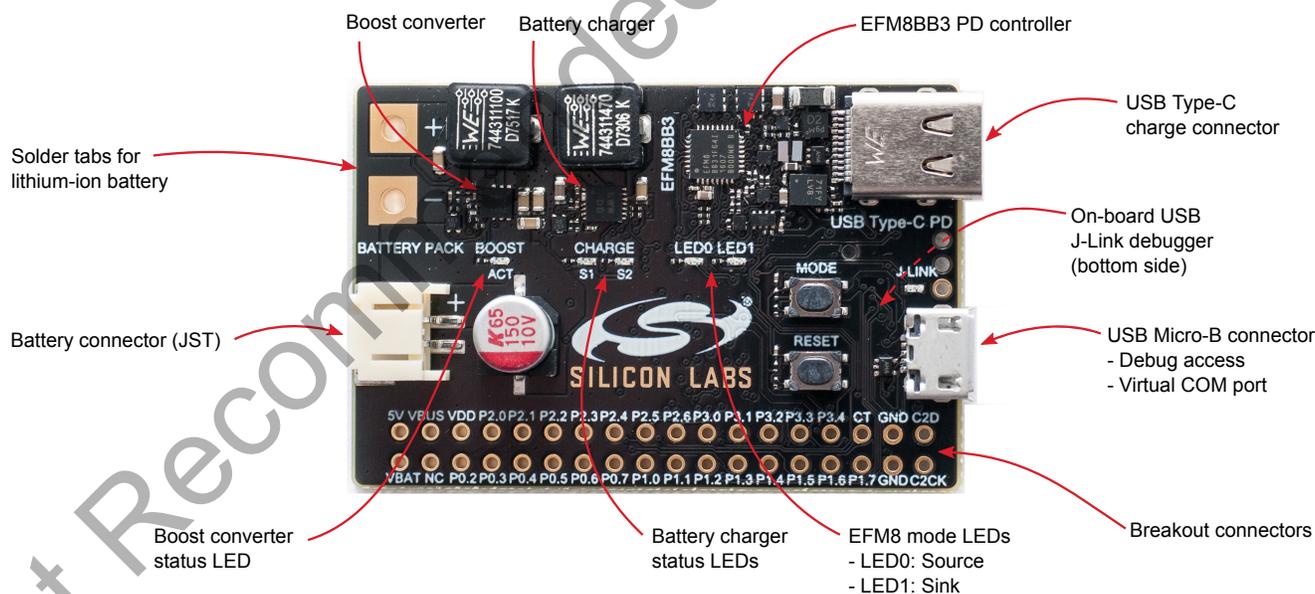


Figure 1.1. Hardware Layout

1.2 Getting Started

The USB Type-C Battery Pack Reference Design ships with a ready to use demo firmware that is capable of operating in both sink and source mode. Follow these steps to quickly try out the functionality of the design:

1. Connect a Lithium-Ion battery to the JST connector or to the battery terminals. The **S1** and **S2** LEDs should be off for a fully-charged battery.
2. Connect a USB Type-C device (phone, tablet, laptop, etc.) to the board.
3. If **LED0** is on and **LED1** is off, this indicates the board is sourcing power. If **LED0** is off and **LED1** is on, this indicates the board is sinking power. The LED labeled **BOOST ACT** will turn on whenever the output current of the boost converter is higher than 50 mA.
4. Press the **MODE** button to switch between sourcing or sinking power. Sourcing power will charge the USB Type-C device, while sinking power will charge the battery from the USB Type-C device.

A more detailed description on how to get started with the USB Type-C rechargeable battery pack reference design can be found in [QSG151: USB Type-C Rechargeable Battery Pack Reference Design](#). Further information can be found on the Silicon Labs web pages:

<http://www.silabs.com/usb-type-c-battery-pack>

Not Recommended for New Designs

1.3 Lithium-Ion Batteries

The reference design is intended for use with single-cell 3.7 V lithium-ion batteries only. Battery packs consisting of several matched cells in parallel are common and can be used with this reference design, as long as the nominal battery voltage is 3.7 V.

Note: Battery packs with several cells in series resulting in a higher battery pack voltage are NOT supported by this reference design.

Batteries are not included in the kit and must be obtained separately. When the battery pack is used as a source, the worst case maximum battery current is just below 6 A. This should be taken into account when selecting the battery solution.

For convenience, the board features a JST connector for attaching commonly available lithium-ion battery packs. These can be obtained from vendors such as Adafruit or Sparkfun, and have varying capacities and ratings. Note that the JST connector itself is only rated for 2 A of input current. It is only intended for quick demonstrations or for light loads. Self-heating in the battery cables and connector will occur with prolonged use at high output currents. For example, charging a phone at 5 V, 1 A will require an input current of about 1.5 A at 3.7 V and about 1.8 A as the battery approaches 3.0 V.

The reference design supports charging batteries at two different rates - 400 mA and 1.8 A. This should be set up in firmware to match the battery that is being used. Care must be taken not to charge battery packs at a rate that is not supported.

The table below shows some examples of commercially available lithium-ion batteries. Because these battery packs are rated for lower currents than the board is capable of handling, it is recommended to use these with care and only under supervision, since they may become overheated under heavy load or during fast charging.

