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Application Note

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Li-Ion, Li-Pol Charger Using MC9S08QD4

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1 Introduction

In the present time, there is a continuously growing amount of battery-powered appliances, Li-Ion and Li-Pol batteries are frequently used. They are best suited to power supply requirements of used microcontrollers. It is possible to combine several battery cells in series to reach higher supply voltage. But most of applications use single-cell configuration. The batteries are charged by standard wall adapters or directly through USB interface of the PC. Charging is ensured by the dedicated battery charger in an appliance. This charger maintains safe charging conditions and proper, full charge of the battery cell. On the other side, a microcontroller in an appliance can replace a dedicated battery charger too. This can lower the final cost of the whole appliance. This microcontroller needs only several added external components to build the whole charger. These components are needed in most of chargers, specially powered by universal wall AC/DC adapter. On the other side, the microcontroller can boost the Li-Ion battery voltage (from 2.8 to 4.2 V) to higher voltage with tight

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tollerance, for example +5.0 V or more, to supply some other circuits in the application. Both parts — the Li-Ion and Li-Pol charger and boost converter implemented in MC9S08QD4 MCU will be discussed in this application note. The software for both implementations can be used in any other stand-alone application too. As an example of this implementation, the metronome application for musicians is presented with detailed schematic. The whole software pack is in the AN3825SW.zip file.

2 Li-Ion and Li-Pol Battery Description

Li-Ion batteries employ a graphite material used in conjuction with a lithiated transition metal oxide, such as lithium cobalt oxide. The electrolyte consists of a lithium salt dissolved in a mixture of organic carbonates. During the charge and discharge reaction, lithium ions move across the cell between the carbon and metal oxide electrodes.

A lithium battery cell typicaly consists of a spiral-wound roll of two composite electrodes separated by a microporous film, containing the electrolyte solution. This all is sealed in a metallic case. The operating voltage ranges from 2.8 to 4.2 V per cell. This very useful voltage level combined with high energy density has lead to rapid grow of use in a wide range of electronic appliances, mainly in mobile phone market and as battery packs for notebooks. But these batteries are very useful in all applications, where a power supply is about 3.3 V — a level mostly used in microcontroller applications.

The lithium-polymer (Li-Pol) batteries are very similar to the Li-Ion technology. They have the same properties as Li-Ion type, but a slightly higher energy density, and they can be manufactured as very thin cells, whilst retaining the performance and cost profile of Li-Ion.

The Li-Ion and Li-Pol batteries have some important advantages over a previously used NiCd or NiMH types:

- They have no memory effect.
- They have a very low self-discharge.
- Another advantage is simpler charging than nickel-based batteries.
- There is an absence of topping and trickle charge.
- They have a higher energy density.
- Li-Ion and Li-Pol batteries can share the same charger.

On the other side you have to pay attention to:

- You have to maintain a proper charging voltage level; maximum is 4.20 V per cell.
- You have to avoid deep discharging under 2.7 V per cell.
- You have to avoid exposing the battery to high temperatures.
- You have to avoid excessive heating of battery whilst charging or discharging (higher than +45 °C).

3 Charger Description

The main goal was to use as simple configuration as possible, and meet all requirements for safe and proper charging of Li-Ion battery. The next aim was to reach a very low price of the whole solution. The software in the MCU controls the charging to maintain charging sequence defined by the manufacturer. This sequence is known as CCCV type. This means constant current and constant voltage shape. It is shown in Figure 1.

