1 Introduction

This User Manual describes how to use Qorvo's Energy Budget Calculator ("tool") to estimate energy usage of Qorvo IoT battery-powered solutions. This tool is designed to assist users in estimating energy consumption tailored to applications including Matter-over-Thread and Zigbee Sleepy End Devices (SED), Bluetooth® Low Energy Peripherals and Ultra-wideband (UWB) Initiators, using Qorvo communication controllers ("chip").

It provides insights, not only on the distribution of use cases, but also the peak and average current of a regular RF event. These can help developers further optimize their applications to maximize battery life without diving into too much detail of communication protocols.

Please note that only regular RF activities, typical numbers of DC currents, and the averaging of random behaviors are taken into account. Connection setup, connection drop and reconnection will not be considered. The calculated results may have a small discrepancy when compared to measurements. The results provided are intended solely for evaluation purposes.

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2 Getting Start

2.1 User Interface Overview

Figure 1: User Interface of Energy Budget Calculator

Battery specification, RF activities and peripheral usages are the three major portions that determine the maximum achievable battery life of a battery powered wireless connectivity device. The user interface is organized as follows:

The tab [Energy Distribution] contains the most essential parameters for a quick evaluation. This section also provides an overview of energy consumption across various use cases of user specified applications, and thus the impact on battery life. The tab [Chip & RF Setting] defines the configurations of Qorvo communication controller and regular RF events with respect to the communication protocol. This section also visualizes the current waveform of a single RF event and gives the average and peak current numbers. [Peripheral Use Case] allows users to add the external peripherals and the corresponding use cases.

[Model Setup] models the network behavior such as the probabilities of random backoff (CSMA-CA attempts) and MAC retries due to packet loss, which are only applicable for IEEE 802.15.4 – 2.4GHz RF PHY. The guidelines for these application specific user cases will be detailed in the following sections.