Table 1.1. JST Battery Pack Comparison

Parameter	Adafruit 3.7 V 6600 mAh Lithium Ion Battery Pack	Sparkfun 3.7 V 6000 mAh Lithium Ion Battery Pack
Part Number	353	PRT-13856
Manufacturer's Part Number	PKCELL ICR18650 6600mAh 3.7V 1S3P	DATAPOWER DTP605068-3P
Nominal Capacity	6600 mAh	6000 mAh
Standard Discharge Current	1320 mA	1200 mA
Maximum Discharge Current	3300 mA	6000 mA
Standard Charge Current	–	1200 mA
Maximum Charge Current	1650 mA	6000 mA
Nominal Voltage	3.7 V	3.7 V
Discharge Cut-off Voltage	3.0 V	2.8 V
Charging Cut-off Voltage	4.2 V	4.2 V

A 150 μ F input capacitor has been added to the design to negate inductive effects of long battery leads. In a real application this input capacitor can be reduced or removed, depending on the distance to the batteries and the cables connecting them.

To fully utilize the 15 W specification, a battery pack is required that can deliver enough current, and it needs to be connected with short leads directly to the solder pads on the board.

2. Hardware

2.1 Block Diagram

An overview of the EFM8BB3 USB Type-C Battery Pack Reference Design is illustrated in the figure below.

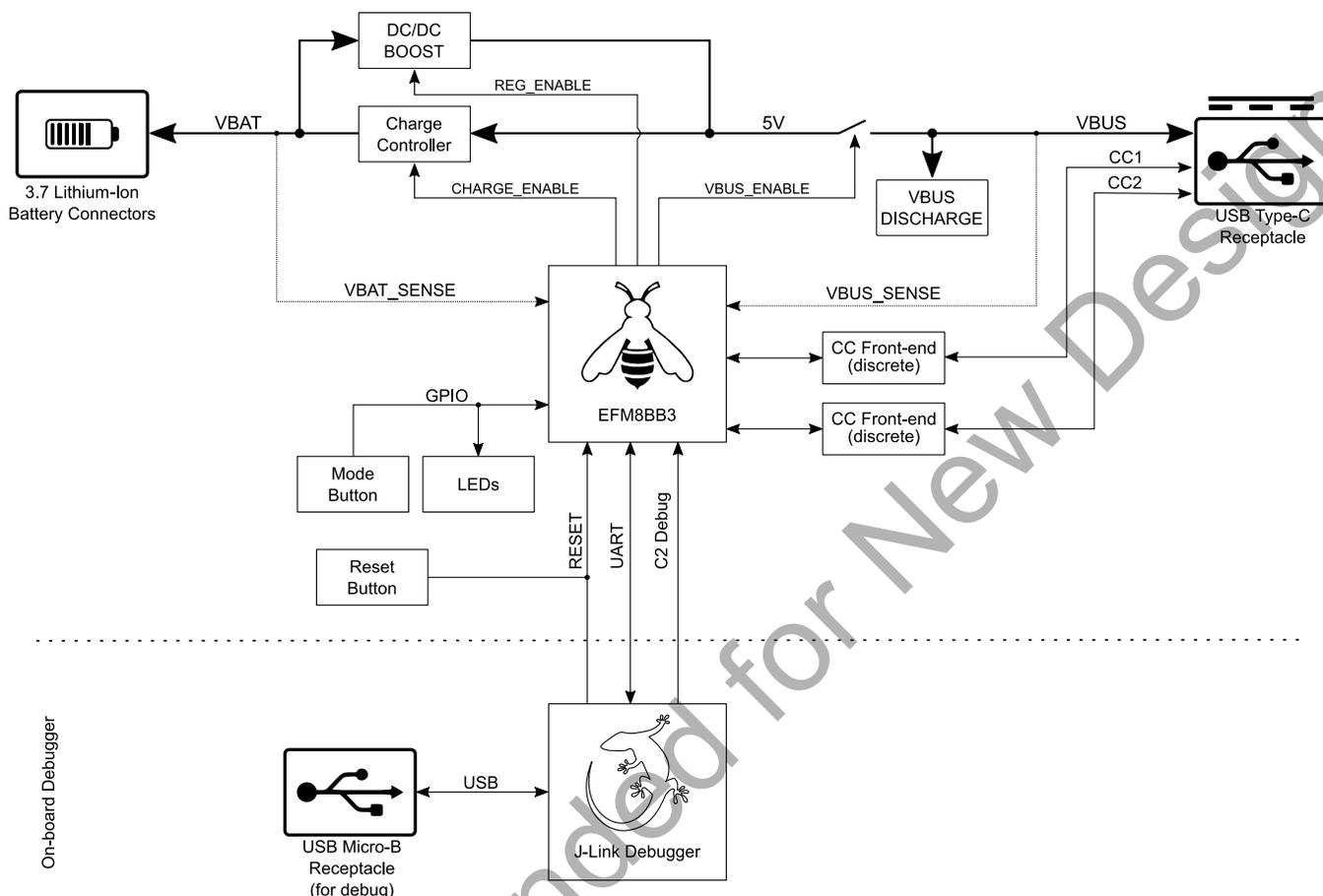


Figure 2.1. Kit Block Diagram

2.2 Connectors

2.2.1 USB Type-C Connector

The USB Type-C connector is a USB Power Delivery charge-only port. Depending on the board operating mode, the port supports acting as either source - a downstream facing port (DFP), or as a sink - an upstream facing port (UFP). The design is capable of operating as a dual-role power port (DRP), and allows dynamically switching between modes using DRP mode-swap.

In source mode, the board can supply up to 15 W. When USB Power Delivery is used, the board advertises 3.0 A current at 5.0 V.

In sink mode, the board requests 2100 mA and 5 V to enable fast charging of the connected battery pack.

2.2.2 Battery Connectors

The board features two ways of connecting batteries. The JST connector allows for quick demonstrations using standard off-the-shelf battery packs, while solder tabs can be used to connect a custom battery pack.