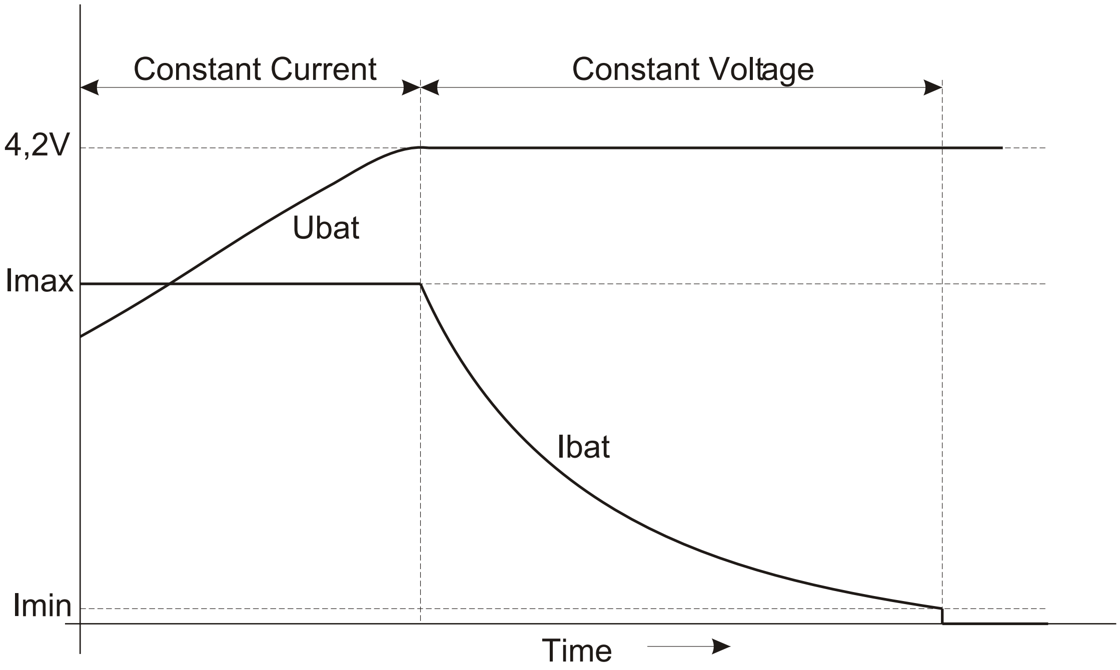

Figure 1. CCCV Charging Characteristic

During the first part of the charging process named as “constant current,” the battery voltage grows. At the end of this part the battery is charged up to 70 % of the nominal capacity. The charging processor must look up to actual battery voltage to avoid over-voltage of the battery. The maximal construction limit is 4.30 V, thus the real charging limit is 4.20 V. The charging current during this period is defined by the battery properties. The standard mobile phone battery can be charged by 1 C current, the larger types (for example the 18650 type) usually 0.8 C or less. The C means current in mA, equal to capacity in mAh; for example 700 mA for capacity of 700 mAh. There are Li-Pol batteries on the market that can be charged by a much higher current.

The next part of charging process is named “constant voltage”. In this state the charging processor must maintain a constant voltage of 4.20 V on the battery. The charging current decreases and battery is going to a full charge. When the charging current reaches the low limit, which is about 3 % of rated charging current I_{max}, the battery is considered as fully charged and charging process is finished.

The schematic of this charger solution is shown in Figure 2. This charger is based on the standard buck DC/DC converter structure. The power P-MOSFET is controlled by a PWM signal from the MCU. The duty cycle of the generated PWM signal with the inductor determines the charging current. The MCU measures the actual battery voltage by an ADC converter input ADC1. The mentioned QD4 type of MCU includes a 10-bit ADC, which is sufficient of accurate measurement of the voltage of charged Li-Ion battery. It is possible to use the next free ADC inputs to measure temperature of the battery using the internal temperature sensor too. On the other side, if you design this charger for a certain range of battery capacity, you can set the maximal charging current by limit of PWM duty cycle.