2.2 Energy Distribution

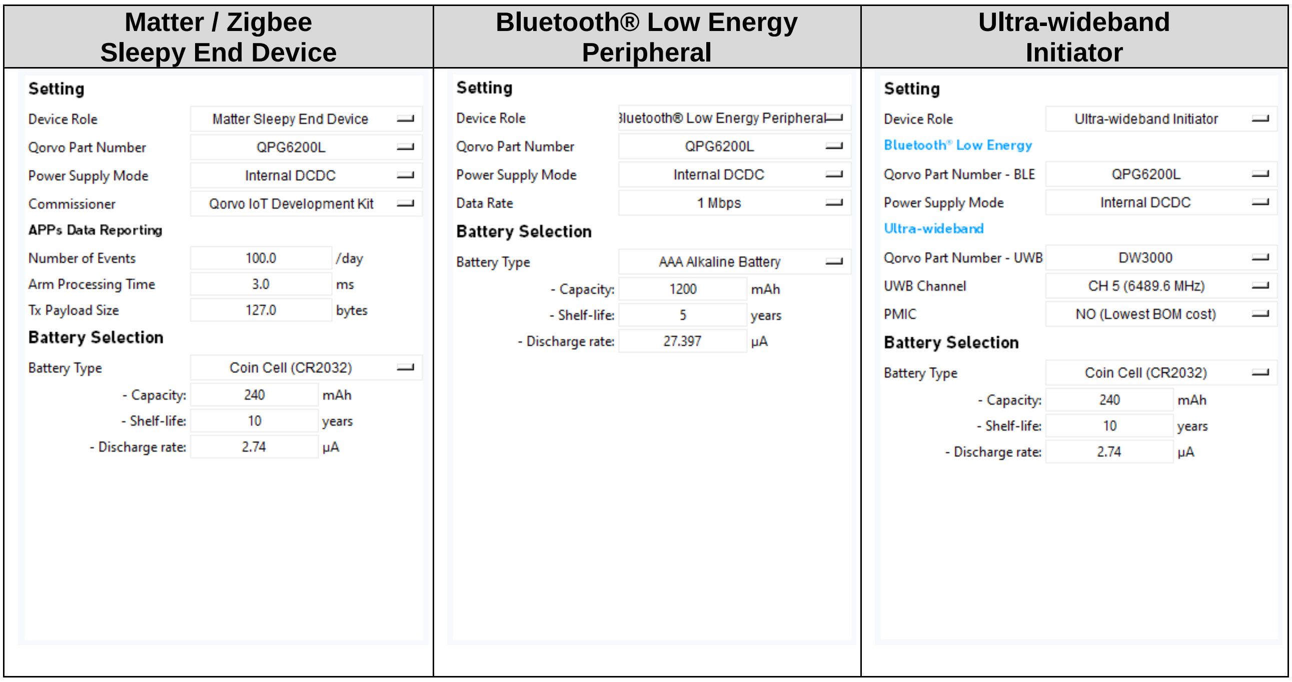

Figure 2: Basic Settings of Different Device Roles

Users have to first select the device role as shown in **Error! Reference source not found.**. The supported communication controllers can be then selected through the drop-down menu of Qorvo part number. After that, the available settings will pop up, i.e.,

Matter / Zigbee Sleepy End Device:

- Power Supply Mode: Internal LDO mode, or DCDC mode (if applicable)
- Commissioner: Qorvo IoT Development Kit, or Third Parties from json file (refer to section 3.3)
- 2.4GHz Network Traffic
- APPs Data Reporting.

Bluetooth® Low Energy Peripheral:

- Power Supply Mode: Internal LDO mode, or DCDC mode (if applicable)
- Data Rate: 1 Mbps or 2 Mbps (connected mode).

Ultra-wideband Initiator:

- Power Supply Mode (BLE): Internal LDO mode, or DCDC mode (if applicable)
- Channel (UWB): CH5 (6489.6 MHz) or CH 9 (7987.2 MHz)
- PMIC (UWB): NO (lowest BOM cost) or YES (highest power efficient).

The last user input is battery selection including battery type, its capacity and shelf-life. Then the discharge rate can be calculated by

$$Discharge\ Rate\ [\mu A] = \frac{Capacity\ [mAh] \times 1000}{ShelfLife\ [years] \times 365\ [days] \times 24\ [hours]}$$

These numbers can be, of course, overruled by user inputs.

Figure 3: Demonstration of Tooltip and Highlight Effects

An overview of energy consumption across various categories is presented in two formats:

- Donut Chart: top level overview of each share of energy consumption per day
- Distribution Overview: detailed figures per day ranked in descending order

The calculated battery life can be found below Distribution Overview. To optimize battery performance, users can hover the cursor over the ⓘ icon, as shown in Figure 3. A tooltip will appear, providing guidance and directing users to relevant sections for optimizing use cases.

2.3 Chip & RF Settings

This page is divided into two main sections: user inputs and the plot of the expected current waveform. The user inputs include configurations for chip settings, key parameters related to the communication protocol and profiler plot settings. The expected current waveform will be updated in real time based on these inputs over a specified observation period.

Please note that the current waveform is generated using several approximations, including typical values from the datasheet, average behavior over time, and worst-case scenarios for the listening window. Spikes caused by internal DC-DC converters are not taken into account, which may lead to discrepancies between the generated waveform and actual measurements.

Figure 4: User Interface of the Chip & RF Setting Section

2.3.1 Chip Configuration

The default configuration, primarily used in Qorvo SDK sample applications, is designed to achieve optimal RF performance. Users can adjust the chip settings to modify DC current consumption, as outlined in Table 1.

Table 1: Correlation between Chip Configuration and Current Consumptions

Parameters	Default Setting	Descriptions
ARM State: ACTIVE		
running from	Main Memory (NVM)	Location from where Firmware is running. Qorvo standard SDK only supports main memory.
ARM Clock	64 MHz	The higher the clock frequency is selected, the faster processing time, but comes at the cost of higher **ARM active current**. Those time parameters correlated with ARM active need to be updated manually.
ARM State: Standby		
Real Time Clock	Internal LjRC	The internal Low jitter RC (LjRC) is regularly calibrated by the main digital clock (i.e. 32 MHz) in software. For high clock accuracy requirement applications, “External 32 kiHz” is recommended. This selection will result in higher **standby current**.
RAM Retention Size	128 KB	**Standby current** is increased with higher RAM retained when chip enters sleep mode.
Radio Settings		
Tx power	10 dBm	Higher Tx power provides better RF range but comes with higher **Tx current.**
Antenna Diversity	Enabled (Dual Antenna)	Qorvo ConcurrentConnect™ Antenna Diversity can improve reliable RF range against multipath fading but comes with higher **Rx current** (< 1mA)**.**
Listening Mode	Single Channel	Single channel is low power listening mode, which receiver is switching ON and OFF for lower **Rx current**. Sensitivity can be improved by high sensitivity listening (the receiver to be always ON). In addition, Qorvo ConcurrentConnect™ technology also supports multi-channel listening for 3 channels.

