To our customers,

Old Company Name in Catalogs and Other Documents

On April 1\textsuperscript{st}, 2010, NEC Electronics Corporation merged with Renesas Technology Corporation, and Renesas Electronics Corporation took over all the business of both companies. Therefore, although the old company name remains in this document, it is a valid Renesas Electronics document. We appreciate your understanding.

Renesas Electronics website: \url{http://www.renesas.com}

April 1\textsuperscript{st}, 2010
Renesas Electronics Corporation

Issued by: Renesas Electronics Corporation (\url{http://www.renesas.com})
Send any inquiries to \url{http://www.renesas.com/inquiry}. 
Notice

1. All information included in this document is current as of the date this document is issued. Such information, however, is subject to change without any prior notice. Before purchasing or using any Renesas Electronics products listed herein, please confirm the latest product information with a Renesas Electronics sales office. Also, please pay regular and careful attention to additional and different information to be disclosed by Renesas Electronics such as that disclosed through our website.

2. Renesas Electronics does not assume any liability for infringement of patents, copyrights, or other intellectual property rights of third parties by or arising from the use of Renesas Electronics products or technical information described in this document. No license, express, implied or otherwise, is granted hereby under any patents, copyrights or other intellectual property rights of Renesas Electronics or others.

3. You should not alter, modify, copy, or otherwise misappropriate any Renesas Electronics product, whether in whole or in part.

4. Descriptions of circuits, software and other related information in this document are provided only to illustrate the operation of semiconductor products and application examples. You are fully responsible for the incorporation of these circuits, software, and information, in the design of your equipment. Renesas Electronics assumes no responsibility for any losses incurred by you or third parties arising from the use of these circuits, software, or information.

5. When exporting the products or technology described in this document, you should comply with the applicable export control laws and regulations and follow the procedures required by such laws and regulations. You should not use Renesas Electronics products or the technology described in this document for any purpose relating to military applications or use by the military, including but not limited to the development of weapons of mass destruction. Renesas Electronics products and technology may not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable domestic or foreign laws or regulations.

6. Renesas Electronics has used reasonable care in preparing the information included in this document, but Renesas Electronics does not warrant that such information is error free. Renesas Electronics assumes no liability whatsoever for any damages incurred by you resulting from errors in or omissions from the information included herein.

7. Renesas Electronics products are classified according to the following three quality grades: “Standard”, “High Quality”, and “Specific”. The recommended applications for each Renesas Electronics product depends on the product’s quality grade, as indicated below. You must check the quality grade of each Renesas Electronics product before using it in a particular application. You may not use any Renesas Electronics product for any application categorized as “Specific” without the prior written consent of Renesas Electronics. Further, you may not use any Renesas Electronics product for any application for which it is not intended without the prior written consent of Renesas Electronics. Renesas Electronics shall not be in any way liable for any damages or losses incurred by you or third parties arising from the use of any Renesas Electronics product for an application categorized as “Specific” or for which the product is not intended where you have failed to obtain the prior written consent of Renesas Electronics. The quality grade of each Renesas Electronics product is “Standard” unless otherwise expressly specified in a Renesas Electronics data sheets or data books, etc.

   “Standard”: Computers; office equipment; communications equipment; test and measurement equipment; audio and visual equipment; home electronic appliances; machine tools; personal electronic equipment; and industrial robots.

   “High Quality”: Transportation equipment (automobiles, trains, ships, etc.); traffic control systems; anti-disaster systems; anti-crime systems; safety equipment; and medical equipment not specifically designed for life support.

   “Specific”: Aircraft; aerospace equipment; submersible repeaters; nuclear reactor control systems; medical equipment or systems for life support (e.g. artificial life support devices or systems), surgical implantations, or healthcare intervention (e.g. excision, etc.), and any other applications or purposes that pose a direct threat to human life.

8. You should use the Renesas Electronics products described in this document within the range specified by Renesas Electronics, especially with respect to the maximum rating, operating supply voltage range, movement power voltage range, heat radiation characteristics, installation and other product characteristics. Renesas Electronics shall have no liability for malfunctions or damages arising out of the use of Renesas Electronics products beyond such specified ranges.

