AN12180

Kinetis MKW36 Power Consumption Analysis

Rev. 4 — 02/2021 Application Note

Contents

1 Introduction

This document provides information about:

- The power consumption of Kinetis KW35Z/36Z/35A/36A wireless MCU.
- How the hardware is designed and optimized for low-power operation.
- How the software shall be configured in order to achieve the low-power profile measurements.

The role of this document is to offer an overview and guidance on how to achieve the best low-power profile while still keeping the high performance of the system. The setup and the procedures to measure the current consumption of the MKW36 chip is also described in this document.

The power consumption of wireless devices is a critical requirement for the fast-coming Internet of Things (IoT) world. As a result, the hardware has been gradually improved and optimized from the power consumption perspective and new communication standards have been developed. Bluetooth® Low Energy (BLE) is part of these new standards that have been developed for long-term battery operation, typically years.

Kinetis MKW36Z is a radio wireless MCU that supports Bluetooth LE v5.0 protocol.

The readers of this document are expected to have a good knowledge about Bluetooth Smart protocol, as well as basic knowledge about Arm MCU architecture and radio communication basics.

2 Bluetooth smart power metrics

- FRDM-KW36 board is used to perform the several current measurements.
- Both application software are used (Heart Rate Sensor and Temperature Collector) to set the device in different modes for the current measurements.
- Both MCU and radio are in one or another sleep or Deep Sleep Mode (DSM). The time spent in sleep/deep sleep is the longest time compared to all other operation modes.
- The MCU is woken up and performs system initialization and some pre-processing.
- The transceiver is woken up and ready to operate. The MCU may enter into stop mode if the software allows it.
- The transceiver is performing one or more RX/TX sequences.
- The MCU is processing the received or transmitted packets.
- The transceiver is put back into sleep mode.
- The MCU enters low-power (sleep/deep sleep).

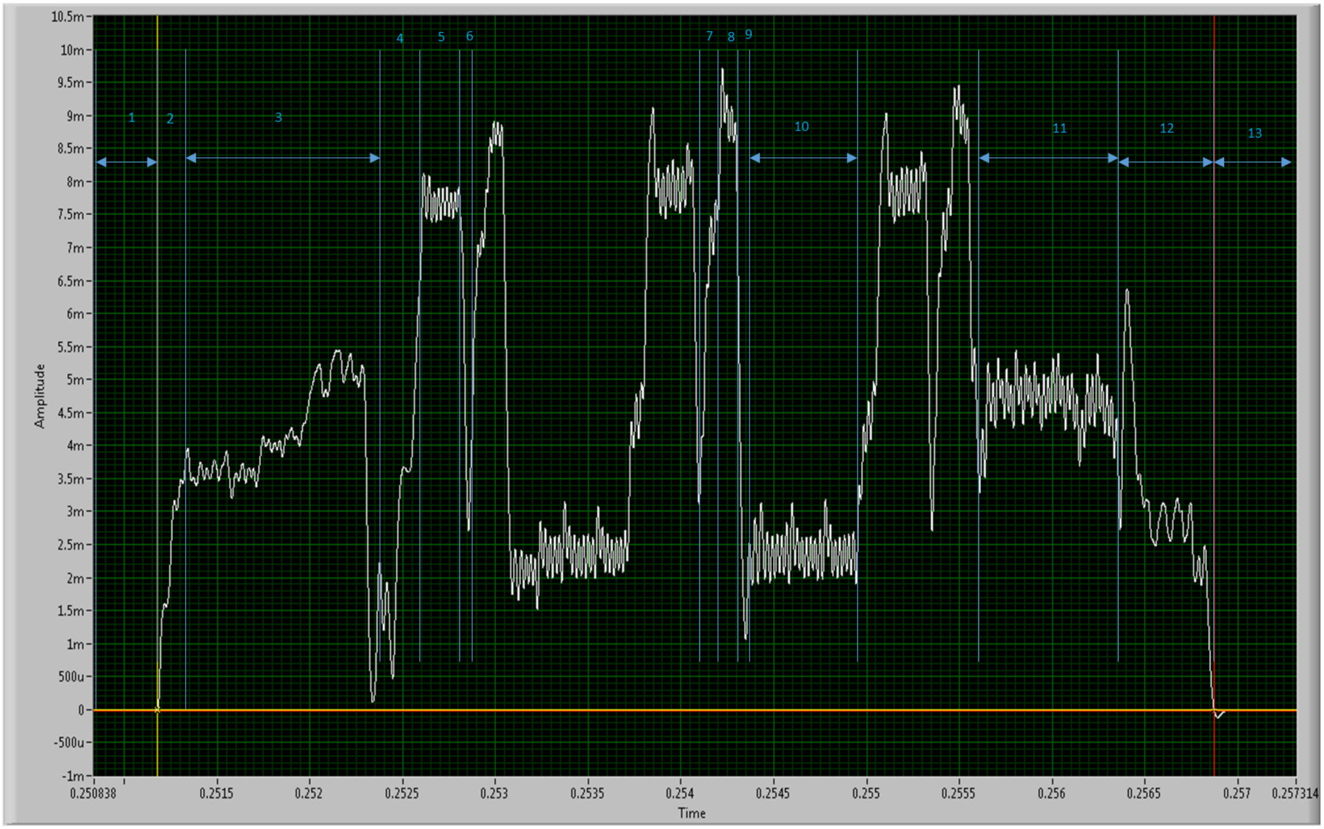

Figure 1. Typical operation cycle of a wireless low-power end device

- In Figure 1, it is depicted how the current consumption varies over time for each operation cycle of the device.
- At power-up, the system performs the so-called power-on reset and after that it performs the system initialization. After initialization is completed, the system enters into low-power mode. There are several low-power modes available for both MCU and the radio, but usually the software defines only the most suitable combinations of MCU and XCVR low-power modes (for example; LLS3 for MCU and DSM for LL).
- All the timings from Figure 1 are explained in Table 1.

Table 1. Timings of a typical low-power device

No.	Event
1	SoC in SlEEP mode
2	SoC awakes from SLEEP mode
3	MCU run: Pre-processing
4	XCVR TX warm-up
5	XCVR Active TX
6	XCVR TX warm-down
7	XCVR RX warm-up
8	XCVR Active RX
9	XCVR RX warm-down

Table continues on the next page...

Table 1. Timings of a typical low-power device (continued)

No.	Event
10	MCU STOP: RX to TX
11	MCU RUN: Post-processing
12	SoC goes back to SLEEP mode
13	SoC in SLEEP mode

- The time the transceiver switches from RX to TX is called RX-to-TX turnaround time and it is an important parameter of the transceiver.

NOTE

When the radio is operational, the MCU may also perform various tasks, like serving interrupts or controlling various peripherals.

- Thus, the best metric to be applied is current consumption over time, considering the average current of all the entities that are implied.

2.1 Bluetooth LE

Bluetooth® LE is a promising candidate for low-power communication and a good candidate for the IoT deployments. Bluetooth LE is operating in 2.4 GHz ISM band and uses GFSK modulation. The bandwidth bit period product is 0.5 and the modulation index is 0.5 (between 0.45 and 0.55).

Bluetooth LE uses 40 × 1 MHz wide channels, each separated by 2 MHz, three channels for advertising packets and 37 channels for data exchange. The channels are numbered from 0 to 39.

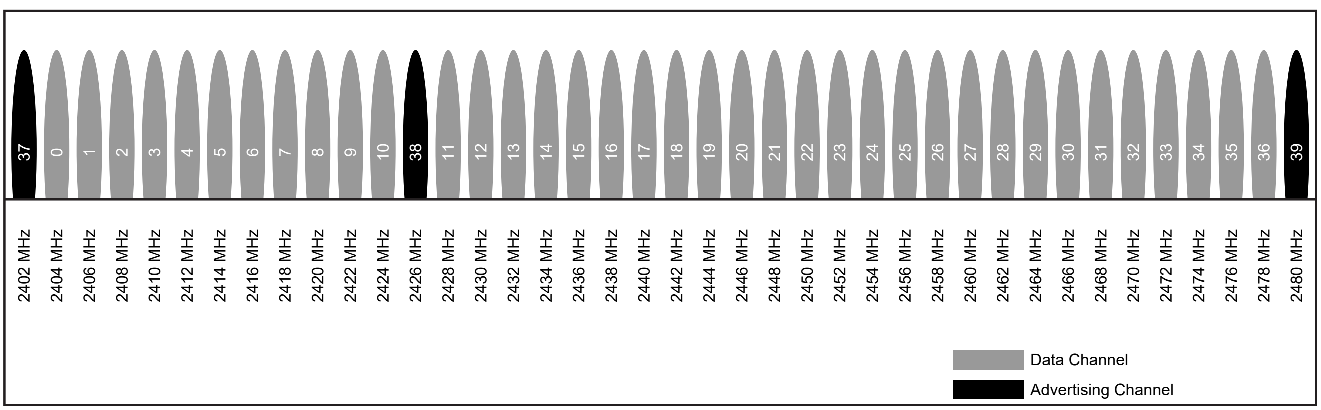

Figure 2. Bluetooth LE radio channels

The low energy is achieved by having a low duty cycle of transmission and/or reception of data and by using short advertising and data packets. Asynchronous and connection-less link layer ensures low latency and fast transactions.

At the GAP layer level, the roles that Bluetooth LE devices may have, are the GAP Central and the GAP Peripheral, as can be observed in Figure 3.

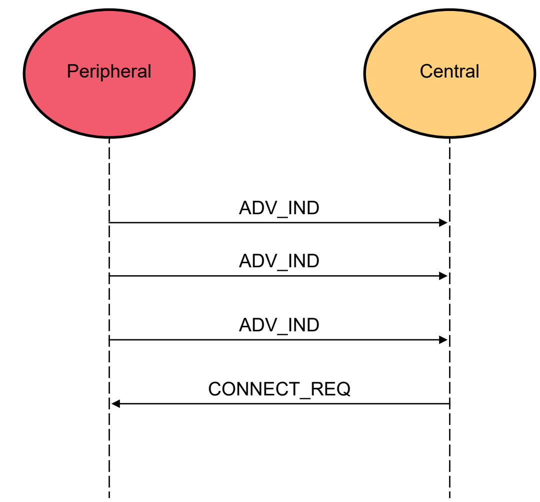

Figure 3. GAP peripheral and central

The Peripheral starts sending advertising data to Central. If Central is willing to establish a connection with the Peripheral, it sends back to advertiser a connection request. After the connection is established, data exchange may start.

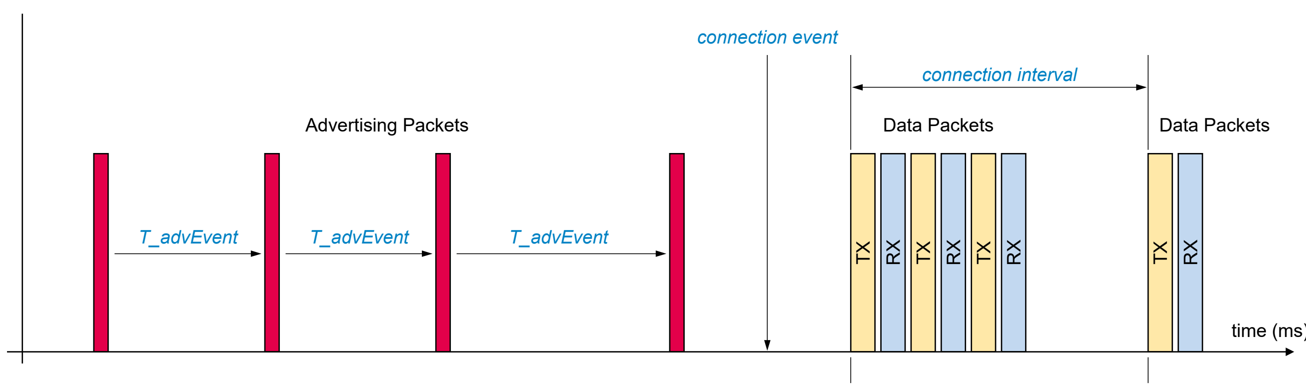

Figure 4. Bluetooth LE advertising and connection events

According to Bluetooth LE specifications, there are four types of advertising packets:

- ADV_IND – Connectable Undirected Advertising
- ADV_DIRECT_IND – Connectable Directed Advertising
- ADV_NONCONN_IND – Non-connectable Undirected Advertising
- ADV_SCAN_IND – Scannable Undirected Advertising (formerly known as ADV_DISCOVER_IND)

All the above types, except the non-connectable advertising, are using a TX followed by an RX sequence, as can be observed in Figure 5. This is because after sending the advertising packet, the device is waiting for a Scan Request or Connect Request from a peer device, if any.

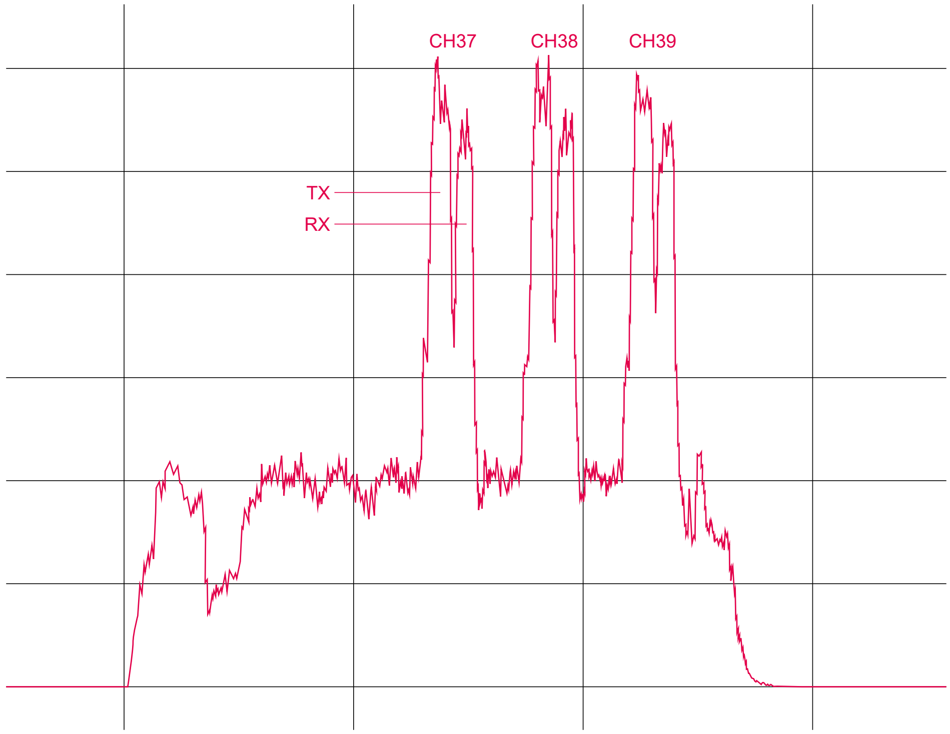

Figure 5. Current consumption vs. time in ADV phase for a Bluetooth LE peripheral device

The current variation in time when the system is in a typical advertising event is presented in Figure 5. All three advertising channels are used. For each channel, a TX operation followed by an RX operation is performed.

Another noteworthy feature of Bluetooth LE is that the advertising events have a random temporal component, according to Bluetooth LE specifications.

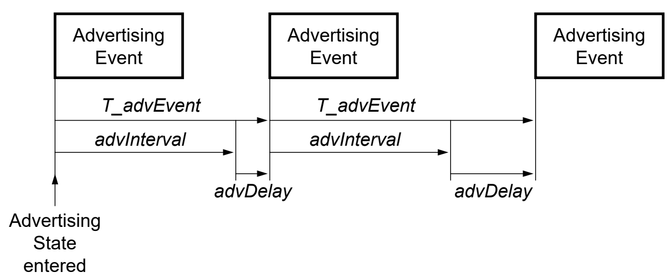

Figure 6. Advertising events occurring at unequal intervals

As can be noticed, *T_advEvent = advInterval + advDelay*, where *advInterval* is an integer multiple of 0.625 ms, with a range from 20 ms to 10.24 s. *advDelay* is a pseudo-random value generated by the Link Layer (LL), with a range from 0 ms to 10 ms. Thus, a minimum advertising event interval is 20 ms and a maximum interval is 10.25 s.

Bluetooth LE is designed and implemented for ultra-low power battery operated devices, but the actual power consumption of a real Bluetooth LE device strongly depends on:

- Bluetooth LE application profile
- Application duty cycle
- TX power
- Software management of low-power modes

- Board design and layout

3 Kinetis MKW36 low-power features

The KW35Z/36Z/35A/36A (called MKW36 throughout this document) is an ultra-low power, highly integrated single-chip device that enables Bluetooth® LE v5.0 and Generic FSK (at 250 kbit/s, 500 kbit/s, and 1000 kbit/s) RF connectivity for portable, extremely low-power embedded systems (Version Z) and automotive (Version A). KW36 supports up to eight simultaneous Bluetooth LE connections as either a master, a slave, or any combination. The KW36 is designed for applications that center on bridging the embedded world to smart phones to enhance the human interface experience, share embedded data with the cloud, or enable wireless firmware updates.

Leading the automotive applications (KW35/36A) is the Digital Key where the smartphone can:

- be used as an alternative to the key FOB for unlocking and personalizing the driving experience;
- provide select and authorized access when a key is not needed like you might see in car sharing.

KW36 integrates a Bluetooth LE v 5.0 compliant radio transceiver operating in the 2.4 GHz ISM band supporting a range of Generic FSK, an Arm Cortex-M0+ CPU, up to 512 kB Flash and up to 64 kB SRAM, Bluetooth LE LL hardware and peripherals optimized to meet the requirements of the target applications.

The RF section of KW36 is optimized to require very few external components, achieving the smallest RF footprint possible on a printed circuit board.

NXP provides a certified Bluetooth LE stack to support KW36.

Extremely long battery life is achieved though efficiency of code execution in the Cortex-M0+ CPU core and the multiple low power operating modes of the KW35/36Z. Additionally, an integrated DC-DC converter enables a wide operating range from 2.1 V to 3.6 V in buck mode and 1.76 V to 3.6 V in bypass mode. The DC-DC in Buck mode allows KW36Z to operate from a single coin cell battery with a significant reduction of peak RX and TX current consumption. The DC-DC in buck mode allows a single alkaline battery to be used throughout its entire useful voltage range of 2.1 V to 3.6 V.

3.1 MKW36 hardware support for low-power operation

Kinetis MKW36 SoC was designed and built with hardware features that allow the chip to operate in various low-power modes. Noteworthy features are:

- Multiple MCU power modes including low leakage with memory retention modes
- Bluetooth® LE Link Layer sleep mode support
- Peripheral modules clock gating
- Several peripheral dozed modes
- DC-to-DC converter
- Transceiver Sequence Manager (TSM) that assures that transceiver analog and digital blocks are not consuming power when no RX/TX sequence is in progress
- Dedicated Power Management Controller (PMC)
- Low-power peripherals (Low-Power Timer (LPTMR), Low-Power UART (LPUART)) that can be configured as wake-up sources to exit a particular low-power state

The software is responsible for configuring all the hardware to achieve the best power scheme required by the applications. As presented below, the chip low-power modes are combinations of MCU and LL/Packet Processor sleep modes. The clock gating of peripherals, as well as GPIO states before entering into low-power mode, takes charge of application developer. The connectivity software stack provides callbacks that are called before entering into low-power mode and after exiting from low-power mode. The system enters into low-power mode when the system is in idle and all the software layers agrees on that. The system exits from low-power mode once a synchronous or asynchronous event is happening and requires to be processed.

3.1.1 KW36 MCU power modes

The PMC module provides a variety of power options to allow the user to optimize and personalize the power consumption with respect to the level of functionality that the application requests. Based on Arm® architecture power modes, there are two power modes defined: Sleep mode and DSM. From the connectivity software perspective, only DSMs are of interest. These modes are:

- STOP
- LLS3
- VLLS0
- VLLS1
- VLLS2

The CPU recovery method is by wake-up interrupt for low-leakage stop modes and by wake-up reset for very low-leakage stop modes.

All the listed power modes can be found in *MKW36Z Reference Manual* (document MKW36A512RM).

3.1.2 KW36Z LL power modes

The Bluetooth® Link Layer (BTLL) has the following power modes available:

- IDLE
- RUN
- DSM

For Bluetooth LE, the connectivity software package implements six low-power modes for the KW36Z SoC, as it can be observed in Table 2.

Table 2. KW36Z low-power modes for Bluetooth LE applications

Low-power mode	Required status		Wake-up sources				
	MCU	BTLL	GPIO	BTLL	LPTMR	DC-DC	UART
1	LLS3	DSM	×	×	×	—	—
2	LLS3	IDLE	×	×	—	—	—
3	LLS3	IDLE	×	—	×	×	—
4	VLLS0/1[1]	IDLE	×	—	—	×	—
5	VLLS2	IDLE	×	—	—	×	—
6	STOP	IDLE/RUN	×	×	×	×	×

- VLLS0 if DC-DC in bypass mode, VLLS1 otherwise.

NOTE

The Bluetooth LE is using a common radio transceiver digital block, the TSM that is used to sequence on/off the analog regulators and circuits needed for RX/TX operations so that these circuits only consume power during RX/TX.

3.1.3 KW36Z XCVR power modes

Being a SoC, the KW36Z transceiver is tightly coupled with the MCU. Therefore, the transceiver analog regulators are powered off whenever the MCU enters a low-power mode. Depending on the low-power mode, transceiver digital logic is power-gated or has its state retained.

3.1.4 KW36Z DC-to-DC converter

The DC-DC module is a Switched Mode Power Supply (SMPS) DC-to-DC converter, including:

- Buck mode: V_{in} = 2.1 V to 3.6 V
- Bypass mode: V_{in} = 1.71 V to 3.6 V

The module is configurable through internal registers to operate in continuous or pulsed mode and provides two voltage outputs in Buck mode: VDD_1P8OUT = 1.8 V, VDCDC = 3.0 V and VDD_1P8OUT = 3.0 V, VDCDC = 3.0 V, with MCU in RUN mode, peripherals are disabled.

The selection of operating mode is done by setting the DCDC_CFG pin. The converter may be started with the PSWITCH pin or can be set to auto-start mode.

For detailed information about DC-DC converter, refer to *MKW4xZ/3xZ/3xA/2xZ DC-DC Power Management* (document AN5025).

3.1.5 GPIO, analog pins, and clock gating

Clock gating mechanism was implemented to reduce power dissipation. For example, whenever a peripheral is not used, it can be turned off with SCGCx registers in the SIM module. Clock gating applies to peripherals, including the GPIO module. Pruning the clock to a peripheral assures that the peripheral internal circuitry does not have switch states and therefore no power consumption, except the leakage currents.

After reset, the clock gating bits are cleared and this implies that before using any peripheral the corresponding clock gating bit must be set, otherwise any access to peripheral registers will cause a hardware fault. To turn a peripheral clock (gate) OFF, the peripheral must be turned OFF prior to clock.

The user application must control and set the state of the GPIO ports before the device goes to sleep as well as after the device is exiting the low-power state. The Connectivity Software provides callback functions that are called before the device enters a low-power state and after it wakes up.

Related to the analog pins, the device has several analog blocks that have selectable reference voltages. The main blocks are the 16-bit SAR ADC and CMP. The board design shall consider the chip analog pins and use them appropriately.