2.3.2 RF Activities Configuration

This section is organized according to different device roles and the configuration will be briefly described in the following sub-sections.

2.3.2.1 Matter / Zigbee Sleepy End Device

Polling is identified as the most power-intensive RF activity in energy budget estimations. This allows the Target Device (Open Thread Border Router or Zigbee Coordinator) to periodically check the status of Sleepy End Devices (SED). A complete polling event begins with SED transmitting a media access control (MAC) data request to, then receiving an acknowledgement (ACK) from the Target.

Whenever there is a data request/response event triggered, short (active) polling will be used for high frequency data transfer. If there is no new event after the Threshold Time, polling activities will be switched from high to low duty cycle as known as long (idle) polling, for maintaining the heartbeat connection. Hence, this adaptive scheme saves energy by reducing the frequency of polling events.

The Target can also extend the polling session (frame pending bit = 1) to deliver queued messages or retrieve event data (not considered in this tool) from the SED, which is known as Rx Frame Reception Activity.

In practical case, ACK may be lost due to interference from environment or simply missed from the Target. SED will retransmit the data request packet until timeout or received an ACK, which is known as MAC level retries.

Table 2: RF Activities – Matter / Zigbee Sleepy End Device

Category	Parameters	Descriptions
Polling	Idle Polling Interval	interval of one polling event in low duty cycle default: 5000 ms
	Polling Active Time	the active time of polling activities from SED default: 24 hours/day, i.e. 86,400 sec
	Active Polling Interval	interval of MAC data request in high duty cycle default: 200 ms
	Threshold Time	timeout threshold to switch from short (active) to long (idle) polling default: 4000 ms
App Data Reporting	Number of Events	expected number of data request/response events. default: application specific
	Arm Process Time	the time requires Arm to process one data event default: application specific
	Tx Payload Size	payload size of one data event range: 5 to 127 bytes; application specific
RX Frame Reception Activity	Probability	likelihood of total polling sessions are extended with frame pending (Additional energy consumption for frame reception.)
	Rx Payload Size	expected payload size of frame pending range: 5 to 127 bytes; application specific
MAC Level Retry	Probability	probability of total polling activities without ACK (Additional energy consumption for packet retries.)

2.3.2.2 Bluetooth® Low Energy Peripheral

Connection events are identified as the most power-intensive RF activity in energy budget estimations. Similarly, this allows Bluetooth® Low Energy (BLE) Central to periodically check the status of peripherals after connection is setup. A complete connection event begins with the Peripheral receiving an empty packet or write/read request from, then transmitting an empty packet or write/read response to the Central.

For the consideration of better battery life, it is allowed to reduce the frequency of connection event by the last anchor point (the last completed connection event) and maximum allowable sleep time, which has high dependency on the clock accuracies at both Central and Peripheral. Slave Latency, the maximum number of consecutive connection events can be skipped, is used in this tool.

In practical case, a scheduled connection event may be lost due to interference from environment or simply missed from the Central. The Peripheral will keep listening until timeout.

Table 3: RF Activities - Bluetooth® Low Energy Peripheral

Category	Parameters	Descriptions
General	Data Rate	BLE supports uncoded 1 or 2 Mbps in connection status
	Advertising Interval	interval between each advertising event range: 20 – 10240 ms
Clock Accuracies	Central (Master) – Clock Type and Accuracy	The Bluetooth® Core Specifications defines active and sleep clock accuracies. And the worst numbers are taken into account, i.e. **Active**: ±50 ppm, **Sleep**: ±500 ppm, or **User Input:** ± 20 to 500 ppm. Recommended to set with the following numbers: 20, 30, 50, 75, 100, 150, 250 or 500.
	Peripheral (Slave) – Clock Type and Accuracy	Qorvo communication controller supports **32KiHz** (external 32768 Hz crystal): ±100 ppm, **RC** (internal low jitter RC) : ±500 ppm, or overruled by user input with the following numbers: 20, 30, 50, 75, 100, 150, 250 or 500.
Connection Setting	Connection Interval	interval between two consecutive connection events range: 7.5 – 4000 ms (a multiple of 1.25 ms)
	Slave Latency	maxAllowedLatency is calculated from maximum allowable sleep time by the tool range: 0 – maxAllowedLatency
Empty Packet Connection	Active Time	the active time of connection activities between Central and Peripheral default: 24 hours/day, i.e. 86,400 sec
Data Transmission	Transmission Interval	An approximated interval of write/read request from Central. It is used to calculate the number of data transmission events per day, e.g., a keypress event is approximately triggered in 1 s.
	Active Time	Duration of data transmission activities, e.g., a remote control is approximately active for 8 hours/day, i.e. 28800 sec.
	Rx Payload Size	approximated payload size received from Central in one data transmission event range: 0 – 256 bytes
	Tx Payload Size	approximated payload size transmitted to Central in one data transmission event range: 0 – 256 bytes
Missed Connection Packet	Probability	Probability of a scheduled connection event (empty packet) is missed. Additional energy consumption when waiting for a connection event from Central.

