Application Note

Application Guidance for Reverse Wake-up via OVUVOTUT with BQ79616 in Sleep Mode

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ABSTRACT

This document was translated from a simplified Chinese source. (ZHCAG94)

In addition to performing comprehensive cell voltage and temperature sampling during normal vehicle operation and conducting chip self-diagnostics to achieve a specific functional safety level (ASIL level) requirement, the Battery Management System (BMS) of new energy vehicles must also monitor the voltage and temperature of the vehicle battery pack under the low-power premise of the vehicle entering sleep mode. When an overvoltage/undervoltage or overtemperature/undertemperature fault occurs, the BMS or the entire vehicle can be woken up in a timely manner, thereby initiating a comprehensive inspection of the vehicle. This application guidance will introduce the logic, configuration, and considerations of reverse wake-up via OVUVOTUT based on the BQ79616 in sleep mode.

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1 Basic Principle of Reverse Wake-up for BQ79616

1.1 Basic Principle of Reverse Wake-up Implemented by BQ79616 and BQ79600

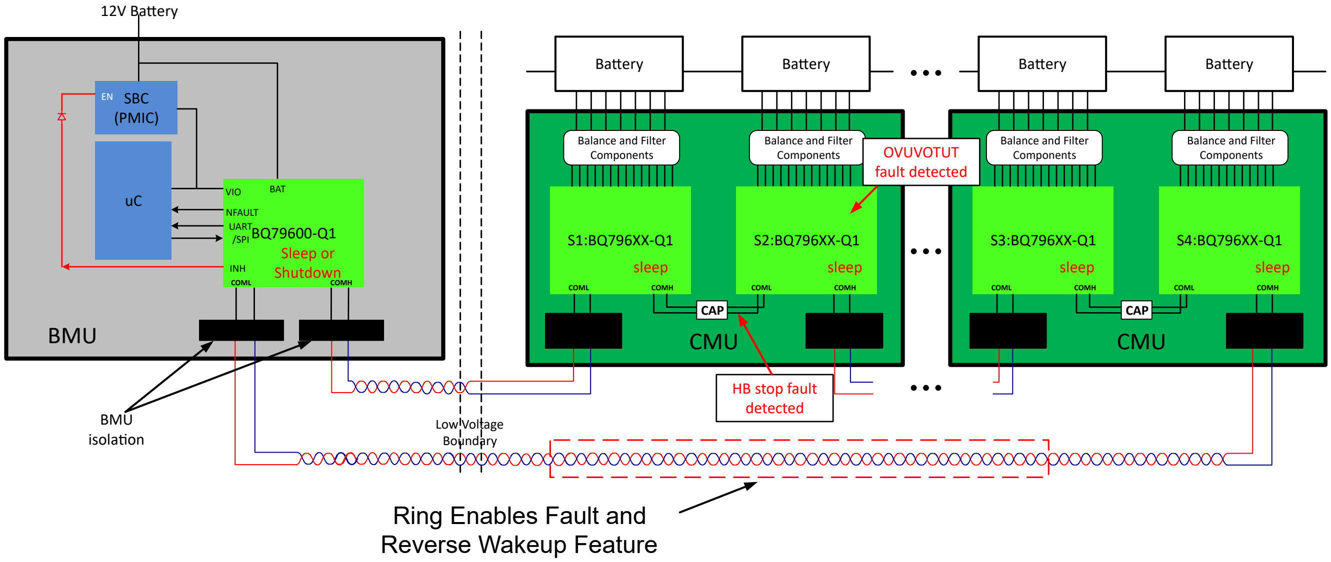

Figure 1-1. Block Diagram of BQ79600/BQ79616 Reverse Wake-up Function

The figure above shows the reverse wake-up system block diagram of a conventional BMS, wherein multiple BQ79616 chips are used as AFEs to accomplish the monitoring of all cell voltages and temperatures of the battery pack. The BQ79600 is used as a bridge chip connecting the AFEs and the MCU to perform the conversion and transmission of communication data. The function where the BMS operates in low-power mode to monitor the battery pack for OVUVOTUT and Heartbeat signals and reverse-wakes the BMS after a battery pack fault occurs is referred to as the reverse wake-up function of the AFE. Usually, the reverse wake-up function requires a loop daisy chain.

To realize the reverse wake-up function, the BQ79600 can operate in Sleep mode or Shutdown mode with the Sniff function enabled. The power consumption of the BQ79600 operating in Sleep mode is slightly higher than that in Shutdown mode; Shutdown mode saves power consumption but loses the diagnostic capability for the two communication lines—forward and reverse—between the BQ79600 and the first AFE, as well as the last AFE.

Unlike the BQ79600, the BQ79616 must operate in Sleep mode. Before the BQ79616 enters Sleep mode, the alarm thresholds for OVUVOTUT must be properly configured. After entering Sleep mode, the TSREF of the BQ79616 remains constantly powered, executing real-time fault diagnostics for OVUVOTUT. Concurrently, if the diagnostic function for the Heartbeat tone signal is enabled, the BQ79616 can also diagnose the Heartbeat signal to judge the integrity of the AFE ahead of it as well as the intermediate communication lines. In a fault-free state, the BQ79616 periodically transmits a Heartbeat tone every 400ms. Once an OVUVOTUT fault occurs or the Heartbeat is lost for over 1s, the BQ79616 will immediately cease transmitting the Heartbeat tone and switch to transmitting a Fault tone instead. After receiving the Fault tone, the BQ79616 behind it will also immediately begin transmitting the Fault tone, ultimately relaying the Fault tone to the BQ79600.

Upon receiving the Fault tone at its communication port, the BQ79600 pulls the INH level high. The INH level acts as a hardware wake-up signal for the SBC/PMIC after being stepped down by a voltage divider resistor network to wake up the SBC/PMIC. Then, the MCU is woken up by the SBC/PMIC. After being woken up, the MCU first wakes up the BQ79600, and then transmits a Sleep2active tone via the BQ79600 to wake up the BQ79616. Once woken up, the BMS performs fault diagnostics. After obtaining the specific fault, it executes the corresponding measures according to the severity of the fault level hazard.

