AN1082: EFR32 Receive and Transmit Current Measurements

Measurements of receive and transmit current for EFR32 to support data sheet values are performed using specific settings for voltage, clock frequency, power supply configuration, and demodulator state. In addition, the operation of the MCU is minimized to reduce current consumption for non-radio blocks. These settings are not, by default, available to customers who use Silicon Labs supplied software packages.

The purpose of this application note is to compare results used to support radio receive and transmit current values as seen in the EFR32 data sheets, to values customers are likely to measure (using Silicon Labs supplied hardware and software) and give an explanation of the registers settings responsible for the difference in performance.

Note: This document focuses on 2.4 GHz 802.15.4 and BLE standards for receive and transmit currents. Settings for bands below 2.4 GHz and other standards or protocols will be similar to the ones shown in this document.

KEY POINTS

- Discusses device test configuration
- Compares 2.4 GHz 802.15.4 and BLE Receive Current Measurement Data on EFR32xG1
- Offers an overview of transmit current measurements
- Discusses DUT power configuration

1. Device Compatibility

This application note supports multiple device families, and some functionality is different depending on the device.

EFR32 Wireless Gecko Series 1 support consists of:

- EFR32BG1
- EFR32BG12
- EFR3BG13
- EFR32BG14
- EFR32MG1
- EFR32MG12
- EFR32MG13
- EFR32MG14

EFR32 Wireless Gecko Series 2 support consists of:

- EFR32BG22
- EFR32FG22
- EFR32MG21
- EFR32MG22

2. Device Test Configuration

2.1 General Differences

The table below highlights general settings differences between the RF Validation current measurement configuration using validation test software (used to determine data sheet values), the RAILTEST configuration, and the BLE SDK configuration.

Table 2.1. General Settings Differences

Setting	RF Validation (Data Sheet)	Customer (802.15.4)	Customer (BLE)
Test Software	Validation test code	RAILTEST	SDK
PCB	RF Validation PCB	EFR32 Radio Board	EFR32 Radio Board[2] Module Radio Board[1]
DC-DC Voltage	1.7 V for EFR32xG1 1.8 V for EFR32xG12/ EFR32xG13/EFR32xG14/ EFR32xG22 N/A for EFR32xG21	1.8 V [2]	1.8 V [2]
Clock Scaling Divide Ratio for Active Mode Current Measurements	3 for 802.15.4 4 for BLE	1	1
Clock Scaling Divide Ratio for Listen Mode Current Measurements	1 for 802.15.4 1 for BLE		
Quite Mode Operation	Yes	No, by default (code can be modified but UART must remain on)	No (UART, LFXO, and RTCC remain on)
EM1 operation	Yes	Yes, for Listen Only	Yes, for Listen Only

Notes:

1. For BLE testing, Silicon Labs offers both modules and single-die SoC solutions for Bluetooth applications. Along with this hardware, a Bluetooth Smart SDK package is provided for customer development.
2. EMLIB will not support 1.7 V so this voltage cannot be implemented in RAILTEST.

2.2 Active Mode vs Listen Mode Receive Currents and Setup

For receive current measurements, two primary demodulator modes can be enabled:

- **Listen Mode**: The receiver is on and waiting for a signal to be received. During this state, no packets are received or processed.
- **Active Mode**: The receiver is on, receiving packets.

Values for Active Mode Receive currents are presented in the EFR32xG1 data sheet (see section 4.1.5.4 Table 4.8) for all frequency bands. For Active and Listen currents for all other devices, see the device’s data sheet.

For Active Mode Receive current measurement, the radio needs to be actively receiving packets in order to make accurate measurement in the proper demodulator mode. Automated measurements using the Validation software are made with a Digital Multi-Meter (DMM), however the DMM is not fast enough to capture only the time when the receiver is only in Active Mode. To accomplish this, the receiver must be set to continuously receive packets by placing it in “Infinite Receive Mode” (Infinity Mode), where it can receive a continuous packet and stay in the Active Mode during the entire time the measurement is made.