2.3.2.3 Ultra-wideband Initiator

A complete Qorvo Ultra-wideband (UWB) tag solution contains two radios. The BLE communication controller is primarily used for neighbor discovery, while the UWB transceiver is responsible for ranging. A two-way ranging (TWR) event is initiated by BLE advertising. After being discovered, the BLE chip wakes up the UWB radio to exchange TWR packets with the access point (Responder). And the accuracy of ranging can be improved by the number of attempts.

In the lowest BOM cost reference design, VDDs of UWB chip can be designated at the same supply voltage as the BLE chip. For the consideration of the highest power efficiency, an external power management IC (PMIC) can be used to further reduce the current consumptions of the UWB chip.

Table 4: RF Activities – Ultra-wideband Initiator

Category	Parameter	Description
General	UWB Channel	CH 5 (6489.6 MHz) / CH 9 (7987.2 MHz)
	PMIC	NO (lowest BOM cost) YES (highest power efficiency)
	Xtal Stabilization Duration	the start-up time of 38.4 MHz crystal (Xtal) oscillator from SLEEP/DEEPSLEEP default: 2000 µs The FiRa standard allows negotiated duration and the default value is 2 ms. This number is critical that prevent the UWB chip enters DEEPSLEEP or remains IDLE after Tx or Rx activities.
	PLL Lock Duration	the required time for PLL locked for RF activities from idle default: 100 µs
Bluetooth® Low Energy Neighbor Discovery		
Advertising Event	Advertising Interval	interval between each advertising event default: 2 s
	Active Time	the active time of Neighbor Discovery default: 24 hours/day, i.e. 86,400 sec
Scan Response Event	Number of Event	The same number as that of TWR attempts since Neighbor Discovery is to wake up the UWB radio.
FiRa Initiator Two-Way Ranging		
Two Way Ranging Event	TWR Event Mode	four Modes from FiRa: • DS-TWR Deferred Mode, • DS-TWR Non-Deferred Mode (4 messages) • DS-TWR Non-Deferred Mode (3 messages) • SS-TWR Non-Deferred Mode
	Number of Attempts	total number of ranging attempts per day
	Duration of Attempt	Time allocated for each ranging attempt. This will increase the number of TWR events with the defined attempt rate below.
	Attempt Rate	the frequency of attempts per second

2.3.3 Profiler Plot Setting

Under the Profiler Plot Settings, users can view both the average and peak current for individual events displayed in the plot. Key parameters relevant to the selected plot are also prominently presented, providing essential context for analysis. The Display Mode option allows users to zoom in or out, enabling a closer examination of the energy levels of different states or a comprehensive view of the entire waveform for a single event.

Furthermore, users can hover over specific states within the plot to access a tooltip that displays detailed information, including the start time, end time, duration, and current level for that state. This feature enhances the user experience by providing immediate insights, facilitating a more thorough understanding of the current waveform over time.