1.2 OVUVOTUT Function of BQ79616

To achieve the reverse wake-up function, the OVUVOTUT function needs to be configured before the BQ79616 enters Sleep mode, so as to implement its monitoring of battery pack voltage and temperature in Sleep mode. After entering Sleep mode, other modules are deactivated, and only the OVUVOTUT module and communication module continue to operate. The power consumption of the chip in Sleep mode primarily includes the power consumption of the protection module and the communication module.

The implementation logic for the OVUV function of the BQ79616 is shown in the figure below. After configuring the OVUV thresholds via registers, the chip's OVUV DAC generates the corresponding analog voltages to the input terminals of the comparators. The other terminal of the comparator is connected to the cell voltage through a MUX and a BCI shifter. When a cell voltage exceeds the configured threshold, the OVUV fault is asserted.

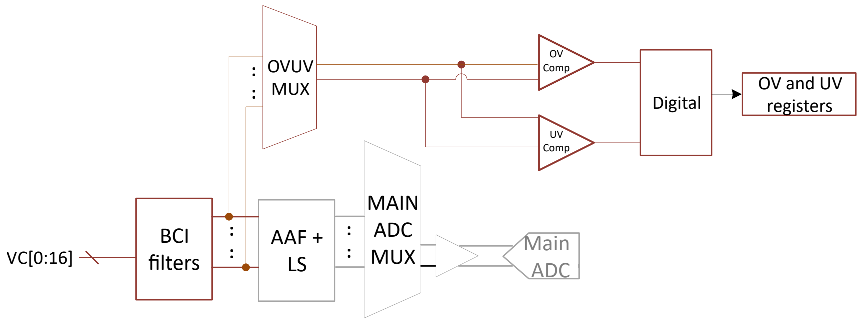

Figure 1-2. Block Diagram of BQ79616 OVUV Function

By the same token, the implementation logic for the OTUT function is shown in the figure below. The divided voltage between the pull-up resistor and the NTC sampled by the GPIO port is compared against the OTUT threshold via a comparator. An OTUT fault bit is asserted after an OTUT event occurs. The OTUT thresholds are configured in terms of percentage. A threshold percentage configuration of 50% means that after the NTC resistance (thermistor) at a certain temperature divides the voltage with the pull-up resistors (R1, R2), the voltage input to the GPIO equals 50% of the TSREF voltage.

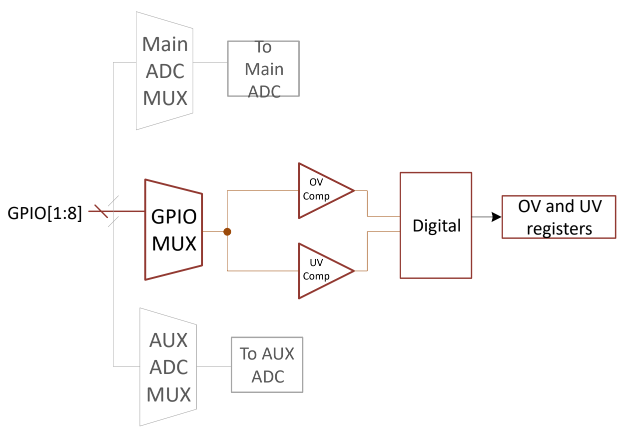

Figure 1-3. Block Diagram of BQ79616 OTUT Function

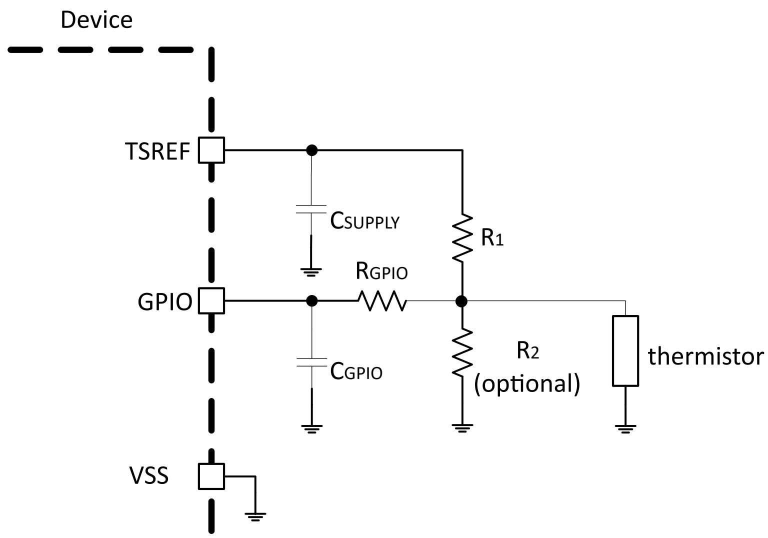

Figure 1-4. BQ79616 Temperature Sampling Circuit

The registers relevant to the OVUVOTUT configuration include:

1. OVUV threshold configuration registers: OV_THRESH 0x009, UV_THRESH 0x00A.
2. OTUT threshold configuration registers: OTUT_THRESH 0x00B.
3. UV disable registers: UV_DISABLE1/2 0x00C/D.
4. Control register for OVUVOTUT: OVUV_CTRL 0x32C, OTUT_CTRL 0x32D

In Sleep mode, the BQ79616 performs real-time periodic checks for OVUVOTUT, OTCB, and CBDONE. As shown in Figure 1-5, the OV check and UV check are carried out simultaneously. The difference lies in that the VCB_DONE balancing end-of-voltage check is interspersed within the UV check. As shown in Figure 1-6, the OT check and UT check are also conducted alternately, and OTCB balancing overtemperature is interspersed within the OT sequence.