Due to the low current rating of the JST connector itself, and the often thin leads used on these battery packs, an additional electrolytic capacitor has been added to reduce peak current when using this connector.

Using the solder tabs with short, thick wires to a battery pack is recommended in order to achieve the full output power.

2.2.3 USB Micro-B Connector

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

2.3 Boost Converter

The boost converter is responsible for generating the VBUS voltage when the board operates as a power source. The lithium-ion battery is connected to the input of the boost converter, and the output is connected to the USB VBUS line of the Type-C connector through a transistor switch when USBC_VBUS_EN (P2.1) is set high.

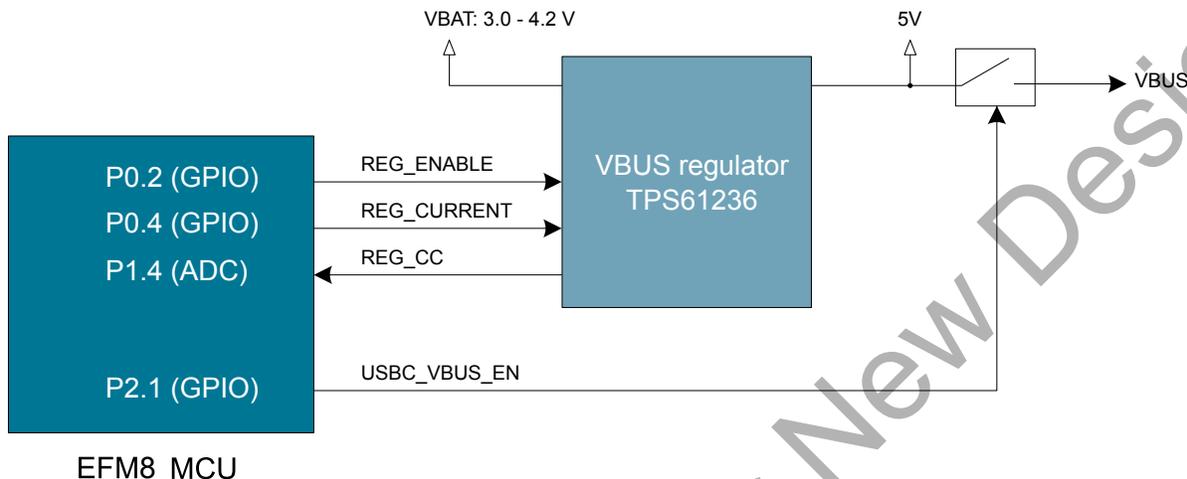


Figure 2.2. Boost Converter Connections

The boost converter is enabled with the REG_ENABLE signal, which is driven by GPIO P0.2 of the EFM8BB3 microcontroller. The output voltage is fixed at 5.3 V, and the output current can be limited to either 900 mA or 3.0 A. The output current limit is selected using the REG_CURRENT signal, which is driven by P0.4 of the EFM8. If the output current exceeds the current limit, the part goes into constant current mode instead of constant voltage regulation mode.

The boost converter output current can be monitored by measuring the voltage on the REG_CC signal, which is connected to P1.4 of the EFM8. The voltage on the REG_CC pin is proportional to the output current.

Table 2.1. Boost Converter

	REG_CURRENT = 0	REG_CURRENT = 1
Output voltage	5.3 V	
Current limit	900 mA	3.0 A
CC pin voltage (P1.4)	$1.1 * I_{OUT}$	$0.33 * I_{OUT}$

2.3.1 Boost Converter Indicator LED

The LED labeled "BOOST ACT" is connected directly to the INACT signal on the boost converter IC. The LED will turn on whenever the output current of the converter is higher than 50 mA.

Table 2.2. Boost Converter Indicator LED

Condition	BOOST ACT
Boost converter inactive, or output current is < 50 mA	OFF
Boost converter enabled and output current is > 50 mA	ON

2.4 Battery Charger

The board contains a lithium-ion battery charger capable of charging a single-cell lithium-ion battery at up to 1.8 A of continuous current. The battery charge controller is enabled by setting the CHARGER_EN signal (P0.7) high. The charge current is selectable to be either 400 mA or 1.8 A, and is set using the CHARGER_ISET (P1.0) signal.

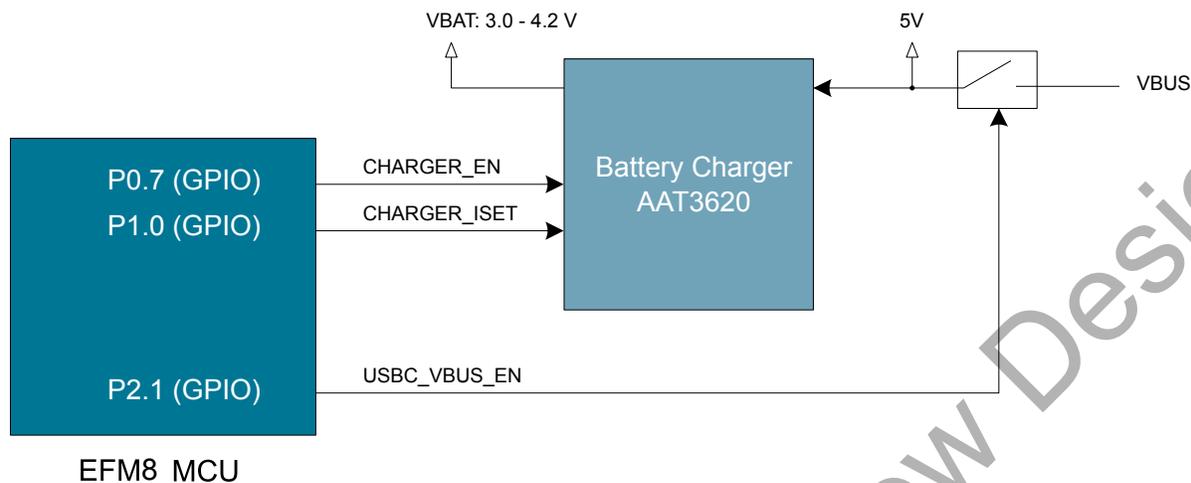


Figure 2.3. Battery Charger Connections

The charge current can be monitored on the TERM pin of the charge controller. This pin is not connected to the EFM8, but is available on the breakout header, labeled "CT". Refer to the Skyworks AAT3620 data sheet for more information.