The external analog inputs are typically shared with digital I/O. To improve the performance in the presence of noise or when the source impedance is high, it is recommended to use capacitors on these inputs. The capacitors shall be placed as close as possible to chip analog pins.

For more details, please check KW35/36Z, KW35/36A reference designs, and the chip reference manual.

3.2 Software configuration for low-power operation

3.2.1 Bluetooth smart applications configuration

The connectivity software package offers a variety of Bluetooth® LE demo projects. These projects are located at the following relative path (SDK 2.2 release):

<installation_path>SDK_2.2_FRDM-KW36\boards\frdmkw36\wireless_examples\bluetooth

The Heart Rate Sensor application included in the KW36 SDK is used to set the device for advertising and connect current measurements. It requires some changes depending on the configuration check. The default settings are RF output power at 0 dBm and buck mode. These changes must be also applied to temperature sensor application if needed. FreeRTOS or Bare-metal versions of the application can be used.

The Heart Rate Sensor application is selected for current measurements, mainly because it is an application that is typically optimized for low-power consumption and it is a commonly used Bluetooth LE profile. The relative project path is:

<installation_path>SDK_2.2_FRDM-KW36\boards\frdmkw36\wireless_examples\bluetooth\heart_rate_sensor\freertos\iar\heart_rate_sensor.eww

The Temperature Collector application included in the KW36 SDK is used to set the device for scan current measurements.

In the next chapter, different built are described to set the FRDM-KW36 in different states:

Heart Rate Sensor application:

- Advertising and connection events: (default software setting @0 dBm)
  - MCU stop, Flash dozed, RF output power = 0 dBm (default), +3.5 dBm, or +5 dBm
  - MCU run, Flash enabled, RF output power = 0 dBm or +3.5 dBm
- DSM

Temperature Collector:

- Scan event
  - MCU stop, Flash dozed, RF output power = 0 dBm or +3.5 dBm, Scan interval 100 ms
  - MCU run, Flash enabled, RF output power = 0 dBm or +3.5 dBm, Scan interval 100 ms

The FRDM-KW36 board is used to perform the current consumption. It is programmed with the Heart Rate Sensor binary (advertising and connect events) or Temperature Collector (scan event).

There are two different ways to flash the FRDM-KW36:

- Drag and drop the binary using OpenSDA.
- Use J-Link for Arm as programming/debug tool.

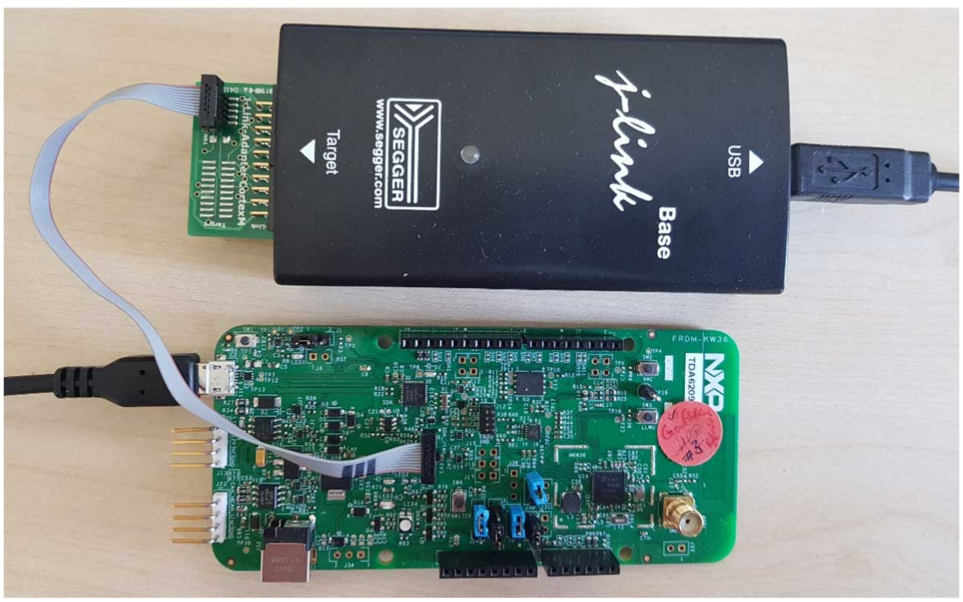

Figure 7. J-Link for Arm programmer/debugger

3.2.1.1 Preparing the software

3.2.1.1.1 MCU stop, flash dozed, RF output power = 0 dBm

1. Open the `heart_rate_sensor.eww` file (FreeRTOS version is used) located in: `SDK_2. 2 _FRDM-KW36 -> boards -> frdmkw36 -> wireless_examples -> Bluetooth -> heart_rate_sensor -> freertos -> iar`

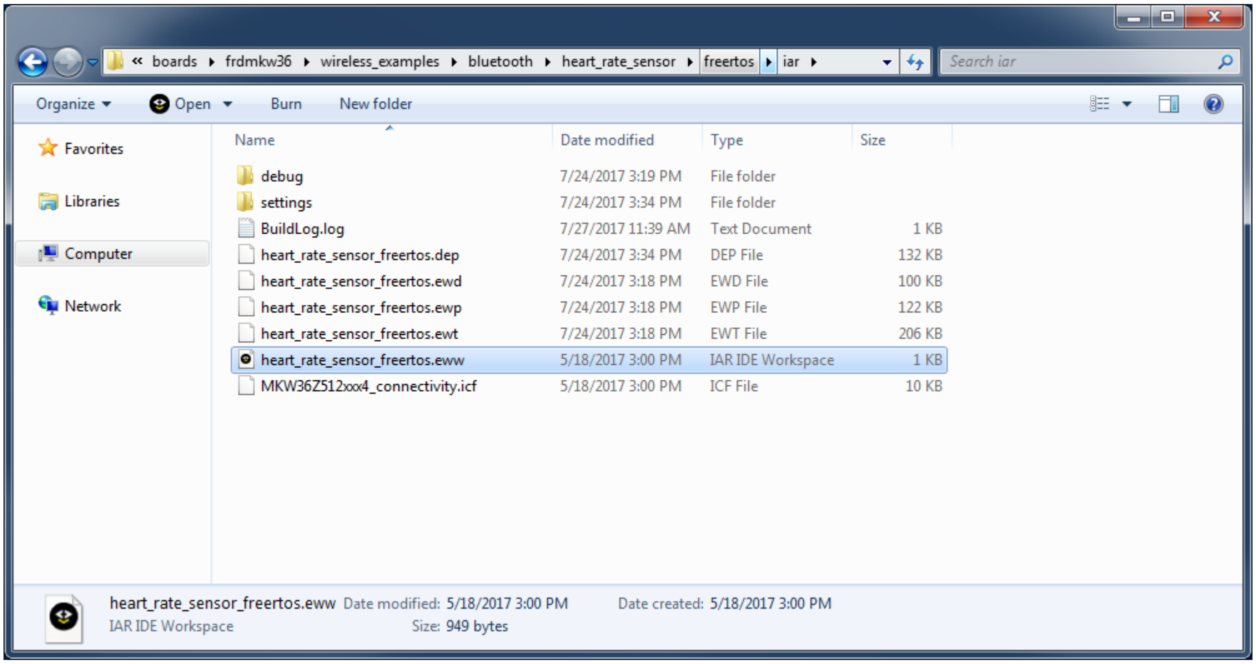

Figure 8. Heart Rate Sensor project

2. Open the `app_preinclude.h` file.

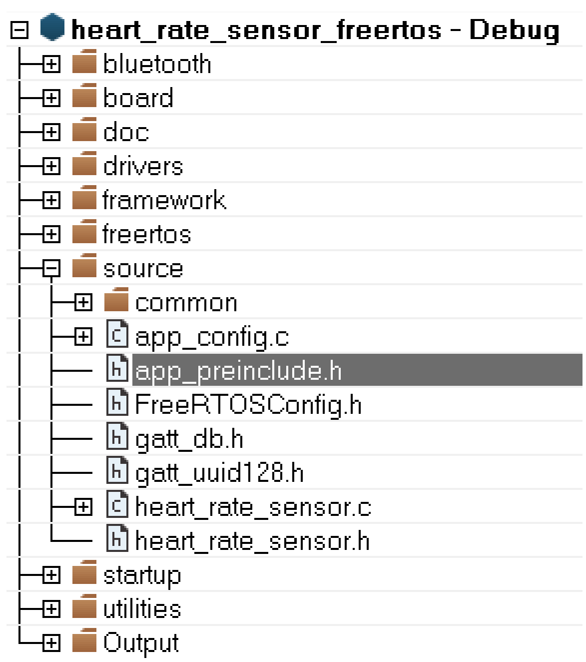

Figure 9. `app_preinclude.h` file

3. Make sure that the following macro is enabled, if not, enable it changing its value from 0 to 1. This macro enables the low-power functionality in the application.

```
/* Enable/Disable PowerDown functionality in PwrLib */
#define cPWR_UsePowerDownMode           1
```

4. Open the `board.c` file.

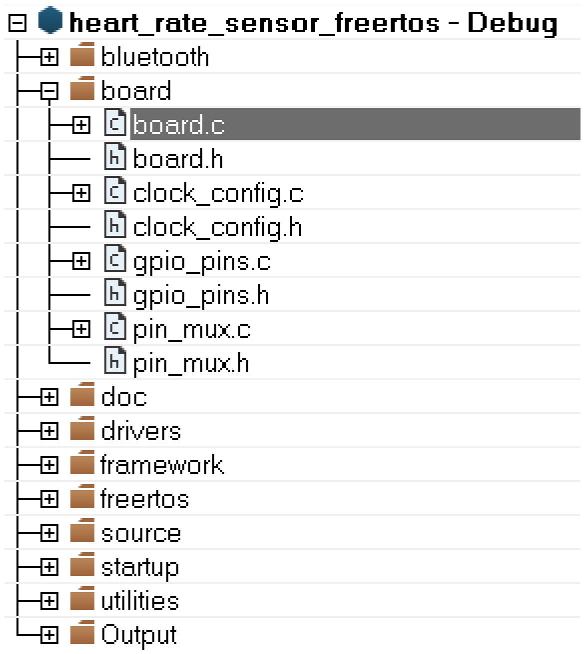

Figure 10. board.c file

5. Locate `maPinsDisabledInLowPower[mNoOfPinsDisabledInLowPower_c]` variable and modify its content to reflect the following one. This variable controls which pins must be disabled before entering into low-power mode and enable after leaving low-power mode.

```
const gpioPinId_t maPinsDisabledInLowPower[mNoOfPinsDisabledInLowPower_c]={
{gpioPort_A_c, 0},
{gpioPort_A_c, 1},
{gpioPort_A_c, 16},
{gpioPort_A_c, 17},
{gpioPort_A_c, 18},
{gpioPort_A_c, 19},
{gpioPort_B_c, 0},
{gpioPort_B_c, 1},
{gpioPort_B_c, 2},
{gpioPort_B_c, 3},
{gpioPort_B_c, 16},
{gpioPort_B_c, 17},
{gpioPort_B_c, 19},
{gpioPort_C_c, 0},
{gpioPort_C_c, 1},
{gpioPort_C_c, 3},
{gpioPort_C_c, 4},
{gpioPort_C_c, 5},
{gpioPort_C_c, 6},
{gpioPort_C_c, 7},
{gpioPort_C_c, 16},
{gpioPort_C_c, 17},
{gpioPort_C_c, 18},
{gpioPort_C_c, 19},
};
```

6. Locate `mNoOfPinsDisabledInLowPower_c macro` and modify its value to **24**, reflecting the number of pins that will be disabled and enabled before entering into low-power mode and after leaving low-power mode.

```
#define mNoOfPinsDisabledInLowPower_c (24)
```

7. Open the `board.h` file.

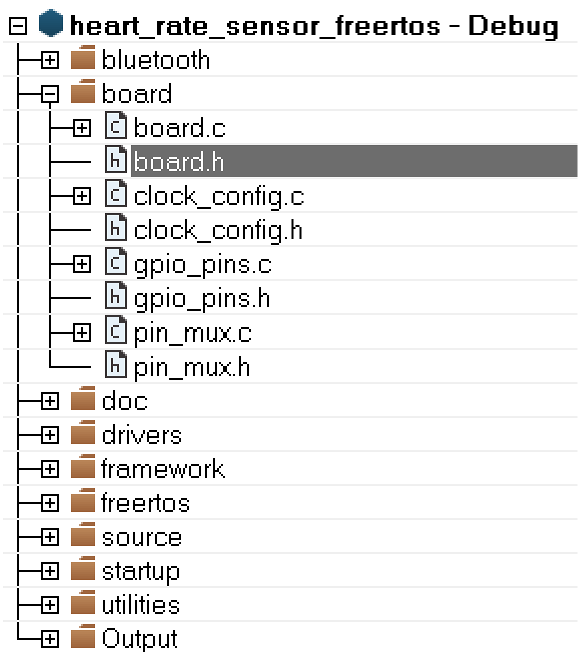

Figure 11. **`board.h`** file

8. Open the `heart_rate_sensor.c` file.

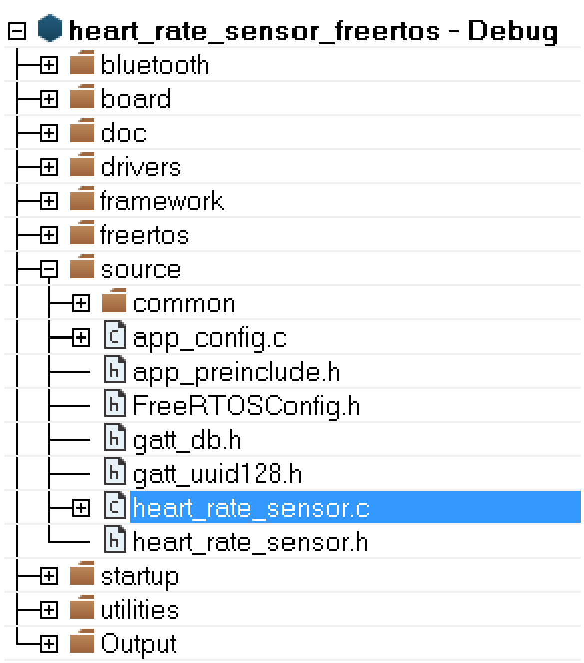

Figure 12. **`heart_ratde_sensor.c`** file

9. Locate the `BleApp_HandleKeys` function.

10. Since SW3 (PTC2) is used as wake-up source and is handled by `gKBD_EventPressPB2_c` and `gKBD_EventLongPB2_c` events in `BleApp_HandleKeys`, the actions performed by `gKBD_EventPressPB1_c` and `gKBD_EventPressPB2_c` must be switched in order to call `BleApp_Start` function after leaving low-power mode and start the advertising procedure. Once `BleApp_HandleKeys` function is modified, it should look like the following:

```
void BleApp_HandleKeys(key_event_t events)
{
    switch (events)
    {
        case gKBD_EventPressPB1_c:
        {
            mToggle16BitHeartRate = (mToggle16BitHeartRate)?FALSE:TRUE;
            break;
        }
        case gKBD_EventPressPB2_c:
        {
            if (mPeerDeviceId == gInvalidDeviceId_c)
            {
                BleApp_Start();
            }
            break;
        }
        break;
        case gKBD_EventLongPB1_c:
        {
            mContactStatus = mContactStatus?FALSE:TRUE;
            Hrs_SetContactStatus(service_heart_rate, mContactStatus);
            break;
        }
        case gKBD_EventLongPB2_c:
        {
            if (mPeerDeviceId != gInvalidDeviceId_c)
            {
                Gap_Disconnect(mPeerDeviceId);
            }
            break;
        }
        default:
            break;
    }
}
```

11. Save and build the project with the changes.

The application starts by initializing the MCU hardware, peripherals, connectivity framework, OS tasks, timers and queues, transceiver, and finally the Bluetooth® LE host stack. On the idle task, if device is eligible, it enters DSM1 (`MCU->LLS3, LL->IDLE, Wakeup Source->GPIO/LL`).

The device exits from low-power mode and the Bluetooth LE application starts when the SW3 pushbutton is to be pressed (`app.c` source file).

After wake-up, the device will start to advertise. The advertising parameters are defined in `gap_types.h` header file.

```
typedef struct gapAdvertisingParameters_tag {
    uint16_t                            minInterval;
    uint16_t                            maxInterval;
    bleAdvertisingType_t                advertisingType;
    bleAddressType_t                    ownAddressType;
    bleAddressType_t                    directedAddressType;
    bleDeviceAddress_t                  directedAddress;
```

```
    gapAdvertisingChannelMapFlags_t     channelMap;
    gapAdvertisingFilterPolicyFlags_t   filterPolicy;
} gapAdvertisingParameters_t;
```

Default advertising parameters values are also defined in `gap_types.h` header file:

```
#define gGapDefaultAdvertisingParameters_d \
{ \
    /* minInterval */         gGapAdvertisingIntervalDefault_c, \
    /* maxInterval */         gGapAdvertisingIntervalDefault_c, \
    /* advertisingType */     gAdvConnectableUndirected_c, \
    /* addressType */         gBleAddrTypePublic_c, \
    /* directedAddressType */ gBleAddrTypePublic_c, \
    /* directedAddress */     {0, 0, 0, 0, 0, 0}, \
    /* channelMap */          (gapAdvertisingChannelMapFlags_t) (gAdvChanMapFlag37_c |
gAdvChanMapFlag38_c | gAdvChanMapFlag39_c), \
    /* filterPolicy */        gProcessAll_c \
}
```

The values of the advertising parameters are set in the `app_config.c` file and the values can be changed at runtime:

```
gapAdvertisingParameters_t gAdvParams = {
    /* minInterval */         gGapAdvertisingIntervalDefault_c, \
    /* maxInterval */         gGapAdvertisingIntervalDefault_c, \
    /* advertisingType */     gAdvConnectableUndirected_c, \
    /* addressType */         gBleAddrTypePublic_c, \
    /* directedAddressType */ gBleAddrTypePublic_c, \
    /* directedAddress */     {0, 0, 0, 0, 0, 0}, \
    /* channelMap */          (gapAdvertisingChannelMapFlags_t) (gGapAdvertisingChannelMapDefault_c),
\
    /* filterPolicy */        gProcessAll_c \
};
```

Default advertising interval is 1.28 seconds, but it is overwritten by the application profile, within `heart_rate_sensor.h` header file:

```
#define gFastConnMinAdvInterval_c       32 /* 20 ms */
#define gFastConnMaxAdvInterval_c       48 /* 30 ms */

#define gReducedPowerMinAdvInterval_c   1600 /* 1 s */
#define gReducedPowerMaxAdvInterval_c   4000 /* 2.5 s */
```

As noticed, there are two types of advertising: a fast advertising interval and a reduced power (slow) advertising interval. Both have minimum and maximum values that are set in the Bluetooth LE controller. The controller itself chooses the advertising interval considering the interval set plus a random advertising delay. These values are specific to a profile and it is not recommended to be modified. Moreover, each type of advertising (fast, slow) has a defined timeout. If no connection request is received during advertising and the timeout occurs, the advertising type will be switched (fast to slow and slow to fast). These timeouts are defined in `heart_rate_sensor.h`:

```
#define gFastConnAdvTime_c              30  /* s */
#define gReducedPowerAdvTime_c          300 /* s */
```

Within `heart_rate_sensor.c` there is implemented an advertising callback (`BleApp_AdvertisingCallback`) that is called by the host stack each time an advertising event occurs. When the advertising is started, the application code will start a so-called advertising timer that will be used to countdown the timeouts mentioned earlier.

```
PWR_ChangeDeepSleepMode(1);
/* Start advertising timer */
```

```
TMR_StartLowPowerTimer(mAdvTimerId,gTmrLowPowerSecondTimer_c,
         TmrSeconds(mAdvTimeout), AdvertisingTimerCallback, NULL);
Led1On();
```

After an advertising packet is sent (according to advertising channel mask), the same callback will be called again and the application code will put the device to DSM1 (as defined in Table 1):

```
Led1Off();
PWR_ChangeDeepSleepMode(1);
PWR_SetDeepSleepTimeInMs(cPWR_DeepSleepDurationMs);
PWR_AllowDeviceToSleep();
```

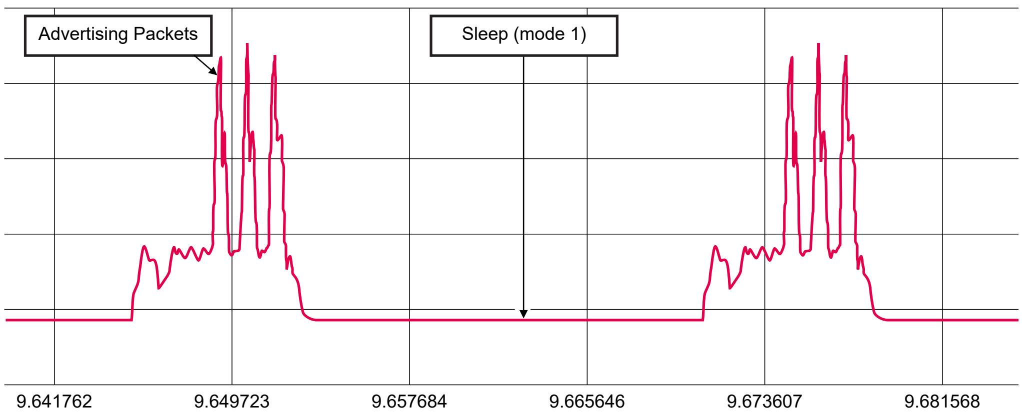

Figure 13. Bluetooth LE ADV packets

When a connection is established with a central, the advertising is stopped and the peripheral starts reporting. In this particular case, there are two characteristics that are reported: the heart rate value and the battery level. The report interval is defined in the `heart_rate_sensor.c` source file.

```
#define mHeartRateReportInterval_c    (1) /* heart rate report interval in seconds */
#define mBatteryLevelReportInterval_c   (10) /* battery level report interval in seconds */
```

By changing these values, the device duty cycle and therefore its power consumption may be modified.

The connection interval is negotiated and set by the central but the peripheral can send a connection parameter update request that the central can accept or reject.

Another important connection parameter is the slave latency, that is; the Peripheral can choose not to answer when central asks for data, up to the slave latency number of times.

Between connection events, the device will enters DSM1.

`MCU->LLS3`, `LL->DSM`, `Wakeup sources->GPIO/LL/LPTMR`

```
PWR_SetDeepSleepTimeInMs(900);
PWR_ChangeDeepSleepMode(1);
PWR_AllowDeviceToSleep();
```

To maintain the connection, the peripheral may send to central empty packets (keep alive) but this will happen only at LL level, that is; the MCU will not leave sleep mode.

The connection can be ended by the central, or by the peripheral by long pressing switch SW3. When disconnect event is received, the application code (`heart_rate_sensor.c`, `BleApp_ConnectionCallback`) will put the device to DSM1 (as defined in Table 1, `MCU->LLS3, LL->IDLE, Wakeup Sources->GPIO/LL`).

```
/* Go to sleep */
PWR_ChangeDeepSleepMode(3); /* MCU=LLS3, LL=IDLE, wakeup on switches/LL */
PWR_SetDeepSleepTimeInMs(cPWR_DeepSleepDurationMs);
PWR_AllowDeviceToSleep();
```

A very important configuration file is the `app_preinclude.h` header file. The macros defined in this file overwrite all the macros with the same name within the entire project.

Related to low-power functionalities, the following macros are implied. The settings are only for the Heart Rate Sensor project, other projects may have different low-power settings.