An additional complication is created however when the radio is in this mode. As the Frame Controller Buffer continuously receives a very long packet, the buffer will overflow, causing the device to fall out of receive mode. The figure below demonstrates this problem. The grey trace shows the current drop after the overflow occurs, corrupting the current measurement. To remedy this issue, the Frame Controller Buffer must be disabled. The orange trace shows an active current measurement with the buffer disabled.

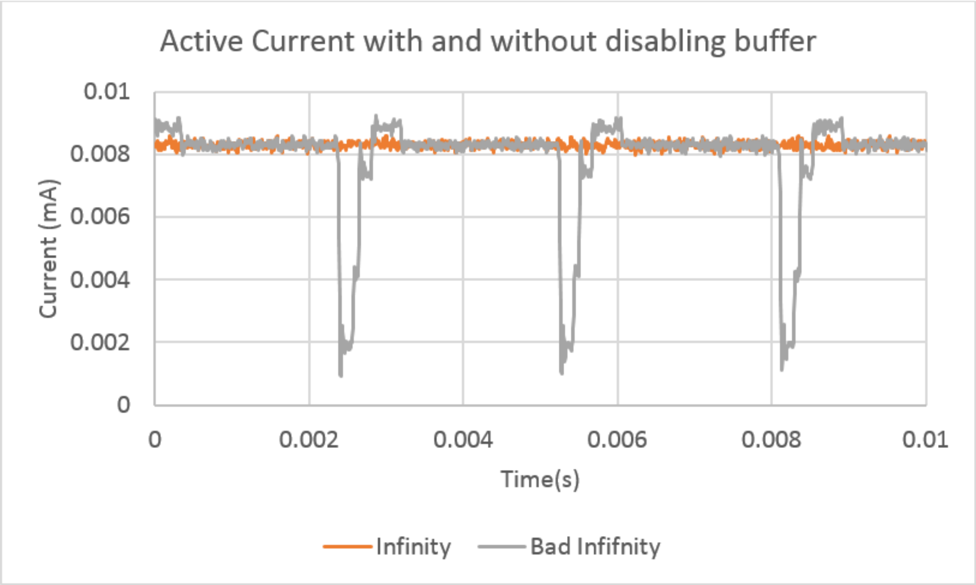


Figure 2.1. Active Mode Current Measurement with and without Disabling Frame Controller Buffer

The figure below shows that turning off the buffer does not significantly affect the value of current. The Active current measured when the Frame Controller Buffer is disabled is the same as that measured when the Frame Controller Buffer is enabled, for both Listen and Active Modes.

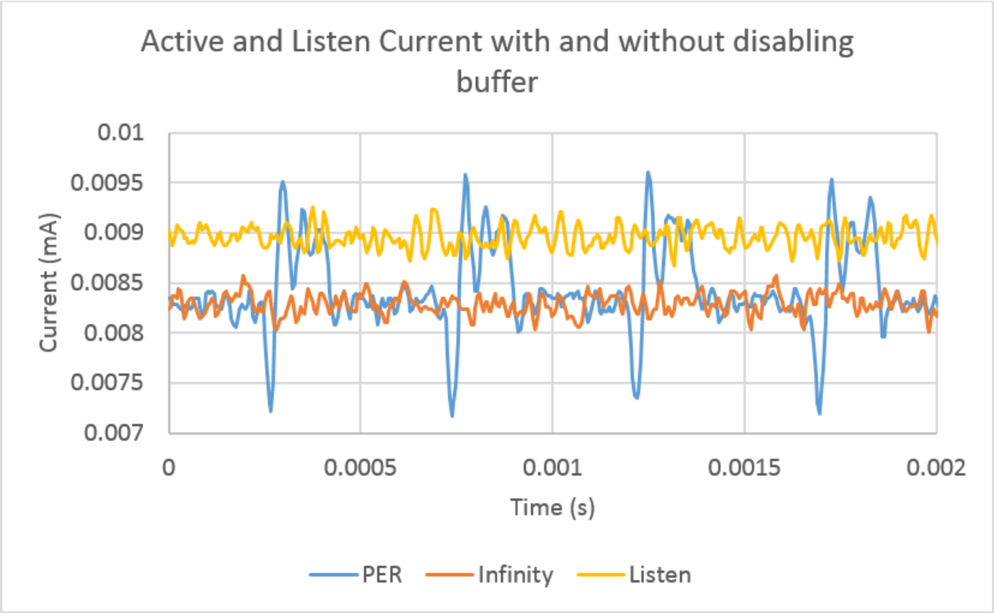


Figure 2.2. Active and Listen Mode Current Measurement with and without disabling Frame Controller Buffer

Orange Trace:	Active Mode current measured with a continuous receive packet with Frame Controller Buffer disabled. (Infinity Mode)
Yellow Trace:	Listen Mode current measured with a continuous receive packet. Frame Control Buffer disabled.
Blue Trace:	Active and Listen Mode currents when receiving non-continuous packet. Frame Controller enabled.

