Introduction
This document describes measurement method of current consumption when BLE connection.

Target Device
- RL78/G1D

Note: The contents of this document are provided as a reference and differ in system structure and measurement condition.

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1. Overview

This document explains about a procedure of method for measurement of the current consumption which is at the time of a BLE connection by Generic Access Profile (GAP). This document is described by assumption that is understood about Bluetooth Low Energy and RL78/G1D Bluetooth low energy protocol stack.

Measurement method are explained by Sample Program or GUI tool execution of Bluetooth Low Energy protocol stack. The current consumption measurement provides durability time of the battery for application with useful information.

1.1 Related documents

The following document is related to this application note. Also refer to this document when using this application note.

- Bluetooth Low Energy Protocol Stack Sample Program Application Note (R01AN1375)
- Bluetooth Low Energy Protocol Stack Quick Start Guide Application Note (R01AN2767)
- Bluetooth Low Energy Protocol Stack GUI Tool Manual Application Note (R01AN2469)
- RL78/G1D User’s Manual: Evaluation Board (R30UZ0048)
2. Preparation for measurement

This section is described about measurement machine for current consumption measurement. The current consumption has to be measured with time for the current consumption amount measurement. Therefore, Not a multi-meter, but an oscilloscope is needed. The easy method to measure current consumption with an oscilloscope is the method to measure the current consumption which flows to a system directly using a current probe. When there are no current probes, it's possible to use resistance of the small resistance value for a power supply feed line of a system as shown in Figure 1 as the easy substitution means.

The voltage drop measures the difference between the two voltage probes of across the resistor with an oscilloscope. The current consumption value can be calculated by dividing the voltage drop by the resistance value \( I = \frac{V}{R} \). The better resistance value for using is 10\( \Omega \). This resistance value is the small value which doesn't influence a circuit. And, the voltage has to be a big range for measurement accuracy. It's easy of calculation to use 10\( \Omega \) of resistance value.

At the time of measurement, the power supply uses DC stabilized power source like an actual battery. DC stabilized power source can remove voltage limit.

![Figure 1 Preparation for measurement environment](image-url)
2.1 Example of evaluation board’s connection

When not using a current probe, the connection example at the evaluation board is indicated. The evaluation board opens a power supply line, and can catch measuring machines between the power supply line. When SW10 of “Figure 2 RL78/G1D evaluation board” is 1-2, power line is connected. When SW10 is 2-3, the power line is opened and can insert measurement machine and so on at the terminal of TP7 and TP8.

![Figure 2 RL78/G1D evaluation board (Switch settings of the current measurement time)](image)

The method to measure the voltage with an oscilloscope around resistance is indicated on “Figure 3 Insertion of registration and connection of oscilloscope”. Resistance is inserted between TP7 and TP8. Set SW10 switch to 2-3. Connect the voltage probe A of the oscilloscope to TP7 side. The voltage probe B connect to the TP8 side.

![Figure 3 Insertion of registration and connection of oscilloscope](image)
At the time of current measurement, to remove the leakage current of the signal level shift buffer between the RL78/G1D and UART-USB change IC, please set the slide switch SW9 to 1-2 and SW13 to 2-3 after the “3. Execution of connection operation”.
3. Execution of connection operation

The execution method of connection operation is explained.

Use the sample program or GUI tool, and then connect the two RL78/G1D evaluation board.

The RL78/G1D must have written a pre-built program file (Intel HEX format) of Modem configuration. Method of writing the program, please refer to the "Bluetooth Low Energy Protocol Stack Quick Start Guide Application Note (R01AN2767)".

3.1 Connection by the sample program

The execution example in the master side and the slave side is indicated by Bluetooth Low Energy Protocol Stack Software's sample program. Please refer to the "Bluetooth Low Energy Protocol Stack Sample Program Application Note (R01AN1375)".

At Slave side, execute Sample Program, select [1.GAP & SM & GATT Test]. And, execute [1.GAP Reset], execute [5.GAP Broadcast_Enable]. Please execute to transmission of Advertising data.

```
-- BLE Sample Program Menu Version 1.00.000 --
1.GAP & SM & GATT Test
2.Profile Test
3.Vendor Specific Test
4.PTS Test Case Select
5.FW Update Start
ESC Key: Menu exit
>> rBLE Mode (ACTIVE)
>> 1
-- BLE Sample Program GAP & SM & GATT Test Menu --
1.GAP Reset
2.GAP Set_Name
3.GAP Observation_Enable
4.GAP Observation_Disable
5.GAP Broadcast_Enable
...
48.GATT Set_Permission
49.GATT Set_Data
ESC Key: Menu exit
>> 1
CMD -> GAP Reset
Status(RBLE_OK)
>>
rBLE GAP EVENT (RESET RESULT) Status(RBLE_OK)
rBLE Version = Major(01),Minor(01)
>> 5
CMD -> GAP Broadcast_Enable
Select Parameter No 0
Status(RBLE_OK)
>>
rBLE GAP EVENT (BROADCAST_ENABLE_COMP) Status(RBLE_OK)
>>
```