Table 3. Macro linked to the Heart Rate Sensor

Name	Value for low-power enabled	Description
`gTMR_EnableLowPowerTimers`	1	Enable/disable low-power timer
`cPWR_UsePowerDownMode`	1	Enable/disable PowerDown functionality in PwrLib software module
`cPWR_BluetoothLE_LL_Enable`	1	Enable/disable Bluetooth LE LL DSM
`cPWR_DeepSleepMode`	3	Default power mode: MCU=LLS3, LL=IDLE
`APP_DISABLE_PINS_IN_LOW_POWER`	1	Disable all pins when entering into low-power mode
`cPWR_DeepSleepDurationMs`	30000	Default deep sleep duration [ms]
`cPWR_BluetoothLE_LL_OffsetToWakeupInstant`	2	Number of slots (1slot = 625 us) before the wake-up instant, before which the hardware must exit from DSM. This parameter gives the flat zone before first advertising event.
`gDCDC_Enabled_d`	1	Enable/disable the DC-DC platform component
`APP_DCDC_MODE`	`gDCDC_Mode_Buck_c`	Default DC-DC mode used by the application

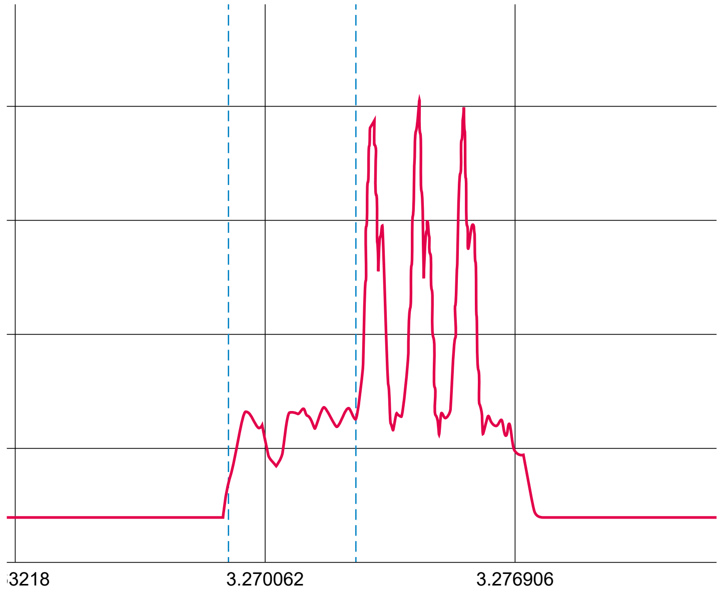

Figure 14. Offset to wake-up instant

Another important thing related to low-power functionalities is that the user can register callback functions that will be called from the low-power software module, just before entering low-power state and after exiting low-power state. These callbacks are registered in the board.c source file:

```
void BOARD_InstallLowPowerCallbacks()
{
#if cPWR_UsePowerDownMode
  PWR_RegisterLowPowerEnterCallback((pfPWRCallBack_t)BOARD_EnterLowPowerCb);
  PWR_RegisterLowPowerExitCallback((pfPWRCallBack_t)BOARD_ExitLowPowerCb);
#endif
}
```

In the particular case of the Heart Rate Sensor, `BOARD_EnterLowPowerCb()` callback disables all used GPIOs and will change the DC-to-DC converter to pulsed mode operation. After exiting low-power mode, the SWD and LED pins will be enabled and the DC-to-DC converter will be changed to continuous mode.

```
void BOARD_EnterLowPowerCb()
{
#if APP_DISABLE_PINS_IN_LOW_POWER
    BOARD_TogglePins(TRUE);
#endif

#if gDCDC_Enabled_d
    DCDC_BWR_REG0_DCDC_VBAT_DIV_CTRL(DCDC_BASE_PTR, 0);
    DCDC_PrepareForPulsedMode();
#endif
}

void BOARD_ExitLowPowerCb()
{
#if APP_DISABLE_PINS_IN_LOW_POWER
  BOARD_TogglePins(FALSE);
#endif

#if gDCDC_Enabled_d
```

```
    DCDC_PrepareForContinuousMode();
#endif
```

3.2.1.1.2 MCU run and flash enabled

Another possibility of current measurement setting is to activate the MCU and enable the flash. To do so, some software modification is necessary and describe below:

In the `framework/LowPower/Source/PWR.c` file, part of the `PWR_HandleDeepSleepMode_6` function, below lines must be masked:

- MCU in run mode:

  Mask the function (around line 750): `PWRLib_MCU_Enter_Stop()`; (in green in Example 1)
- MCU in stop mode:

  Does not mask the function (around line 750): `PWRLib_MCU_Enter_Stop();`
- Flash in the Enabled mode:
  - Mask the following command (around line 749):

    `SIM->FCFG1 |= SIM_FCFG1_FLASHDOZE_MASK`; (in blue in Example 1)
  - Mask the following command (around line 752):

    `SIM->FCFG1 |= SIM_FCFG1_FLASHDOZE_MASK`; (in blue in Example 1)
- Flash in the Dozed mode:
  - The following command (around line 749) is not masked:

    `SIM->FCFG1 |= SIM_FCFG1_FLASHDOZE_MASK;`
  - The following command (around line 752) is not masked:

    `SIM->FCFG1 &= ~SIM_FCFG1_FLASHDOZE_MASK;`

Example 1

```
RSIM->CONTROL |= RSIM_CONTROL_RSIM_STOP_ACK_OVRD_EN_MASK |
RSIM_CONTROL_RSIM_STOP_ACK_OVRD_MASK;
SIM->FCFG1 |= SIM_FCFG1_FLASHDOZE_MASK;

//PWRLib_MCU_Enter_Stop();
SIM->FCFG1 &= ~SIM_FCFG1_FLASHDOZE_MASK;
RSIM->CONTROL &= ~RSIM_CONTROL_RSIM_STOP_ACK_OVRD_EN_MASK;
BOARD_BLPItoBLPE();
RSIM->CONTROL = RSIM_CONTROL_MODIFY_FIELD(RSIM_CONTROL_RF_OSC_EN, rfOscEn);
}
```

3.2.1.1.3 RF output power settings (0 dBm, +3.5 dBm, or +5 dBm)

RF output power could be set to different values. Here are three examples of RF output power setting: 0 dBm, +3.5 dBm, or 5 dBm (maximum output power). Modification of the software code is necessary and described as below:

In the *source/common/ble_controller_task_config.h* file:

```
Line101:
/* Default Tx Power on the advertising channel.
* Power level as defined in the table for Controller_SetTxPowerLevel
*/
#ifndef mAdvertisingDefaultTxPower_c
```

```
#define mAdvertisingDefaultTxPower_c 20 // (20;0dBm, 31:+3.5dBm, 32:+5dBm)
#endif
```

The default RF output power is set to 0 dBm (level 20). This level could be set to a maximum of +5 dBm (level 31).

3.2.1.1.4 Scan interval 100 ms

To be able to measure the full scan signal event by using the Temperature Collector application, the scan interval must be increase from 10 ms (default value) to 100 ms.

In the `Bluetooth/host/interface/gap.types.h` file:

Replace the line 158 by the blue one:

```
#define gGapScanIntervalDefault_d   0x0010      //10ms
#define gGapScanIntervalDefault_d   0x0064      //100ms
```

4 Power managements and analysis

4.1 Setup test environment and DUT

This section describes how to set up the test environment, what hardware tools and boards are required and all the necessary operations that are needed to be done before performing the measurements.

All the measurements are performed using a Power Analyzer: CX3322A and a current probe: CX1101A from Keysight, formerly Agilent Technology.

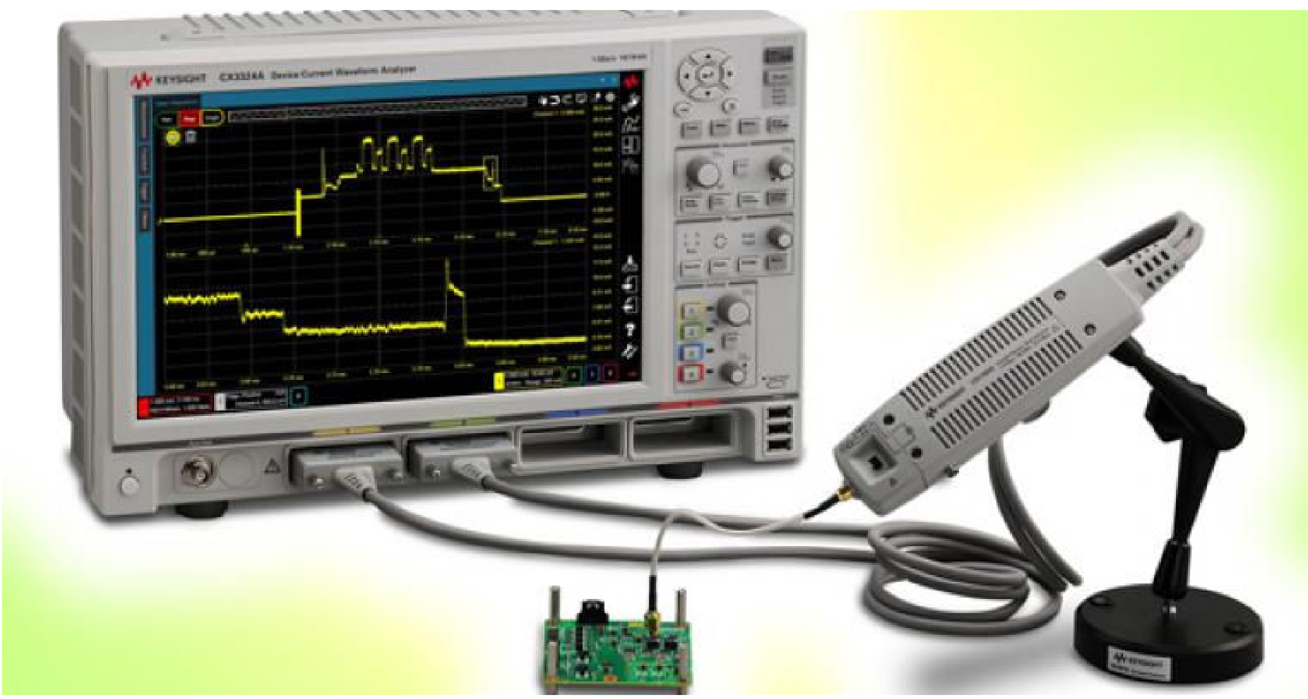

Figure 15. Keysight CX3322A power analyzer and CX1101A current probe

External power source was used to supply the FRDM-KW36 board while the Power Analyser module 1 was used as Ampere meter. The power supply was set to provide 3.6 V DC. Two pairs of high-quality cables are required, one for supplying the board and one for current measurement. The connections between Power Analyzer and the FRDM board must be perfect to avoid unwanted spikes or power loses or resets of the board.

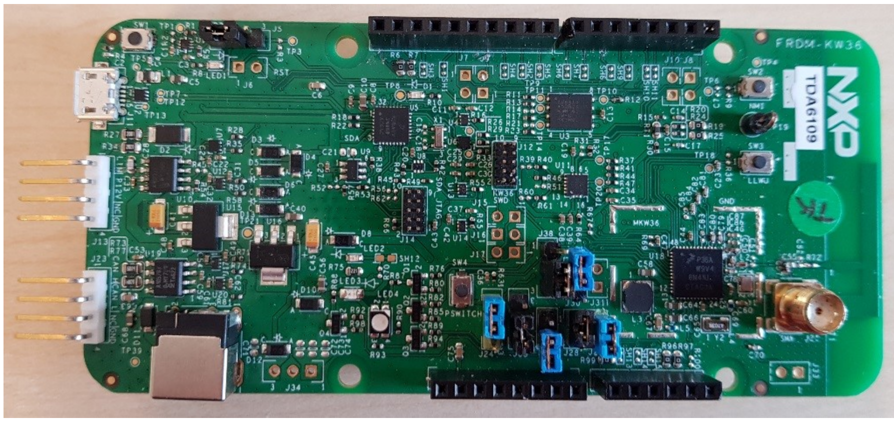

Figure 16. FRDM-KW36Z board, Rev. B

The current measurements are performed in two setup modes using the FRDM-KW36Z board: Bypass and Buck modes. A minimum of jumpers is soldered into the PCB to avoid radio disturbance.

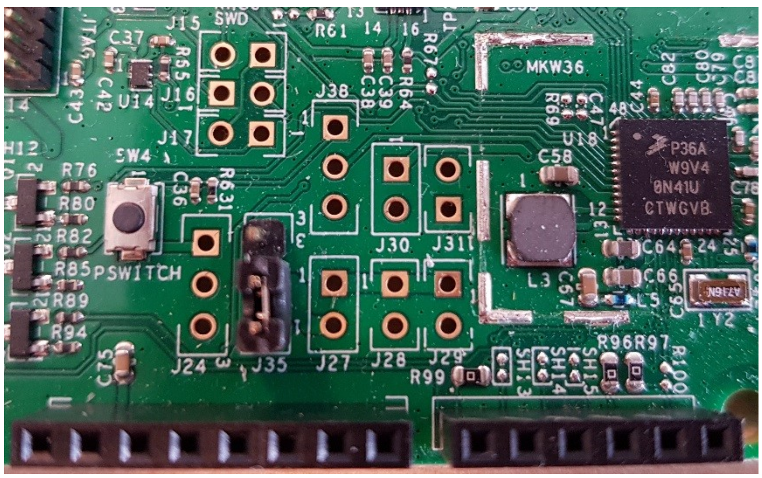

Figure 17. FRDM-KW36Z board, Rev. B, default jumper setup – Top view

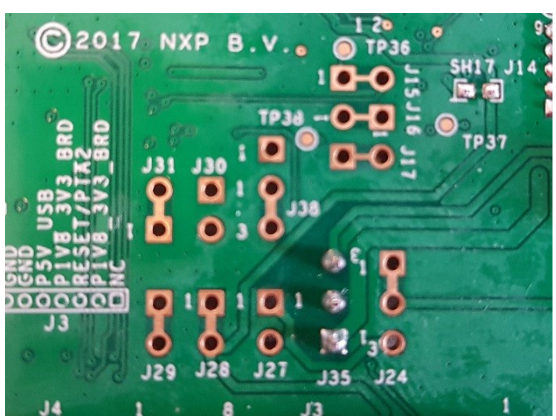

Figure 18. FRDM-KW36Z board, Rev. B, default copper shunt setup – Bottom view

4.1.1 Preparing the hardware

The FRDM-KW36Z-revB is configured by default in Buck mode with several hard-wired connections and the proper space to add jumpers in case of switching to bypass Mode is needed.

To make the board capable of entering low-power modes and measure the lowest possible values of the SOC and XCVR, it is necessary to perform some changes on the board, which are listed below:

1. Locate four copper shunts on the back side of the board and cut the trace on J24, J28, J29, and J38.
   - J24: This isolates P_LED line, removing the power to the LEDs.
   - J28: This isolates P1V8_3V3_BRD line, removing the power of the peripherals.
     - — M20 device will be not supplied anymore. It is used for flashing the KW36Z through the USB connector J11.
   - J29: This isolates VDD_MCU from DCDC_ IN.
   - J38: This disconnects the default buck mode. Choice of Bypass or Buck mode could be set depending on the jumper J38 position.

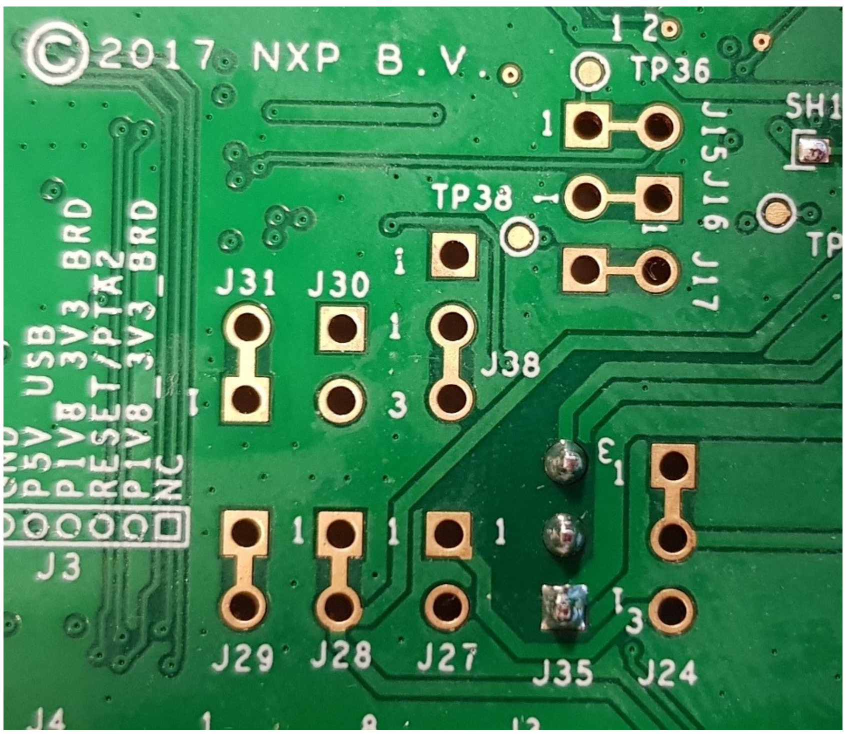

Figure 19. Cut traces to the bottom side of the FRDM-KW36Z board, Rev. B

2. Populate the head connectors to the following jumpers: J24, J27, J28, J29, J30, and J38.

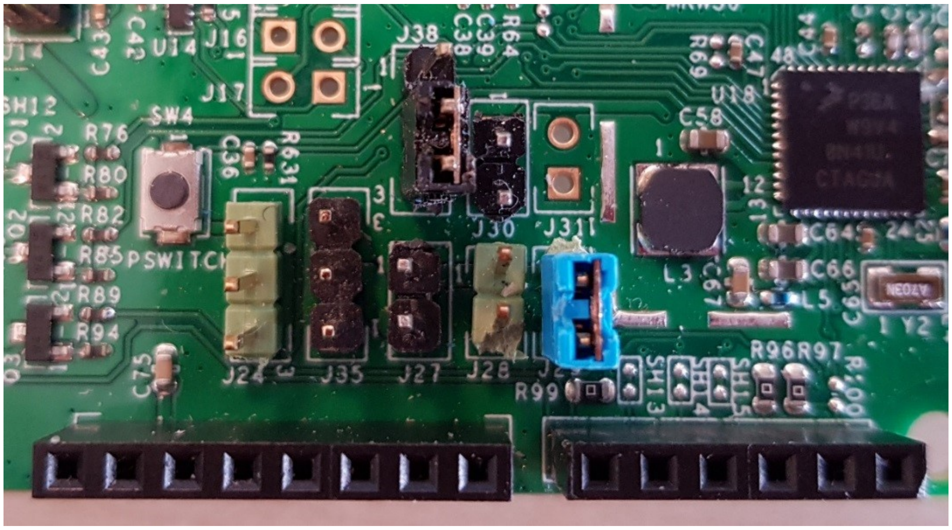

Figure 20. Header connector setup on FRDM-KW36Z board, Rev. B

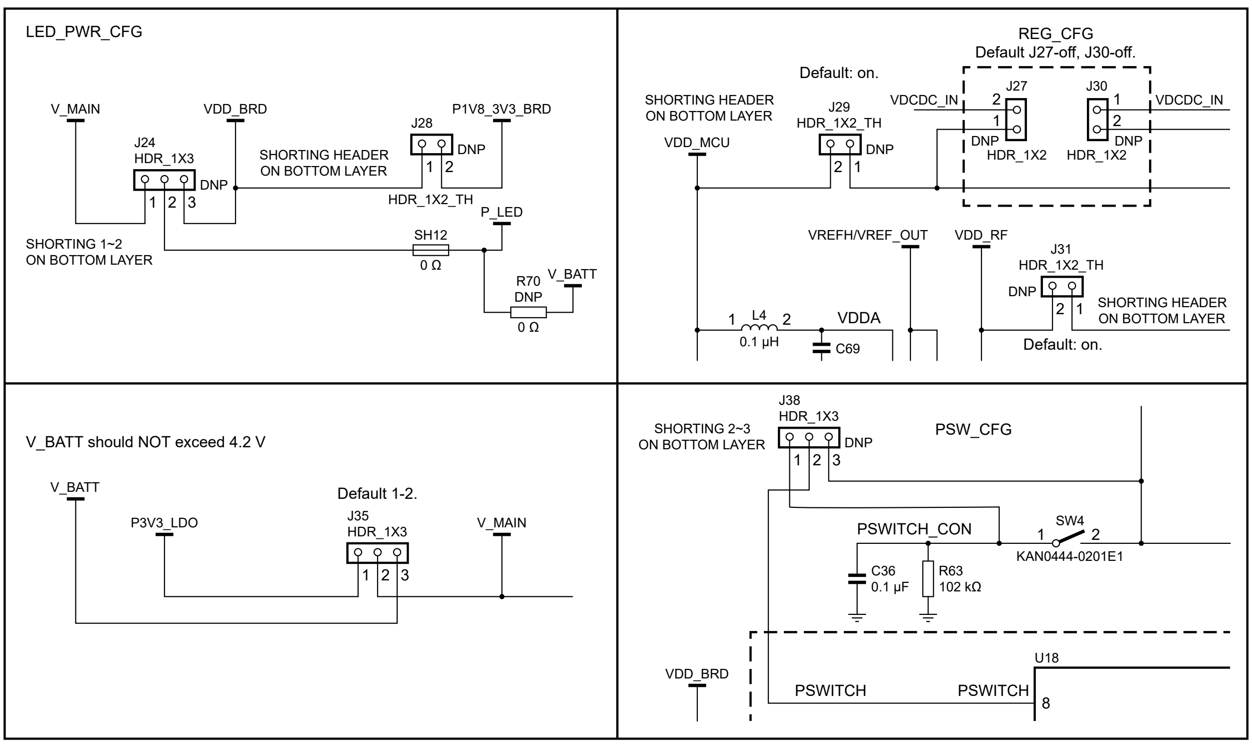

Figure 21. FRDM-KW36Z board setup

The FRDM-KW36 is now ready for the different Buck or Bypass configurations.

NOTE

For flashing the KW36Z via the USB connector J11, the jumper J35 must be shunt to the 2-3 position.

Current measurement in buck mode and Current measurements in bypass mode explain how to set the jumpers for the buck or bypass mode configuration.

4.1.1.1 Current measurement in buck mode

The jumpers must be placed as in Figure 22 to measure the KW36Z current consumption in buck mode.

- Jumper J38 must be shunt at 2-3 position to allow Pswitch connected to the `V_main` (`DCDC_in` in buck mode).
- Jumper J29 must be shunt at 1-2 position to allow VDD_1P8out to be connected to the Analog and Digital power supply of the KW36Z.
- Remove the jumper J35 completely.

The current measurement is performed at J35-2 pin.