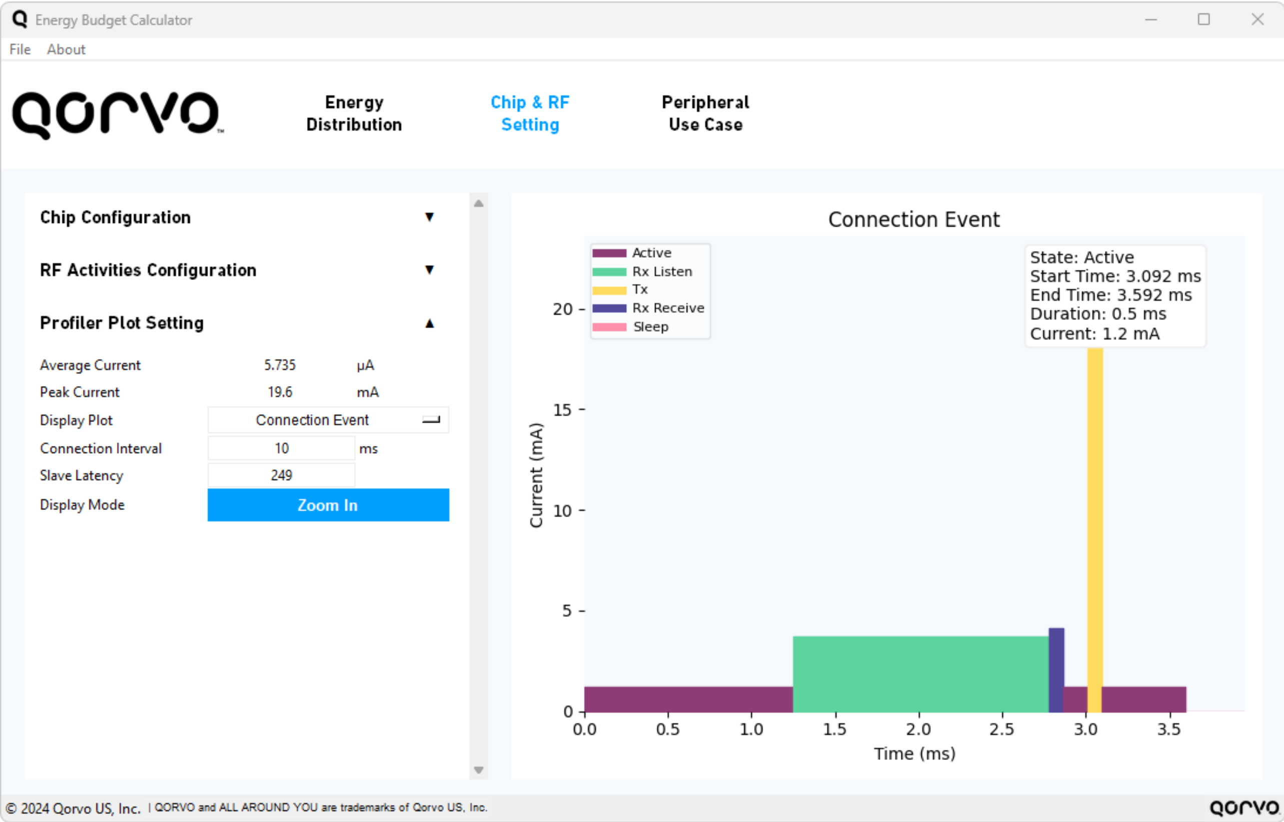

Figure 5: Demonstration of Profiler Plot Setting and ToolTip Effect

2.4 Peripheral Use Case

In this section, users can add customized devices with known or predefined specifications. The goal is to generate estimated values that closely match practical use cases, helping users select the appropriate battery or further adjust chip and RF activity configurations to optimize energy consumption.