During the diagnostic process, if any fault among OVUVOTUT is monitored, the BQ79616 will transmit a fault tone to the BQ79600, and the BQ79600 reverse-wakes the MCU.

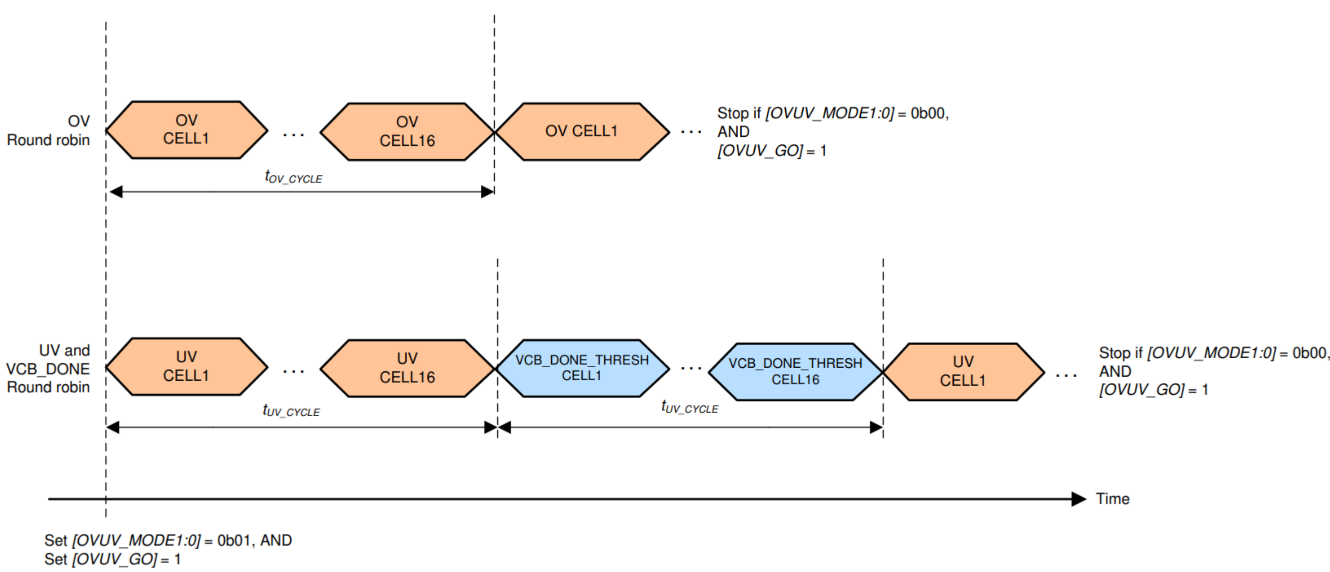

Figure 1-5. Operation Timing of BQ79616 OVUV/CBDONE in Sleep Mode

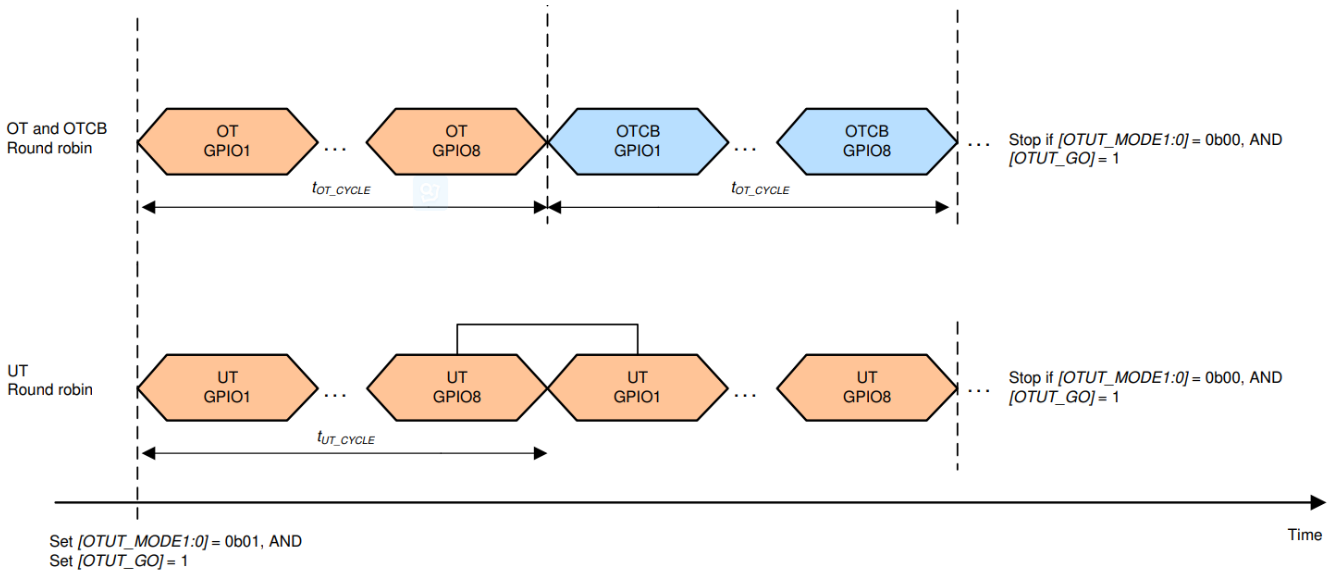

Figure 1-6. Operation Timing of BQ79616 OTUT/OTCB in Sleep Mode

1.3 Logic for BQ79600 to Implement Reverse Wake-up

During the reverse wake-up process, the BQ79600 can operate in Sleep mode or Shutdown mode with the Sniff function enabled.