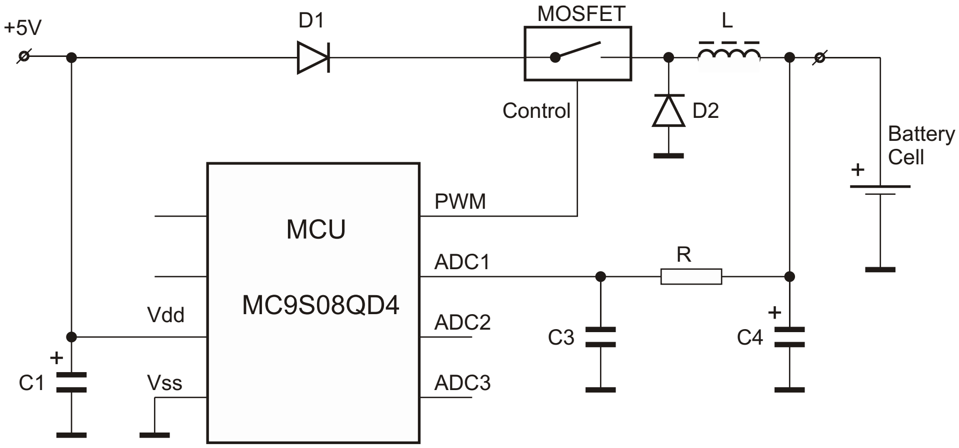

Figure 2. Simplified Charger Schematic

It is a very simple configuration, while the power supply voltage will be only +5.0 V, for example from the USB port of PC. If you need to use a higher input voltage, the low-cost low-power linear voltage regulator must be used to power the MCU only. All other parts are powered by input voltage higher than V_{DD} of MCU. The final version shown in Figure 3 can be used with input supply in range up to 16 V DC.

There are several small changes, when compared to the previous simple schematic of charger. The MCU is powered from a dedicated +3.3 V linear voltage regulator. This voltage level maintains a proper functionality, when the whole charger is powered from an external power source in the range from 5 V to 16 V. The upper limit depends on the properties of used components — capacitor C8, C9, power MOSFET Q2, and voltage regulator U1. The values of the inductor L1, capacitor C8 and C9 depend on the used power source and level of the charging current. They can be reduced in accordance to final design. Values on the schematic are usable for charging current up to 300 mA.