2.3 DC-DC Output Voltage

This information does not apply to EFR32xG21 devices.

EFR32 RF characterization (validation) sets the dc-dc output voltage to 1.7 V for the EFR32xG1 devices. To better correlate to what the customer will see, characterization (validation) has changed to use 1.8 V for EFR32xG12, EFR32xG13, EFR32xG14, and EFR32xG22. For both RAILTEST and the SDK software, EMLIB has a minimum setting of 1.8 V. The Bluetooth SDK also sets the dc-dc voltage to 1.8 V.

2.4 Clock Scaling

This information does not apply to EFR32xG21 and EFR32xG22 devices.

Clock scaling is the division of the 38.4 MHz reference crystal by an integer number. This reduces the system clock speeds and hence the digital current consumption. Validation uses clock scaling to get a value that represents the radio by minimizing the MCU power consumption.

Reducing the clock speed also may have adverse effects when real-time software applications are running, so clock scaling is not supported nor recommended for radio and stack operation. Therefore, both RAILTEST and the BLE SDK packages do not, by default allow clock scaling.

RAILTEST software source code can be modified to support clock scaling and measurements can be performed. This is not possible with the BLE SDK software.

Since clock scaling is not recommended or supported for customers, RAILTEST and BLE SDK measurements in this document use a factor of 1.

The table below gives a comparison of setting for clock scaling using the Validation code, RAILTEST code and BLE SDK code.

Table 2.2. Clock Scaling Comparison for Validation SW, RAILTEST, and BLE SDK

Band	Register	Validation SW Clock Scaling Value	RAILTEST Clock Scaling Value	BLE SDK Clock Scaling Value
2.4 GHz 802.15.4 RX	CMU_HFPRESC.PRESC	3	1	1
2.4 GHz BLE	CMU_HFPRESC.PRESC	4	1	1

2.5 EM1 Operational Mode

Receive and transmit current measurements performed by the Validation Software code used to support the EFR32 data sheets are performed with the device under test in EM1 mode.

In EM1 mode, all MCU core is not active, awaiting to be awakened by an interrupt. The clock to the core is gated off until this interrupt occurs. See 'Energy Modes' chapter in the EFR32 Reference Manuals for detailed information on EM1 operation and settings.

EM1 mode is not the default state for RAILTEST software while it is idle, however it can be configured to operate in EM1 by modifying the source code. When the device under test is configured to Listen Mode, RAILTEST can consistently keep the device in EM1. However, during packet reception the energy mode of the device under test will move from EM1 to EM0. The current measurement will show higher current values and be more unstable. This makes the measurement for Active current in EM1 mode difficult for customers using either RAILTEST or the BLE SDK software. Listen Mode currents measured by customers will be more stable and the device under test can remain in EM1 mode during this measurement since packet reception is not necessary.

2.6 Quiet Mode Operation

Quiet Mode is an operational mode specifically created to disable as many non-radio peripheral devices and clocks and still allow radio functionality. It was created specifically to minimize measured current for validation and characterization of the radio blocks and all data sheet receiver current measurements enable this mode of operation. It is not a mode that is available, by default, to customers in either the RAILTEST or SDK software platforms.

It is possible for customers to modify the RAILTEST code since they have access to the source code and the RAILTEST measurements shown in this document utilize these changes. However the internal UART register needs to be turned on for RAILTEST and the SDK.

The table on the following page gives register and block settings for Quiet Mode using the validation software as well as register and block settings for RAILTEST and the BLE SDK. Under the RAILTEST settings, the column noted as “default” is the setting value default to the RAILTEST software package. The column noted as “Mod” is the value modified in the source code to enable operation to that used by the validation test code. For the BLE SDK code, only default values were used.