If the BQ79600 operates in Sleep mode to realize reverse wake-up, the BQ79600 needs to enable the INH function, whereas the Heartbeat tone function can be selectively enabled. After entering Sleep mode, the communication module of the BQ79600 monitors whether a Fault tone is received at all times. Once a Fault tone is detected, the BQ79600 pulls the INH pin high, and the INH serves as a hardware wake-up signal to wake up the BMS SBC or PMIC power management chip. After being woken up, the SBC/PMIC continues to wake up the MCU, which in turn wakes up the BQ79600 and BQ79616 to confirm the cause of the reverse wake-up after data interaction. As shown in the figure below, the BQ79600 switches from Sleep mode to active mode.

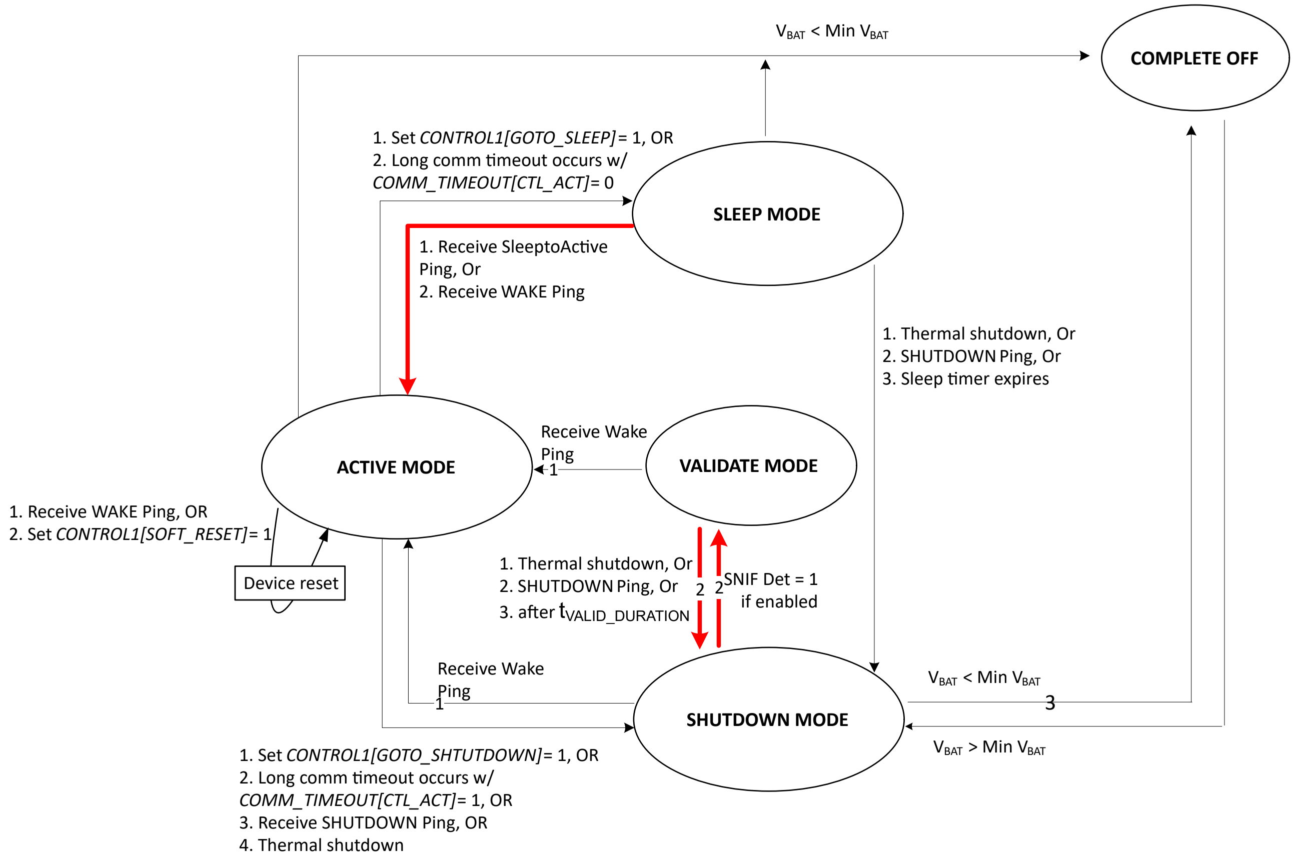

Figure 1-7. Logic of BQ79600 Operation Mode Switching

The BQ79600 can also operate in Shutdown mode, provided that its Sniff function is enabled before entering Shutdown mode. As shown in the switching logic among Shutdown mode, VALIDATE mode, and ACTIVE mode in the figure above, when a fault occurs in the battery system and the Fault tone is relayed to the BQ79600, the first Fault tone triggers the logic of SNIF Det=1, thereby prompting the BQ79600 to enter VALIDATE mode. After entering VALIDATE mode, CVDD is pulled high, but the INH is not pulled high immediately at this point. The chip waits for a duration of $t_{VALID\_DURATION}$. If a second Fault tone is detected, the BQ79600 pulls INH high to reverse-wake the BMS. Otherwise, the BQ79600 switches from VALIDATE mode back to Shutdown mode, CVDD is pulled low, and the chip continues to await the next Fault tone.

Note

After the BQ79600 enables the Sniff function and enters Shutdown mode, the BQ79600 no longer transmits the Heartbeat tone to the S1 BQ79616; therefore, the Heartbeat tone fault detection of the S1 BQ79616 needs to be masked.

The enabling principle of INH is illustrated in Figure 1-8, which shows the functional block diagram of the BQ79600. After a Fault tone is detected at COMH/L, the switch tube between INH and BAT is turned on, and INH is pulled up to BAT. If the BAT supply is 12V, a resistor divider method must be used after INH to step down the voltage to 5V or 3V to wake up the SBC/PMIC.

Note

The power consumption of the BQ79600 operating in Sleep mode is slightly higher than that in Shutdown mode. Shutdown mode saves power consumption but loses the diagnostics of the direct communication line from the BQ79600 to the first BQ79616. This is because during the sleep process, the BQ79600 in Shutdown mode no longer transmits or detects the Heartbeat tone.