9. Although Renesas Electronics endeavors to improve the quality and reliability of its products, semiconductor products have specific characteristics such as the occurrence of failure at a certain rate and malfunctions under certain use conditions. Further, Renesas Electronics products are not subject to radiation resistance design. Please be sure to implement safety measures to guard them against the possibility of physical injury, and injury or damage caused by fire in the event of the failure of a Renesas Electronics product, such as safety design for hardware and software including but not limited to redundancy, fire control and malfunction prevention, appropriate treatment for aging degradation or any other appropriate measures. Because the evaluation of microcomputer software alone is very difficult, please evaluate the safety of the final products or system manufactured by you.

10. Please contact a Renesas Electronics sales office for details as to environmental matters such as the environmental compatibility of each Renesas Electronics product. Please use Renesas Electronics products in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. Renesas Electronics assumes no liability for damages or losses occurring as a result of your noncompliance with applicable laws and regulations.

11. This document may not be reproduced or duplicated, in any form, in whole or in part, without prior written consent of Renesas Electronics.

12. Please contact a Renesas Electronics sales office if you have any questions regarding the information contained in this document or Renesas Electronics products, or if you have any other inquiries.

(Note 1) “Renesas Electronics” as used in this document means Renesas Electronics Corporation and also includes its majority-owned subsidiaries.

(Note 2) “Renesas Electronics product(s)” means any product developed or manufactured by or for Renesas Electronics.
Low power implementation of SLP (LowPower)

Introduction
In today world, many embedded products are expected to be compact, portable and wearable. In other word, low power design is becoming very important.

Common questions raised during product specification stage are:

- How long does the product last?
- How much power can it consumed?
- What type of battery? Can it be Rechargeable?
- How fast shall be the response time?
- What type of interface is required? LCD? LED? I/O?
- Reliability & Quality level?
- Cost?

Developers who have selected SLP as their microcomputer (MCU) for their lower power application, has already achieved a great power saving in their product. However, if the developers pay more attention to their overall design, further reduction in power can be achieved. As the scope of the topics is very broad, the objective of this application note is to create the awareness and knowledge for low power design.

Topics involved are basic theory, SLP characteristic, SLP peripherals, battery operation, supply regulation, and external interfacing consideration.

Target Device
H8/300L Super Low Power Devices
## Contents

1 Theory ......................................................................................................................... 4

2 SLP (Super Low Power) Characteristics ................................................................. 5
2.1 Low & wide range of voltage operation (1.8-5V) ......................................................... 5
2.2 Oscillation Stabilizer Timer Reduction Function (<20 µs) ........................................... 5
2.3 Seven Low Power modes ......................................................................................... 6
2.4 Module standby mode selection ............................................................................. 7
2.5 Internal step down VCC ......................................................................................... 7
2.6 Two clocks ............................................................................................................. 7

3 Usage SLP Peripherals ............................................................................................ 8
3.1 LCD ....................................................................................................................... 9
  3.1.1 On Chip Driver & 5V voltage booster ................................................................. 9
  3.1.2 Backlight ......................................................................................................... 9
  3.1.3 Low power mode ........................................................................................... 9
  3.1.4 Frame frequency ........................................................................................... 9
3.2 SCI ....................................................................................................................... 10
3.3 I/O Port ................................................................................................................ 10
  3.3.1 High current output port (Port 9 & 3) ................................................................. 10
  3.3.2 High Voltage input port (IRQAEC) ................................................................. 10
  3.3.3 Pull-up MOS port (Port 3,5,6) ....................................................................... 10
3.4 IRQ/WK pins ...................................................................................................... 10
3.5 PWM .................................................................................................................. 10
3.6 ADC ................................................................................................................... 10
3.7 AEC ................................................................................................................... 10

4 Battery operation .................................................................................................... 11
4.1 Type of Battery ................................................................................................. 11
4.2 Battery usage ................................................................................................... 12
  4.2.1 Premature voltage cut-off ......................................................................... 12
  4.2.2 Current discharge rate .............................................................................. 12

5 Power Supply Regulation ....................................................................................... 13

6 Consideration for External Interfacing .................................................................. 14
6.1 Low power parts .............................................................................................. 14
6.2 Pull up/down resistor ....................................................................................... 14
6.3 Unused pins ....................................................................................................... 14
6.4 Driving of LED ................................................................................................. 14
6.5 Switching off external devices ........................................................................... 15
6.6 Analogue Signal ............................................................................................... 16
6.7 High impedance states during standby ............................................................... 16
6.8 Driving state during low power operation .......................................................... 16
1 Theory