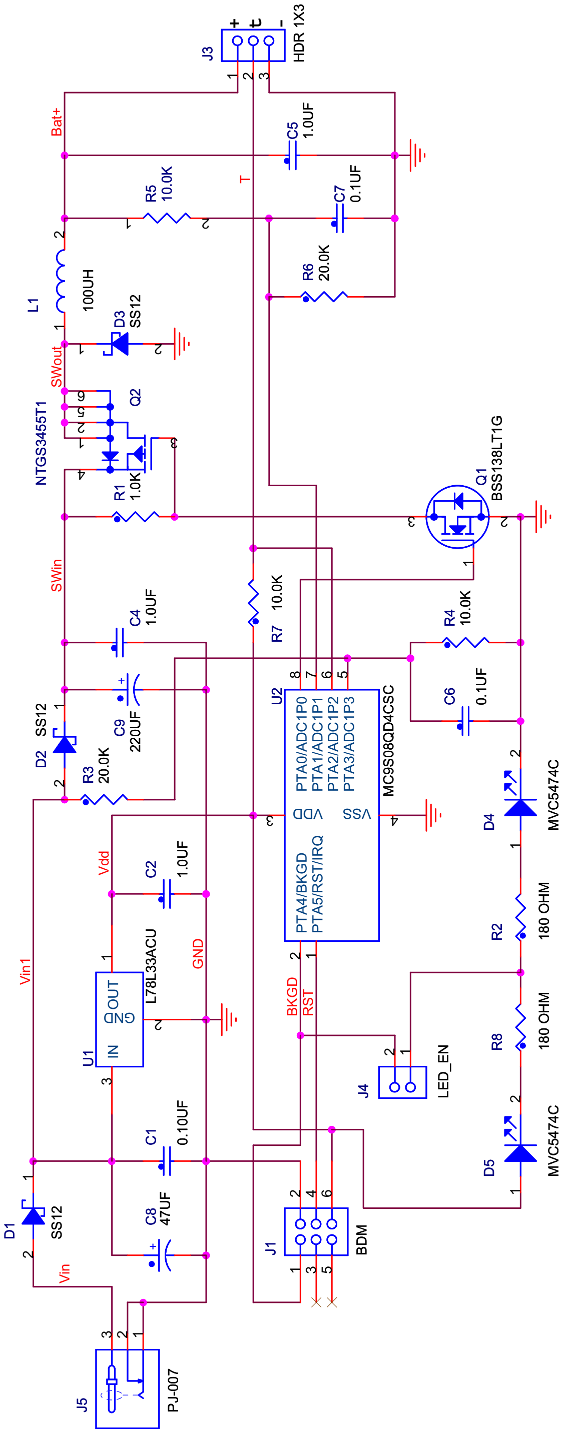

Figure 3. Detailed Charger Schematic

4 DC/DC Boost Converter Description

The DC/DC boost converter converts the battery cell voltage to a higher desired output voltage. This converter utilizes a very simple schematic shown in Figure 4.

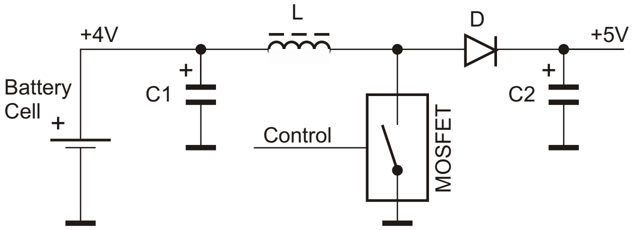

Figure 4. DC/DC Boost Converter

The switcher N-MOSFET is controlled by a PWM signal from a microcontroller (MCU) of the application. Diode D is a standard Schottky type, capacitors C1 and C2 are low-ESR aluminium electrolyte types. In the real application the output voltage +5 V powers the MCU. In this case this MCU can simply measure this level, and directly set the PWM duty cycle to maintain a proper regulation of the output voltage +5 V. Values of the capacitors C1, C2, and inductor L are selected in accordance to output current and voltage ripple requirements. The capacitor values in the range from 47 μF to 330 μF are sufficient in most applications. The inductor value is in the range from 22 μH to 330 μH. You need to pay attention to select the proper size of this inductor in accordance to output current. In this configuration it is very easy to reach the output voltage in tolerance of ±0.1 V or better. You can use this converter for any other output voltage level in real range. Then the output-voltage divider must be used to measure the output voltage, because this level can be out of input range of the MCU’s analog-to-digital converter (ADC).

5 Software Implementation

The Li-Ion battery charger and DC/DC boost converter can be used as stand-alone application, but they can be implemented in the real application as an added software pack. In case you want use it as a stand-alone charger, you can use schematic shown in Figure 3. It can be corrected in accordance to user requirements — it can tightly fit the dedicated battery. Then you can reach the lowest cost possible. In case you want to use a whatever wall adapter in voltage range up to 16 V DC, you can use the schematic shown in Figure 3. This design is made as an example for testing purposes and it works very well.

The DC boost converter can be used as a stand-alone application too. It can be implemented in a low-cost MCU with PWM and ADC capability. For example it can be the MC9S08QD4.

6 Application Example

Both the charger and the converter can be used as an added software in any other application too. One small design was made as an example for this implementation — it is an accurate metronome for musicians. The software is implenemted in a new type of MCU — the MC9S08SG8. The whole schematic is shown in Figure 5.