Table 2.3. Register and Block Settings for Quiet Mode Validation SW, RAILTEST, and BLE SDK

Bit	Name	Description	Quiet Mode Validation 802.15.4 & BLE	RAILTEST 802.15.4		BLE SDK
				Mod[2]	Default[1]	Default[1]
CMU_HFBUSCLKEN0 REGISTER SETTINGS						
0	LE	Low Energy Peripheral Interface Clock Enable	0	0	1	0
1	CRYPTO	Advanced Encryption Accelerator Clock Enable	0	0	0	0
2	GPIO	GPIO Clock Enable	0	0	1	0
3	PRS	Peripheral Reflex System Clock Enable	0	0	0	0
4	LDMA	Linked Direct memory Access Controller Clock Enable	0	0	0	0
5	GPCRC	General Purpose CRC Clock Enable	0	0	0	0
CMU_HFPERCLKEN0 REGISTER SETTINGS						
0	TIMER0	Timer 0 Clock Enable	0	1	1	0
1	TIMER1	Timer 1 Clock Enable	0	0	1	0
2	UART0	UART0 Clock Enable	0	1	1	0
3	UART1	UART1 Clock Enable	0	0	1	1
4	ACMP0	Analog Comparator 0 Clock Enable	0	0	1	0
5	ACMP1	Analog Comparator 1 Clock Enable	0	0	1	0
6	CRYOTIMER	Cryo-Timer Clock Enable	0	0	1	0
7	I2C0	I2C Clock Enable	0	0	1	1
8	ADC0	A/D Converter 0 clock Enable	0	0	1	0
9	IDAC0	Current D/A Converter 0 Clock Enable	0	0	1	0
10	SYSCFG (Reserved)	System Configuration block Clock Enable	0	0	1	0
OSCILLATOR BLOCK Operation						
LFRCO		Frequency reference for medium accuracy RTCC Timing	Off	Off	On	Off
LFXO		Frequency reference for high accuracy RTCC Timing	Off	Off	Off	On
RTCC		32 bit Real Time Counter and Calendar	Off	Off	On	On

Notes:
1. Setting for SW are not modified from default settings.
2. Settings for SW are modified from default settings for measurements in this document.

Refer to the device-specific EFR32 Reference Manuals for more details on these settings.

3. 2.4 GHz 802.15.4 Receive Current Measurement Data on EFR32xG1

The table below gives a comparison for 802.15.4 current measurements.

Table 3.1. 2.4 GHz 802.15.4 Receive Current Measurement Data on EFR32xG1

SW/PCB	Energy Mode (EMx)	QUIET MODE Configuration	DC-DC Voltage	Clock Scaling For Active Current Measurement	Receiving Packets	UART	Trace Color[1]	Average Listen Current (mA)	Average Active Current (mA)
Validation SW/ Validation PCB **(Data sheet)**[2]	EM1	Quiet Mode Validation SW 802.15.4 & BLE[3]	1.7 V	3	Yes	OFF	**Grey**	9.4	9.2
Validation SW/ Validation PCB	EM1	Quiet Mode Validation SW 802.15.4 & BLE[3]	1.8 V	1	Yes	OFF	**Yellow**	10.9	10.7
RAILTEST/ Validation PCB	EM1	RAILTEST 802.15.4 “Mod”[3]	1.8 V	1	No	ON	**Blue**	11	n/a
RAILTEST/ Validation PCB	EM0	RAILTEST 802.15.4 “default”[3]	1.8 V	1	Yes	ON	**Green**	12.3	11.7

Notes:
1. See Figure 3.1 Comparison of Current Modes on page 9.
2. The wording "data sheet" refers to the measurement method used to support the data sheet current values. However, if one compares the Active mode current in this table (9.2 mA) with the number provided in the EFR32MG1 data sheet (9.8 mA), some discrepancy will be found. The reason for this discrepancy is that current values within this document are measured on one particular device (averaged in time), while the data sheet numbers are average results measured on multiple devices.
3. See table in section 2.6 Quiet Mode Operation, which defines the “Quiet Mode” Configuration for this test condition

The figure on the following page presents a graphical description of this data.