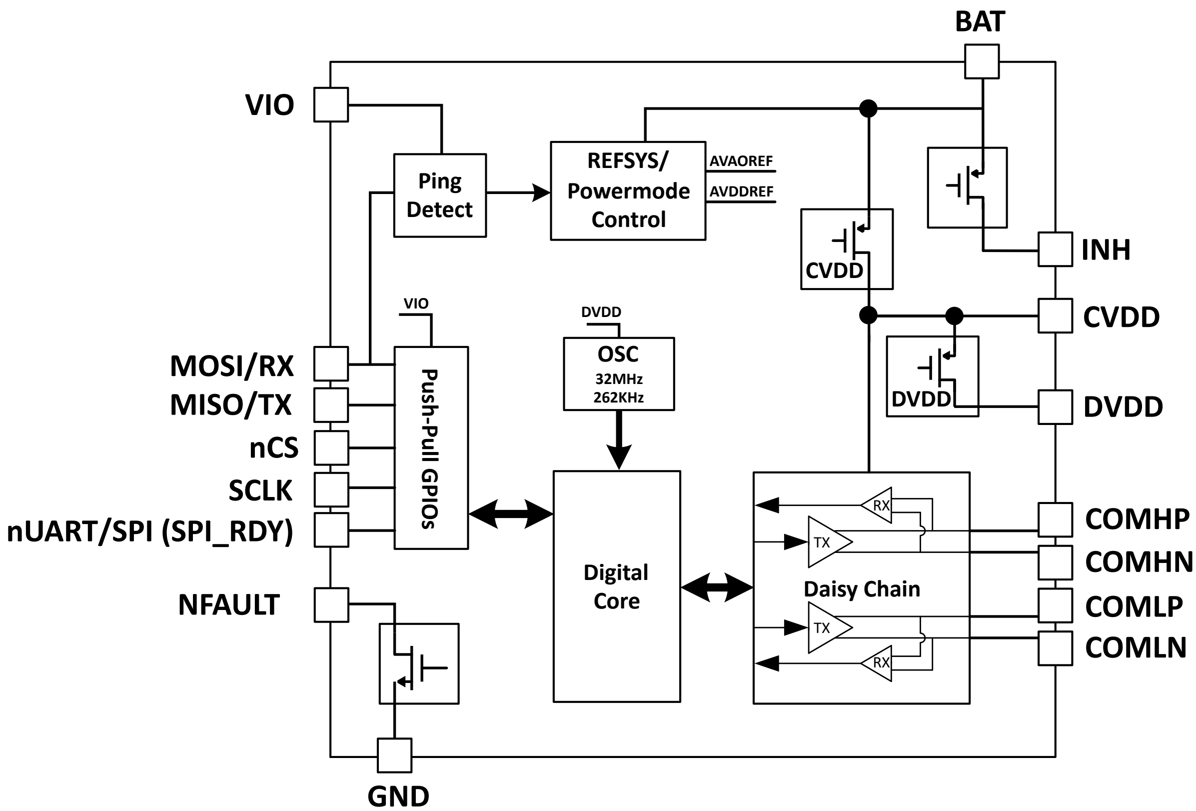

Figure 1-8. BQ79600 function block diagram

2 How to Configure BQ79616 and BQ79600 to Achieve Reverse Wake-up Function

Before configuring the reverse wake-up for the BQ79616 and BQ79600, the two chips need to be woken up and addressed first, and then configured respectively.

2.1 Configuration for BQ79616 to Implement Reverse Wake-up Function

The configuration of the BQ79616 can be divided into two parts: 1. Configuration of Heartbeat and Fault tone. 2. Configuration of effective channels and thresholds for OVUVOTUT.

Wherein, if the BQ79600 uses Sleep mode to run reverse wake-up, the configuration routine for the Heartbeat and Fault tone, as well as the sleep diagnostic cycle, is as follows:

Enable Heartbeat and Fault tone for BQ79616

90 01 00 02 03 A4 80

If the BQ79600 uses Shutdown mode, the Heartbeat tone detection mechanism of the first BQ79616 needs to be additionally masked:

Mask HB Fault for S1 AFE, because BQ79600 no longer sends Heartbeat tone after entering Shutdown mode

90 01 00 17 04 EB D2

Then, the configuration routine for the effective channels, thresholds, and diagnostic cycles of OVUVOTUT is as follows:

Configure overvoltage threshold, OV threshold=2700mV

90 01 00 09 02 62 70

Configures undervoltage threshold, UV threshold=1200mV

90 01 00 0A 00 E3 41

Configure Enable Channels, CELL9-16 ENABLE

90 01 00 0C 00 E0 E1

Configure Enable Channels, CELL0-8 ENABLE

90 01 00 0D 00 E1 71

Configure over- and under-temperature thresholds, UT=66%, OT=10%

90 01 00 0B 00 E2 D1

Turn on OVUV comparison, OVUV-GO Round robin with all cells

90 01 03 2C 05 C9 22

Turn on OTUT comparison, OTUT-GO Round robin with all cells

90 01 03 2D 05 C8 B2

The above routine completes the configuration of the BQ79616 OVUVOTUT with an OV threshold of 2700mV, an UV threshold of 1200mV, and an OT threshold of 10%. The UT threshold is 66%. The Heartbeat and Fault tone signals are enabled.

An additional explanation is required for the configuration of OTUT. In some cases, the chip needs to simultaneously detect the temperature of the off-board battery pack and the temperature of the on-board balancing resistors, and the temperature protection thresholds for these two positions are generally different —the temperature protection threshold for the balancing resistors is higher than that for the battery pack. Therefore, there are two ways to resolve this issue: 1. Use different NTCs to match the same temperature protection threshold. 2. Use different pull-up/pull-down matching resistors R1/R2 to achieve alarms for the two temperatures under the premise of identical GPIO voltage protection thresholds.