Table 2.3. Battery Charge Controller

	CHARGE_ISET = 0	CHARGE_ISET = 1
Output charging voltage regulation	4.2 V	
Battery conditioning voltage threshold	2.6 V	
Fast charge current	1800 mA	400 mA

2.4.1 Battery Charger Indicator LEDs

The following table summarizes the function of the charger status LEDs, labeled "CHARGE S1/S2" on the board. Further details are found in the charger data sheet (Skyworks AAT3620).

Table 2.4. Charge Controller Indicator LEDs

Conditions	S1	S2
Pre-charging	ON	ON
Fast-charging	ON	OFF
End-of-charging (charging complete)	OFF	ON
Charging disabled	OFF	OFF
Sleep mode	OFF	OFF
No battery with charging enabled	FLASH, 50% duty cycle	FLASH, 50% duty cycle
Fault condition (battery 0 V)	OFF	OFF
Fault condition (battery over-temperature/ under-temperature)	OFF	OFF
Fault condition (device over-temperature)	OFF	OFF
Fault condition (pre-charging time out)	OFF	FLASH, 50% duty cycle
Fault condition (time out)	OFF	OFF

2.5 USB Type-C Configuration Channels

The CC1 and CC2 lines are used to determine orientation and to negotiate power capabilities between the downstream facing port (DFP) and the upstream facing port (UFP). In addition, this design supports operation as a dual-role power port (DRP), meaning that a DRP role-swap can be negotiated to swap from being a source to a sink.

Pull-up resistors R_p are used when acting as a DFP. The EFM8 enables R_p on both CC1 and CC2, and monitors the voltage on the lines. When a sink is attached, it will have R_d enabled, and either CC1 or CC2 will be pulled low, depending on the cable orientation. Pull-down resistors R_d are enabled when the board functions as a UFP.

In addition to controlling the pull-up and pull-down resistors R_p and R_d , the EFM8 is also capable of performing PD communication over the CC. This is made possible with the PD libraries provided by Silicon Labs.

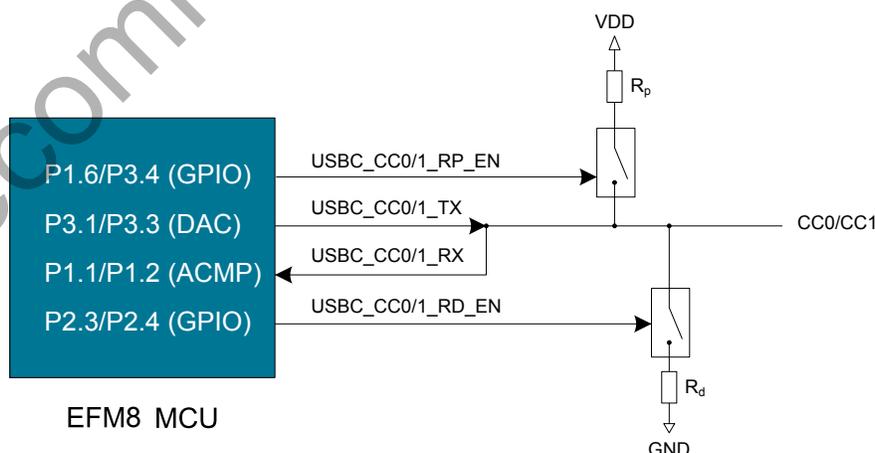


Figure 2.4. Configuration Channel

2.6 Miscellaneous

In addition to the boost converter and charge controller, the board contains some miscellaneous features:

- Push buttons - MODE and RESET
- 2x user programmable indicator LEDs
- USB VBUS power switch and VBUS discharge circuit
- Voltage monitoring of battery and VBUS voltages