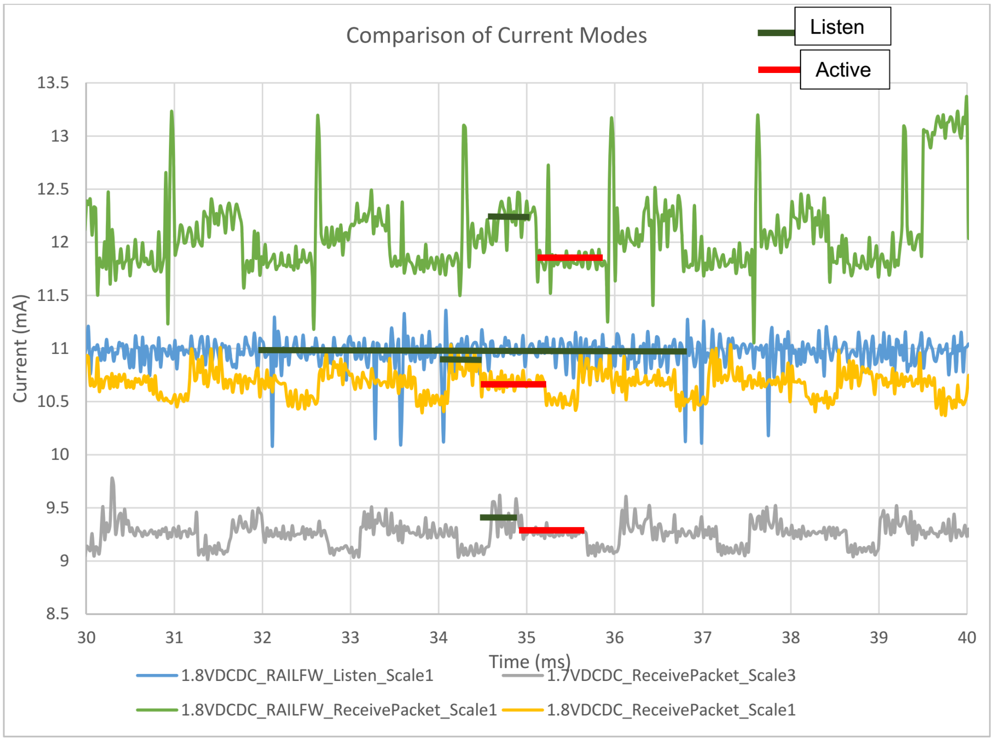


Figure 3.1. Comparison of Current Modes

4. 2.4 GHz BLE Receive Current Measurement Data on EFR32xG1

Customers will initially evaluate BLE radio current performance using the Silicon Labs SDK application software and customer evaluation boards. Two different customer evaluation boards are available, one using the SoC and the other using a module design (BGM111).

The table below gives a comparison for BLE current measurement.

Table 4.1. 2.4 GHz BLE Receive Current Measurement Data on EFR32xG1

SW/PCB	Energy Mode (EMx)	QUIET MODE Configuration	DC-DC Voltage	Clock Scaling For Active Current Measurement	Receive Packets	SPI/I2C	Average Listen Current (mA)	Average Active Current (mA)
Validation SW/Validation PCB **(Data sheet)**[2]	True	Quiet Mode Validation SW 802.15.4 & BLE[1]	1.7 V	4	Yes	OFF	8.9	8.3
Validation SW/ Validation PCB	True	Quiet Mode Validation SW 802.15.4 & BLE[1]	1.8 V	1	Yes	OFF	10.4	9.7
Validation SW/ EFR32BG1 Radio Board	True	Quiet Mode Validation SW 802.15.4 & BLE[1]	1.8 V	1	Yes	OFF	10.4	9.8
Validation SW/ BGM111 Radio Board	True	Quiet Mode Validation SW 802.15.4 & BLE[1]	1.8 V	1	Yes	OFF	10.96	10.29
BLE SDK/ EFR32BG1 Radio Board	True for Listen	BLE SDK “default”[1]	1.8 V	1	No	ON	10.5	na
BLE SDK/ BGM111 Radio Board	True for Listen	BLE SDK “default”[1]	1.8 V	1	No	ON	11	na

Notes:

1. See table in section 2.6 Quiet Mode Operation, which defines the “Quiet Mode” Configuration for this test condition.
2. The wording "data sheet" refers to the measurement method used to support the data sheet current values. However, if one compares the Active mode current in this table (8.3 mA) with the number provided in the EFR32BG1 data sheet (8.7 mA), some discrepancy will be found. The reason for this discrepancy is that current values within this document are measured on one particular device (averaged in time), while the data sheet numbers are average results measured on multiple devices.