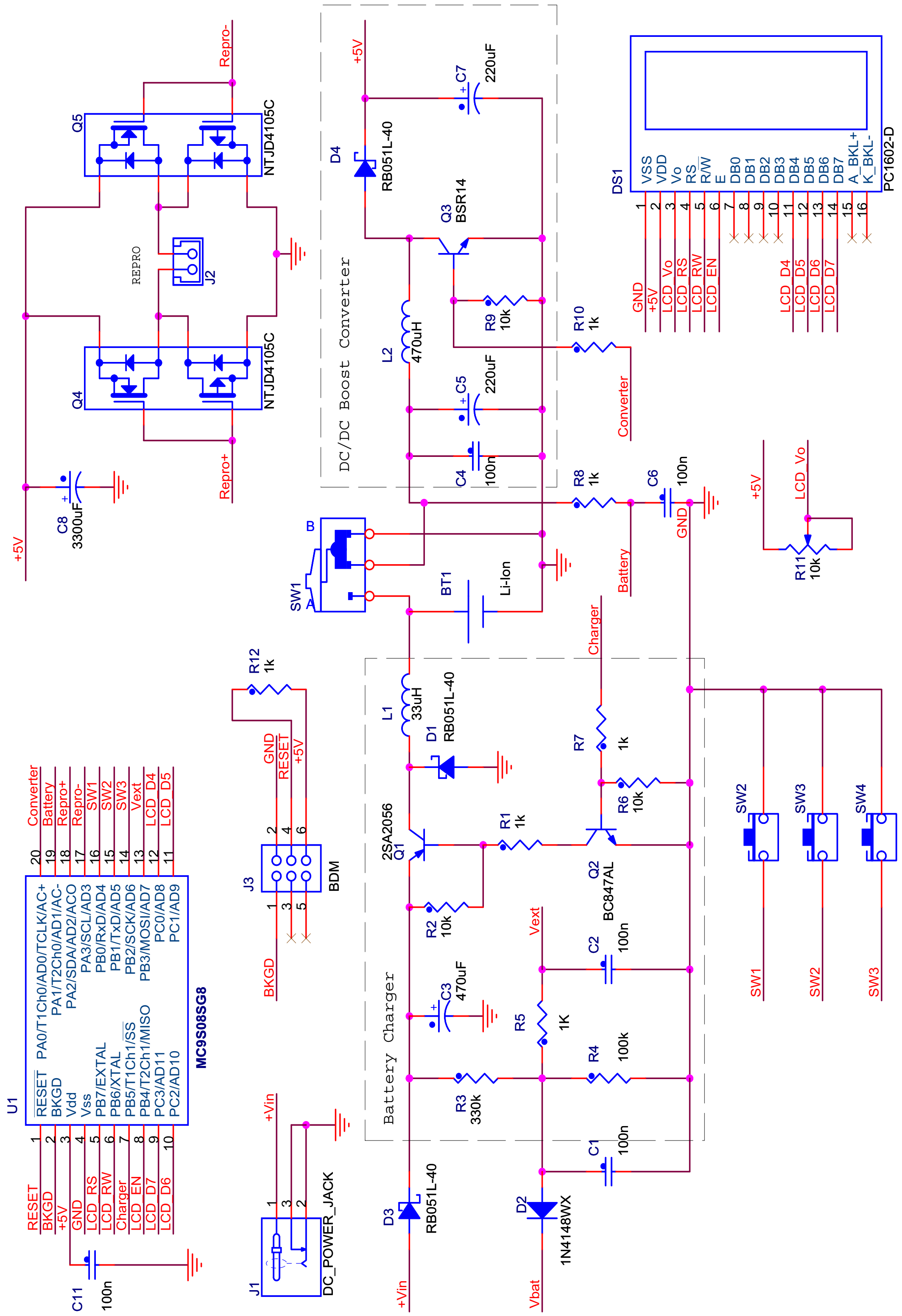

Figure 5. Metronome Schematic

The application provides:

- Li-Ion battery charger
- DC/DC boost converter
- LCD display driver
- Sound generator
- Speaker driver

6.1 Schematic Description

The heart of this shematic is the MC9S08SG8 MCU. This MCU maintains all functions needed. It can be powered with voltage ranging from +2.7 to +5.5 V. The main power source is one-cell Li-Ion battery BT1. It is in the center of the schematic. The parts on the left belong to Li-Ion charger, and parts on the right belong to DC/DC boost converter. The next part is a standard LCD display (powered by +5 V) and sound driver — full bridge MOSFET powered by +5 V with a small speaker as a load. A relatively large capacitance C8 is used, because of high-current impulse load of +5 V line. When your application doesn't require as high impulse load, the small capacitance C7 is sufficient in most applications.