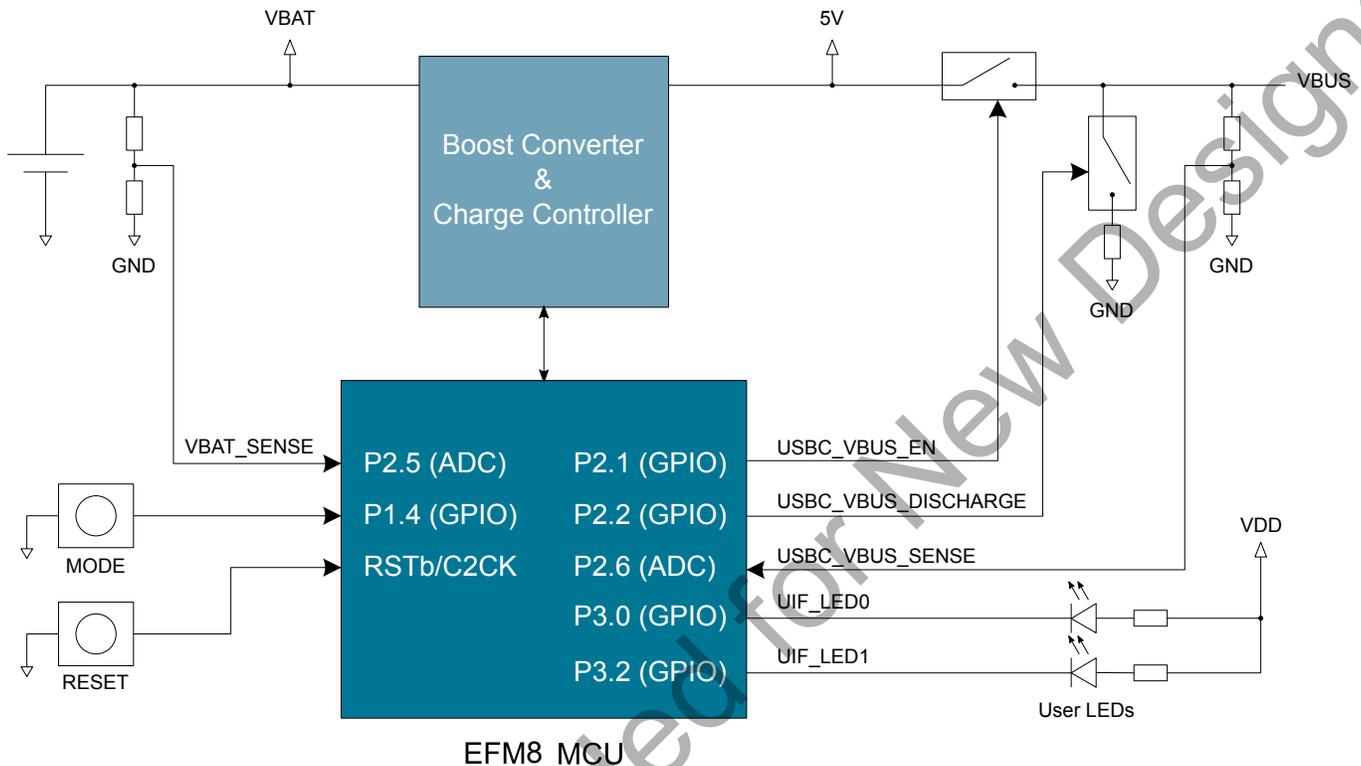


Figure 2.5. Miscellaneous Features

2.6.1 Push Buttons

Two push buttons are placed on the board, one labeled RESET and one labeled MODE.

The reset button is tied directly to the RSTb/C2CK pin of the EFM8, and a press on this button resets the microcontroller.

The "mode" button is a general purpose push button connected to P1.3 of the EFM8. In the demo application, it is used to switch between advertising as a source and as a sink.

2.6.2 USB VBUS Switch and Discharge Circuit

The design contains a back-to-back MOSFET switch that connects and disconnects the 5V net from the VBUS pin of the USB Type-C connector. The switch is controlled by the USBC_VBUS_EN signal (P2.1). The switch consists of two P-channel MOSFET devices, with an on-resistance of about 15 mΩ each for a total of 30 mΩ.

In addition to the VBUS switch, a discharge circuit is also implemented using a resistor and a transistor. The discharge feature is controlled by the USBC_VBUS_DISCHARGE signal connected to P2.2 on the EFM8. The USB Type-C specification requires a source to discharge VBUS within 650 ms of a detached sink.

2.6.3 Voltage Monitoring

Resistor dividers are placed on both the battery voltage net (VBAT) and the USB bus voltage net (VBUS), allowing the EFM8 firmware to measure a scaled version of these voltages using its internal ADC. VBAT_SENSE (P2.5) measures the battery voltage scaled by 1:2, and USBC_VBUS_SENSE (P2.6) measures USB bus voltage scaled by 1:10.

2.7 Power Supply

A low-dropout linear regulator (LDO) on-board the kit powers the EFM8 whenever power is available from either the battery, the USB Type-C connector, or the USB Micro-B connector. Schottky diodes with low forward voltage drop are inserted between the LDO input and each power rail to prevent current from flowing between the sources. This topology is illustrated in the figure below and ensures that the EFM8 is powered up as long as at least one of the power sources are present.

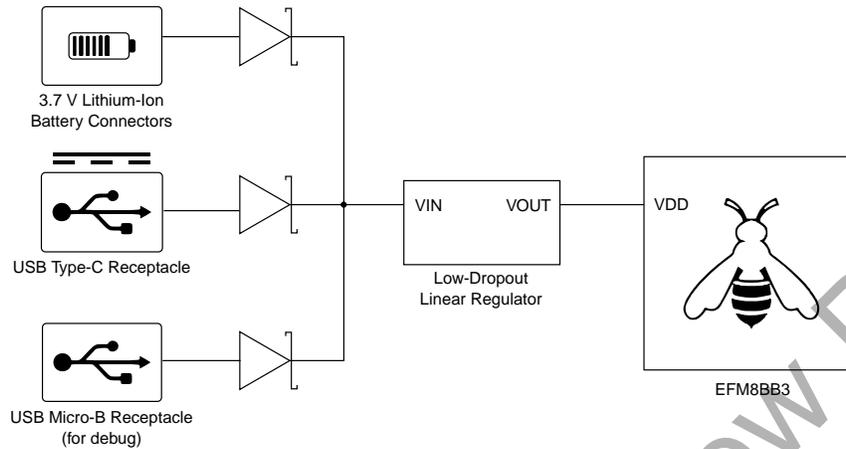


Figure 2.6. Power Supply

The output of the LDO is also used to power parts of the on-board debugger circuit. However, most parts of the circuit will be powered down or in a low current state whenever the debug USB cable is not inserted in the USB Micro-B connector.