5. Transmit Current Measurements

The previous sections showed the measurement methods of receive current measurements on EFR32. Transmit mode currents are primary dominated by the PA current, that is why customers are likely to measure similar transmit currents using RAILTEST and BLE SDK packages as presented in the data sheet.

The following information does not apply to EFR32xG21 and EFR32xG22 devices.

However, for 2.4 GHz 0 dBm output power validation current measurements, clock scaling is used (see section 2.4 Clock Scaling for details), which is, by default, not allowed in RAILTEST and BLE SDK packages.

Note: The EFR32xG1 data sheet shows transmit current at 0 dBm with clock scaling used (prescaled by 3), while the EFR32xG12, EFR32xG13, EFR32xG14, and EFR32xG22 data sheets show both clock scaling of 3 and 1 (none) for 0 dBm.

6. Notes on DUT Power Configuration

The power supply configuration used for the EFR32xG1 data sheet radio current testing is shown below, and is described in more detail in the EFR32xG1 Reference Manual. For power supply configuration details used for other devices, refer to the related reference manual.

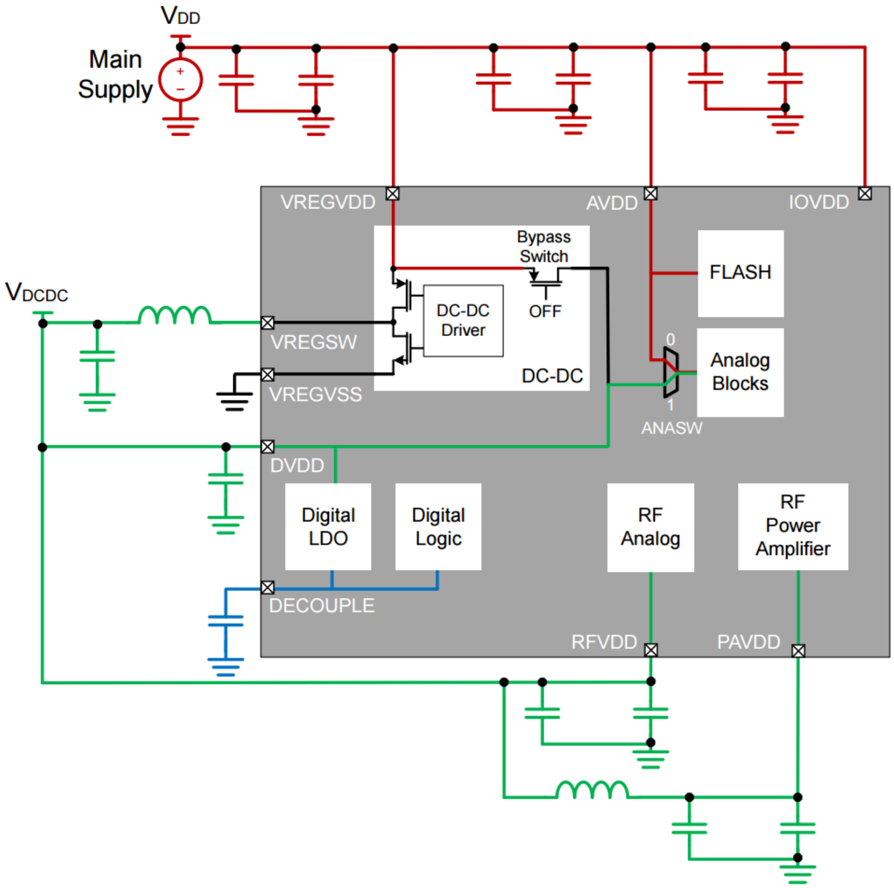


Figure 6.1. EFR32xG1 Power Supply Configuration (DVDD, RFVDD and PAVDD Running from DC-DC)

The input supply pins, AVDD, IOVDD, and VREGVDD are connected to a single external 3.3 V supply. The dc-dc output supplies both the DVDD and RFVDD supply pins. PAVDD is connected to the dc-dc output for output power levels ≤13 dBm (see the figure above), while connected to the external 3.3 V line otherwise (see the figure below). PAVDD voltage does not contribute to current when the device is in receive mode.