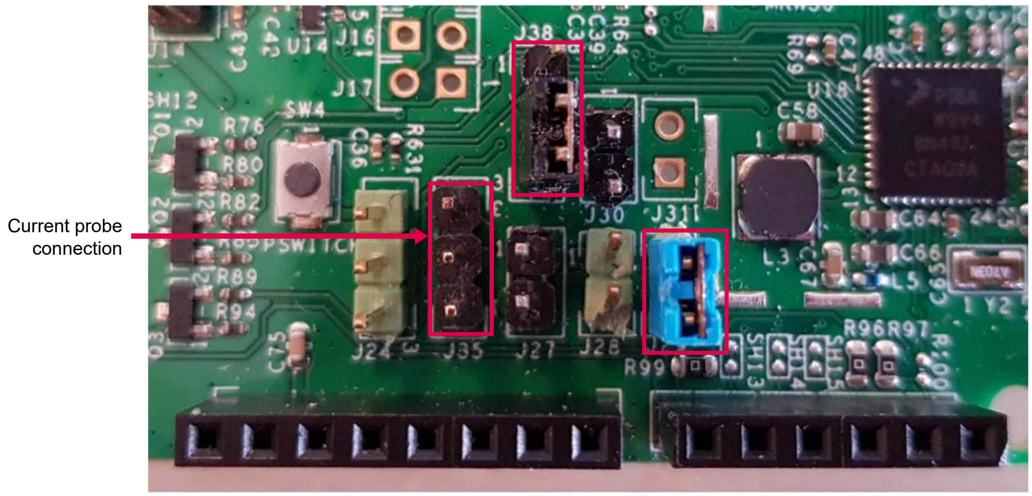

Figure 22. FRDM-KW36Z board, Rev. B, buck mode

NOTE

When programming the board, J35 has the jumper on 1-2 position. After programming the board, remove the jumper.

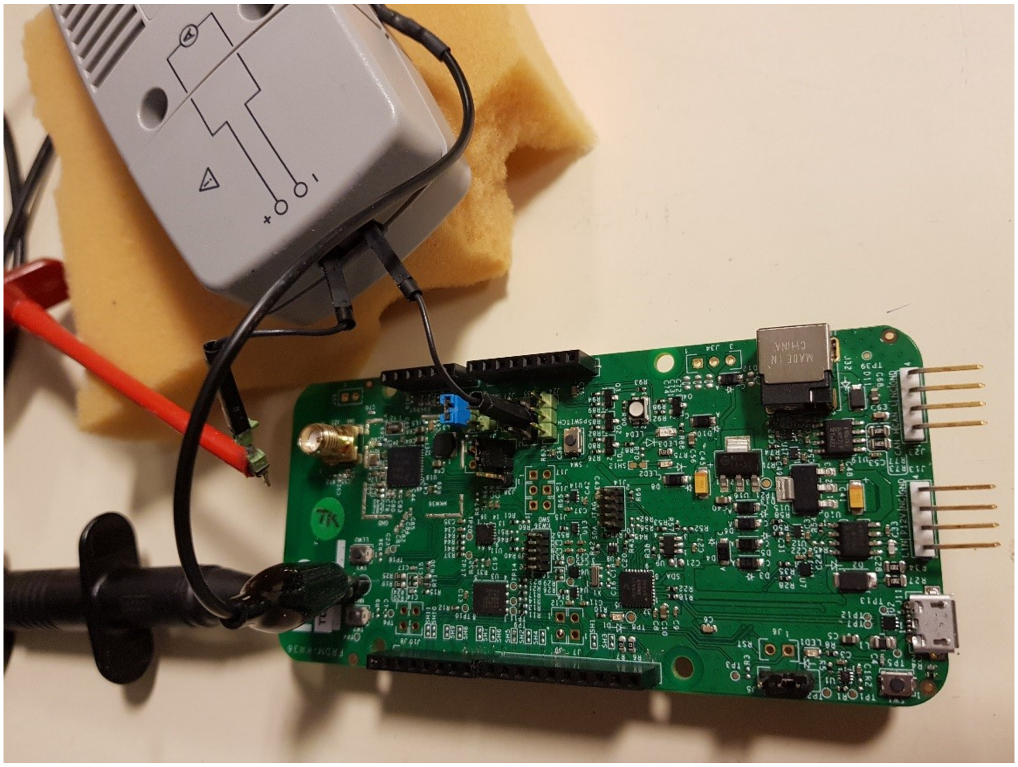

Figure 23. FRDM-KW36Z board, Rev. B, buck mode with current probe

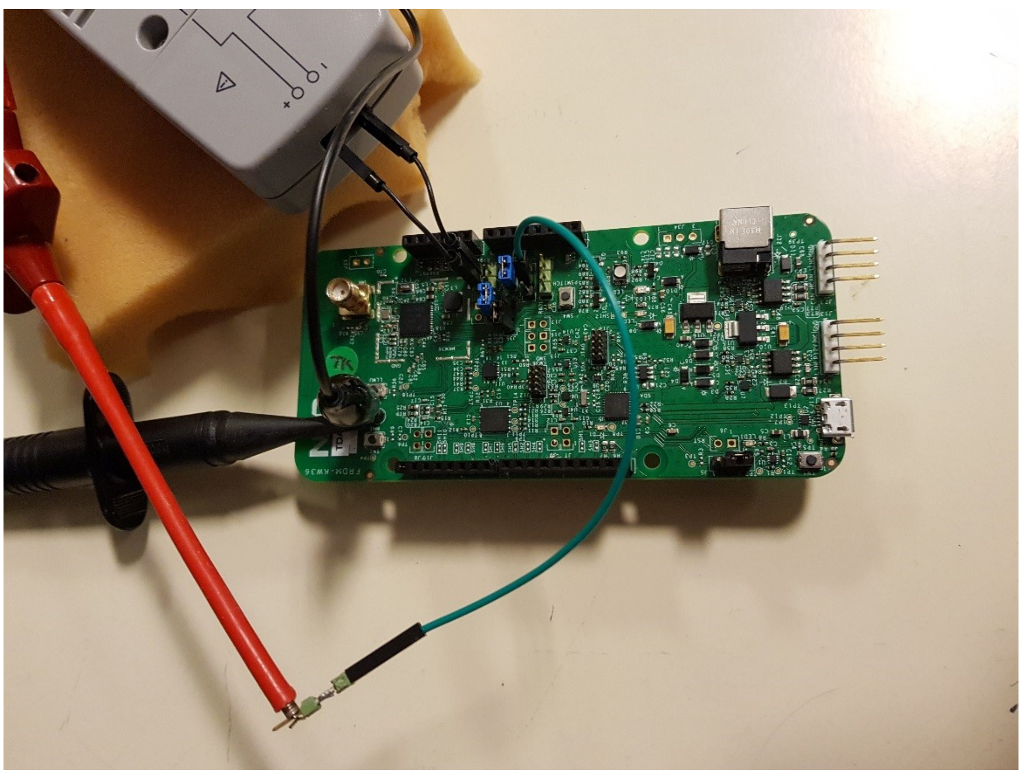

Figure 24. FRDM-KW36Z board, Rev. B, buck mode with current probe on MCU (J29)

4.1.1.2 Current measurements in bypass mode

The jumpers must be placed as in Figure 25 to measure the KW36Z current consumption in bypass mode.

- Jumper J38 must be shunt at 1-2 position to allow Pswitch connected to the ground (`DCDC_ IN` in bypass mode)
- Jumpers J27, J29, and J30 must be shunt at 1-2 position to allow `V_MAIN` to be connected to the analog and digital power supply of the KW36Z.
- Remove the jumper J35 completely.

The current measurement is performed at J35-2 pin.

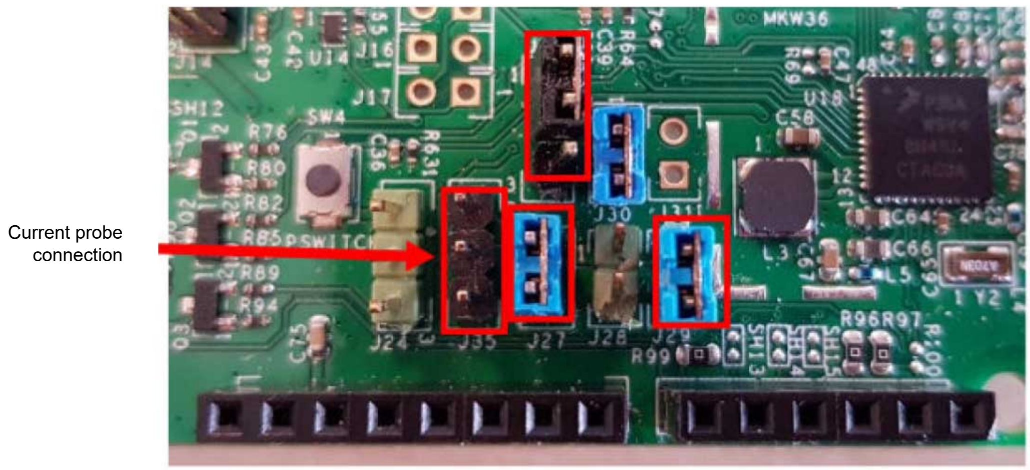

Figure 25. FRDM-KW36Z board, Rev. B, bypass mode

NOTE

When programming the board, J35 has the jumper on 1-2 position. After programming the board, remove the jumper.

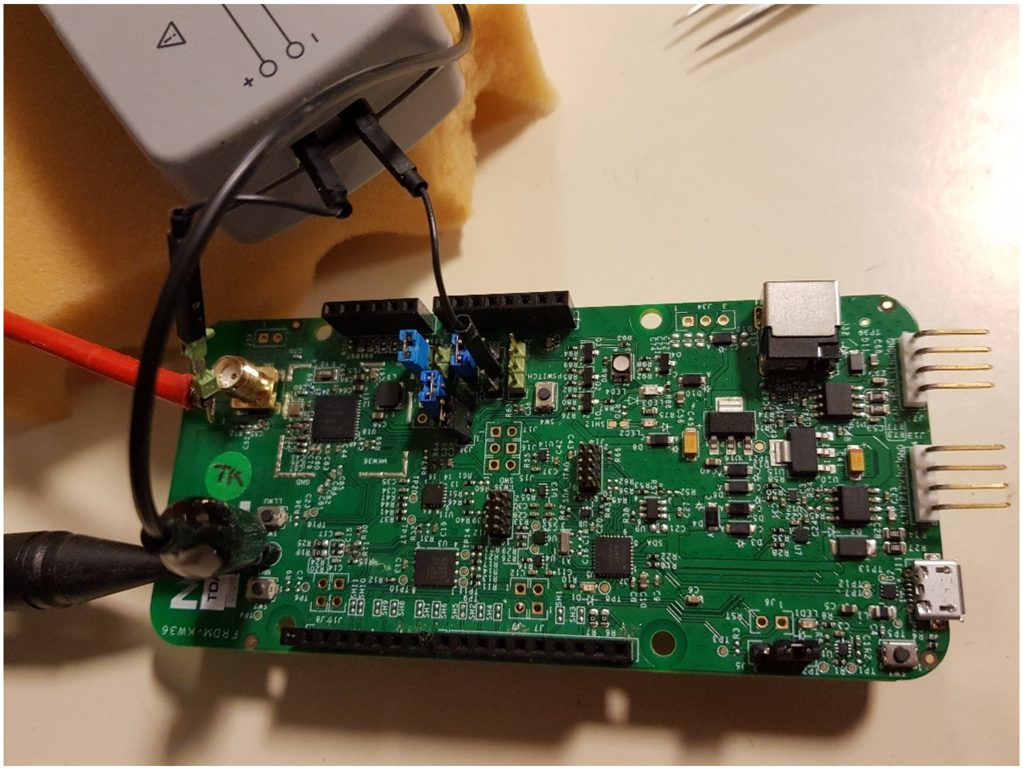

Figure 26. FRDM-KW36Z board, Rev. B, bypass mode with current probe

If the board has SMA connector, C57 capacitor is populated and C55 not populated, then a SMA antenna is required to be connected to the board.

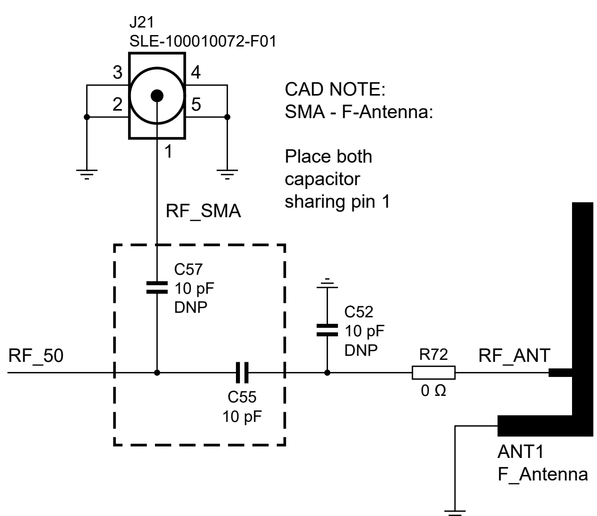

Figure 27. SMA configuration

4.2 Measuring the current assumption

This section guides you to set up the hardware and software to measure the current consumption using the FRDM-KW36.

4.2.1 Instruction

1. Choose the buck or bypass mode (refer to Current measurement in buck mode for buck mode or Current measurements in bypass mode for bypass mode).
2. Place the jumper J24 in 1-2 position, J28 in 1-2 position, and J35 in 1-2 position.
3. Connect the board to a PC and download the Heart Rate Sensor project created in Software configuration for low-power operation to the board.
4. Once the board is programmed, disconnect the board from the PC and remove the jumpers from J24, J28, and J35.
5. Remove any external debugger if connected.
6. Set the output voltage of the power source to 3.6 V.

   (Reminder: voltage range must be within 2.1 V and 3.6 V)
7. Connect TP19 (GND) to the power source. Make sure to disable the output of the power source to avoid any damage to the board.
8. Connect the Keysight CX3322A Power Analyzer and CX1101A Current Probe to J35-2 and to the power source.

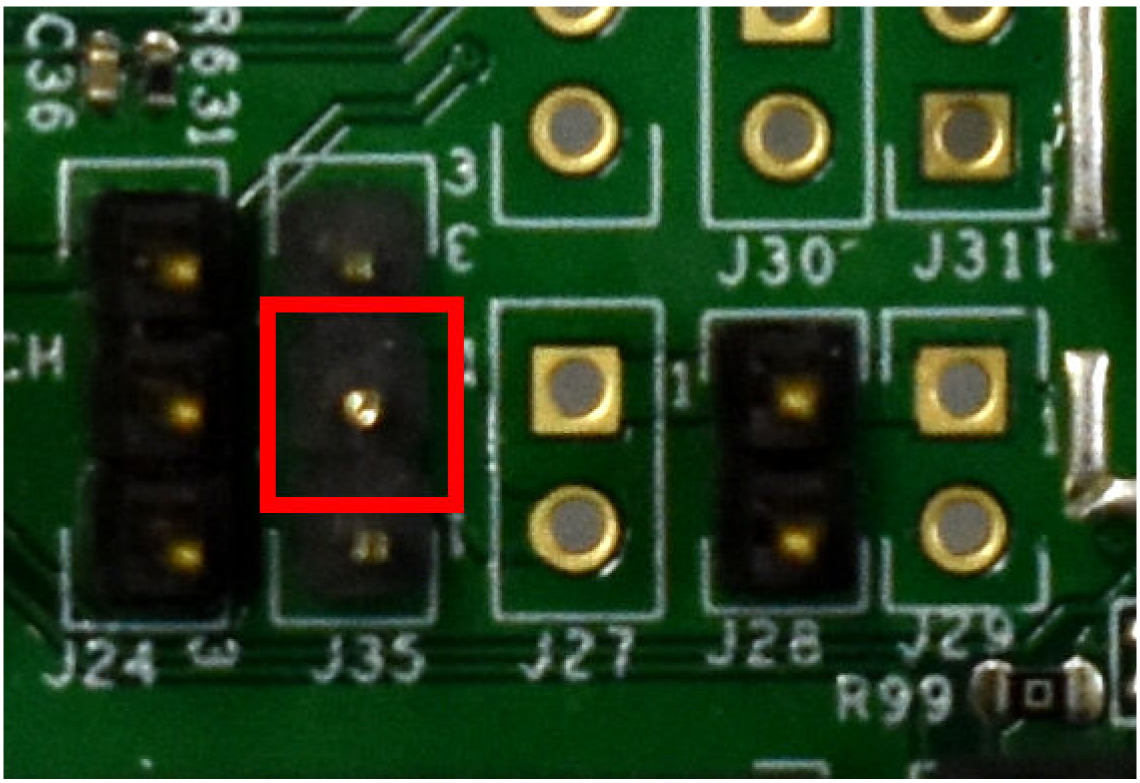

Figure 28. J35-2

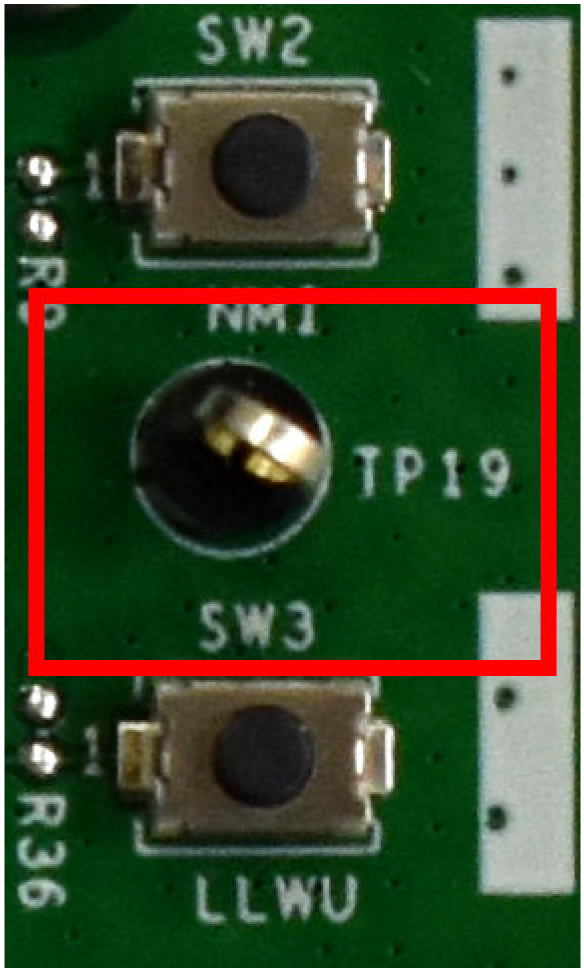

Figure 29. GND TP19

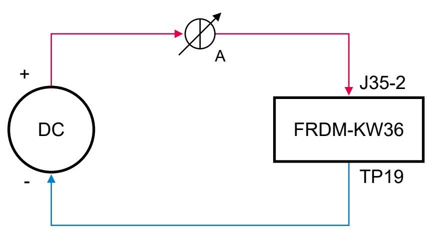

Figure 30. Connection block diagram

9. Apply voltage to the board.

The current measurement is performed by using the Power Analyzer built-in display and a USB flash memory stick to save the results.

4.2.2 Measurements and results

All the measurements within this subchapter are done with MCU in stop mode, the flash in the dozed mode, RF output at 0 dBm (1 mW) (power level 20, see the `controller_interface.h` header file), power supply at 3.6 V and room temperature (25 degC). KW36 device is coming from typical process. All the phases from Figure 30 are analyzed and measured. In Reports, all measurement results are presented in both buck and bypass mode with two different RF output power (0 dBm and +3.5 dBm).

How to use the Power Analyzer is not discussed in this document.

4.2.2.1 Overview

Using the steps provided in Software configuration for low-power operation, partial Bluetooth® LE scenario (Heart Rate Sensor application) was captured and can be observed in Figure 31. The main events and phases are documented within the capture. All the plots that follows depicts current consumption (y-axis) vs. time (x-axis).

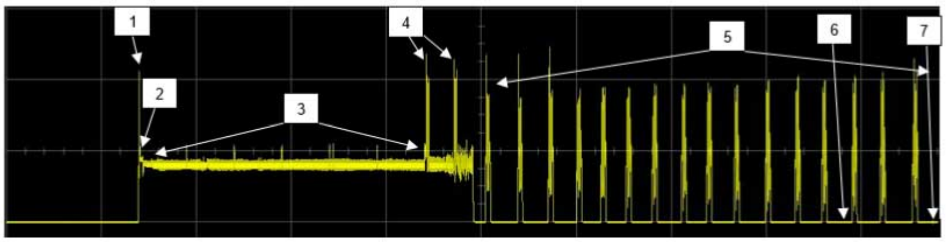

Figure 31. KW36Z SoC current consumption sequence

Figure 31 shows the current consumption of the KW36Z SoC during different operational phases, as noted in Table 4.

Table 4. Different operational phase current consumption

Phase	Description
1	Power On Reset (POR), just after the SoC is connected to power supply. The spike from Figure 31 is about 26 mA and is because of the coupling capacitors as well as the SoC internal circuitry (regulators, clock oscillators, MCU, radio digital, radio analog, and so on).
2	The MCU is initialized among all the software: low-level drivers, framework, RTOS, Bluetooth LE stack, application.
3	The MCU running The spikes are because of the DC-DC converter that operates in pulsed mode.
4	The MCU leaves low-power mode 3 (by pushing the SW3 button) and resumes its execution. The Bluetooth LE LL goes to the RUN state.
5	Fast advertising is started. Between advertising events the system enters low-power mode 1 (MCU=LLS3, LL=DSM)
6	Between advertising events the system enters power mode 1 (MCU=LLS3, LL=DSM)
7	After a disconnect, the SoC enters power mode 3 (MCU = LLS3, LL = IDLE)

4.2.2.2 DSM

When the SoC is connected to the power supply, a power-up spike occurs due to coupling of the board to power supply. After MCU POR, the software execution begins, the clocks and peripherals are enabled and configured, the connectivity framework is initialized, RTOS tasks are initialized and started, the Bluetooth® LE stack is up and running, the Bluetooth LE application is started. After all these are completed, the system enters low-power mode 1 (MCU=LLS3, LL=IDLE). The initialization phase before the system enters deep sleep takes about 250 ms with an average current consumption of 2.81 mA.

The device operates in low-power mode 1 until SW3 key is pressed. By pressing SW3 the system wakes-up because the GPIO associated to SW3 is configured as interrupt source in Low-leakage Wake-up (LLWU) Unit module. While in low-power mode 1, the module has an average consumption of 2.75 μA (Δ = 20 s, Supply at 3.0 V).

The spikes from Figure 32 are at the moments when DC-DC is refreshing. This results into a higher average current consumption performed with a voltage differential probe on a 10 ohms resistor in serial with the power supply (V_main).