2.8 Breakout Pads

Thirty-six breakout pads are provided for easy access to all EFM8 I/Os for monitoring and prototyping. The pads are located in two rows along the bottom edge of the board. The bottom row is named "J1", and the top row "J2". These pads enable connection of peripherals or add-on boards. Additionally, all voltage rails are also available on the breakout pads.

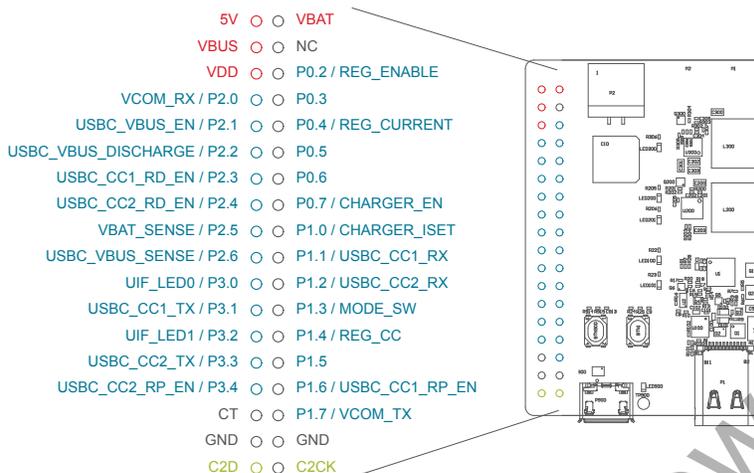


Figure 2.7. Breakout Pads

The table below includes an overview of the pin functionality on each breakout pad.

Table 2.5. Expansion Header Pinout

Pin	Function	Description
Lower Row Breakout Pins (J1)		
VBAT	Battery Voltage	Directly connected to the input battery voltage
NC	–	–
P0.2	REG_ENABLE	VBUS regulator (boost converter) enable signal
P0.3	Reserved	Used internally by PD library
P0.4	REG_CURRENT	VBUS regulator current select. Selects between 900 mA and 3 A output current.
P0.5	Reserved	Used internally by PD library
P0.6	Reserved	Used internally by PD library
P0.7	CHARGER_EN	Charge controller enable
P1.0	CHARGER_ISET	Charge controller current select. Selects between 400 mA and 1.8 A charge current.
P1.1	USBC_CC1_RX	USB Type-C configuration channel 1 receive
P1.2	USBC_CC2_RX	USB Type-C configuration channel 2 receive
P1.3	MODE_SW	Push button input
P1.4	REG_CC	VBUS regulator current monitor
P1.5	Reserved	Used internally by PD library
P1.6	USBC_CC1_RP_EN	USB Type-C Rp pull-up enable for channel 1
P1.7	VCOM_TX	Virtual COM Port transmit data from EFM8
GND	–	–

Pin	Function	Description
C2CK	Reset/C2 clock	Reset and C2CK, connected to both RESET button and debugger
Upper Row Breakout Pins (J2)		
5V	5 V net	Output directly from boost converter. Input to charge controller
VBUS	USB Type-C VBUS	USB Type-C bus voltage
VDD	3.3 V	Power rail for EFM8 and on-board debugger
P2.0	VCOM_RX	Virtual COM Port receive data to EFM8
P2.1	USBC_VBUS_EN	VBUS switch enable signal
P2.2	USBC_VBUS_DISCHARGE	VBUS discharge enable signal
P2.3	USBC_CC1_RD_EN	USB Type-C Rd pull-down enable for channel 1
P2.4	USBC_CC2_RD_EN	USB Type-C Rd pull-down enable for channel 2
P2.5	VBAT_SENSE	Battery voltage sense pin - VBAT * 0.5
P2.6	USBC_VBUS_SENSE	VBUS voltage sense pin: VBUS * 0.099
P3.0	UIF_LED0	General purpose indicator LED0
P3.1	USBC_CC1_TX	USB Type-C configuration channel 1 transmit
P3.2	UIF_LED1	General purpose indicator LED1
P3.3	USBC_CC2_TX	USB Type-C configuration channel 2 transmit
P3.4	USBC_CC2_RP_EN	USB Type-C Rp pull-up enable for channel 2
CT	CHARGER_TERM	TERM pin on charge controller. Can be used to read charge current.
GND	–	–
C2D	C2 Data	C2 Data for debugging of EFM8. Connected to on-board debugger.

3. Specifications

3.1 Electrical Specifications

3.1.1 Absolute Maximum Ratings

Parameter	Symbol	Min	Typ	Max	Unit
Battery input voltage	$V_{BAT-MAX}$	-0.3		+6.0	V
USB Input Voltage	$V_{USB-MAX}$	-0.3		+6.0	V
Electrostatic discharge voltage – USB Type-C connector	V_{ESD_USB}			30	kV
Operating ambient temperature ¹	T_{AMB}	-40		+85	°C

1 Actual limit will be less than +85°C because of board self-heating, which again depends on output power.

3.1.2 Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
USB input voltage range	V_{VBUS}	4.5	5.0	5.5	V
Battery input voltage range	V_{VBAT}	3.0	3.7	4.2	V
Boost converter output voltage in PFM mode (low output current)	$V_{BOOST, PFM}$	–	5.33	–	V
Boost converter output voltage in PWM mode (high output current)	$V_{BOOST, PWM}$	5.10	5.28	5.47	V
Boost converter current limit, REG_CURRENT = 0	I_{OUT_CC0}	1.10	1.13	1.17	A
Boost converter current limit, REG_CURRENT = 1	I_{OUT_CC1}	3.67	3.78	3.89	A
Battery charger voltage regulation	V_{BAT_REG}	4.16	4.20	4.24	V
Battery charge current, CHARGE_ISET = 0	I_{CH_CC0}	0.34	0.40	0.46	A
Battery charge current, CHARGE_ISET = 1	I_{CH_CC1}	1.53	1.80	2.07	A
VBUS MOSFET switch on-resistance, $I_{OUT} = 3.0$ A	$R_{DS(ON)_VBUS}$	–	24	29.6	mΩ

3.2 Thermal Characteristics

Even with >90% efficient voltage regulators, the board will still have a significant power dissipation when delivering 15 W of output power. This reference design displays a temperature increase in certain hot spots of up to 62°C above the ambient temperature, when running at the maximum output power and minimum battery voltage.