Generally average power consumption can be simplified as:

\[ P_{\text{average}} = P_{\text{short}} + P_{\text{leakage}} + P_{\text{static}} + P_{\text{dynamic}} \]

In simple word,

**Short-Circuit Power:** power dissipated during the short switching interval whereby a short circuit current flow from power to ground

**Leakage Power:** power dissipated by leakage current through non-conducting transistor & reversed biased diode.

**Static Power:** power dissipated by current flowing from power to ground during idle time.

**Dynamic Power:** power dissipated during switching activities.

The dynamic power, which took up 80% of total energy lost can be explain using the fundamental equation

\[ P_{\text{dynamic}} = a \times C \times Vcc^2 \times F \]

- Reduce the CPU activities/ Switch on the circuit when necessary
- Minimize the output load
- Lower the operating power supply (quadratic effect)
- Operate at the lowest possible frequency
2 SLP (Super Low Power) Characteristics

SLP devices are designed to save power. The various low power features are

2.1 Low & wide range of voltage operation (1.8-5V)

There are not many MCU that is able to support 1.8V operation. As mentioned in the last topics, a lower power supply will lower the power consumption dramatically. The wide operating range will enable the device operation to last longer when the battery voltage has been dropped. E.g if two alkaline battery is used, the system will be able to run from 3V (2x1.5V) to 1.8V(2x0.9V) [The alkaline battery’s cut-off voltage is 0.9 Volts].

2.2 Oscillation Stabilizer Timer Reduction Function (<20 µs)

During mode switching, such as watch to active mode, or exiting from standby mode, there is considerable amount of current flow during oscillation stabilization. SLP has taken steps to reduce such power losses by reducing the oscillation to be less than 20 us.

If the product has frequent mode switching activities, developers have to consider the necessity of such activity, as the average current consume may be larger than when the SLP is operating at other modes.
2.3 Seven Low Power modes

Unlike most other microcomputers, which has only 2-4 types of low power modes (e.g. halt, sleep, idle...), SLP has seven low power modes which allow developers to have a better control of their system power consumption. A brief description & typical power consumption is listed as follow:

<table>
<thead>
<tr>
<th>Operating Mode</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active (high-speed)</td>
<td>The CPU and all on-chip peripheral functions are operable on the system clock in high-speed operation</td>
</tr>
<tr>
<td>Active (medium-speed)</td>
<td>The CPU and all on-chip peripheral functions are operable on the system clock in low-speed operation</td>
</tr>
<tr>
<td>Subactive</td>
<td>The CPU is operable on the subclock in low-speed operation</td>
</tr>
<tr>
<td>Sleep (high-speed)</td>
<td>The CPU halts. On-chip peripherals functions are operable on the system clock</td>
</tr>
<tr>
<td>Sleep (medium-speed)</td>
<td>The CPU halts. On chip peripherals functions operate at a frequency of 1/64, 1/32, 1/16, or 1/8 of the system clock frequency</td>
</tr>
<tr>
<td>Subsleep</td>
<td>The CPU halts. The time-base function of timer A, timer F, SCI3, AEC and LCD controller/driver are operable on the subclock</td>
</tr>
<tr>
<td>Watch</td>
<td>The CPU halts. The time-base function of timer A, timer F, AEC and LCD controller/driver are operable on the subclock</td>
</tr>
<tr>
<td>Standby</td>
<td>The CPU and all on-chip peripheral functions halt</td>
</tr>
</tbody>
</table>

The following table shows the typical power consumption at 25 °C temperature from a random sample

<table>
<thead>
<tr>
<th>Operating Mode</th>
<th>Vcc</th>
<th>Frequency</th>
<th>Icc (typical) 25 °C</th>
<th>Power Consumption*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active (high-speed)</td>
<td>3V</td>
<td>10 MHz</td>
<td>3.42 mA</td>
<td>10.26 mW</td>
</tr>
<tr>
<td>Active (medium-speed)</td>
<td>3V</td>
<td>10 MHz</td>
<td>1.16 mA</td>
<td>3.48 mW</td>
</tr>
<tr>
<td>Subactive</td>
<td>3V</td>
<td>32 KHz</td>
<td>19 uA</td>
<td>608 mW</td>
</tr>
<tr>
<td>Sleep (high-speed)</td>
<td>3V</td>
<td>10 MHz</td>
<td>2.74 mA</td>
<td>8.22 mW</td>
</tr>
<tr>
<td>Subsleep</td>
<td>3V</td>
<td>32 KHz</td>
<td>5.5 uA</td>
<td>16.5 uW</td>
</tr>
<tr>
<td>Watch</td>
<td>3V</td>
<td>32 KHz</td>
<td>2.2 uA</td>
<td>6.6 uW</td>
</tr>
<tr>
<td>Standby</td>
<td>3V</td>
<td>32 KHz</td>
<td>0.32 uA</td>
<td>0.96 uW</td>
</tr>
</tbody>
</table>
The following charts show the current consumption of the SLP operating at different conditions.