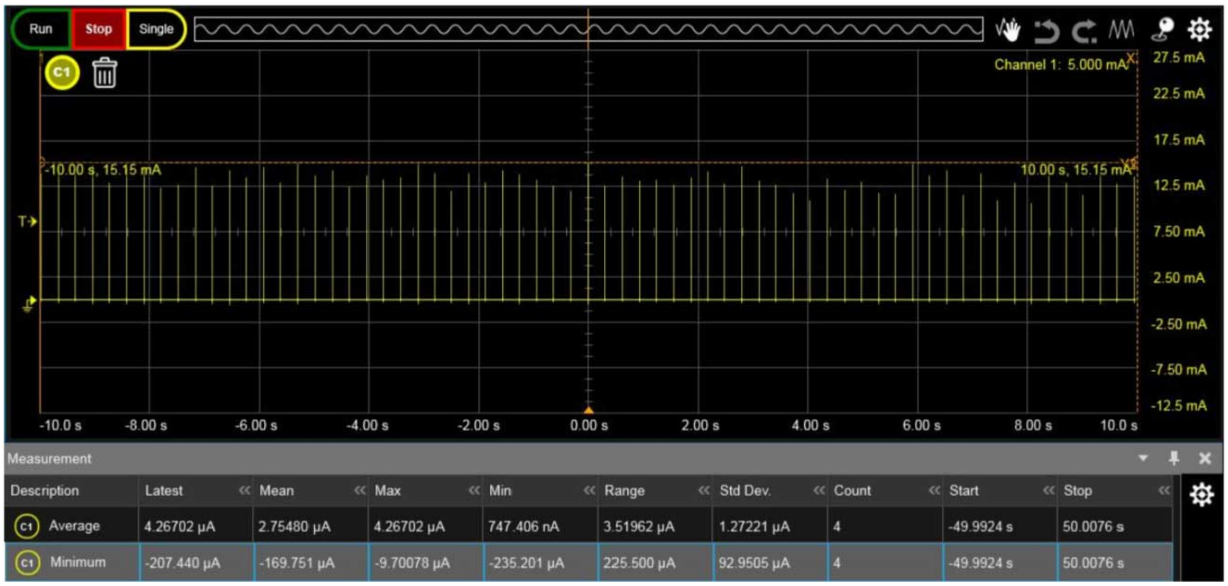

Figure 32. KW36Z current consumption in low-power mode 1

Table 5. Low-power mode 1 current consumption

		Measured current		
DCDC voltage	Time difference	Avg.	Max.	Min.
3.0 V	20 s	2.75 µA	15.1 mA	-169 µA

Figure 33. KW36Z current consumption in DSM LLS3 two peaks interval

Table 6. DSM LLS3 interval current consumption between 2 DC-DC peaks

DCDC_IN = 3.6 V	Measured current		
Time difference	Avg.	Max.	Min.
200 ms	292 nA	160 µA	-182 µA

4.2.2.2.1 Coin cell 3.0 V power supply

DSM current measurement is performed on the FRDM-KW36 board supplied with a coin cell 3.0 V (CR2032 Lithium). The direct impact is on the peak current.

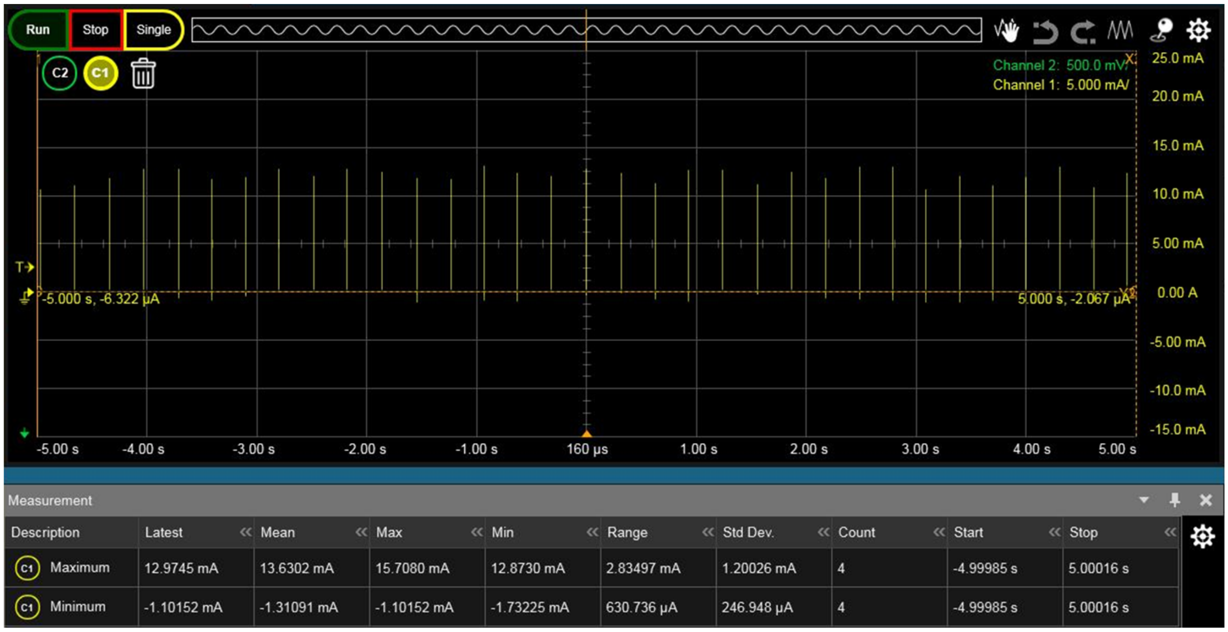

Figure 34. KW36 current consumption in low-pwoer mode 1 with a coin cell

Table 7. Low-pwoer mode 1 interval current consumption with a coin cell

DCDC_IN = 3.0 V	Measured current		
Time difference	Avg.	Max.	Min.
10 s	2.72 µA	15.7 mA	-1.31 mA

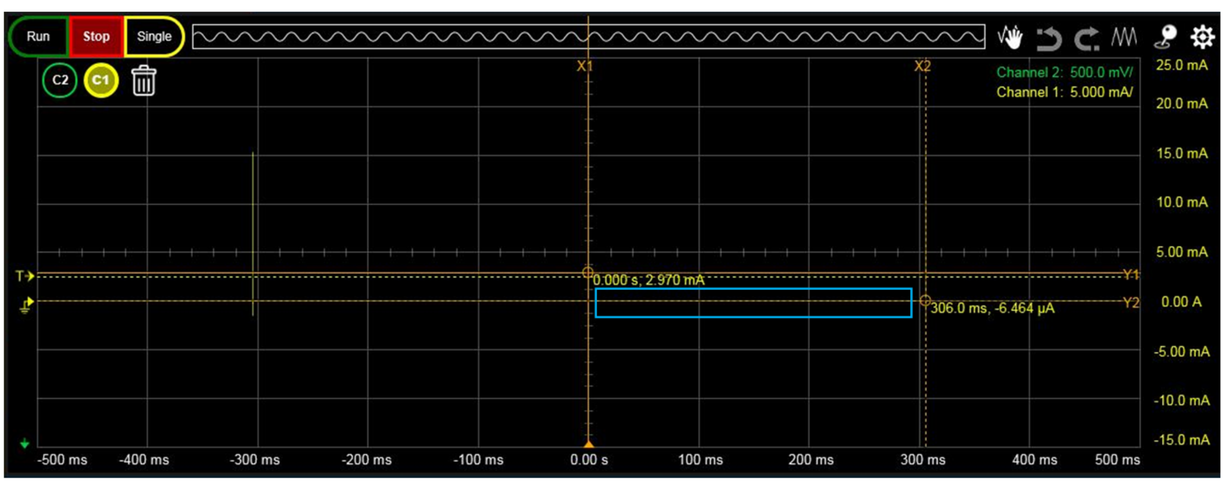

Figure 35. KW36 current consumption in DSM1 two peaks interval with a coin cell

Table 8. DSM1 two peaks interval current consumption with a coin cell

DCDC_IN = 3.0 V	Measured current		
Time difference	Avg.	Max.	Min.
100 ms	273 nA	320 nA	253 nA

4.2.2.2.2 DC-DC peak information

When the internal DC-DC is used (buck mode) in addition to the low-power mode IC, DC-DC peak current occurs (refer to the Figure 36 and Figure 37) and are observable on the Vdcdc_in pin on the KW36 device. The current signal peak, duration, and periodicity are directly linked to the total power consumption of the 1P5 (radio block power supply) and 1P8 pins (digital blocks power supply and some other external devices depending on the customer applications). 1P8 output power supply on the FRDM-KW36 supply the KW36 only.

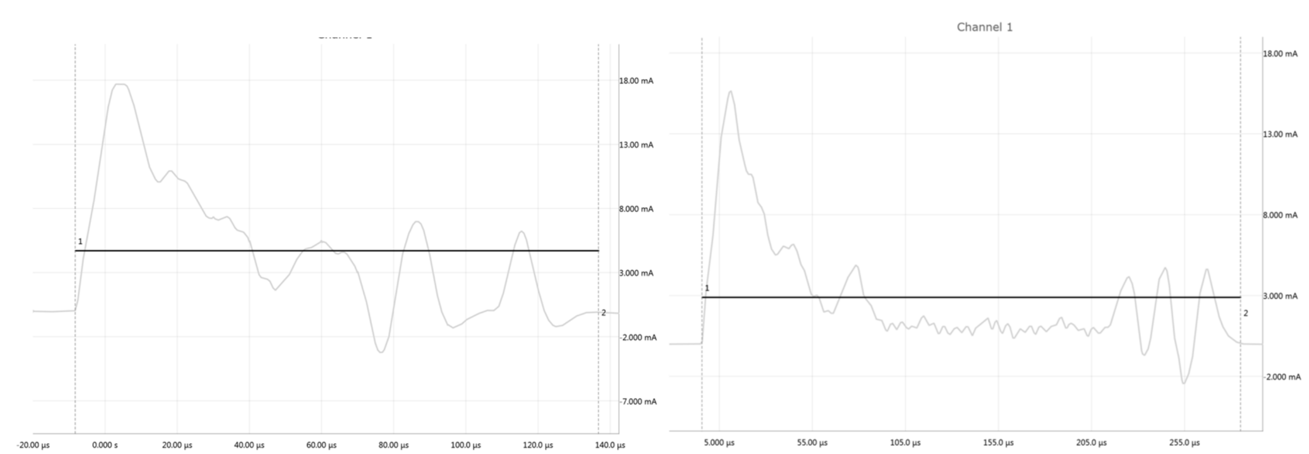

Figure 36. KW36 DC-DC peak current consumption in low-power mode 1 with a 3 V external power supply

Table 9. KW36 DC-DC peak current in low-power mode 1 with a 3 V external power supply

DCDC_IN = 3.0 V		Measured current		
Signal type	Duration	Mean current consumption	Peak current	Total energy
1 (left curve behind)	145 µs	4.7 mA	17.9 mA	189.4 pAh
2 (right curve behind)	289 µs	2.88 mA	15.7 mA	231.8 pAh

DC-DC regulation is composed with signal 1 and signal 2 linked to the DC-DC consumption (Idd_1P5 and Idd_1P8).

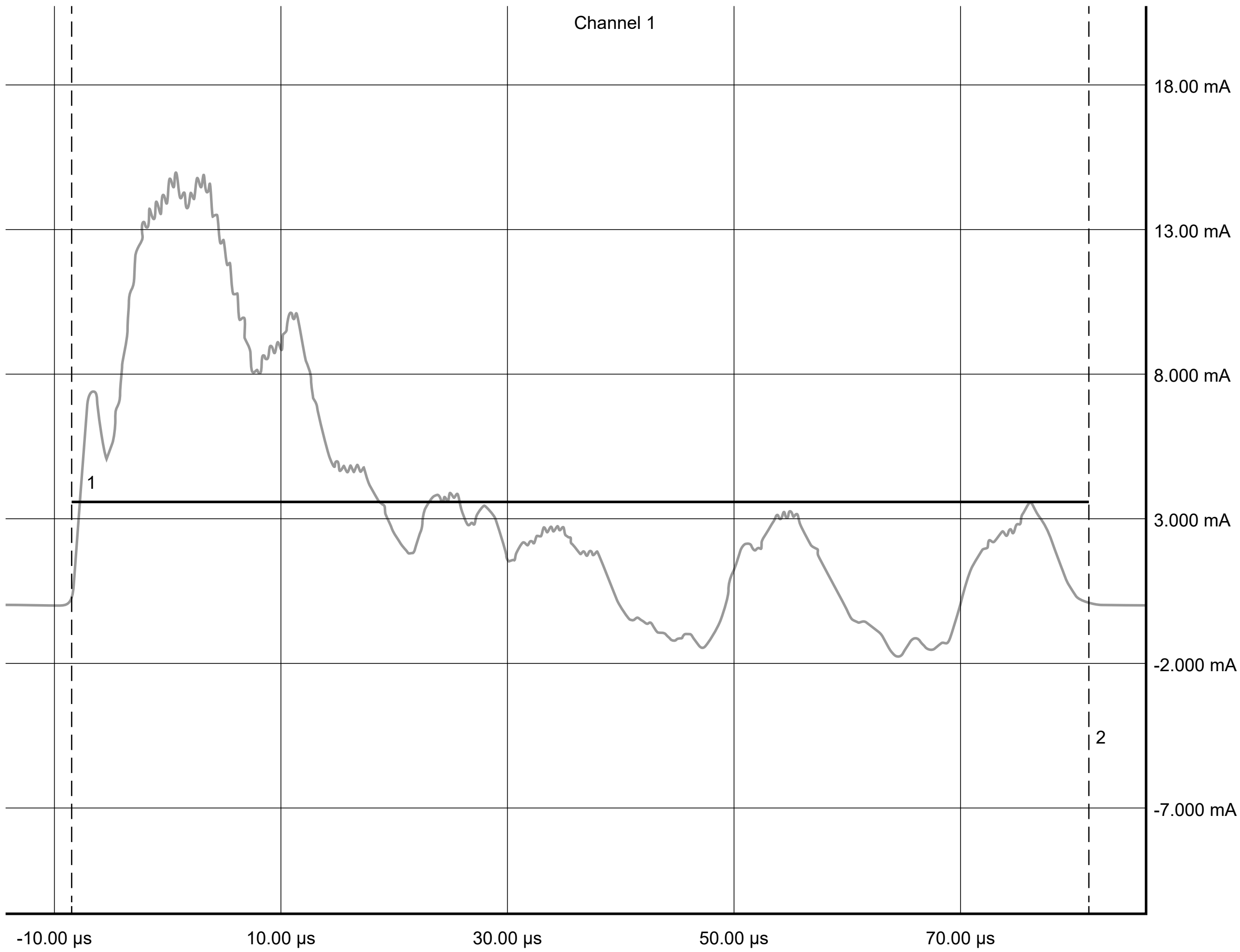

Figure 37. KW36 DC-DC peak current consumption in low-power mode 1 with a 3 V coincell

Table 10. KW36 DC-DC peak current in low-power mode 1 with a 3 V external power supply

DCDC_IN = 3.0 V	Measured current		
Duration	Mean current consumption	Peak current	Total energy
90 µs	3.55 mA	15.7 mA	88.8 pAh

4.2.2.3 Advertising mode

An advertising event is where the Bluetooth® LE peripheral device broadcasts some information in order to either share it or become connected to a Bluetooth LE central device, such as a smartphone. The device wakes up and broadcasts packets on three separate channels and listens on each of these channels for scan requests or connection requests.

Figure 38 captures the current consumption during the advertising event.

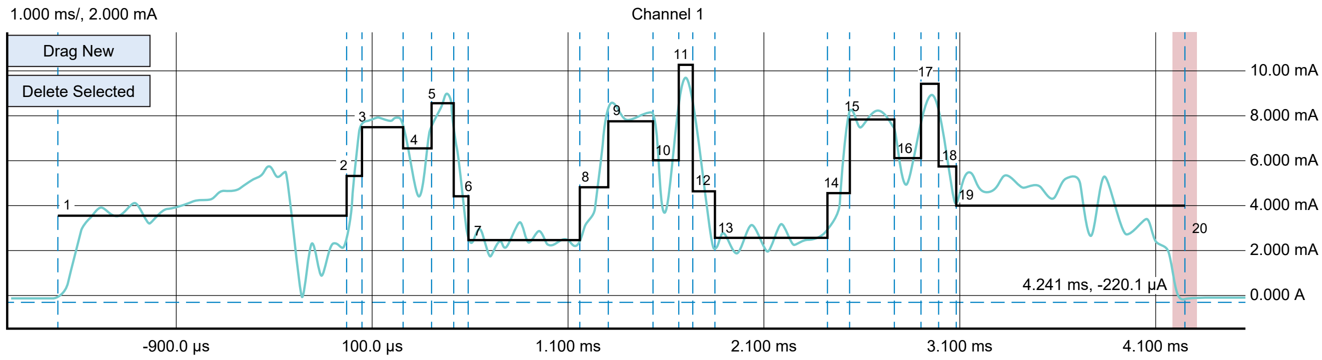

Figure 38. Current consumption - advertising event period

Table 11. ADV events

Phase	Events
1	ADV pre-processing
2	TX warm-up
3	Active TX
4	TX to RX transition
5	Active RX
6	RX warm-down
7	MCU stop
8	TX warm-up
9	Active TX
10	TX to RX transition
11	Active RX
12	RX warm-down
13	MCU stop
14	TX warm-up
15	Active TX
16	TX to RX transition
17	Active RX
18	RX warm-down
19	Post-processing

4.2.2.3.1 Test environment 1

Table 12. Advertising event, Buck and Bypass mode, 0 dBm, Flash dozed, MCU stop

DC-DC: mode	BUCK	BYPASS
Supply	VDCDC_IN = 2.1 V, 2.6 V, 3.6 V	VDDRF = 1.5 V VDDMCU = 1.8 V
RF output power	+0 dBm	
Payload	23 bytes	
Flash	Dozed	
MCU	Stop	
Setting	Advertising Interval = 20 ms Slave to Master	
Software	Heart Rate Sensor (SDK 2.2 release)	

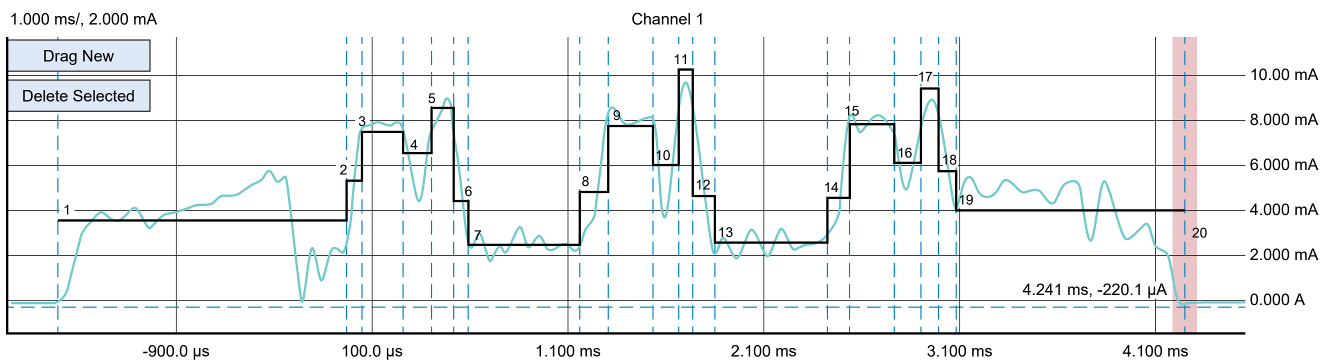

Figure 39. Current consumption during advertising event, 0 dBm, Flash dozed, MCU stop

Table 13. Current consumption during advertising event, 0 dBm, Flash dozed, MCU stop

Phase	Event	Time	Buck mode Avg.			Bypass mode Avg.
			@2.1 V	@2.6 V	@3.6 V	
1	Pre-processing	1.6 ms	5.31 mA	4.65 mA	3.63 mA	5.48 mA
2	TX warm-up	100 µs	5.10 mA	4.65 mA	4.51 mA	8.5 mA
3	Active TX	100 µs	12.37 mA	9.94 mA	7.79 mA	15.95 mA
4	TX to RX transition	150 µs	9.42 mA	7.38 mA	5.87 mA	11.48 mA
5	Active RX	80 µs	12.98 mA	10.77 mA	8.54 mA	17.32 mA
6	RX warm-down	75 µs	7.23 mA	5.32 mA	5.28 mA	6.52 mA
7	MCU stop	550 µs	2.72 mA	2.64 mA	2.28 mA	3.22 mA
8	TX warm-up	100 µs	5.10 mA	4.65 mA	4.51 mA	8.5 mA

Table continues on the next page...

Table 13. Current consumption during advertising event, 0 dBm, Flash dozed, MCU stop (continued)

Phase	Event	Time	Buck mode Avg.			Bypass mode Avg.
			@2.1 V	@2.6 V	@3.6 V	
9	Active TX	100 µs	12.37 mA	9.94 mA	7.79 mA	15.95 mA
10	TX to RX transition	150 µs	9.42 mA	7.38 mA	5.87 mA	11.48 mA
11	Active RX	80 µs	12.98 mA	10.77 mA	8.54 mA	17.32 mA
12	RX warm-down	75 µs	7.23 mA	5.32 mA	5.28 mA	6.52 mA
13	MCU stop	550 µs	2.72 mA	2.64 mA	2.28 mA	3.22 mA
14	TX warm-up	100 µs	5.10 mA	4.65 mA	4.51 mA	8.5 mA
15	Active TX	100 µs	12.37 mA	9.94 mA	7.79 mA	15.95 mA
16	TX to RX transition	150 µs	9.42 mA	7.38 mA	5.87 mA	11.48 mA
17	Active RX	80 µs	12.98 mA	10.77 mA	8.54 mA	17.32 mA
18	RX warm-down	75 µs	7.23 mA	5.32 mA	5.28 mA	6.52 mA
19	Post-processing	1.3 ms	4.81 mA	4.62 mA	4.04 mA	6.53 mA
—	**Full period ADV**	**5.75 ms**	**6.33 mA**	**5.59 mA**	**4.58 mA**	**8.85 mA**
—	**DSM1**	**14.25 ms**	**3.57 µA**	**3.14 µA**	**2.72 µA**	**292 nA**
—	**Total consumption**	**20 ms**	**1.822 mA**	**1.609 mA**	**1.319 mA**	**2.546 mA**

4.2.2.3.2 Test environment 2

Table 14. Advertising event, Buck and Bypass mode,+3.5 dBm, Flash dozed, MCU stop

DC-DC: mode	BUCK	BYPASS
Supply	VDCDC_IN = 3.6 V	VDDRF = 1.5 V VDDMCU = 1.8 V
RF output power	+3.5 dBm	
Payload	23 bytes	
Flash	Dozed	
MCU	Stop	
Setting	Advertising Interval = 20 ms Slave to Master	
Software	Heart Rate Sensor (SDK 2.2 release)	

Table 15. Current consumption during advertising event, +3.5 dBm, Flash dozed, MCU stop

Phase	Event	Time	Buck mode Avg.	Bypass mode Avg.
			@3.6 V	
1	Pre-processing	1.6 ms	3.71 mA	5.19 mA
2	TX warm-up	100 µs	5.61 mA	8.69 mA
3	Active TX	100 µs	9.17 mA	18.3 mA
4	TX to RX transition	150 µs	6.41 mA	12.81 mA
5	Active RX	80 µs	8.48 mA	18.17 mA
6	RX warm-down	75 µs	4.62 mA	7.47 mA
7	MCU stop	550 µs	2.06 mA	3.12 mA
8	TX warm-up	100 µs	5.61 mA	8.69 mA
9	Active TX	100 µs	9.17 mA	18.3 mA
10	TX to RX transition	150 µs	6.41 mA	12.81 mA
11	Active RX	80 µs	8.48 mA	18.17 mA
12	RX warm-down	75 µs	4.62 mA	7.47 mA
13	MCU stop	550 µs	2.06 mA	3.12 mA
14	TX warm-up	100 µs	5.61 mA	8.69 mA
15	Active TX	100 µs	9.17 mA	18.3 mA
16	TX to RX transition	150 µs	6.41 mA	12.81 mA
17	Active RX	80 µs	8.48 mA	18.17 mA
18	RX warm-down	75 µs	4.62 mA	7.47 mA
19	Post-processing	1.3 ms	3.59 mA	6.42 mA
—	**Full period ADV**	**5.75 ms**	**5.72 mA**	**9.08 mA**
—	**DSM1**	**14.25 ms**	**2.72 µA**	**292 nA**
—	**Total consumption**	**20 ms**	**1.646 mA**	**2.612 mA**

4.2.2.3.3 Test environment 3

Table 16. Advertising event, Buck and Bypass mode, +5 dBm, Flash dozed, MCU stop

DC-DC: mode	BUCK	BYPASS
Supply	VDCDC_IN = 3.6 V	VDDRF = 1.5 V VDDMCU = 1.8 V
RF output power	+5 dBm	
Payload	23 bytes	
Flash	Dozed	

Table continues on the next page...