2.2 Configuration for BQ79600 to Implement Reverse Wake-up Function

The configuration of the BQ79600 needs to be executed according to Sleep mode and Shutdown mode. The configuration for running in Sleep mode requires enabling the Heartbeat tone and TONE_RX_EN of the BQ79600, and also requires enabling the INH function.

Note

The BQ79600 needs to perform a reset on INH after each wake-up, and then enable INH again; otherwise, the previously pulled-high INH will remain pulled high.

Below is the configuration for BQ79600 Sleep mode:

Enable HB and TONE_RX_EN for BQ79600

90 00 20 01 35 24 50

If manipulating 0x2001 or 0x2020, CONF_MON_GO must be sent once while resetting RST_REG.

90 00 20 00 20 E4 0F

Reset INH of BQ79600

90 00 20 02 03 A4 B6

Re-enable INH of BQ79600

90 00 20 02 00 E4 B7

Below is the configuration for BQ79600 Shutdown mode:

Enable snif function for BQ79600

90 00 20 01 94 E5 E8

Enable HB and TONE_RX_EN for BQ79600

90 00 20 01 35 24 50

If manipulating 0x2001 or 0x2020, CONF_MON_GO must be sent once while resetting RST_REG.

90 00 20 00 20 E4 0F

Reset INH of BQ79600

90 00 20 02 03 A4 B6

Re-enable INH of BQ79600

90 00 20 02 00 E4 B7

2.3 Other Configurations for BQ79600 and BQ79616 Prior to Entering Sleep

With the configurations in the above two subsections, the BQ79600 and BQ79616 can be successfully configured into the reverse wake-up state. Next, the preparatory work before entering sleep needs to be performed.

1. For the BQ79616, mask the fault bits that are not desired to report errors in the sleep state, and reconfigure them as required after waking up the chip.
2. Reset all fault registers of the BQ79616 and BQ79600.
3. The chips enter Sleep or Shutdown mode.

The routine is described as follows:

Mask all faults of BQ79616 except OVUVOTUT, Heartbeat and Fault tone

91 01 00 16 87 73 E2 8B

Reset all faults for BQ79616

91 01 03 31 FF FF 71 61

Reset all faults for BQ79600

90 00 20 30 FF B1 97

All BQ79616 enter sleep mode

B0 03 09 04 D1 77

If the BQ79600 uses Sleep mode, use the following command:

BQ79600 go to Sleep mode

90 00 03 09 04 13 8E

If the BQ79600 uses Shutdown mode, use the following command:

BQ79600 go to Shutdown mode

90 00 03 09 08 13 8B

3 Testing of Reverse Wake-up Based on EVM Board

The figure above is the system block diagram for testing, wherein the BQ79600 is the bridge chip and the BQ79616 is the AFE.

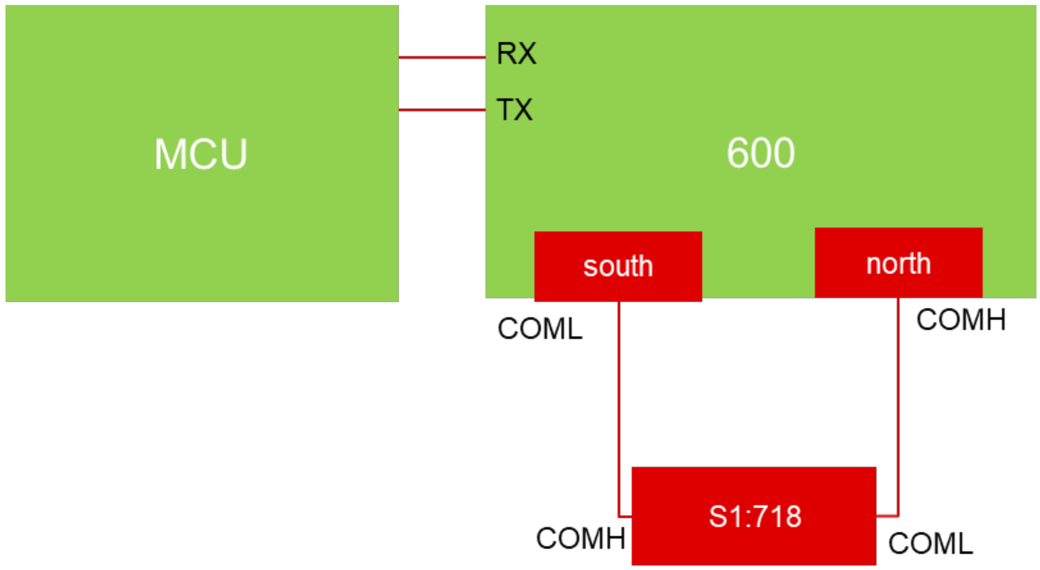

Figure 3-1. EVM Board Test System Block Diagram

3.1 Reverse Wake-up Test with BQ79600 Operating in Sleep Mode

First, conduct the reverse wake-up test under BQ79600 Sleep mode. Here, it is not necessary to mask the Heartbeat detection of the first AFE. After waking up the system and addressing, run the following code:

```
#First wake up all chips, perform addressing and configure GPIOs, the test uses GPIO4 as the OT channel

# GPIO4 configured as ADC input and OTUT

90 01 00 0F 08 E1 D7

# Enable TSREF

90 01 03 0A 01 D2 81

# ADC_GO, enable GPIO configuration

90 01 03 0D 0E 90 B5

# Enable Heartbeat and Fault tone for BQ79616

90 01 00 02 03 A4 80

# Configure overvoltage threshold, OV threshold=2700mV

90 01 00 09 02 62 70

# Configures undervoltage threshold, UV threshold=1200mV

90 01 00 0A 00 E3 41

# Enable channels 9 to 16, CELL9-16 ENABLE

90 01 00 0C 00 E0 E1

# Enable channels 1 to 8, CELL0-8 ENABLE

90 01 00 0D 00 E1 71

# Configure over- and under-temperature thresholds, UT 66%, OT 10%
```

```
90 01 00 0B 00 E2 D1
# OVUV-GO Round robin with all cells
90 01 03 2C 05 C9 22
# OTUT-GO Round robin with all cells
90 01 03 2D 05 C8 B2
# Enable HB and TONE_RX_EN for BQ79600
90 00 20 01 35 24 50
# If manipulating 0x2001 or 0x2020, CONF_MON_GO must be sent once while resetting RST_REG.
90 00 20 00 20 E4 0F
# Reset INH of BQ79600
90 00 20 02 03 A4 B6
# Re-enable INH of BQ79600
90 00 20 02 00 E4 B7
# Mask all faults of BQ79616 except OVUVOTUT, Heartbeat and Fault tone
91 01 00 16 87 73 E2 8B
# Reset all faults for BQ79616
91 01 03 31 FF FF 71 61
# Reset all faults for BQ79600
90 00 20 30 FF B1 97
# All BQ79616 enter sleep mode
B0 03 09 04 D1 77
# BQ79600 go to Sleep mode
90 00 03 09 04 13 8E
```