For EFR32xG1 RF characterization, the dc-dc is programmed to a voltage of 1.7 V.

As noted, RAILTEST and SDK software has a minimum setting of 1.8 V, limited by the EMLIB functionality.

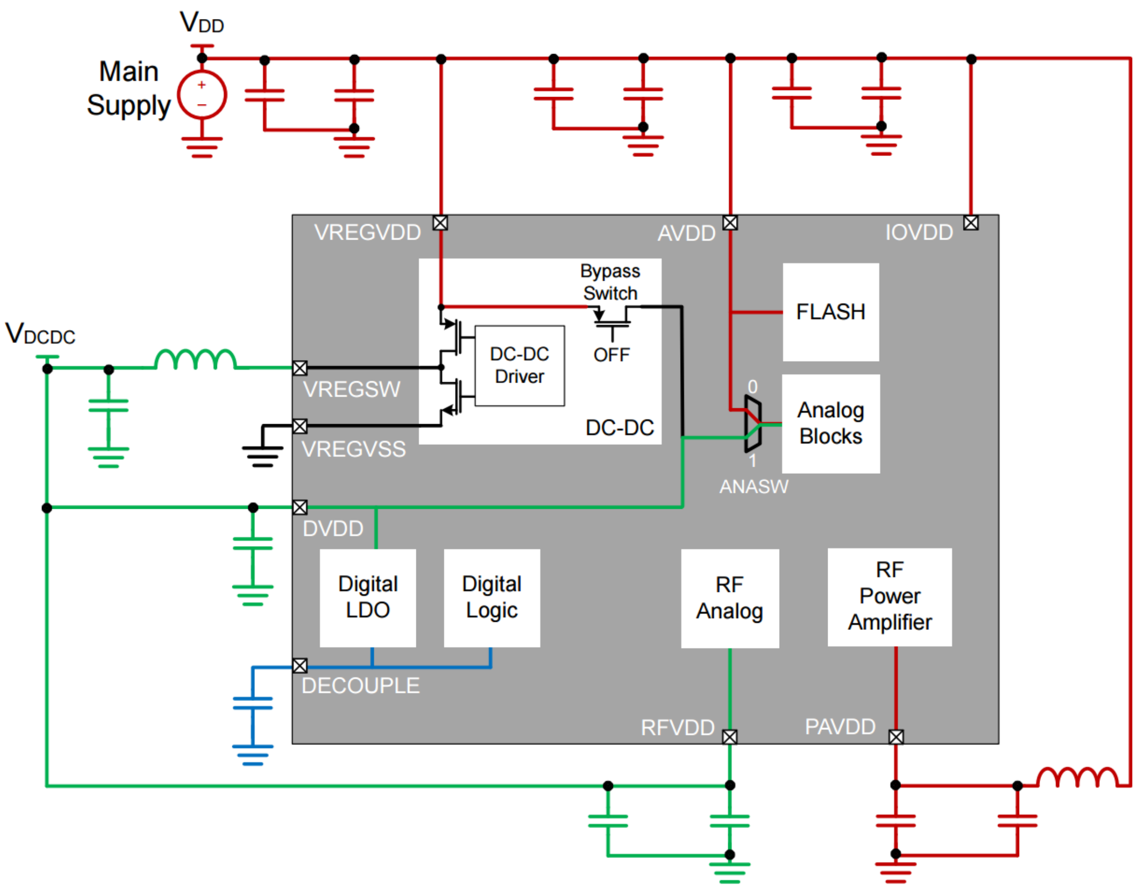


Figure 6.2. EFR32xG1 Power Supply Configuration (DVDD and RFVDD Running from DC-DC, PAVDD Connected to 3.3 V)