Figure 4 Advertising execution by the sample program

The master side executes Scanning and executes connection with Slave side. The master side executes Scanning and executes Connection with the slave side. Execute Sample Program, select [1.GAP & SM & GATT Test]. And, execute [1.GAP Reset], execute [15.GAP Device_Search]. Please execute to device search. Confirm event of rBLE GAP EVENT (DEVICE_SEARCH_COMP). Execute [20.GAP Create_Connection].
When the connection with the slave side is completed, the event of "rBLE GAP EVENT (CONNECTION_COMP)" is displayed to the master side and the slave side.

```
-- BLE Sample Program Menu Version 1.00.000 --
1.GAP & SM & GATT Test
2.Profile Test
3.Vendor Specific Test
4.PTS Test Case Select
5.FW Update Start
ESC Key: Menu exit
>> rBLE Mode (ACTIVE)

>> 1
-- BLE Sample Program GAP & SM & GATT Test Menu --
1.GAP Reset
: 
15.GAP Device_Search
: 
20.GAP Create_Connection
: 
ESC Key: Menu exit
>> 1

CMD -> GAP Reset
Status(RBLE_OK)
>>
rBLE GAP EVENT (RESET RESULT) Status(RBLE_OK)
rBLE Version = Major(01),Minor(01)

>> 15

CMD -> GAP Device_Search
Execute General Discovery
Status(RBLE_OK)
>>
rBLE GAP EVENT (DEVICE_SEARCH_RESULT_IND)
EventType(0x0), AddressType(0x0)
Addr[74:90:50:00:89:59]
Data(0x10)
0x02,0x01,0x06,0xc,0x09,0x52,0x65,0x6e
0x65,0x73,0x61,0x73,2d,0x42,0x45
RSSI(-56)
>>
rBLE GAP EVENT (DEVICE_SEARCH_RESULT_IND)
EventType(0x4), AddressType(0x0)
Addr[74:90:50:00:89:59]
Data(0x0)

RSSI(-56)
>>
rBLE GAP EVENT (DEVICE_SEARCH_COMP)

>> 20

CMD -> GAP Create_Connection
Addr[74:90:50:00:89:59]
Status(RBLE_OK)
>>
rBLE GAP EVENT (CONNECTION_COMP) Status(RBLE_OK)
Connection Handle = 0, Addr[74:90:50:00:89:59]
>>
```

Figure 5 Connection Execution by the sample program
3.2 Connection by the GUI tool

The execution example in the master side and the slave side is indicated by Bluetooth Low Energy Protocol Stack Software's sample program. Please refer to the "Bluetooth® Low Energy Protocol Stack GUI Tool Manual Application Note (R01AN2469)".

Slave side, after starting the GUI tool, please execute the transmission of Advertising data by clicking the [Advertising Enable] of [Main dialog]-[GAP-Advertising tab].

![GUI Tool Interface](image)

**Figure 6 Advertising execution by the GUI tool**

Master side executes a scan, and executes the connection to the slave side. After starting the GUI tool, please execute the device search by clicking on the [Discover] of [Main dialog]-[GAP-Scanning tab]. Double-click on the list when the target(remote) device is displayed in the Advertising data list. BD Address of the target device is set to [Peer Addr column] of [Peer Device tab].

Please execute the Create_Connection by clicking the [Connect] in the [Peer Device-Connection tab].
When the connection is completed, RBLE_GAPEVENT_CONNECTION_COMP event is displayed on the [Log dialog] of both the master side and slave side.

Figure 7 Connection Execution by the GUI tool
4. Current consumption of operation

The current consumption is explained by actual operation example.

Bluetooth Low Energy device receives and transmits by connection event of fixed interval after connection. It's possible to do BLE device to the sleep state between all except for a connection event.

Connected communication time is short time between time of the total. “Figure 8 Bluetooth Low Energy connection operation (Overview)” is that the slave side device is executed reception and transmission operation by every 50 milliseconds (Interval of the connection event, in the BLE specification, is can be set between 4 seconds from 7.5 milliseconds). It's possible to do BLE device to the sleep state between all except for a connection event.

![Figure 8 Bluetooth Low Energy connection operation (Overview)](image)

Detail of connection event is indicated to the next page.
The operation of connection event (DCDC converter and an external slow clock is used) is explained at the slave side device.