Table 16. Advertising event, Buck and Bypass mode, +5 dBm, Flash dozed, MCU stop (continued)

DC-DC: mode	BUCK	BYPASS
MCU	Stop	
Setting	Advertising Interval = 20 ms Slave to Master	
Software	Heart Rate Sensor (SDK 2.2 release)	

Table 17. Current consumption during advertising event, +5 dBm, Flash dozed, MCU stop

Phase	Event	Time	Buck mode Avg.	Bypass mode Avg.
			@3.6 V	
1	Pre-processing	1.6 ms	3.71 mA	5.19 mA
2	TX warm-up	100 µs	5.61 mA	8.69 mA
3	Active TX	100 µs	10.3 mA	20.8 mA
4	TX to RX transition	150 µs	5.96 mA	12.81 mA
5	Active RX	80 µs	8.75 mA	18.2 mA
6	RX warm-down	75 µs	4.62 mA	7.47 mA
7	MCU stop	550 µs	2.4 mA	3.4 mA
8	TX warm-up	100 µs	5.61 mA	8.69 mA
9	Active TX	100 µs	10.3 mA	20.8 mA
10	TX to RX transition	150 µs	5.96 mA	12.81 mA
11	Active RX	80 µs	8.75 mA	18.2 mA
12	RX warm-down	75 µs	4.62 mA	7.47 mA
13	MCU stop	550 µs	2.4 mA	3.4 mA
14	TX warm-up	100 µs	5.61 mA	8.69 mA
15	Active TX	100 µs	10.3 mA	20.8 mA
16	TX to RX transition	150 µs	5.96 mA	12.81 mA
17	Active RX	80 µs	8.75 mA	18.2 mA
18	RX warm-down	75 µs	4.62 mA	7.47 mA
19	Post-processing	1.3 ms	3.59 mA	6.42 mA
—	**Full period ADV**	**5.75 ms**	**5.72 mA**	**9.08 mA**
—	**DSM1**	**14.25 ms**	**2.72 µA**	**292 nA**
—	**Total consumption**	**20 ms**	**1.646 mA**	**2.612 mA**

4.2.2.3.4 Test environment 4

Table 18. Advertising event, Buck and Bypass mode, 0 dBm, Flash enabled, MCU run

DC-DC: mode	BUCK	BYPASS
Supply	VDCDC_IN = 2.1 V, 2.6 V, 3.6 V	VDDRF = 1.5 V VDDMCU = 1.8 V
RF output power	+0 dBm	
Payload	23 bytes	
Flash	Enabled	
MCU	Run	
Setting	Advertising Interval = 20 ms Slave to Master	
Software	Heart Rate Sensor (SDK 2.2 release)	

Table 19. Current consumption during advertising event in Buck mode, 0 dBm, Flash enabled, MCU run

Phase	Event	Time	Buck mode Avg.			Bypass mode Avg.
			@2.1 V	@2.6 V	@3.6 V	
1	Pre-processing	1.6 ms	5.20 mA	4.02 mA	3.02 mA	4.93 mA
2	TX warm-up	100 μs	8.78 mA	7.80 mA	6.35 mA	12.47 mA
3	Active TX	100 μs	17.04 mA	13.87 mA	10.28 mA	19.27 mA
4	TX to RX transition	150 μs	9.42 mA	7.38 mA	5.87 mA	15.51 mA
5	Active RX	80 μs	17.50 mA	14.14 mA	10.62 mA	21.87 mA
6	RX warm-down	75 μs	10.10 mA	7.18 mA	6.73 mA	11.81 mA
7	MCU stop	550 μs	5.66 mA	2.83 mA	4.69 mA	7.87 mA
8	TX warm-up	100 μs	8.78 mA	7.80 mA	6.35 mA	12.47 mA
9	Active TX	100 μs	17.04 mA	13.87 mA	10.28 mA	19.27 mA
10	TX to RX transition	150 μs	9.42 mA	7.38 mA	5.87 mA	15.51 mA
11	Active RX	80 μs	17.50 mA	14.14 mA	10.62 mA	21.87 mA
12	RX warm-down	75 μs	10.10 mA	7.18 mA	6.73 mA	11.81 mA
13	MCU stop	550 μs	5.66 mA	2.83 mA	4.69 mA	7.87 mA
14	TX warm-up	100 μs	8.78 mA	7.80 mA	6.35 mA	12.47 mA
15	Active TX	100 μs	17.04 mA	13.87 mA	10.28 mA	19.27 mA
16	TX to RX transition	150 μs	9.42 mA	7.38 mA	5.87 mA	15.51 mA

Table continues on the next page...

Table 19. Current consumption during advertising event in Buck mode, 0 dBm, Flash enabled, MCU run (continued)

Phase	Event	Time	Buck mode Avg.			Bypass mode Avg.
			@2.1 V	@2.6 V	@3.6 V	
17	Active RX	80 µs	17.50 mA	14.14 mA	10.62 mA	21.87 mA
18	RX warm-down	75 µs	10.10 mA	7.18 mA	6.73 mA	11.81 mA
19	Post-processing	1.3 ms	4.18 mA	3.84 mA	3.62 mA	6.22 mA
—	**Full period ADV**	**5.75 ms**	**8.46 mA**	**7.36 mA**	**5.87 mA**	**11.37 mA**
—	**DSM1**	**14.25 ms**	**3.57 µA**	**3.14 µA**	**2.72 µA**	**292 nA**
—	**Total consumption**	**20 ms**	**2.435 mA**	**2.118 mA**	**1.690 mA**	**3.271 mA**

4.2.2.3.5 Test environment 5

Table 20. Advertising event, Buck and Bypass mode, +3.5 dBm, Flash enabled, MCU run

DC-DC: mode	BUCK	BYPASS
Supply	VDCDC_IN = 3.6 V	VDDRF = 1.5 V VDDMCU = 1.8 V
RF output power	+3.5 dBm	
Payload	23 bytes	
Flash	Enabled	
MCU	Run	
Setting	Advertising Interval = 20 ms Slave to Master	
Software	Heart Rate Sensor (SDK 2.2 release)	

Table 21. Current consumption during advertising event, +3.5 dBm, Flash enabled, MCU run; Flash dozed, MCU stop

Phase	Event	Time	Buck mode Avg.	Bypass mode Avg.
			@3.6 V	
1	Pre-processing	1.6 ms	3.71 mA	5.68 mA
2	TX warm-up	100 µs	6.60 mA	12.58 mA
3	Active TX	100 µs	11.71 mA	22.36 mA
4	TX to RX transition	150 µs	8.48 mA	16.76 mA
5	Active RX	80 µs	10.37 mA	21.81 mA
6	RX warm-down	75 µs	6.17 mA	15.75 mA
7	MCU stop	550 µs	4.70 mA	7.35 mA

Table continues on the next page...

Table 21. Current consumption during advertising event, +3.5 dBm, Flash enabled, MCU run; Flash dozed, MCU stop (continued)

Phase	Event	Time	Buck mode Avg. @3.6 V	Bypass mode Avg.
8	TX warm-up	100 µs	6.60 mA	12.58 mA
9	Active TX	100 µs	11.71 mA	22.36 mA
10	TX to RX transition	150 µs	8.48 mA	16.76 mA
11	Active RX	80 µs	10.37 mA	21.81 mA
12	RX warm-down	75 µs	6.17 mA	15.75 mA
13	MCU stop	550 µs	4.70 mA	7.35 mA
14	TX warm-up	100 µs	6.60 mA	12.58 mA
15	Active TX	100 µs	11.71 mA	22.36 mA
16	TX to RX transition	150 µs	8.48 mA	16.76 mA
17	Active RX	80 µs	10.37 mA	21.81 mA
18	RX warm-down	75 µs	6.17 mA	15.75 mA
19	Post-processing	1.3 ms	3.64 mA	6.54 mA
—	**Full period ADV**	**5.75 ms**	**6.15 mA**	**12.01 mA**
—	**DSM1**	**14.25 ms**	**2.72 µA**	**292 nA**
—	**Total consumption**	**20 ms**	**1.770 mA**	**3.455 mA**

4.2.2.3.6 Test environment 6

Table 22. Advertising event with response, Buck and Bypass mode, 0 dBm, Flash dozed, MCU stop

DC-DC: mode	BUCK	BYPASS
Supply	VDCDC_IN = 2.1 V, 2.6 V, 3.6 V	VDDRF=1.5 V VDDMCU=1.8 V
RF output power	+0 dBm	
Payload	23 bytes	
Flash	Dozed	
MCU	Stop	
Setting	Advertising Interval = 20 ms Slave to Master	
Software	Heart Rate Sensor (SDK 2.2 release)	

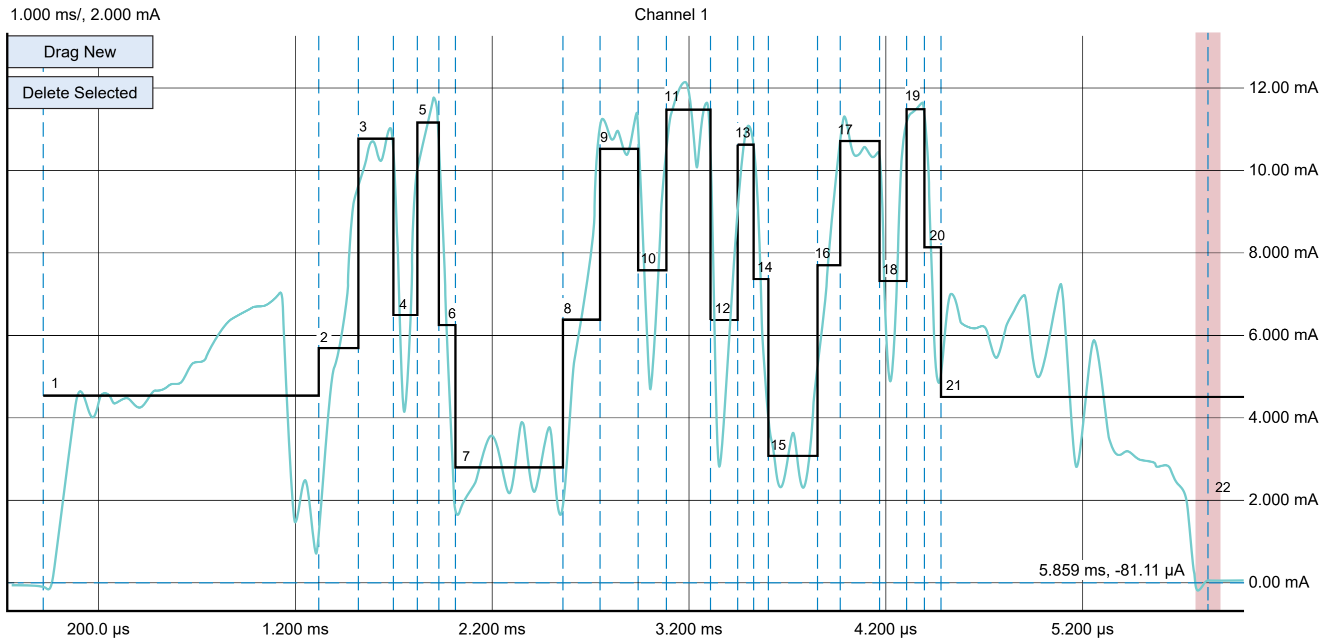

Figure 40. Current consumption during advertising event with response, Buck and Bypass mode, 0 dBm, Flash dozed, MCU stop

Table 23. Current consumption during advertising event with response, Buck mode, 0 dBm, Flash dozed, MCU stop

Phase	Event	Time	Buck mode Avg.			Bypass mode Avg.
			@2.1 V	@2.6 V	@3.6 V	
1	Pre-processing	1.6 ms	5.01 mA	4.53 mA	3.02 mA	4.93 mA
2	TX warm-up	100 µs	8.58 mA	5.35 mA	6.35 mA	12.47 mA
3	Active TX	100 µs	14.11 mA	9.96 mA	10.28 mA	19.27 mA
4	TX to RX transition	150 µs	8.78 mA	7.30 mA	8.18 mA	15.51 mA
5	Active RX	80 µs	15.98 mA	11.09 mA	10.62 mA	21.87 mA
6	RX to TX transition	150 µs	8.64 mA	6.38 mA	6.89 mA	13.55 mA
7	Active TX (2)	100 µs	13.62 mA	10.34 mA	9.99 mA	20.14 mA
8	TX warm-down (2)	75 µs	9.71 mA	5.99 mA	6.41 mA	13.18 mA
9	MCU stop	525 µs	2.64 mA	2.75 mA	4.69 mA	7.87 mA
10	TX warm-up	100 µs	8.58 mA	5.35 mA	6.35 mA	12.47 mA
11	Active TX	100 µs	14.11 mA	9.96 mA	10.28 mA	19.27 mA
12	TX to RX transition	150 µs	8.78 mA	7.30 mA	8.18 mA	15.51 mA
13	Active RX	80 µs	15.98 mA	11.09 mA	10.62 mA	21.87 mA

Table continues on the next page...

Table 23. Current consumption during advertising event with response, Buck mode, 0 dBm, Flash dozed, MCU stop (continued)

Phase	Event	Time	Buck mode Avg.			Bypass mode Avg.
			@2.1 V	@2.6 V	@3.6 V	
14	RX warm-up	20 µs	7.81 mA	4.57 mA	6.73 mA	11.81 mA
15	MCU stop	800 µs	2.64 mA	2.75 mA	4.69 mA	7.87 mA
16	TX warm-up	100 µs	8.58 mA	5.35 mA	6.35 mA	12.47 mA
17	Active TX	100 µs	14.11 mA	9.96 mA	10.28 mA	19.27 mA
18	TX to RX transition	150 µs	8.78 mA	7.30 mA	8.18 mA	15.51 mA
19	Active RX	80 µs	15.98 mA	11.09 mA	10.62 mA	21.87 mA
20	RX warm-down	20 µs	7.81 mA	4.57 mA	6.73 mA	11.81 mA
21	Post-processing	1.2 ms	4.32 mA	4.56 mA	3.62 mA	6.22 mA
—	**Full period**	**5.75 ms**	**7.12 mA**	**5.98 mA**	**5.05 mA**	**9.18 mA**
—	**DSM3**	**14.25 ms**	**3.57 µA**	**3.14 µA**	**2.72 µA**	**2.57 µA**
—	**Total consumption**	**20 ms**	**2.050 mA**	**1.721 mA**	**1.454 mA**	**2.641 mA**

4.2.2.3.7 Test environment 7

Table 24. Advertising event with response, Buck and Bypass mode, +3.5 dBm, Flash dozed, MCU stop

DC-DC: mode	BUCK	BYPASS
Supply	VDCDC_IN = 3.6 V	VDDRF = 1.5 V VDDMCU = 1.8 V
RF output power	+3.5 dBm	
Payload	23 bytes	
Flash	Dozed	
MCU	Stop	
Setting	Advertising Interval = 20 ms Slave to Master	
Software	Heart Rate Sensor (SDK 2.2 release)	

Table 25. Current consumption during advertising event with response, +3.5 dBm, Flash dozed, MCU stop

Phase	Event	Time	Buck mode Avg.	Bypass mode Avg.
			@3.6 V	
1	Pre-processing	1.6 ms	3.64 mA	5.19 mA

Table continues on the next page...

Table 25. Current consumption during advertising event with response, +3.5 dBm, Flash dozed, MCU stop (continued)

Phase	Event	Time	Buck mode Avg.	Bypass mode Avg.
			@3.6 V	
2	TX warm-up	100 µs	6.01 mA	12.69 mA
3	Active TX	100 µs	9.57 mA	19.3 mA
4	TX to RX transition	150 µs	7.18 mA	16.81 mA
5	Active RX	80 µs	9.25 mA	22.17 mA
6	RX to TX transition	150 µs	5.93 mA	16.81 mA
7	Active TX (2)	100 µs	9.75 mA	19.3 mA
8	TX warm-down (2)	75 µs	8.66 mA	13.47 mA
9	MCU stop	525 µs	2.46 mA	4.12 mA
10	TX warm-up	100 µs	6.01 mA	12.69 mA
11	Active TX	100 µs	9.57 mA	19.3 mA
12	TX to RX transition	150 µs	7.18 mA	16.81 mA
13	Active RX	80 µs	9.25 mA	22.17 mA
14	RX warm-down	20 µs	5.93 mA	11.47 mA
15	MCU stop	800 µs	2.46 mA	4.12 mA
16	TX warm-up	100 µs	6.01 mA	12.69 mA
17	Active TX	100 µs	9.57 mA	19.3 mA
18	TX to RX transition	150 µs	7.18 mA	16.81 mA
19	Active RX	80 µs	9.25 mA	22.17 mA
20	RX warm-down	20 µs	5.93 mA	11.47 mA
21	Post-processing	1.2 ms	3.92 mA	6.42 mA
—	**Full period ADV**	**5.75 ms**	**6.06 mA**	**9.68 mA**
—	**DSM1**	**14.25 ms**	**2.72 µA**	**2.57 µA**
—	**Total consumption**	**20 ms**	**1.744 mA**	**2.785 mA**

4.2.2.4 MCU consumption

MCU consumption measurement is performed by placing the current probe on jumper J29. The power supply is always applied on jumper J35-2.

4.2.2.4.1 Test environment 1

Table 26. MCU consumption event, Buck and Bypass mode, 0 dBm, Flash dozed, MCU stop

DC-DC: mode	BUCK	BYPASS
Supply	VDCDC_IN = 2.1 V, 2.6 V, 3.6 V	VDDRF = 1.5 V

Table continues on the next page...

Table 26. MCU consumption event, Buck and Bypass mode, 0 dBm, Flash dozed, MCU stop (continued)

DC-DC: mode	BUCK	BYPASS
		VDDMCU = 1.8 V
RF output power	+0 dBm	
Payload	23 bytes	
Flash	Dozed	
MCU	Stop	
Setting	Advertising Interval = 20 ms Slave to Master	
Software	Heart Rate Sensor (SDK 2.2 release)	

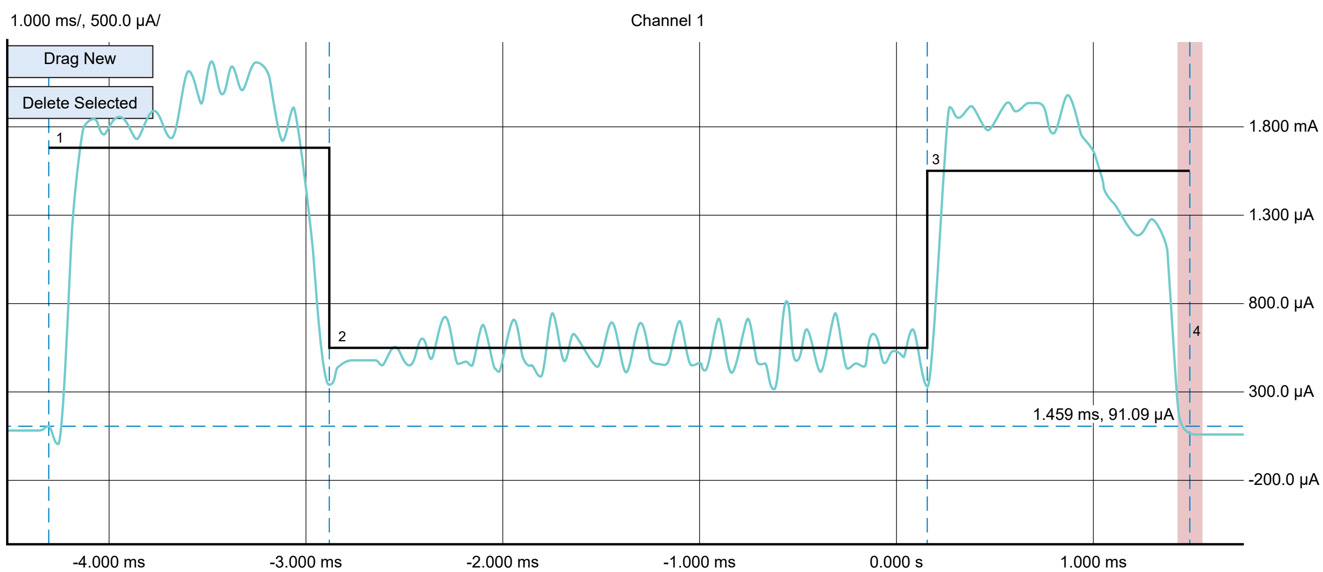

Figure 41. MCU current consumption, Flash dozed, MCU stop

Table 27. MCU current consumption, Flash dozed, MCU stop

Phase	Event	Time	Buck mode Avg.			Bypass mode Avg.
			@2.1 V	@2.6 V	@3.6 V	
1	Pre-processing	1.5 ms	1.72 mA	1.70 mA	1.63 mA	1.72 mA
2	MCU	3 ms	505.5 µA	503.5 µA	515.9 µA	505.5 µA
9	Post-processing	1.25 ms	1.43 mA	1.49 mA	1.53 mA	1.43 mA
—	**Full period**	**5.75 ms**	**1.022 mA**	**1.018 mA**	**1.006 mA**	**1.022 mA**

4.2.2.4.2 Test environment 2

Table 28. MCU consumption event, Buck and Bypass mode, 0 dBm, Flash enabled, MCU run

DC-DC: mode	BUCK	BYPASS
Supply	VDCDC_IN = 3.6 V	VDDRF = 1.5 V VDDMCU = 1.8 V
RF output power	+0 dBm	
Payload	23 bytes	
Flash	Enabled	
MCU	Run	
Setting	Advertising Interval = 20 ms Slave to Master	
Software	Heart Rate Sensor (SDK 2.2 release)	

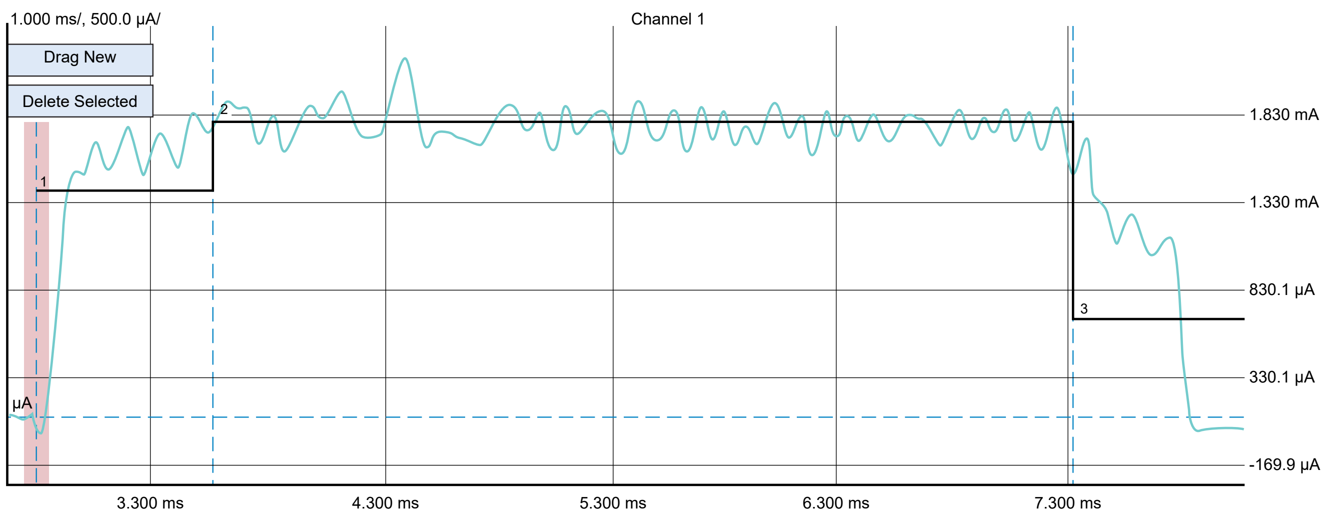

Figure 42. MCU current consumption, Flash enabled, MCU run

Table 29. MCU current consumption, Flash enabled, MCU run

Phase	Event	Time	Buck mode Avg.			Bypass mode Avg.
			@2.1 V	@2.6 V	@3.6 V	
1	Pre-processing	1.5 ms	1.76 mA	1.72 mA	1.65 mA	1.76 mA
2	MCU	3 ms	1.87 mA	1.85 mA	1.75 mA	1.87 mA
9	Post-processing	1.25 ms	1.09 mA	1.19 mA	1.72 mA	1.09 mA
—	**Full period**	**5.75 ms**	**1.73 mA**	**1.71 mA**	**1.66 mA**	**1.73 mA**

4.2.2.5 CONNECTION mode

NXP android app has been used to perform connection.