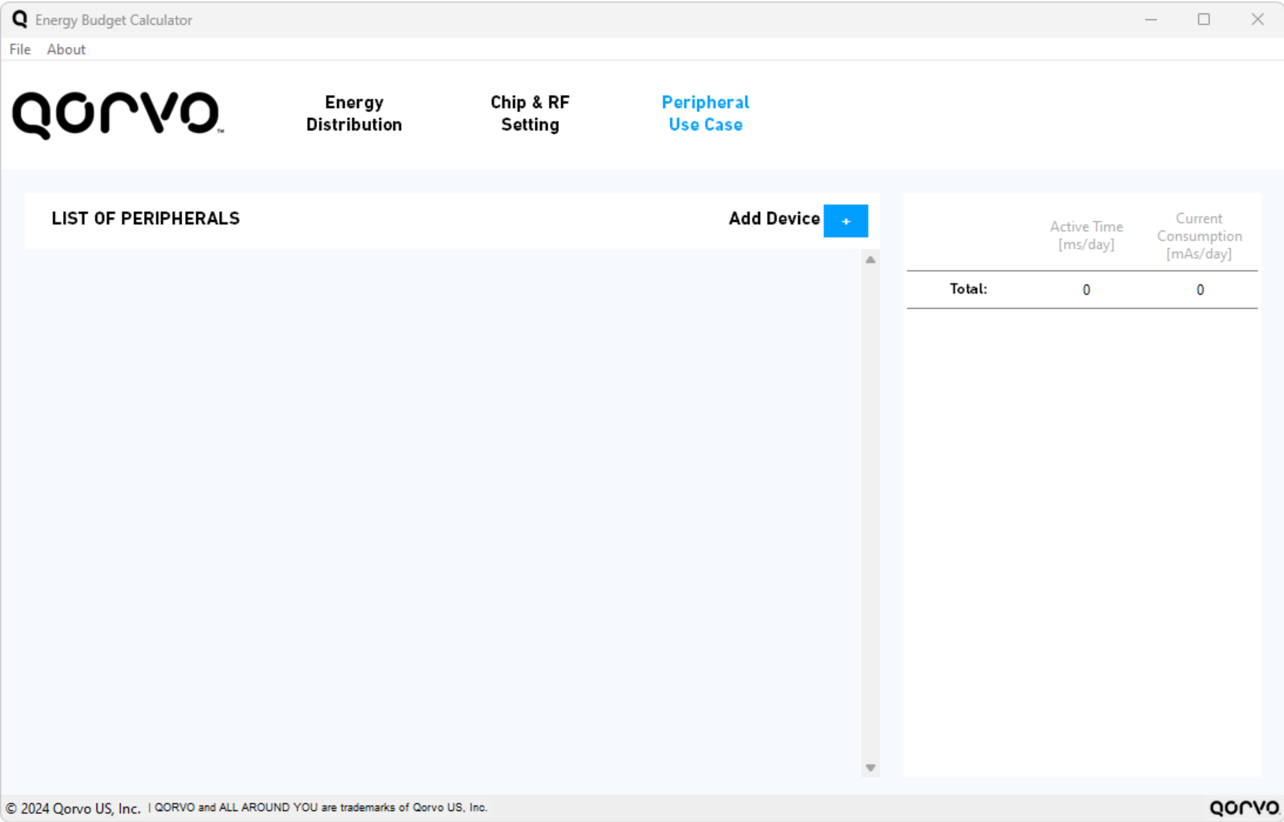

Figure 6: User Interface of Peripheral Use Case Section

2.4.1 Estimating Peripheral Energy Consumption

The estimation of peripheral energy consumption begins by calculating the active and idle durations per day based on user inputs for active time, the number of events, and active days per year.

- **Equation 1:**

$$Active\ Duration\ [ms] = Active\ time[ms] \times Number\ of\ Event \times \left(\frac{Active\ Days}{365}\right)$$

- **Equation 2:**

$$Idle\ Duration\ [ms] = 24 \times 60 \times 60 \times 1000 - Active\ Duration\ [ms]$$

Next, the current consumption in both active and idle states are calculated:

- **Equation 3:**

$$Active\ State\ Charge\ [mAs] = \frac{(ARM\ Active\ Current\ [mA] \times S + Drive\ Current\ [mA]) \times Active\ Duration\ [ms]}{1000}$$

where $S = 1$ if the ARM is active; otherwise, $S = 0$.

- **Equation 4:**

$$Idle\ State\ Charge\ [mAs] = \frac{Standby\ Current\ [\mu A] \times Idle\ Duration\ [ms]}{1000000}$$

- **Equation 5:**

$$Total\ Charge\ [mAs] = Active\ State\ Charge\ [mAs] + Idle\ State\ Charge\ [mAs]$$

Finally, the total energy consumption per day will be presented in the right panel. If the Peripheral State is enabled, this consumption will be included in the summary and the donut chart in the Energy Distribution section, contributing to the battery life estimation.

2.4.2 Example Peripherals Use Case

Figure 7 illustrates a use case involving three similar peripherals, all sharing the same drive current, standby current, and active time per day or per year. The key differences among them lie in the ARM state, ARM clock frequency, and peripheral state.

- **Peripheral 1** demonstrates that less energy is consumed when the ARM state is inactive.
- **Peripheral 2** shows increased energy consumption at a higher ARM clock frequency. However, since the state is disabled, its current consumption is not included in the total energy consumption calculation in the right panel and donut chart.