After running the example code, while both the BQ79616 and BQ79600 are in Sleep mode, adjust the cell voltage or temperature or disconnect the communication line to trigger an OVUVOTUT or Heartbeat fault. The logic analyzer data of the test results are shown in Figure 3-3. Triggering a Heartbeat fault by disconnecting the communication line is shown in Figure 3-4.

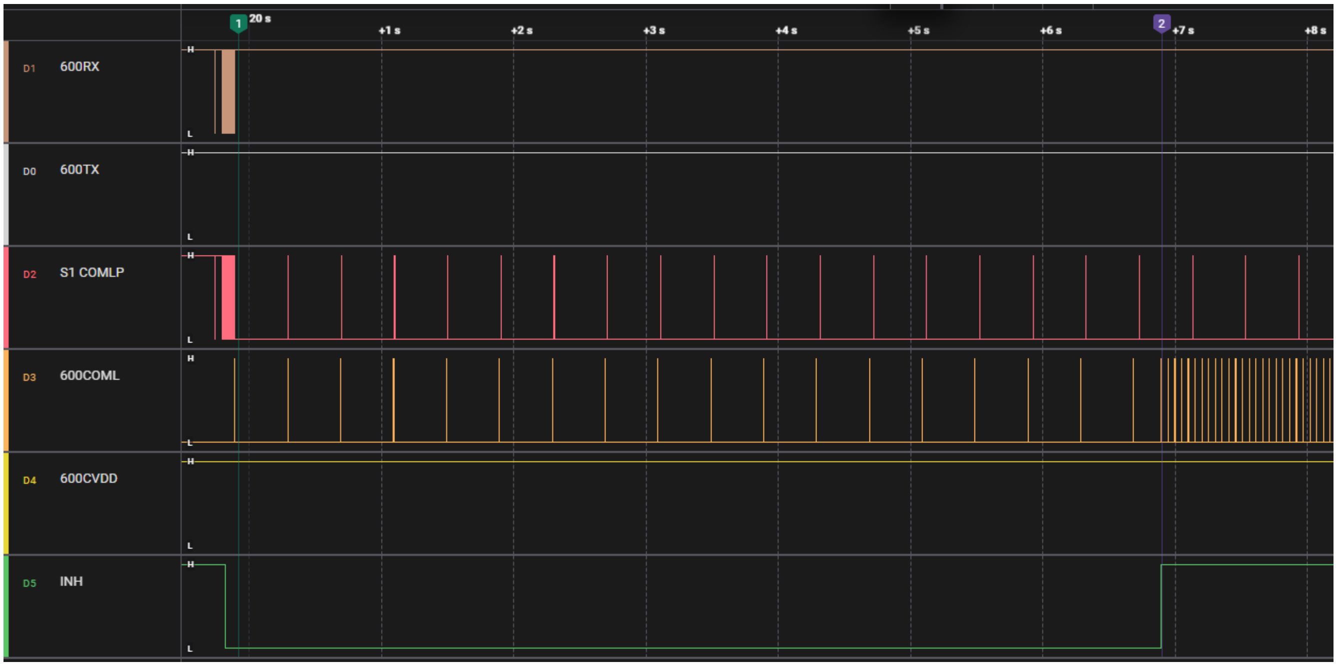

Figure 3-2. Logic Analyzer Data for Implementing OVUVOTUT Reverse Wake-up with BQ79600 Operating in Sleep Mode