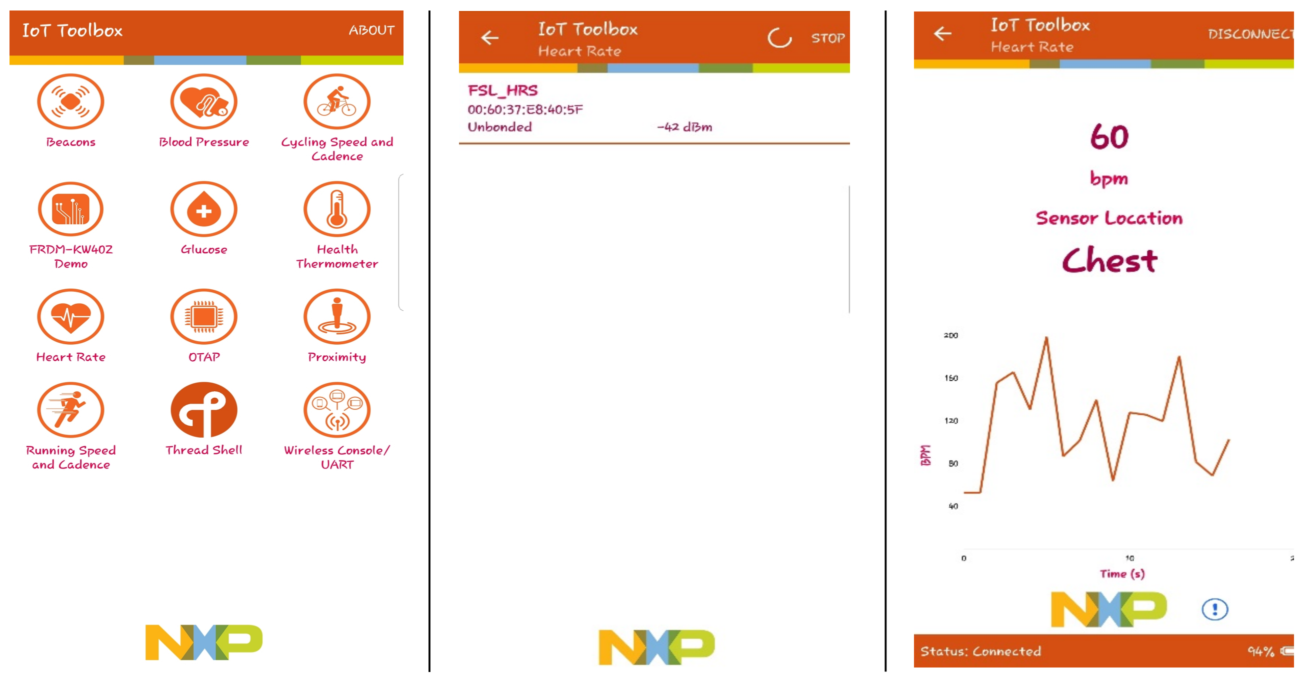

Figure 43. IoT Toolbox

On the Central side (in this case a mobile phone or a tablet with Bluetooth® LE available) the following application must be installed: IoT Toolbox available on Google® Play as well as on Apple® iTunes.

The HEART RATE application should be used. For measuring advertising events, there is no need for a connecting device, but for measuring connection events it is mandatory. To connect to the FRDM-KW36 board the procedure is simple and straight forward:

- Open IoT Toolbox.
- Press SW3 on.
- Power-up FRDM-KW36 board and press SW3 to start advertising.
- On Android application the FSL_HRS will be reported at scan phase.
- Connect to FSL_HRS peripheral.
- Wait for measurements.

4.2.2.5.1 Templates

DSM1 is activated between the connection events.

Figure 44. Current consumption - CONNECTION event period

Table 30. CONNECTION event

Phase	Event
1	Pre-processing
2	MCU stop
3	RX warm-up
4	Active RX
5	RX warm-down
6	RX to TX transition
7	TX warm-up
8	Active TX
9	TX warm-down
10	Post-processing

4.2.2.5.2 Test environment 1

Table 31. CONNECTION event, Buck mode, 0 dBm, Flash dozed, MCU stop

DC-DC: mode	BUCK
Supply	VDCDC_IN = 2.1 V, 2.6 V, 3.6 V
RF output power	+0 dBm
Payload	23 bytes
Flash	Dozed
MCU	Stop
Setting	Advertising Interval = 10 ms Slave to Master
Software	Heart Rate Sensor (SDK 2.2 release)

Table 32. Current consumption during CONNECTION event

Phase	Event	Time	Avg. @2.1 V	Avg. @2.6 V	Avg. @3.6 V
1 2	Pre-processing + MCU stop	1.2 ms 0.6 ms	4.30 mA	3.85 mA	3.27 mA
3	RX warm-up	110 μs	7.19 mA	6.48 mA	5.22 mA
4	Active RX	65 μs	**13.44 mA**	**11.83 mA**	**9.23 mA**
5	RX warm-down	50 μs	8.59 mA	7.39 mA	8.64 mA
6	RX to TX transition	50 μs	5.78 mA	4.43 mA	3.45 mA
7	TX warm-up	50 μs	8.97 mA	8.91 mA	5.24 mA
8	Active TX	65 μs	**14.87 mA**	**12.07 mA**	**9.01 mA**
9	TX warm-down	20 μs	8.91 mA	5.17 mA	6.02 mA
10	Post-processing	1.2 ms	4.91 mA	4.67 mA	4.06 mA
—	**Full period**	**3.41 ms**	**5.24 mA**	**4.72 mA**	**3.81 mA**
—	**DSM1**	**6.59 ms**	**3.57 μA**	**3.14 μA**	**2.72 μA**
—	**Total consumption**	**10 ms**	**1.789 mA**	**1.612 mA**	**1.301 mA**

4.2.2.5.3 Test environment 2

Table 33. CONNECTION event, Buck mode, 0 dBm, Flash enabled, MCU run

DC-DC: mode	BUCK
Supply	VDCDC_IN = 2.1 V, 2.6 V, 3.6 V
RF output power	+0 dBm

Table continues on the next page...

Table 33. CONNECTION event, Buck mode, 0 dBm, Flash enabled, MCU run (continued)

DC-DC: mode	BUCK
Payload	23 bytes
Flash	Enabled
MCU	Run
Setting	Advertising Interval = 10 ms Slave to Master
Software	Heart Rate Sensor (SDK 2.2 release)

Table 34. Current consumption during CONNECTION event

Phase	Event	Time	Avg. @2.1 V	Avg. @2.6 V	Avg. @3.6 V
1 2	Pre-processing + MCU stop	1.2 ms 0.6 ms	5.12 mA	5.12 mA	4.04 mA
3	RX warm-up	110 µs	10.10 mA	10.10 mA	7.53 mA
4	Active RX	65 µs	**11.65 mA**	**11.65 mA**	**9.14 mA**
5	RX warm-down	50 µs	12.03 mA	12.03 mA	8.82 mA
6	RX to TX transition	50 µs	8.02 mA	8.02 mA	6.47 mA
7	TX warm-up	50 µs	9.68 mA	9.68 mA	9.54 mA
8	Active TX	65 µs	**13. 72 mA**	**13.72 mA**	**10.11 mA**
9	TX warm-down	20 µs	9.61 mA	9.61 mA	6.12 mA
10	Post-processing	1.2 ms	3.97 mA	3.97 mA	3.90 mA
—	**Full period**	**3.41 ms**	**5.90 mA**	**5.90 mA**	**4.61 mA**
—	**DSM1**	**6.59 ms**	**3.57 µA**	**3.14 µA**	**2.72 µA**
—	**Total consumption**	**10 ms**	**2.123 mA**	**2.014 mA**	**1.574 mA**

4.2.2.6 Scan mode

Using the steps provided in Software configuration for low-power operation, partial Bluetooth® LE scenario (Temperature Collector application) was captured and can be observed in Figure 45. The main events and phases are documented within the capture. All the plots that follow depicts current.

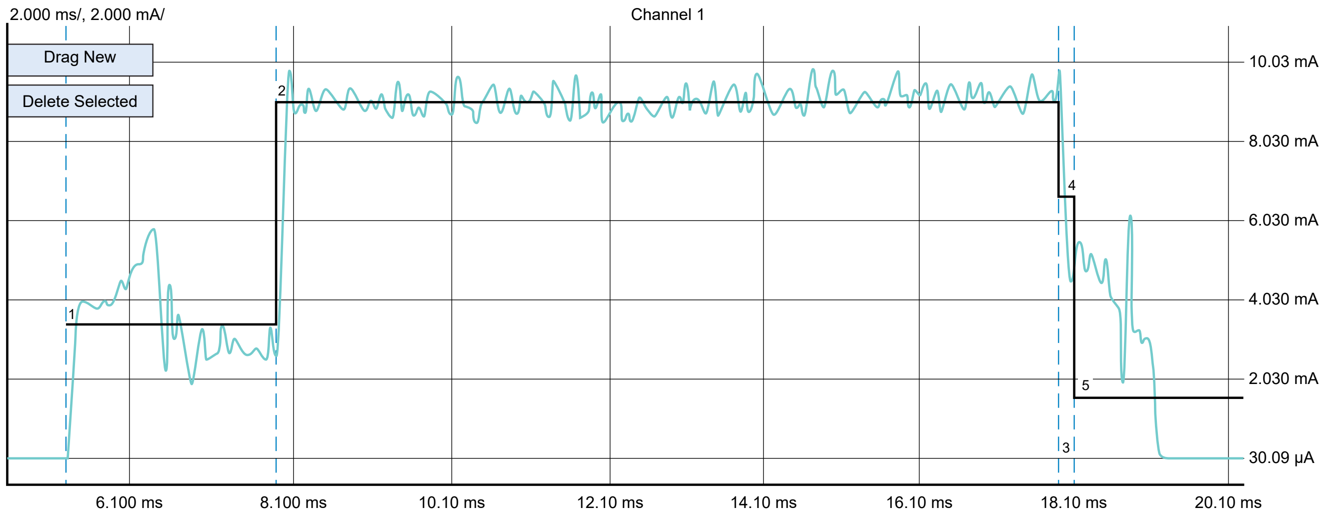

Figure 45. Current consumption - SCAN event period

Table 35. SCAN events

Phase	Event
1	Pre-processing
2	RX warm-up
3	Active RX
4	RX warm-down
5	Post-processing

4.2.2.6.1 Test environment 1

Table 36. SCAN event, Buck and Bypass mode, Flash dozed, MCU stop

DC-DC: mode	BUCK	BYPASS
Supply	VDCDC_IN = 2.1 V, 2.6 V, 3.6 V	VDDRF = 1.5 V VDDMCU = 1.8 V
Flash	Dozed	
MCU	Stop	
Setting	Scanning Interval = 100 ms Active Scan Duration = 10 ms Slave to Master	
Software	Temperature Collector (SDK 2.2 release)	

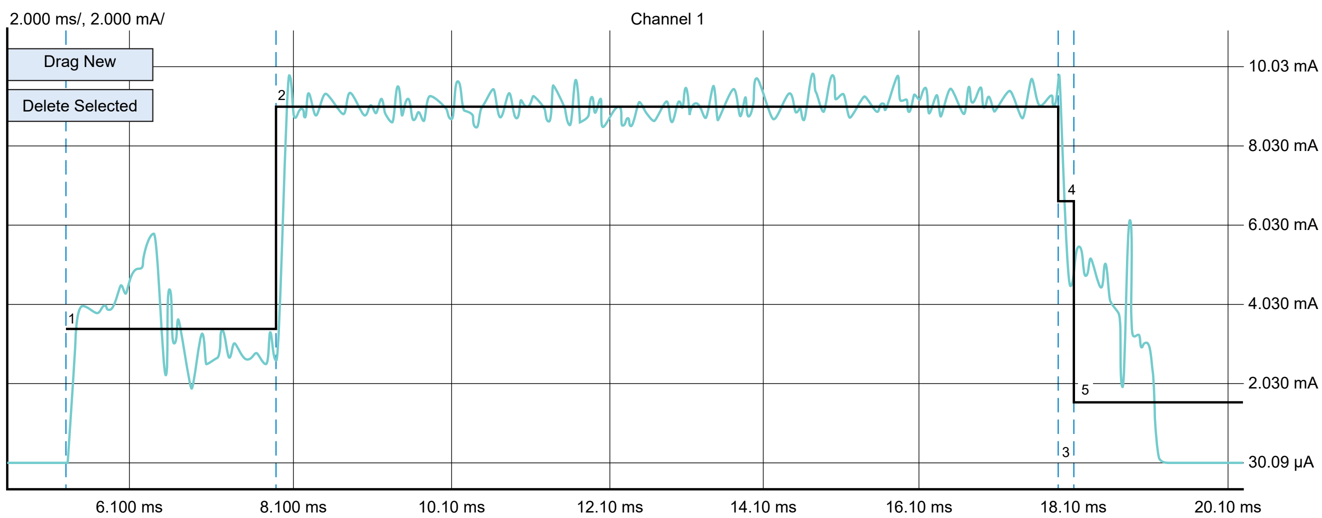

Figure 46. Current consumption during SCAN event, Buck and Bypass mode, Flash dozed, MCU stop

Table 37. Current consumption during SCAN event, Flash dozed, MCU stop

Phase	Event	Time	Buck mode Avg.			Bypass mode Avg.
			@2.1 V	@2.6 V	@3.6 V	
1	Pre-processing	1.8 ms	4.25 mA	3.67 mA	3.30 mA	4.82 mA
2	RX warm-up	0.1 ms	10.11 mA	8.19 mA	7.54 mA	12.2 mA
3	Active RX	10 ms	14.11 mA	11.69 mA	8.98 mA	17.51 mA
4	RX warm-down	0.1 ms	10.25 mA	7.41 mA	7.30 mA	11.67 mA
5	Post-processing	1.3 ms	4.47 mA	4.25 mA	3.84 mA	6.81 mA
—	**Full period**	**13.3 ms**	**11.18 mA**	**9.38 mA**	**7.44 mA**	**14.67 mA**
—	**DSM1**	**86.7 ms**	**3.57 µA**	**3.14 µA**	**2.72 µA**	**292 nA**
—	**Total consumption**	**100 ms**	**1.490 mA**	**1.250 mA**	**0.992 mA**	**1.953 mA**

4.2.2.6.2 Test environment 2

Table 38. SCAN event, Buck and Bypass mode, Flash enabled, MCU run

DC-DC: mode	BUCK	BYPASS
Supply	VDCDC_IN = 2.1 V, 2.6 V, 3.6 V	VDDRF = 1.5 V VDDMCU = 1.8 V
Flash	Enabled	
MCU	Run	
Setting	Scanning Interval = 100 ms Active Scan Duration = 10 ms	

Table continues on the next page...

Table 38. SCAN event, Buck and Bypass mode, Flash enabled, MCU run (continued)

DC-DC: mode	BUCK	BYPASS
	Slave to Master	
Software	Temperature Collector (SDK 2.2 release)	

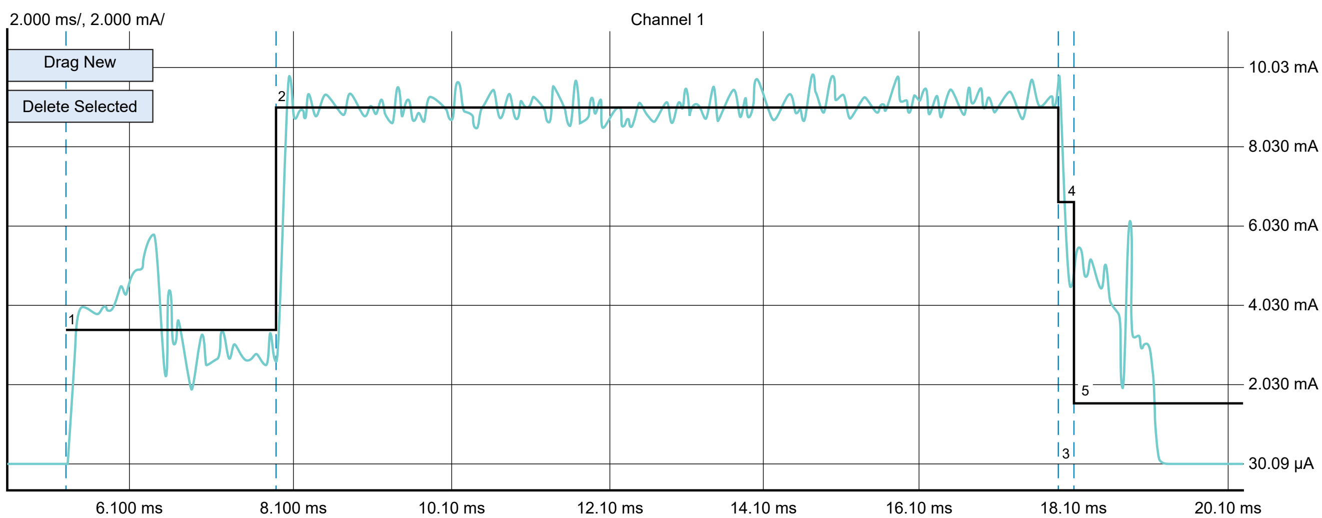

Figure 47. Current consumption during SCAN event, Flash enabled, MCU run

Table 39. Current consumption during SCAN event, Flash enabled, MCU run

Phase	Event	Time	Buck mode Avg.			Bypass mode Avg.
			@2.1 V	@2.6 V	@3.6 V	
1	Pre-processing	1.8 ms	6.06 mA	5.07 mA	4.22 mA	6.86 mA
2	RX warm-up	0.1 ms	16.34 mA	10.18 mA	9.47 mA	16.58 mA
3	Active RX	10 ms	19.11 mA	14.93 mA	11.03 mA	22.10 mA
4	RX warm-down	0.1 ms	11.99 mA	10.30 mA	8.10 mA	12.46 mA
5	Post-processing	1.3 ms	3.96 mA	3.95 mA	3.69 mA	6.77 mA
—	**Full period**	**13.3 ms**	**14.92 mA**	**12.27 mA**	**9.54 mA**	**18.5 mA**
—	**DSM1**	**86.7 ms**	**3.57 µA**	**3.14 µA**	**2.72 µA**	**292 nA**
—	**Total consumption**	**100 ms**	**1.987 mA**	**1.635 mA**	**1.271 mA**	**2.463 mA**

4.3 Reports

Table 40, Table 41, and Table 42 provide power consumption at 2.1 V, 2.6 V, and 3.6 V in buck mode, at different temperature (-20 °C, +25 °C, +65 °C) and bypass mode at 3.6 V at ambient temperature (+25 °C).

Table 40. SoC measurements summary, voltage at 25 °C (ambient temperature)

Temperature	MCU state	Flash state	Radio state	DC-DC state/ voltage =>	Measurement			Bypass	Unit
					@2.1 V	@2.6 V	@3.6 V		
25 °C	STOP	Dozed	Advertising (0 dBm)	Buck	1.82	1.61	1.32	2.55	mA
	STOP	Dozed	Advertising with response (0 dBm)	Buck	2.05	1.72	1.45	3.53	mA
	STOP	Dozed	Advertising (+3.5 dBm)	Buck	1.87	1.76	1.65	2.61	mA
	STOP	Dozed	ADV - MCU	Buck	1.022	1.018	1.006	1.022	mA
	STOP	Dozed	Scan	Buck	1.49	1.25	0.99	—	mA
	STOP	Dozed	Connection	Buck	1.79	1.61	1.30	—	mA
	RUN	Enabled	Advertising (0 dBm)	Buck	2.43	2.12	1.69	3.27	mA
	RUN	Enabled	Advertising with response (0 dBm)	Buck	2.67	2.20	1.72	—	mA
	RUN	Enabled	Advertising (+3.5 dBm)	Buck	—	—	1.77	3.46	mA
	RUN	Enabled	ADV - MCU	Buck	1.73	1.71	1.66	1.73	mA
	RUN	Enabled	Scan	Buck	1.99	1.63	1.27	—	mA
	RUN	Enabled	Connection	Buck	2.12	2.01	1.57	—	mA

Table 41. SoC measurements summary, voltage at +65 °C

Temperature	MCU state	Flash state	Radio state	DC-DC state/ voltage =>	Measurement			Unit
					@2.1 V	@2.6 V	@3.6 V	
+65 °C	STOP	Dozed	Advertising (0 dBm)	Buck	1.90	1.62	1.34	mA
	STOP	Dozed	Advertising with response (0 dBm)	Buck	1.99	1.72	1.39	mA
	STOP	Dozed	Advertising (+3.5 dBm)	Buck	2.51	2.17	1.77	mA
	STOP	Dozed	ADV - MCU	Buck	0.85	0.84	0.82	mA
	STOP	Dozed	Scan	Buck	1.51	1.28	0.99	mA

Table continues on the next page...