It is important to remember that external elements such as encapsulation, air flow, etc., will have to be taken into account when designing a finished product. The purpose of this design is not to solve these design problems, but rather to effectively demonstrate the EFM8BB3 as a PD-controller.

The sections below show some typical performance characteristics of the reference design.

3.2.1 Boost Converter Performance

The VBUS regulator dissipates the most power when the input voltage is low and the output current is high. The image below shows the board when the input voltage is around 3.0 V, and the output power delivered to the USB Type-C connector is about 14.5 W. In this case, the efficiency was measured to 91.3%.

Table 3.1. Boost Converter Measured Typical Operating Values

V_{IN} [V]	I_{IN} [A]	V_{OUT} [V]	I_{OUT} [A]	P_{IN} [W]	P_{OUT} [W]	P_{Loss} [W]	Eff. [%]
3.00	5.28	5.26	2.75	15.8	14.5	1.38	91.3
3.20	4.83	5.26	2.75	15.5	14.5	1.01	93.5
3.70	4.10	5.26	2.75	15.2	14.5	0.71	95.3
4.20	3.57	5.26	2.75	15.0	14.5	0.52	96.5

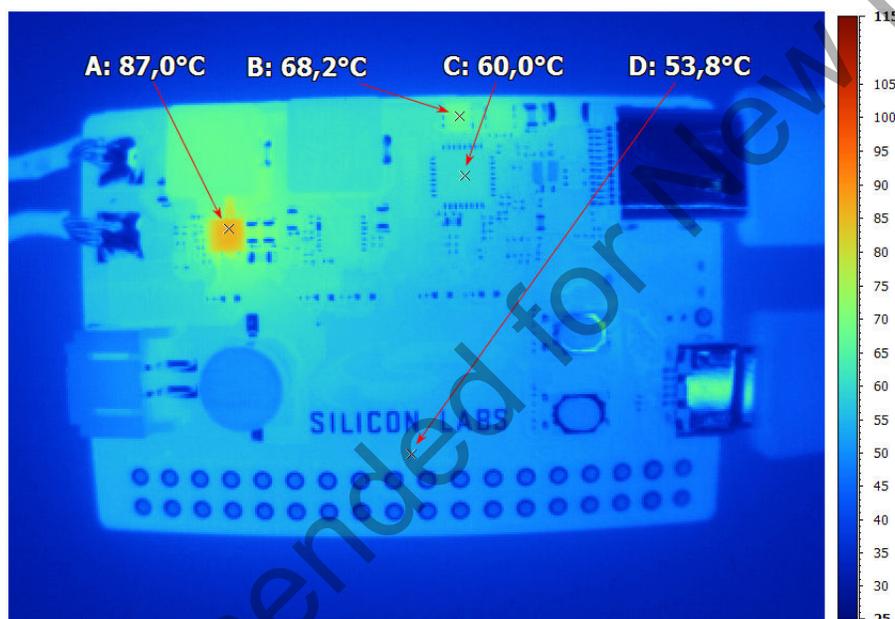


Figure 3.1. Operation as a Source, 14.5 W Output to USB Type-C

3.2.2 Battery Charger Performance

The battery charger has the highest efficiency when the output voltage is close to the input voltage - when the battery is approaching fully charged. At the same time, the output power increases as the battery voltage increases, since the charge current remains constant. The increase in efficiency is offset by the increase in output power, leading to a relatively constant dissipation in the board over the battery charge cycle.

Table 3.2. Battery Charger Measured Typical Operating Values

V_{IN} [V]	I_{IN} [A]	V_{BAT} [V]	I_{BAT} [A]	P_{IN} [W]	P_{BAT} [W]	P_{Loss} [W]	Eff. [%]
5.00	1.28	3.00	1.79	6.40	5.37	1.03	83.9
5.00	1.35	3.20	1.78	6.75	5.70	1.05	84.4
5.00	1.54	3.70	1.77	7.70	6.55	1.15	85.1
5.00	1.64	4.00	1.76	8.20	7.04	1.26	85.9