7. Revision History

Revision 0.3

March, 2020

- Updated for EFR32xG22 support

Revision 0.2

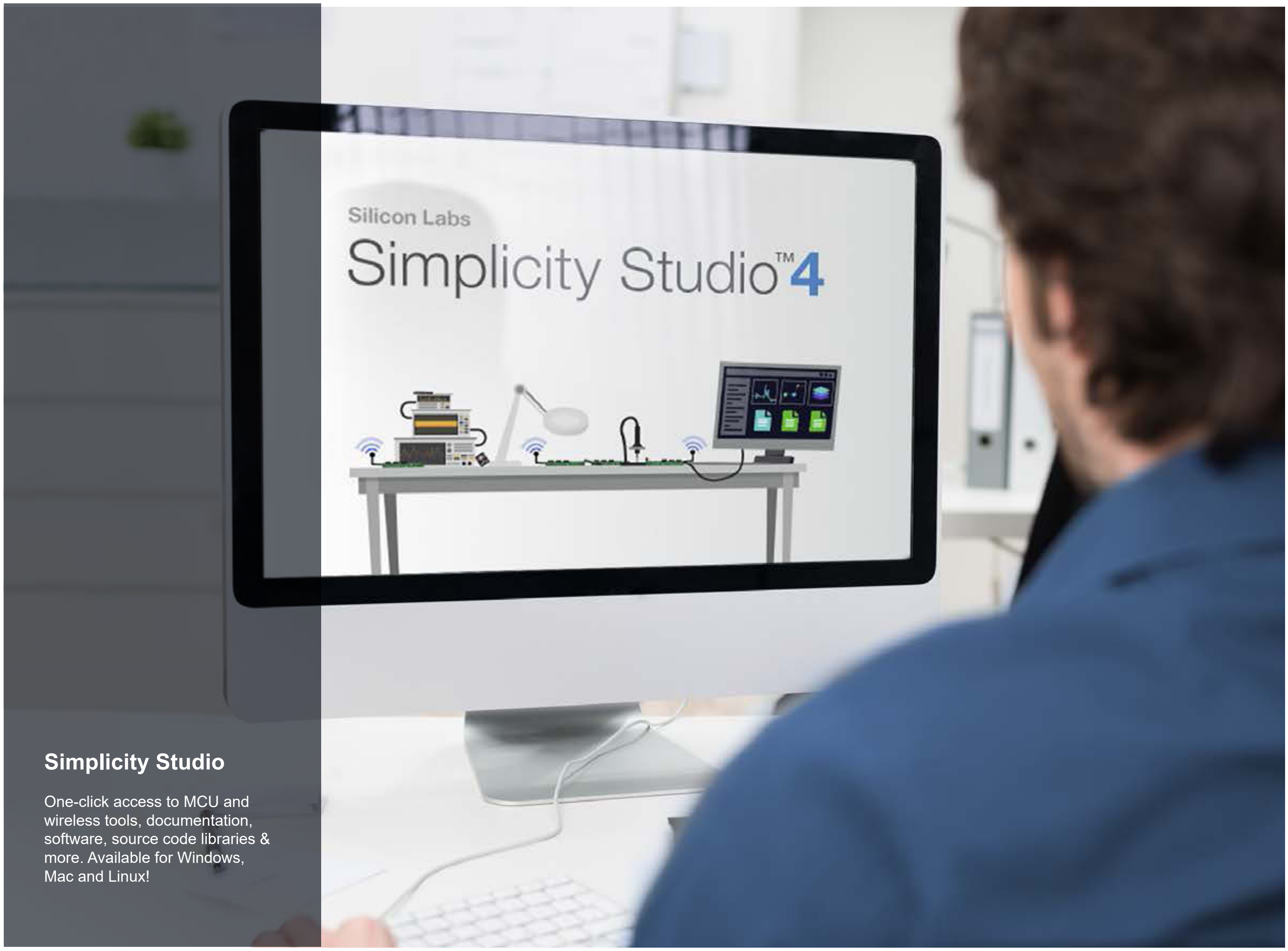
February, 2019

- Updated for EFR32xG21 support
- Added Device Compatibility and Revision History sections

Revision 0.1

June, 2017

- Initial release



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