Note: These are indicating reading taken from a random sample.

Observation: Active [medium speed (fosc/16)] has lower current dissipation than Sleep (high speed mode).


### 2.4 Module standby mode selection

Individual on chip peripheral functions can be put into standby, by mean of disabling the clock input to the modules. This will enable better control over the peripherals usage. I.e. developer may switch any peripheral into active mode only when needed, and thus reducing any unnecessary consumption of current.

### 2.5 Internal step down VCC

The SLP is designed to operate at very low power!

### 2.6 Two clocks

There are two independent clocks (a main clock and a 32KHz clock) allowing developers to have a better control over the system design. Developers may run their system at high-speed active mode (operating at speed of main clock) to have better response, and switch to low speed active mode (main clock divided by 16, 32, 64 or 128) to conserve energy. It can further reduced the operating clock by running in sub-active mode (32KHz clock).
3 Usage SLP Peripherals

Other than the distinctive low power features, the SLP peripherals is also designed to be low-power-application friendly. For example, peripherals can still operate when the CPU is stopped. Essential peripherals are built-in, so that less external components are required.

The following table shows how do each features & peripherals react in different operating modes.

<table>
<thead>
<tr>
<th>Function</th>
<th>Active Mode</th>
<th>Sleep Mode</th>
<th>Watch Mode</th>
<th>Subactive Mode</th>
<th>Subsleep Mode</th>
<th>Standby Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High Speed</td>
<td>Medium Speed</td>
<td>High Speed</td>
<td>Medium Speed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System Clock Oscillator</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions</td>
<td>Halted</td>
<td>Halted</td>
</tr>
<tr>
<td>Subclock Oscillator</td>
<td>Instructions</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions</td>
</tr>
<tr>
<td>CPU operation</td>
<td>RAM</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions</td>
<td>Halted</td>
<td>Halted</td>
</tr>
<tr>
<td></td>
<td>Registers</td>
<td>Retained</td>
<td>Retained</td>
<td>Retained</td>
<td>Retained</td>
<td>Retained</td>
</tr>
<tr>
<td>I/O Port</td>
<td></td>
<td>Retained</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External Interrupts</td>
<td>IRQ0</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions</td>
</tr>
<tr>
<td></td>
<td>IRQ1</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions</td>
<td>Retained*5</td>
<td>Functions</td>
</tr>
<tr>
<td></td>
<td>IRQAEC</td>
<td></td>
<td></td>
<td></td>
<td>Retained*5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WKP[0-7]</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions</td>
</tr>
<tr>
<td>Peripheral functions</td>
<td>Timer A</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions*4</td>
<td>Functions*4</td>
</tr>
<tr>
<td></td>
<td>Asynchronous counter</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions*4</td>
<td>Functions</td>
<td>Functions*4</td>
</tr>
<tr>
<td></td>
<td>Timer F</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions*7</td>
<td>Functions*7</td>
</tr>
<tr>
<td></td>
<td>SCI3</td>
<td></td>
<td>Reset</td>
<td>Functions</td>
<td>Functions*2</td>
<td>Functions*2</td>
</tr>
<tr>
<td></td>
<td>PWM</td>
<td>Retained</td>
<td>Retained</td>
<td>Retained*2</td>
<td>Retained</td>
<td>Retained*2</td>
</tr>
<tr>
<td></td>
<td>ADC</td>
<td>Retained</td>
<td>Retained</td>
<td>Retained</td>
<td>Retained*3</td>
<td>Retained*3</td>
</tr>
<tr>
<td></td>
<td>LCD</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions</td>
<td>Functions*3</td>
<td>Functions*3</td>
</tr>
</tbody>
</table>