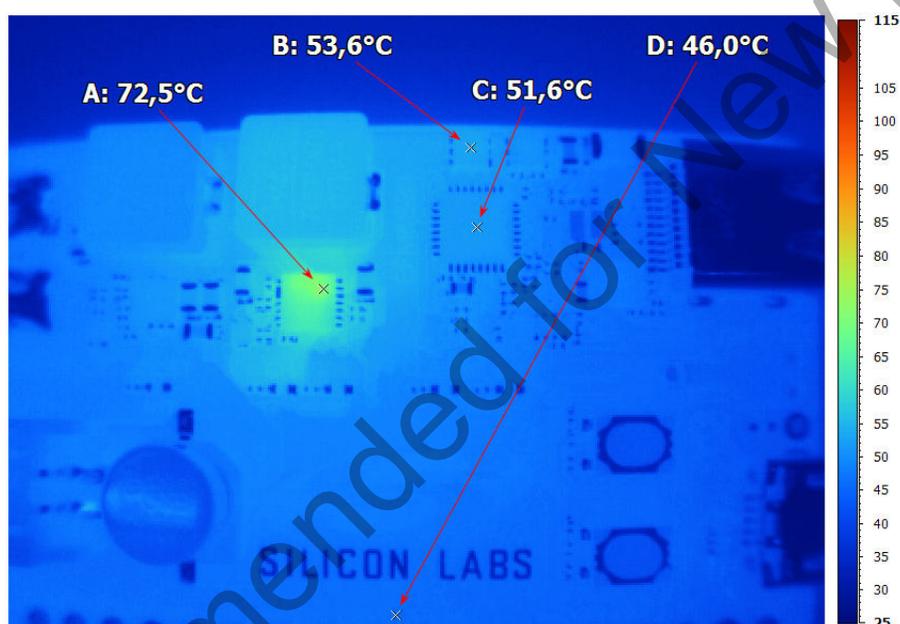


Figure 3.2. Operation as a Sink, Battery Fast Charging at 1.8 A

4. Debugging

The EFM8BB3 USB Type-C Battery Pack Reference Design contains an on-board fully functional SEGGER J-Link Debugger that interfaces to the target EFM8 using the Silicon Labs 2-Wire Interface (C2). The debugger allows the user to download code and debug applications running on the target EFM8. It also provides a USB virtual COM port (VCOM) that is directly connected to the target device's serial port, for general purpose communication between the running application and a host computer. The debugger is accessed through the USB Micro-B connector featured on the board.

4.1 On-board Debugger

The on-board debugger is a SEGGER J-Link debugger running on an EFM32 Giant Gecko. The debugger is directly connected to the debug and VCOM pins of the target EFM8. The on-board debugger enables easy customization and development without any external hardware. It is not considered part of the USB Type-C reference design.

When the debug USB cable is removed, the on-board debugger goes into a low power shutoff mode. This means that an application running on batteries will not be affected by the on-board debugger power consumption. Since the I/O voltage rail of the debugger remains powered in the battery operated mode, the pins connected to the debug and VCOM interfaces maintain proper isolation and prevent leakage currents.

4.2 Virtual COM Port

An asynchronous serial connection to the on-board debugger is provided for application data transfer between a host computer and the target EFM8 through the debug USB port. This eliminates the need for an external serial port adapter.

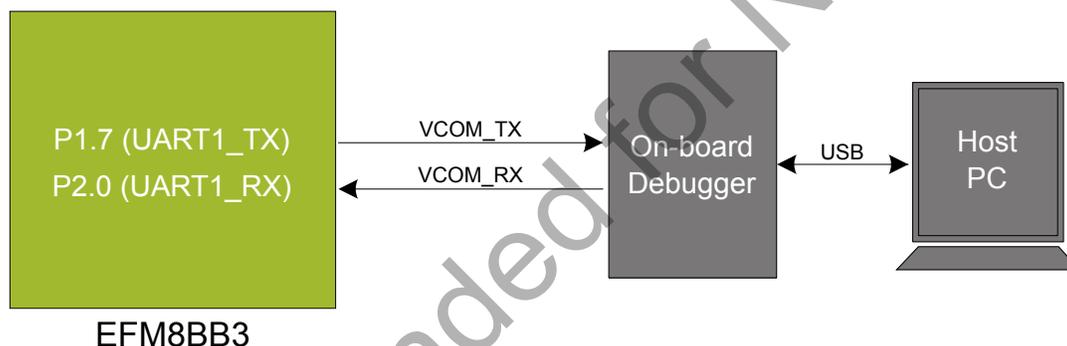


Figure 4.1. Virtual COM Port Interface

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 computer over the debug USB connection.

Table 4.1. Virtual COM Port Interface Pins

Signal	Description
VCOM_TX	Transmit data from the EFM8 to the on-board debugger.
VCOM_RX	Receive data from the on-board debugger to the EFM8.

The physical serial port configuration parameters for the target application running on the EFM8 are:

- Speed: 115200 bps
- Data bits: 8
- Parity bit: None
- Stop bits: 1
- Flow control: None

5. Schematics, Assembly Drawings, and BOM

Schematics, assembly drawings, and bill of materials (BOM) are available through when the kit documentation package has been installed.

Not Recommended for New Designs

6. Revision History and Errata

6.1 Kit Revision History

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



Figure 6.1. Revision Info

Table 6.1. SLRDK1000A Revision History

Kit Revision	Released	Description
A00	2017-08-29	Initial kit release. Includes BRD5203A Rev A04.

6.2 Board Revision History

The revision of the board assembly is printed on the backside of the board.

Table 6.2. BRD5303A Revision History

Board Revision	Release Date	Description
A05	2017-08-25	Minor PCB updates to improve manufacturing.
A04	2017-07-28	Release version. Increased size of R8, VBUS discharge resistor, to 1K.
A03	2017-06-19	Prototype version.

6.3 BRD5302A Errata

There are no known errata at present.

7. Document Revision History

Revision 1.00

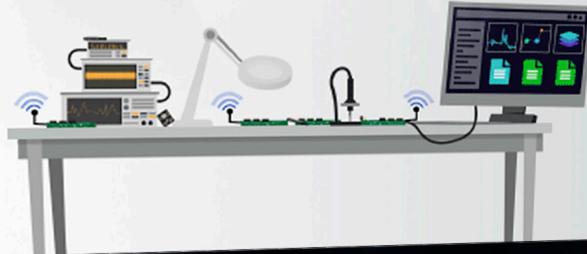
2017-09-01

Initial version.

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