When application operation is no need at sleep status, MCU unit can be set to STOP mode (32kHz clock output), RF unit is retained to DEEP_SLEEP mode.

Wake-up from the sleep state is set as RF part beforehand at the 32 kHz clock counter from MCU part. RF unit is switched to IDLE_MODE by the wake-up at the setting timing. RF unit begins to oscillate 26 MHz at the same time. MCU unit is waked to normal operation by interrupt from RF unit.

MCU unit begins preprocess for receive processing. The pre-process is setting RF operation to the RF unit. When MCU unit is setting to RF register at the DMA and waiting reception timing, MCU unit is switched to STOP mode for low power consumption. Therefore, there are high current and low current at the current value of the operation current consumption.

RF unit switches to reception operation and receives packets from Master side. And RF unit is executing transmission operation for response of reception packet. MCU unit can wait at STOP mode until process end.

After transmission operation, MCU unit saves register value of RF unit to MCU part, and sets register of RF unit after calculates of next wake-up timing at the latter process. RF unit is switched to DEEP_SLEEP mode. MCU unit can switch STOP mode (32 kHz clock output).

Current consumption amount is able to calculate easily by addition function of oscilloscope. The current consumption amount of above-period is 8.3μA by using addition function. When current consumption of sleep is about 1.3μA by STOP mode in MCU part (32 kHz clock output) and DEEP_SLEEP mode in RF part, average current consumption in connection interval of one second will be 8.3μA+1.3μA = 9.6 μA/sec.

Period of preprocess and others are changed by data size and others. Measure with real data and the size several times for estimate of average current consumption and calculate.

When there are no addition functions of the oscilloscope, the method of calculation is indicated to the next page.
Extract the changing point as shown in "Figure 10" from the waveform of the oscilloscope measurement results. The current consumption can be obtained by integrating the period and the current value of the change point.

![Figure 10 Bluetooth Low Energy connection operation (Detail/Calculation)](image)

<table>
<thead>
<tr>
<th></th>
<th>MCU status</th>
<th>RF operation status</th>
<th>period time [ms]</th>
<th>period current consumption [mA]</th>
<th>period current consumption integrated value [μA]</th>
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<tr>
<td>①</td>
<td>WakeUp</td>
<td>STANDBY_RF</td>
<td>1.00</td>
<td>0.75</td>
<td>0.75</td>
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<tr>
<td>②</td>
<td>RUN</td>
<td>IDLE_RF</td>
<td>0.50</td>
<td>1.80</td>
<td>0.90</td>
</tr>
<tr>
<td>③</td>
<td>HALT</td>
<td>IDLE_RF</td>
<td>0.65</td>
<td>1.40</td>
<td>0.91</td>
</tr>
<tr>
<td>④</td>
<td>RUN</td>
<td>IDLE_RF</td>
<td>0.70</td>
<td>2.00</td>
<td>1.40</td>
</tr>
<tr>
<td>⑤</td>
<td>STOP</td>
<td>IDLE_RF</td>
<td>1.00</td>
<td>0.40</td>
<td>0.40</td>
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<tr>
<td>⑥</td>
<td>STOP</td>
<td>SETUP_RF(RX)</td>
<td>0.10</td>
<td>1.40</td>
<td>0.14</td>
</tr>
<tr>
<td>⑦</td>
<td>STOP</td>
<td>RX</td>
<td>0.15</td>
<td>3.10</td>
<td>0.47</td>
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<tr>
<td>⑧</td>
<td>STOP</td>
<td>SETUP_RF(TX)</td>
<td>0.10</td>
<td>2.00</td>
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<td>⑨</td>
<td>STOP</td>
<td>TX</td>
<td>0.15</td>
<td>4.00</td>
<td>0.60</td>
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<td>⑩</td>
<td>RUN</td>
<td>IDLE_RF</td>
<td>1.35</td>
<td>1.85</td>
<td>2.50</td>
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<td>⑪</td>
<td>STOP</td>
<td>IDLE_RF</td>
<td>0.30</td>
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<tr>
<td>⑫</td>
<td>STOP</td>
<td>DEEP_SLEEP</td>
<td>994.00</td>
<td>0.0013</td>
<td>1.29</td>
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</table>

Total 9.68 μA/sec

The calculation result is sometimes different from addition function result of oscilloscope. When calculating usable time at the battery by a system, it's recommended to consider the margin.
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   - The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible. Unused pins should be handled as described under Handling of Unused Pins in the manual.

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   - The state of the product is undefined at the moment when power is supplied.
   - The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the moment when power is supplied.
   - In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the moment when power is supplied until the reset process is completed.
   - In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the moment when power is supplied until the power reaches the level at which resetting has been specified.

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