This example highlights the impact of ARM state and clock frequency on energy usage, providing valuable insights for optimizing peripheral configurations.

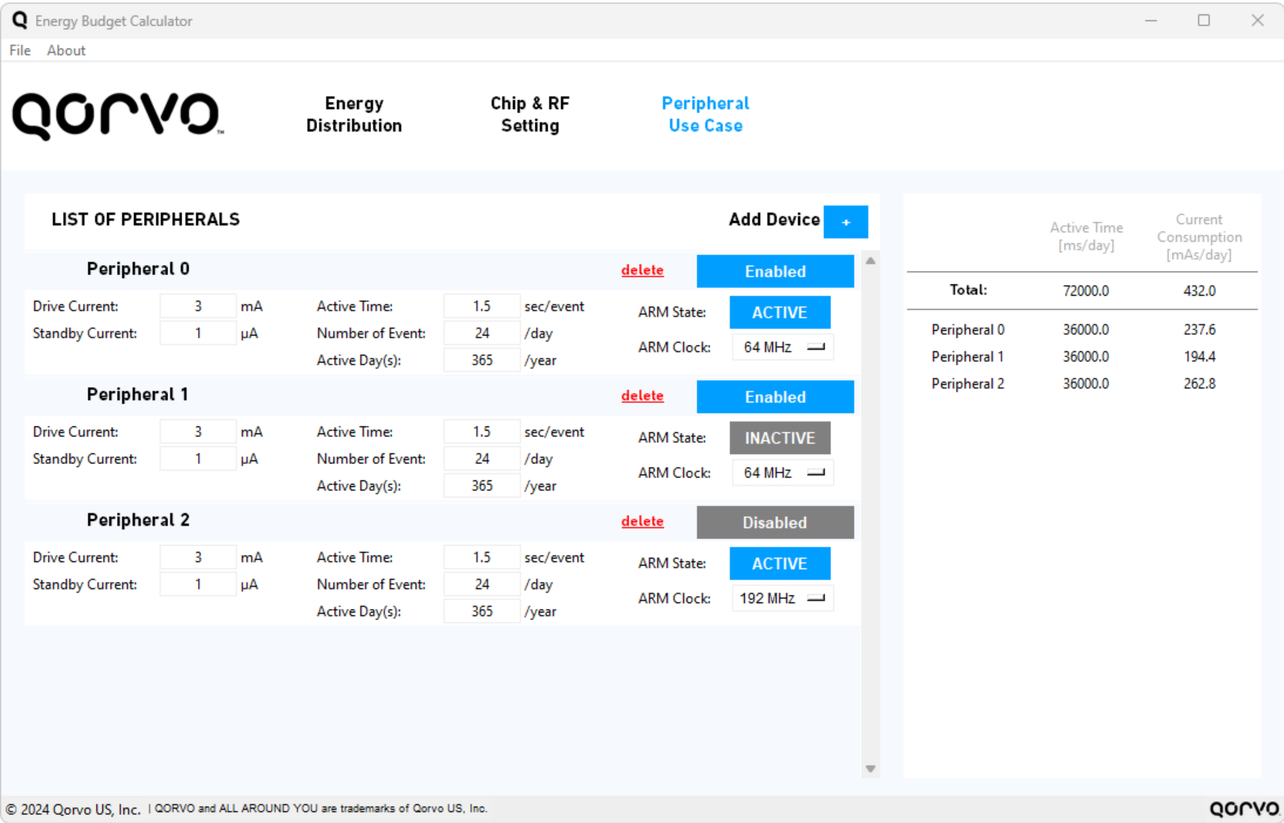

Figure 7: Example Peripherals Use Case

3 Features

3.1 Restore Use Case

The tool provides a restore settings function located under the [File] menu in the menu bar. This feature allows users to revert settings to their default launch state, which includes predefined values as exemplified by Qorvo.

3.2 Import/Export Use Case

The tool offers import and export settings functions located under the [File] menu in the menubar. Settings are generated and stored in a .ini file, which users can share with others by providing the settings file. Conversely, users can import a received .ini file to load the settings.

3.3 Define Commissioner Characteristics

Upon the first launch of the tool, a file named ‘commissioner.json’ will be generated. This file can be opened and edited using Windows Notepad. Users can add or delete commissioners and modify their settings. However, please note that at least one commissioner must be present, and the format must be strictly adhered to; otherwise, the tool will not start or function properly. If the file is corrupted, please delete it and restart the tool. The absence of the file will be detected, and a new file will be created with default commissioner settings.