Table 41. SoC measurements summary, voltage at +65 °C (continued)

Temperature	MCU state	Flash state	Radio state	DC-DC state/ voltage =>	Measurement			Unit
					@2.1 V	@2.6 V	@3.6 V	
	STOP	Dozed	Connection	Buck	1.96	1.69	1.37	mA
	RUN	Enabled	Advertising (0 dBm)	Buck	2.48	2.07	1.73	mA
	RUN	Enabled	Advertising with response (0 dBm)	Buck	2.87	2.31	1.82	mA
	RUN	Enabled	ADV - MCU	Buck	1.86	1.85	1.85	mA
	RUN	Enabled	Scan	Buck	2.01	1.64	1.28	mA
	RUN	Enabled	Connection	Buck	2.20	2.03	1.59	mA

Table 42. SoC measurements summary, voltage at -20 °C

Temperature	MCU state	Flash state	Radio state	DC-DC state/ voltage =>	Measurement			Unit
					@2.1 V	@2.6 V	@3.6 V	
-20 °C	STOP	Dozed	Advertising (0 dBm)	Buck	1.85	1.61	1.36	mA
	STOP	Dozed	Advertising with response (0 dBm)	Buck	1.97	1.75	1.43	mA
	STOP	Dozed	Advertising (+3.5 dBm)	Buck	2.35	1.77	1.74	mA
	STOP	Dozed	ADV - MCU	Buck	0.81	0.79	0.76	mA
	STOP	Dozed	Scan	Buck	1.47	1.24	0.99	mA
	STOP	Dozed	Connection	Buck	1.78	1.59	1.28	mA
	RUN	Enabled	Advertising (0 dBm)	Buck	2.43	2.12	1.72	mA
	RUN	Enabled	Advertising with response (0 dBm)	Buck	2.64	2.18	1.82	mA
	RUN	Enabled	ADV - MCU	Buck	1.82	1.81	1.81	mA
	RUN	Enabled	Scan	Buck	1.87	1.61	1.25	mA

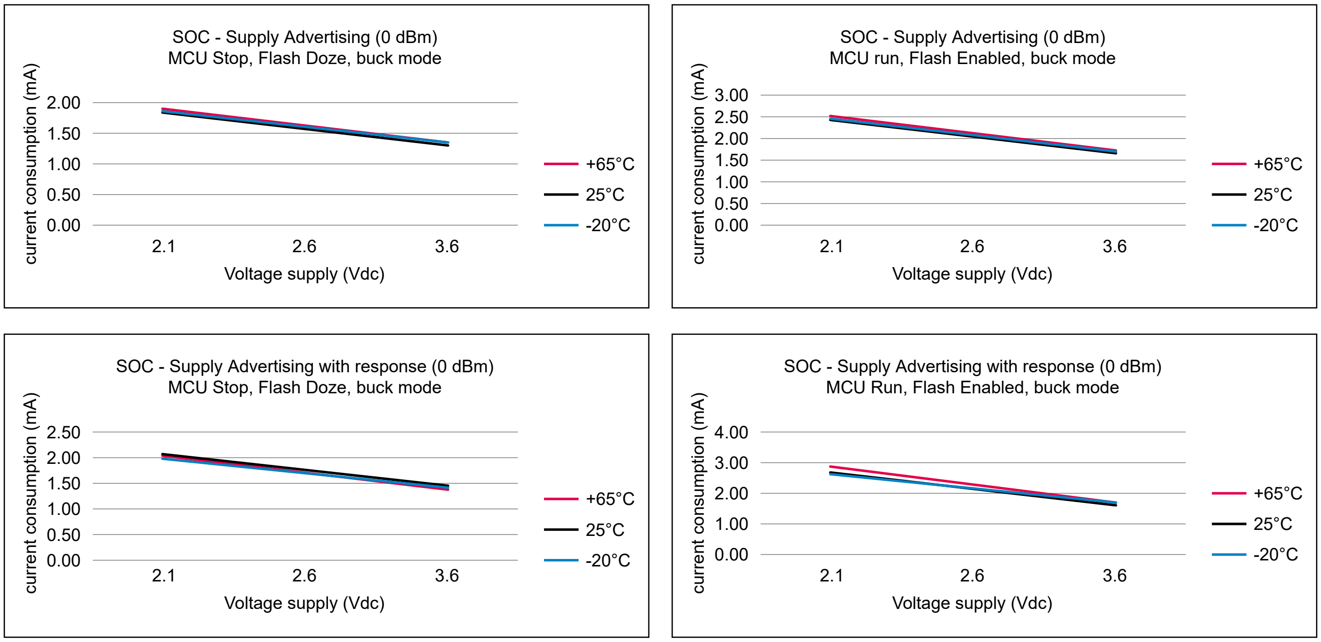

Figure 48. 4 × Advertising event on peripheral side graphs

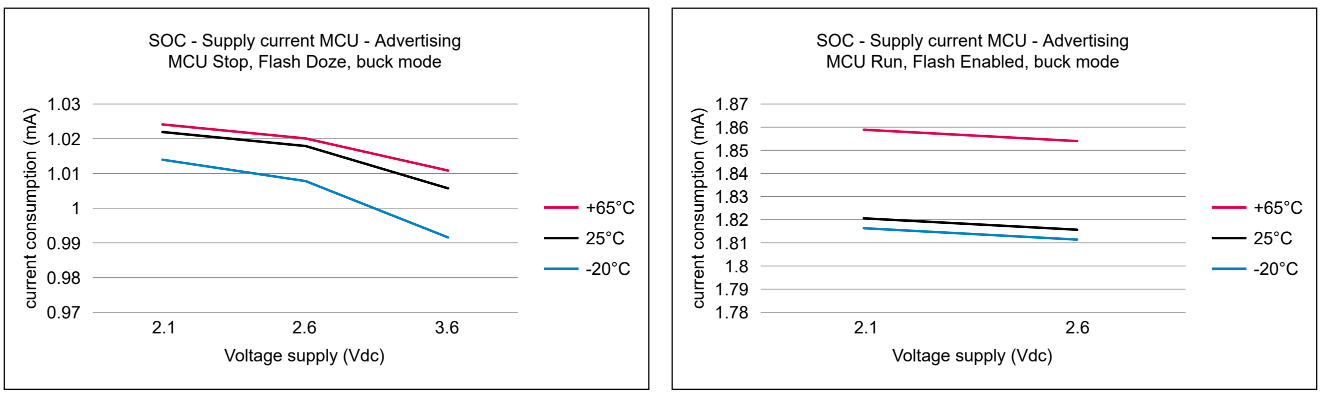

Figure 49. 2 × MCU supply current during advertising event graphs

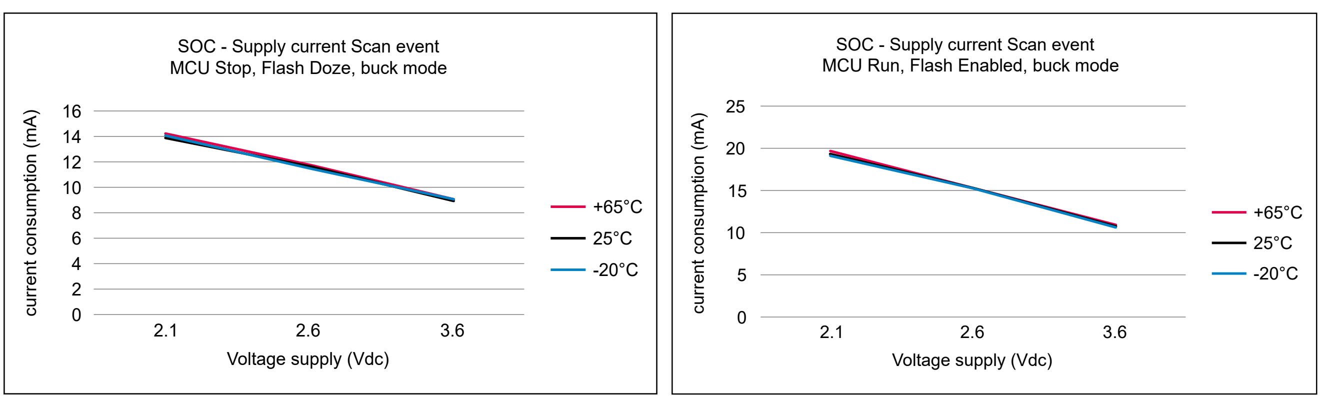

Figure 50. 2 × Scan event on peripheral side graphs

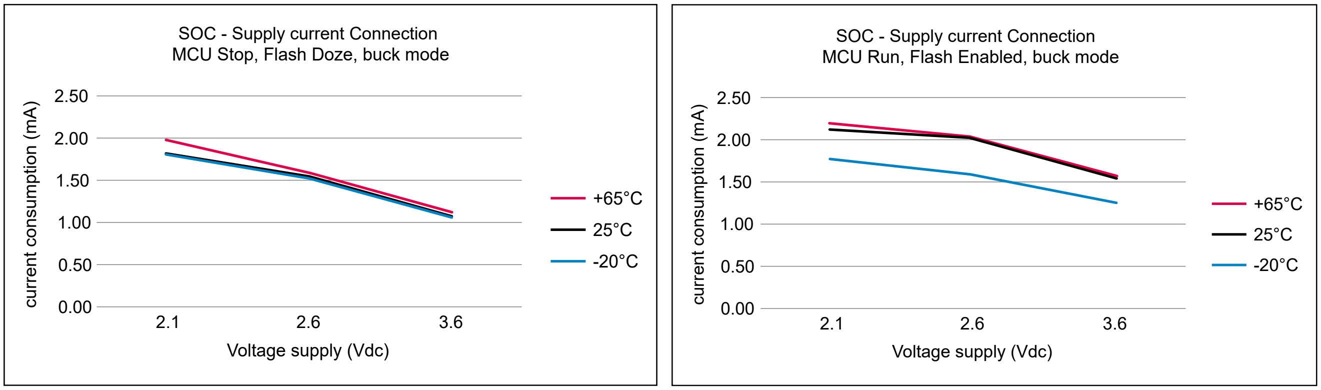

Figure 51. 2 × Connection event on peripheral side graphs

Table 43, Table 44, and Table 45 summarize the static measurements performed on the SoC plus some others (XCVR&DSM1) in three different temperatures (-20 °C, +25 °C, and +65 °C) and voltage (2.1 V, 2.6 V, and 3.6 V), to be easier to observe and to correlate the numbers.

Table 43. Static measurements summary @+25 °C

Temperature	MCU state	Flash state	Radio state	DC-DC state/ voltage =>	Measurement			Unit
					@2.1 V	@2.6 V	@3.6 V	
+25 °C	STOP	Dozed	RX	Buck	12.98	10.77	8.54	mA
	STOP	Dozed	RX (LDO-HF Bumped +5 dBm)	Buck	—	—	8.7	mA
	STOP	Dozed	TX (at 0 dBm)	Buck	12.37	9.94	7.79	mA
	STOP	Dozed	TX (at 3.5 dBm)	Buck	14.27	11.09	9.17	mA
	STOP	Dozed	TX (LDO-HF Bumped +5 dBm)	Buck	—	—	10.3	mA
	STOP	Dozed	Scan	Buck	13.95	11.69	8.95	mA
	STOP	Dozed	ADV – MCU	Buck	1.022	1.018	1.006	mA
	STOP	Dozed	Connection – RX	Buck	14.49	11.99	8.02	mA
	STOP	Dozed	Connection – TX (0 dBm)	Buck	13.38	11.45	8.89	mA
	RUN	Enabled	RX	Buck	17.5	14.14	10.62	mA
	RUN	Enabled	RX (LDO-HF Bumped +5 dBm)	Buck	—	—	11.3	mA

Table continues on the next page...

Table 43. Static measurements summary @+25 °C (continued)

Temperature	MCU state	Flash state	Radio state	DC-DC state/ voltage =>	Measurement			Unit
					@2.1 V	@2.6 V	@3.6 V	
	RUN	Enabled	TX (at 0 dBm)	Buck	17.04	13.87	10.28	mA
	RUN	Enabled	TX (at 3.5 dBm)	Buck	18.08	14.71	11.71	mA
	RUN	Enabled	TX (LDO-HF Bumped +5 dBm)	Buck	—	—	13.1	mA
	RUN	Enabled	Scan	Buck	18.27	14.9	11.16	mA
	RUN	Enabled	ADV – MCU	Buck	1.821	1.816	1.81	mA
	RUN	Enabled	Connection – RX	Buck	18.74	15.23	10.75	mA
	RUN	Enabled	Connection – TX (0 dBm)	Buck	16.7	14.01	10.84	mA
	STOP	Dozed	RX	Bypass	—	—	17.32	mA
	STOP	Dozed	RX (LDO-HF Bumped +5 dBm)	Bypass	—	—	18.2	mA
	STOP	Dozed	TX (at 0 dBm)	Bypass	—	—	15.95	mA
	STOP	Dozed	TX (at 3.5 dBm)	Bypass	—	—	18.3	mA
	STOP	Dozed	TX (LDO-HF Bumped +5 dBm)	Bypass	—	—	20.8	mA
	STOP	Dozed	Scan	Bypass	—	—	17.51	mA
	RUN	Enabled	RX	Bypass	—	—	21.87	mA
	RUN	Enabled	RX (LDO-HF Bumped +5 dBm)	Bypass	—	—	22.6	mA
	RUN	Enabled	TX (at 0 dBm)	Bypass	—	—	19.27	mA
	RUN	Enabled	TX (at 3.5 dBm)	Bypass	—	—	22.36	mA
	RUN	Enabled	TX (LDO-HF Bumped +5 dBm)	Bypass	—	—	26.6	mA
	RUN	Enabled	Scan	Bypass	—	—	22.1	mA

Table 44. Static measurements summary @+65 °C

Temperature	MCU state	Flash state	Radio state	DC-DC state/ voltage =>	Measurement			Unit
					@2.1 V	@2.6 V	@3.6 V	
+65 °C	STOP	Dozed	RX	Buck	14.72	11	8.9	mA
	STOP	Dozed	TX (at 0 dBm)	Buck	13.15	10.03	8.04	mA
	STOP	Dozed	TX (at 3.5 dBm)	Buck	—	—	—	mA
	STOP	Dozed	Scan	Buck	14.23	11.82	9.03	mA
	STOP	Dozed	Scan - MCU	Buck	0.637	0.635	0.63	
	STOP	Dozed	ADV – MCU	Buck	1.024	1.02	1.011	mA
	STOP	Dozed	Connection – RX	Buck	14.87	12.07	9.01	mA
	STOP	Dozed	Connection – TX (0 dBm)	Buck	13.44	11.83	9.23	mA
	RUN	Enabled	RX	Buck	19.49	15.61	13.63	mA
	RUN	Enabled	TX (at 0 dBm)	Buck	16.99	13.99	10.85	mA
	RUN	Enabled	TX (at 3.5 dBm)	Buck	—	—	—	mA
	RUN	Enabled	Scan	Buck	19.11	14.93	11.38	mA
	RUN	Enabled	Scan - MCU	Buck	1.93	1.92	1.9	mA
	RUN	Enabled	ADV – MCU	Buck	1.74	1.73	1.7	mA
	RUN	Enabled	Connection – RX	Buck	19.16	16.23	12.18	mA
	RUN	Enabled	Connection – TX (0 dBm)	Buck	18.38	15.51	12.15	mA

Table 45. Static measurements summary @-20 °C

Temperature	MCU state	Flash state	Radio state	DC-DC state/ voltage =>	Measurement			Unit
					@2.1 V	@2.6 V	@3.6 V	
-20 °C	STOP	Dozed	RX	Buck	11.83	9.6	8.28	mA
	STOP	Dozed	TX (at 0 dBm)	Buck	11.53	9.48	7.56	mA
	STOP	Dozed	TX (at 3.5 dBm)	Buck	—	—	—	mA

Table continues on the next page...

Table 45. Static measurements summary @-20 °C (continued)

Temperature	MCU state	Flash state	Radio state	DC-DC state/ voltage =>	Measurement			Unit
					@2.1 V	@2.6 V	@3.6 V	
	STOP	Dozed	Scan	Buck	14.11	11.55	8.98	mA
	STOP	Dozed	Scan - MCU	Buck	0.582	0.583	0.582	
	STOP	Dozed	ADV – MCU	Buck	1.014	1.008	0.992	mA
	STOP	Dozed	Connection – RX	Buck	13.47	10.22	7.1	mA
	STOP	Dozed	Connection – TX (0 dBm)	Buck	13.22	11.11	8.41	mA
	RUN	Enabled	RX	Buck	17.02	11.79	10.49	mA
	RUN	Enabled	TX (at 0 dBm)	Buck	16.52	13.83	10.22	mA
	RUN	Enabled	TX (at 3.5 dBm)	Buck	—	—	—	mA
	RUN	Enabled	Scan	Buck	18.04	14.88	11.03	mA
	RUN	Enabled	Scan - MCU	Buck	1.87	1.86	1.83	mA
	RUN	Enabled	ADV – MCU	Buck	1.72	1.7	1.63	mA
	RUN	Enabled	Connection – RX	Buck	15.74	13.72	10.11	mA
	RUN	Enabled	Connection – TX (0 dBm)	Buck	13.49	11.65	9.14	mA

Table 46 shows the static measurements on different configuration of the radio block (XCVR).

Table 46. XCVR measurements summary, voltage, and temperature

Temperature	Characteristics	DC-DC state/ voltage =>	Measurement			Unit
			@2.1 V	@2.6 V	@3.6 V	
+65 °C	Supply current RX on with DC-DC converter enabled	Buck	12	8.48	6.46	mA
	Supply current TX on with PRF = 0 dBm and DC-DC converter enabled	Buck	10.43	7.42	5.2	mA
	Supply current TX on with PRF	Buck	—	—	—	mA

Table continues on the next page...

Table 46. XCVR measurements summary, voltage, and temperature (continued)

Temperature	Characteristics	DC-DC state/ voltage =>	Measurement			Unit
			@2.1 V	@2.6 V	@3.6 V	
	= +3.5 dBm and DC-DC converter enabled					
+25 °C	Supply current RX on with DC-DC converter enabled	Buck	10.26	8.13	6.26	mA
	Supply current TX on with PRF = 0 dBm and DC-DC converter enabled	Buck	9.65	7.3	5.51	mA
	Supply current TX on with PRF = +3.5 dBm and DC-DC converter enabled	Buck	11.34	7.52	7.1	mA
	Supply current TX on with PRF = +5 dBm and DC-DC converter enabled	Buck	—	—	7.9	mA
-20 °C	Supply current RX on with DC-DC converter enabled	Buck	8.7	6.86	5.65	mA
	Supply current TX on with PRF = 0 dBm and DC-DC converter enabled	Buck	8.4	6.74	4.93	mA
	Supply current TX on with PRF = +3.5 dBm and DC-DC converter enabled	Buck	—	—	—	mA

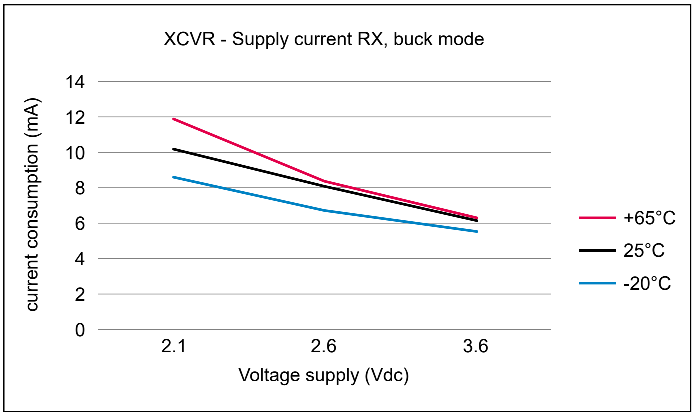

Figure 52. XCVR – Supply current RX, buck mode

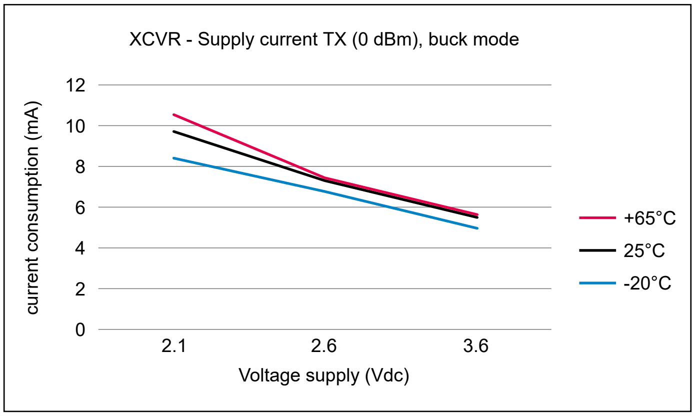

Figure 53. XCVR – Supply current TX, buck mode

Table 47. DSM1 measurements summary, voltage, and temperature

Temperature	Characteristics	DC-DC state/ voltage =>	Measurement			Unit
			@2.1 V	@2.6 V	@3.6 V	
+65 °C	Supply current DSM1 with DC-DC converter enabled, flash dozed, MCU stop	Buck	7.46	6.80	4.83	mA
+25 °C	Supply current DSM1 with DC-DC converter enabled, flash dozed, MCU stop	Buck	3.57	3.14	2.72	mA
-20 °C	Supply current DSM1 with DC-	Buck	3.36	2.97	2.42	mA

Table continues on the next page...

Table 47. DSM1 measurements summary, voltage, and temperature (continued)

Temperature	Characteristics	DC-DC state/ voltage =>	Measurement			Unit
			@2.1 V	@2.6 V	@3.6 V	
	DC converter enabled, flash dozed, MCU stop					
+25 °C	Supply current DSM1 without DC-DC converter, flash dozed, MCU stop	Bypass	—	—	292	nA

5 Acronyms and abbreviations

Table 48. Acronyms and abbreviations

Acronym/Abbreviation	Description
ADC	Analog to Digital Converter
ARM	Advanced RISC Machine (RISC – Reduced Instruction Set Computer)
BPSK	Binary Phase Shift Keying
BTLL	Bluetooth® Link Layer
CMP	Comparator module
DAC	Digital to Analog Converter
DC	Direct Current
DSM	Deep Sleep Mode
DUT	Device Under Test
ESR	Equivalent Series Resistance
FRDM	Freedom board
GAP	Generic Access Profile
GFSK	Gaussian Frequency Shift Keying
GPIO	General Purpose Input / Output
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
ISM	Industrial, Scientific, and Medical bands
LE	Low Energy
LL	Link Layer

Table continues on the next page...

Table 48. Acronyms and abbreviations (continued)

Acronym/Abbreviation	Description
LLS	Low-Leakage Stop
LLWU	Low-Leakage Wake-up Unit
LPTMR	Low-power Timer
LPUART	Low-power UART
MBAN	Medical Body Area Network
MCU	Microcontroller Unit
O-QPSK	Offset Quadrature Phase Shift Keying
PC	Personal Computer
PDU	Protocol Data Unit
PMC	Power Management Controller
RX	Reception
SAR	Successive Approximation Register ADC
SCGC	System Clock Gating Control register
SIM	System Integration Module
SMPS	Switched Mode Power Supply
SRAM	Static Random Access Memory
TMR	Timer
TSM	Transceiver Sequence Manager
TX	Transmission
UART	Universal Asynchronous Receiver Transmitter
USB	Universal Serial Bus
VLLS	Very Low Leakage Stop
XCVR	Transceiver

6 Revision history

Table 49. Revision history

Revision number	Date	Substantive changes
0	10/2018	Initial release.
1	12/2018	Replaced DSM3 with DSM1.
2	06/2019	Updated data in Table 23 and Table 25.
3	04/2020	Added the case of RF output power = +5 dBm in Bluetooth smart applications configuration, RF

Table continues on the next page...

Table 49. Revision history (continued)

Revision number	Date	Substantive changes
		output power settings (0 dBm, +3.5 dBm, or +5 dBm). Added the case of RF output power = +5 dBm in Tables of Table 43 and Table 46 Added a new chapter of Test environment 3.
4	02/2021	Editorial updates. Updated the section DSM. Updated the section Coin cell 3.0 V power supply. Added a new chapter of DC-DC peak information.

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