Standard bipolar transistors are used instead of presented MOSFET; they were "on the hand" and functionality is the same. After powerup by switching the main switch SW1, the MCU starts to run on battery voltage of about 3.6 to 4 V. This voltage is too low for proper functionality of the LCD. The MCU measures its own power supply and starts to run the DC/DC boost converter software. The +5 V power line rises to its level, and then it is possible to run the application software. The DC/DC boost converter software runs in the background and maintains the stabilized power supply of +5 V.

The MCU software continuously senses the external voltage V_{ext} on C2. If the external voltage in range from +6.5 V to +16 V is connected to DC power jack J1, then the Li-Ion charger software starts to run. This routine measures the actual battery voltage and external applied voltage and charges the battery until full charged. Then the charging process is terminated.

6.2 Software Description

The application software uses accurate time intervals generated by RTI interrupt in the MCU. It is important that this time interval serves as the synchronization point for all three software routines to be able to run concurrently. A test was made with a period of RTI interrupt from 5 ms to 30 ms and all applications ran properly. The accurate RTI period depends on the actual application. The state diagram of this application is shown in Figure 6. It is possible to add some other tasks to a software loop and make the RTI interrupt period setting comply with requirements of all tasks to achieve a proper functionality.

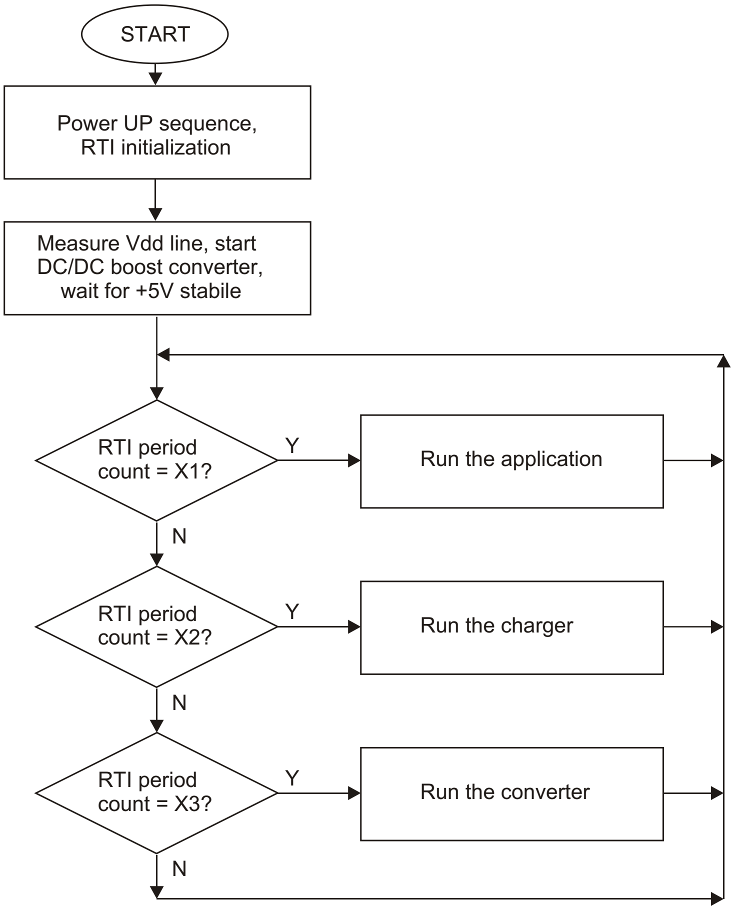

Figure 6. State Diagram

7 Conclusion

This application note is an example how to implement Li-Ion or Li-Pol charger and DC/DC boost converter into real customer application. All tasks and functions are implemented in application software. These applications were tested on a very simple low-cost MCU of the S08 family (MC9S08QD4, MC9S08SG8). The MCUs utilize internal peripherals as 10-bit ADC, real-time interrupt module RTI, PWM module, and internal bandgap reference (constant V_{ref}). It is possible to implement these algorithms to whichever S08 family of MCUs, which comprise mentioned internal peripherals. The whole application source code with a description inside is provided as the AN3825SW.zip file.

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