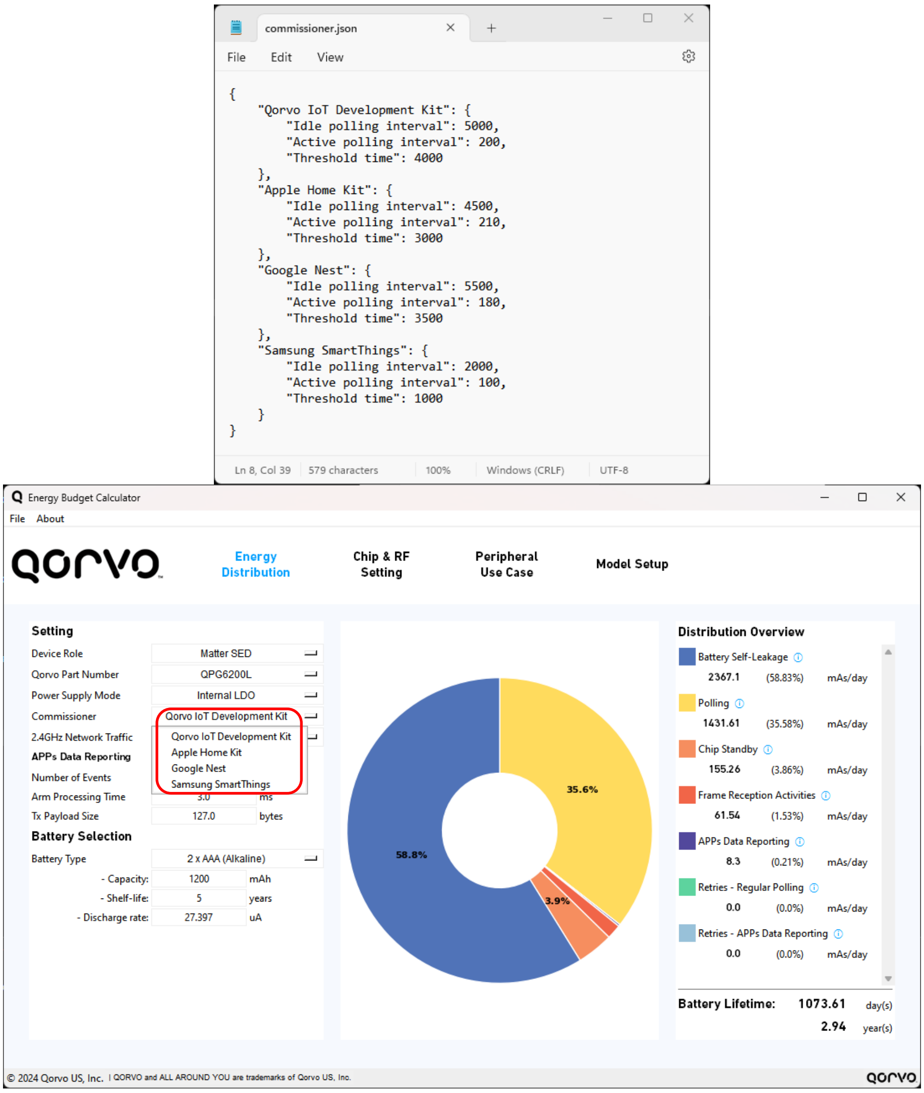

Figure 8: Example of Commissioner File

References

[1] GP570 Data Sheet; Qorvo document GP_P008_DS_13489
[2] QPG6095 Data Sheet; Qorvo document GP_P008_DS_11773
[3] QPG5071 Data Sheet; Qorvo document GP_P008_DS_14601
[4] QPG6100 Data Sheet; Qorvo document GP_P008_DS_16637
[5] QPG5072 Data Sheet; Qorvo document GP_P008_DS_17852
[6] QPG6105 Data Sheet; Qorvo document GP_P008_DS_17366
[7] QPG6200 Data Sheet; Qorvo document GP_P010_DS_20404
[8] DW3000_Datasheet.pdf
[9] QM33110W_Datasheet.pdf
[10] QM33120W_Datasheet.pdf

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Document History

Version	Date	Section	Changes
1.0	11 Mar 2025		Released version.