NOTE: 1. Register contents are retained, but output is high-impedance state.
2. Functions if $\varnothing w/2$ is selected as the internal clock; Otherwise halted and retained
3. Functions if $\varnothing w$, $\varnothing w/2$ or $\varnothing w/4$ is selected as the operating clock; otherwise halted and retained.
4. Functions if the timekeeping time-base function is selected
5. External interrupt requests are ignored. Interrupt request register contents are not altered.
6. Incrementing is possible, but interrupt generation is not.
7. Functions if the $\varnothing w/4$ internal clock is selected; otherwise halted and retained.
3.1 LCD

3.1.1 On Chip Driver & 5V voltage booster
SLP can drive the LCD glass directly, eliminating any extra external components, such as the DC-DC converter. The voltage booster will provide the LCD glass with constant supply, even when the battery voltage is reducing. Thus the application will not have a diminishing LCD contrast level.

If a large LCD glass is used, bypass capacitors must be used to boost the drivability.

3.1.2 Backlight
Backlight can be implemented using either
i. CCFL
ii. EL backlight or
iii. White LED

White LED with the operating range of 3.5-4 Volts and 15-20 mA, will enable a better energy saving than the rest of the implementation.

3.1.3 Low power mode
During low power mode operation, LCD can continue operation if the sub-clock is selected.

3.1.4 Frame frequency
The LCD frame frequency is defined as the rate at which the backplane and segment outputs change. The frame frequency is calculated to be the LCD period/2 * number of backplanes. The range of frame frequencies is from 25 to 250Hz with the most common being between 50 and 150Hz. Higher frequencies result in higher power consumption while lower frequencies cause flicker in the images on the LCD panel.

3.2 SCI
SCI is commonly used to communicate with PC for
i. Product update,
ii. Data logging,
iii. Debug purposes

Thus a RS232 driver is required to interface between the two links. However RS232 driver is not welcome in low power design. Developers can
i. Built the driver externally and plug-on when required
ii. Switch off the driver totally when it is not required. (Beware of leakage current)
iii. Use a lower the Baud rate, if speed of transfer is not a concern.
3.3 I/O Port

Matching the characteristic of each I/O port to the required operation or function is essential. Other than the usual input and output ports, SLP has the following port

3.3.1 High current output port (Port 9 & 3)

Port 9(0,1,2) can output as high as 25 mA of current, whereas port 3(1-7) and port 9(3,4,5) can output 10mA. This provides a simple interface to drive LED or other components that required high current drive. Note port 9 is a open drain output whereas port 3 is not.

3.3.2 High Voltage input port (IRQAEC)

IRQAEC is an input pin that can withstand an input that exceeds its VCC level (max of 7.3V).

3.3.3 Pull-up MOS port (Port 3,5,6)

When interfacing to external devices, developers should consider the need of pull up. If it is required, usage of resistor value must be calculated to provide just enough current drive, if otherwise extra power will be lost. The built in MOS pull up must not be enabled unnecessary, as it can provide to a maximum current of 300 uA.

3.4 IRQ/WK pins

There are two external IRQ interrupt and 8 wake up pins. These provide a very good source of obtaining external events, when SLP CPU is stop operating during the low power modes. Examples, SLP will know which of the wake-up pins had been activated, to wake it up from standby modes. This enabled the SLP to perform the necessary action.

3.5 PWM

The PWM can be used in many applications, such as DAC, tone generation, DTMF generation…

3.6 ADC

An unavoidable peripheral required to interfaces to the analogues world.

3.7 AEC

The Asynchronous Event Counter is able to latch external events even during watch and standby modes.
4 Battery operation

Portable products depend on battery for the source of energy. The operating life span of these products will be determined by the capacity of this energy source, and the energy drawn by the rest of the system. Studies had shown that the amount of energy that can be supplied by a given battery varies significantly, depending on how the energy is being drawn.

4.1 Type of Battery

The following compare some of the commonly available batteries.

<table>
<thead>
<tr>
<th></th>
<th>Alkaline</th>
<th>Nickel Cadmium (NiCd)</th>
<th>Nickel Metal Hydride (NiMH)</th>
<th>Lithium-ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Voltage</td>
<td>1.5</td>
<td>1.25</td>
<td>1.25</td>
<td>3.6</td>
</tr>
<tr>
<td>Operating Voltage</td>
<td>1.25 -1.15</td>
<td>1.25 -1.00</td>
<td>1.25 – 1.00</td>
<td>2.5 – 3.0</td>
</tr>
<tr>
<td>End of Life</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-20 – 55 C</td>
<td>-40 – 60 C</td>
<td>-20 – 60 C</td>
<td>-20 – 60 C</td>
</tr>
<tr>
<td>Energy Density (Wh/Kg)</td>
<td>150</td>
<td>45-80</td>
<td>60-120</td>
<td>100</td>
</tr>
<tr>
<td>Capacity</td>
<td>30 mAh to 45Ah</td>
<td>150 mAh to 4Ah</td>
<td>500 mAh to 5Ah</td>
<td>35 mAh to 4Ah</td>
</tr>
<tr>
<td>Load Current Peak</td>
<td>20C</td>
<td>5C</td>
<td>&gt;2C</td>
<td></td>
</tr>
<tr>
<td>Best result</td>
<td>1C</td>
<td>0.5C or lower</td>
<td>1C or lower</td>
<td></td>
</tr>
<tr>
<td>Advantages</td>
<td>High capacity, good low temp</td>
<td>Low cost, high discharge rate,</td>
<td>Twice capacity than Nicad</td>
<td>High energy densities and cycle life, longer life</td>
</tr>
<tr>
<td>Limitation</td>
<td>Low energy density, toxicity</td>
<td>Shorter cycle life, more expensive, inefficient high discharge rate</td>
<td>Unsafe, more expensive</td>
<td></td>
</tr>
<tr>
<td>Relative cost</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Type</td>
<td>Primary</td>
<td>Secondary</td>
<td>Secondary</td>
<td>Primary</td>
</tr>
<tr>
<td>Application</td>
<td>Portable entertainment devices, defense devices</td>
<td>Camera, medical devices, power tool</td>
<td>Mobile phone, laptop</td>
<td>Camera, notebook computer, cell phone</td>
</tr>
</tbody>
</table>
4.2 Battery usage

Few points to note while designing the system:

4.2.1 Premature voltage cut-off

The developed system should fully utilize the battery’s stored energy. The system should not cut off prematurely before the end-of-discharge voltage is reached and precious battery power remains unused. e.g. The system, using the Li-ion should not cut-off at 3.3V as the Li-ion can be discharged to 3V and lower.

4.2.2 Current discharge rate

Battery can be discharge in three different load conditions;

i. Constant resistance

ii. Constant current, and

iii. Constant power.

Constant Resistance Load will cause excessive and rapid current flow as the discharge voltage fell. This caused a shorter operating life span.

Constant Current Load condition maintains a steady rate of current flow. The average current as compare to constant resistance mode will be smaller. Thus discharge time to the end voltage will also be increased.

Constant Power Load condition has the lowest average current drawn, and therefore has the longest life. During discharge, the current is lowest at the beginning of the cycle and increased as the battery voltage drops. Under this condition, the battery can be discharged below its end voltage.
5 Power Supply Regulation

Below give a quick and simple comparison of Linear and Switching Regulators

<table>
<thead>
<tr>
<th>Function</th>
<th>Linear</th>
<th>Switching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only step down. Input voltage must be greater than output</td>
<td>Steps up or down, or inverts.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>Linear</th>
<th>Switching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low to medium, but actual battery life depends on load current and battery voltage over time. High if Vin-Vout difference is small.</td>
<td>High, except at very low load currents (uAmps), where switch-mode quiescent current is usually higher.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Waste Heat</th>
<th>Linear</th>
<th>Switching</th>
</tr>
</thead>
<tbody>
<tr>
<td>High if the average load and/or the input/output voltage differences are high</td>
<td>Low. Components usually run cool for power levels below 10 watts.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Linear</th>
<th>Switching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low. Usually requires only the regulator and low value bypass capacitors.</td>
<td>Medium to high. Usually requires inductor, diode, and filter caps in addition to IC. For high power circuits, add external FETs.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size</th>
<th>Linear</th>
<th>Switching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small to medium in portable designs, but can be larger if heatsinking is needed</td>
<td>Larger than linear at low power, but smaller at power levels for which linear requires a heatsink.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Cost</th>
<th>Linear</th>
<th>Switching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low.</td>
<td>Medium to high, largely due to external components.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ripple/Noise</th>
<th>Linear</th>
<th>Switching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low. No ripple, low noise. Better noise rejection.</td>
<td>Medium to high, due to ripple at switching rate</td>
<td></td>
</tr>
</tbody>
</table>

Linear regulation is a commonly adopted design due to its simplicity and cost. The main drawbacks are its efficiency and heat generation. However the actual effect of measured efficiency is quite adequate when considered over the battery’s full discharge cycle. Another consideration factor is the justification of the prolonged battery life against the cost reduction.
6 Consideration for External Interfacing

A wrongly configured and selected part may cause much harm to the low power application. A general advises is to use energy saving parts and avoid the following parts:

i. Optically isolated devices
ii. Electro-mechanical relay
iii. Backlight
iv. Serial communication

The reduction of components count is a form of power saving too. However factors such as reliability, safety and cost must be put into consideration.

6.1 Low power parts

Many components have been designed for low power and its data sheet will explicitly defined its low power characteristics, such as lower operating and quiescent current, low voltage operation…etc. For example;

- 74LVCI low voltage CMOS Logic (1.65-5.5 V operation)
- 74LVC low voltage CMOS Logic (2.7-3.6V with 3.3/5 V tolerant input)
- Ultra low power CMOS SRAM
- Low power Operational Amplifier

6.2 Pull up/down resistor

The value of pull up/down resistor should be deal with too. Although the difference between the usage of a 10K and a 100K resistor in a 3.3 Volts system may be just a mere 30uA, but if comparison is made with the total system (e.g SLP consume 19uA during sub-active mode), the power lost is considered enormously.

6.3 Unused pins

It is necessary to pull up or down the input pins. Floating pins will cause the increase of switching current. A recommended value is 100K ohms resistor. For I/O ports, set the pins to be output, and set it permanently high.

The AVcc must be tied to the Vcc pin even if it is not used.

6.4 Driving of LED

LED is commonly used as a form of indicator for the human eye. Since the human eye can retain an image for about 1/60 the second. The LED can be drive periodically in order to save power. Moreover LED can be pulsed for two times its nominal current rating, at 50 % duty cycle, this will make the LED to appear brighter than driving it at nominal current rating at 100 % duty cycle (Mathematically, the average current consumed is the same)
Developers have to choose the correct type of LED for their application. Consideration must be made for the viewing angle, size, colour, brightness and more importantly the typical current consumption. A normal LED consumes about 10-30 mA of current, whereas the low current type is designed to draw only 2 mA of current.

### 6.5 Switching off external devices

SLP may switch off its internal peripherals easily using the module standby register. However if developers are to integrate power switch to cut off power supply to other subsystem, the following factors must be considered:

When the subsystem is turned-off, will it cause loading to other sub-system?

When the battery power supply is lowered, will it cause the subsystem to malfunction earlier due to voltage dropped across the power switch?

An example using Hitachi HD151015 (9-bit level shifter/Transceiver with 3 state Output) is shown as follows:
6.6 Analogue Signal
Do not feed analog signal into a digital input. The analog level will cause more current flow at the digital input. An amplifier or a schmitt-trigger can be used as a conditioner.

6.7 High impedance states during standby
During standby mode, SLP output ports are in the high impedance states. Developers have to consider this case as this may cause external peripherals to go into an unknown state. Pull up or down resistor may be necessary.

6.8 Driving state during low power operation
The designed system will operate in the lowest power mode in most of the time (perhaps 90% of its life span). Thus extra effort must be made to consider the power consume during this period of time. All components must be put into the off state or the lowest power states.
7 System power consumption & life span calculation

In order to know how long the product can last with a particular battery, the average power consumption of the system must be calculated.

For a simplified case, let assume the following
- The board contains only the SLP device.
- SLP operates on only two modes: active medium and standby.
- Two 1.5 Volts 1500mAh alkaline batteries are used.
- The SLP will cycle itself between active medium speed and standby modes. (The initial power up stage can be ignored in the calculation.)
- The current consumption remain constant (ignoring the other factors such as temperature changes, battery voltage drops…)

<table>
<thead>
<tr>
<th>Mode</th>
<th>Current</th>
<th>Time Taken</th>
<th>% covered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Up</td>
<td>25mA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active High Speed</td>
<td>3 mA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active Medium (fosc/128)</td>
<td>1 mA</td>
<td>10 msec</td>
<td>about 10 %</td>
</tr>
<tr>
<td>Oscillation</td>
<td>25 mA</td>
<td>20 usec</td>
<td>about 0 %</td>
</tr>
<tr>
<td>Standby</td>
<td>0.32 uA</td>
<td>90 msec</td>
<td>about 90 %</td>
</tr>
</tbody>
</table>

Total time taken for 1 cycle = (10 msec + 20 usec + 90 msec)
= 100 msec (approximation)

Average current consume = (10 % * 1mA) + (0% * 25 mA) + (90% * 0.32uA)
= 100 uA (approximation)

No of hours the battery can last = 1500 mAh r / 100 uA
= 15 000 hrs
= 625 days
= 21 months (approximation)

Note: when more components are added into the board, the total current may not be the summation of all the components quiescent current (as shown in the data sheet). The effective loading effect of components will affect the quoted value in the data sheet.

The easier method is to measure the actual current consumed at different operating modes /states.
8 Conclusion

Topics covered in this application note raised several low power considerations. Developers are advised to explore further as each application’s expectation is different. The most contradicting factor will be Cost. The implementation of each topics are not detailed in this notes, developers have to refer to each devices hardware manual for the exact setting.

The topics raised in this application note can also be applied to the other MCU. However there are more topics to be covered for higher end application. Topics such as, bus width consideration, speed partitioning of the whole system, coding consideration…

Reference

1.  www.buchmann.ca, ‘Batteries in a portable world’
2.  www.batteryuniversity.com  ‘Battery University’
7.  www.embedded.com
9.  www.renesas.com  ‘Renesas SLP web page’
## Revision Record

<table>
<thead>
<tr>
<th>Rev.</th>
<th>Date</th>
<th>Description</th>
<th>Page</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>Sep.03</td>
<td></td>
<td>-</td>
<td>First edition issued</td>
</tr>
</tbody>
</table>
Keep safety first in your circuit designs!

1. Renesas Technology Corporation puts the maximum effort into making semiconductor products better and more reliable, but there is always the possibility that trouble may occur with them. Trouble with semiconductors may lead to personal injury, fire or property damage. Remember to give due consideration to safety when making your circuit designs, with appropriate measures such as (i) placement of substitutive, auxiliary circuits, (ii) use of nonflammable material or (iii) prevention against any malfunction or mishap.

Notes regarding these materials

1. These materials are intended as a reference to assist our customers in the selection of the Renesas Technology Corporation product best suited to the customer's application; they do not convey any license under any intellectual property rights, or any other rights, belonging to Renesas Technology Corporation or a third party.

2. Renesas Technology Corporation assumes no responsibility for any damage, or infringement of any third-party's rights, originating in the use of any product data, diagrams, charts, programs, algorithms, or circuit application examples contained in these materials.

3. All information contained in these materials, including product data, diagrams, charts, programs and algorithms represents information on products at the time of publication of these materials, and are subject to change by Renesas Technology Corporation without notice due to product improvements or other reasons. It is therefore recommended that customers contact Renesas Technology Corporation or an authorized Renesas Technology Corporation product distributor for the latest product information before purchasing a product listed herein. The information described here may contain technical inaccuracies or typographical errors. Renesas Technology Corporation assumes no responsibility for any damage, liability, or other loss rising from these inaccuracies or errors. Please also pay attention to information published by Renesas Technology Corporation by various means, including the Renesas Technology Corporation Semiconductor home page (http://www.renesas.com).

4. When using any or all of the information contained in these materials, including product data, diagrams, charts, programs, and algorithms, please be sure to evaluate all information as a total system before making a final decision on the applicability of the information and products. Renesas Technology Corporation assumes no responsibility for any damage, liability or other loss resulting from the information contained herein.

5. Renesas Technology Corporation semiconductors are not designed or manufactured for use in a device or system that is used under circumstances in which human life is potentially at stake. Please contact Renesas Technology Corporation or an authorized Renesas Technology Corporation product distributor when considering the use of a product contained herein for any specific purposes, such as apparatus or systems for transportation, vehicular, medical, aerospace, nuclear, or undersea repeater use.

6. The prior written approval of Renesas Technology Corporation is necessary to reprint or reproduce in whole or in part these materials.

7. If these products or technologies are subject to the Japanese export control restrictions, they must be exported under a license from the Japanese government and cannot be imported into a country other than the approved destination. Any diversion or reexport contrary to the export control laws and regulations of Japan and/or the country of destination is prohibited.

8. Please contact Renesas Technology Corporation for further details on these materials or the products contained therein.