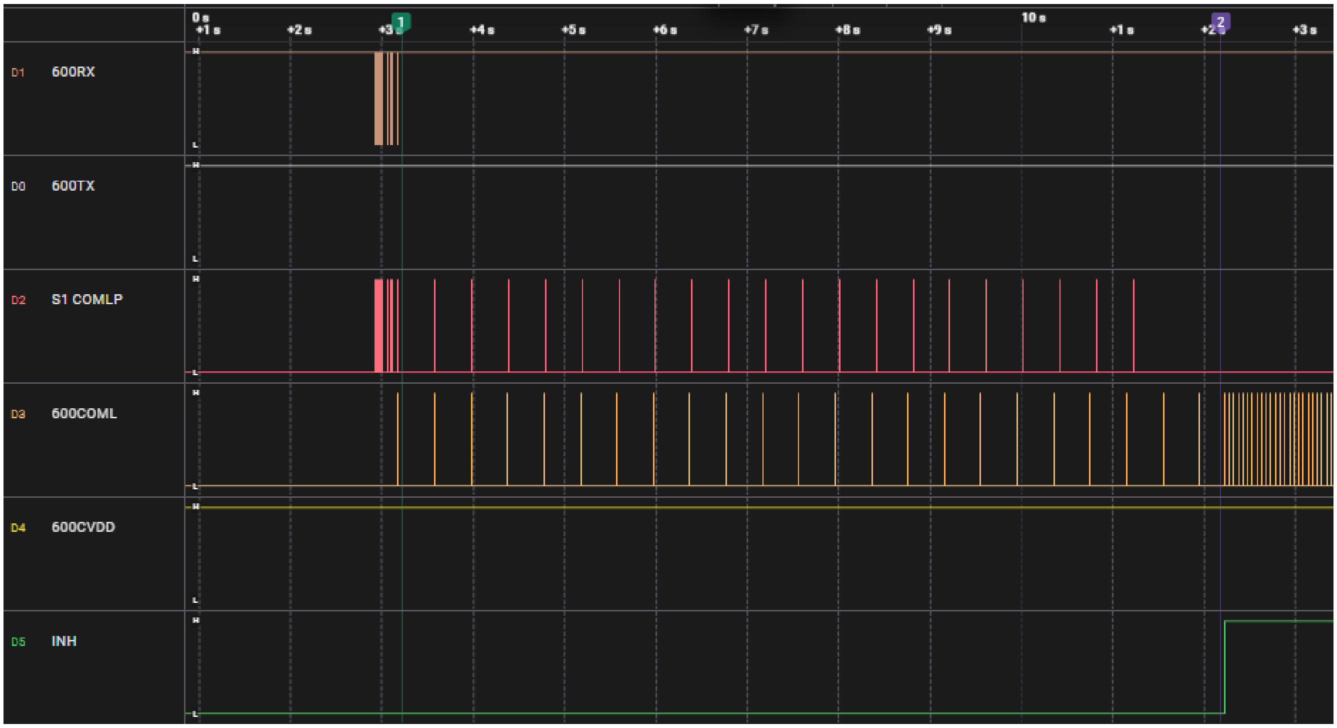

Figure 3-3. Logic Analyzer Data for Implementing HB Fail Reverse Wake-up with BQ79600 Operating in Sleep Mode

Where:

- D0: 600TX is the TX signal of the UART for communication between the BQ79600 and the MCU.
- D1: 600RX is the RX signal of the UART for communication between the BQ79600 and the MCU.
- D2: S1 COMLP is the COML port of the first BQ79616.
- D3: 600COML is the COML port of the BQ79600.

- D4: 600CVDD is the CVDD voltage of the BQ79600, used to characterize whether the BQ79600 is in the active state.
- D5: INH is the INH pin of the BQ79600.

It can be observed that,

1. At time t_1, the BQ79616 enters Sleep mode, the BQ79600 enters Sleep mode, and CVDD is constantly high.
2. Before time t_2, the BQ79600 transmits a Heartbeat tone to the first BQ79616 every 400ms. The BQ79616 also transmits a Heartbeat tone to the subsequent chips every 400ms.
3. At time t_2, an OVUVOTUT or Heartbeat tone fail fault is artificially injected. At this moment, after detecting the fault, the BQ79616 immediately begins transmitting a Fault tone.
4. Upon receiving the Fault tone, the BQ79600 pulls INH high immediately.

3.2 Reverse Wake-up Test with BQ79600 Operating in Shutdown Mode

Next, conduct the reverse wake-up test under BQ79600 Shutdown mode. It is required to enable the SNIF function of the BQ79600, and simultaneously mask the Heartbeat detection of the first AFE. After waking up the system and addressing, run the following code:

```
#First wake up all chips, perform addressing and configure GPIOs, the test uses GPIO4 as the OT channel

# GPIO4 configured as ADC input and OTUT

90 01 00 0F 08 E1 D7

# Enable TSREF

90 01 03 0A 01 D2 81

# ADC_GO, enable GPIO configuration

90 01 03 0D 0E 90 B5

# Enable Heartbeat and Fault tone for BQ79616

90 01 00 02 03 A4 80

# OV threshold=2700mV

90 01 00 09 02 62 70

# UV threshold=1200mV

90 01 00 0A 00 E3 41

# CELL9-16 ENABLE

90 01 00 0C 00 E0 E1

# CELL0-8 ENABLE

90 01 00 0D 00 E1 71

# UT 66%,OT 10%

90 01 00 0B 00 E2 D1

# OVUV-GO Round robin with all cells

90 01 03 2C 05 C9 22

# OTUT-GO Round robin with all cells

90 01 03 2D 05 C8 B2

# Enable HB and TONE_RX_EN for BQ79600

90 00 20 01 35 24 50

# If manipulating 0x2001 or 0x2020, CONF_MON_GO must be sent once while resetting RST_REG.
```

90 00 20 00 20 E4 0F

Reset INH of BQ79600

90 00 20 02 03 A4 B6

Re-enable INH of BQ79600

90 00 20 02 00 E4 B7

#enable snif

90 00 20 01 94 E5 E8

Mask all faults of BQ79616 except OVUVOTUT, Heartbeat and Fault tone

91 01 00 16 87 73 E2 8B

#mask HB fault of S1

90 01 00 17 77 AA 37

Reset all faults for BQ79616

91 01 03 31 FF FF 71 61

Reset all faults for BQ79600

90 00 20 30 FF B1 97

All BQ79616 enter sleep mode

B0 03 09 04 D1 77

600 go to shutdown

90 00 03 09 08 13 8B

After running the example code, the BQ79616 is in Sleep mode and the BQ79600 is in Shutdown mode. Adjust the cell voltage or temperature or disconnect the communication line to trigger an OVUVOTUT or Heartbeat fault. The logic analyzer data of the test results are shown in Figure 3-4 and Figure 3-5:

Wherein:

- D0: 600TX is the TX signal of the UART for communication between the BQ79600 and the MCU.
- D1: 600RX is the RX signal of the UART for communication between the BQ79600 and the MCU.
- D2: S1 COMLP is the COML port of the first BQ79616.
- D3: 600COML is the COML port of the BQ79600.
- D4: 600CVDD is the CVDD voltage of the BQ79600, used to characterize whether the BQ79600 is in the active state.
- D5: INH is the INH pin of the BQ79600.

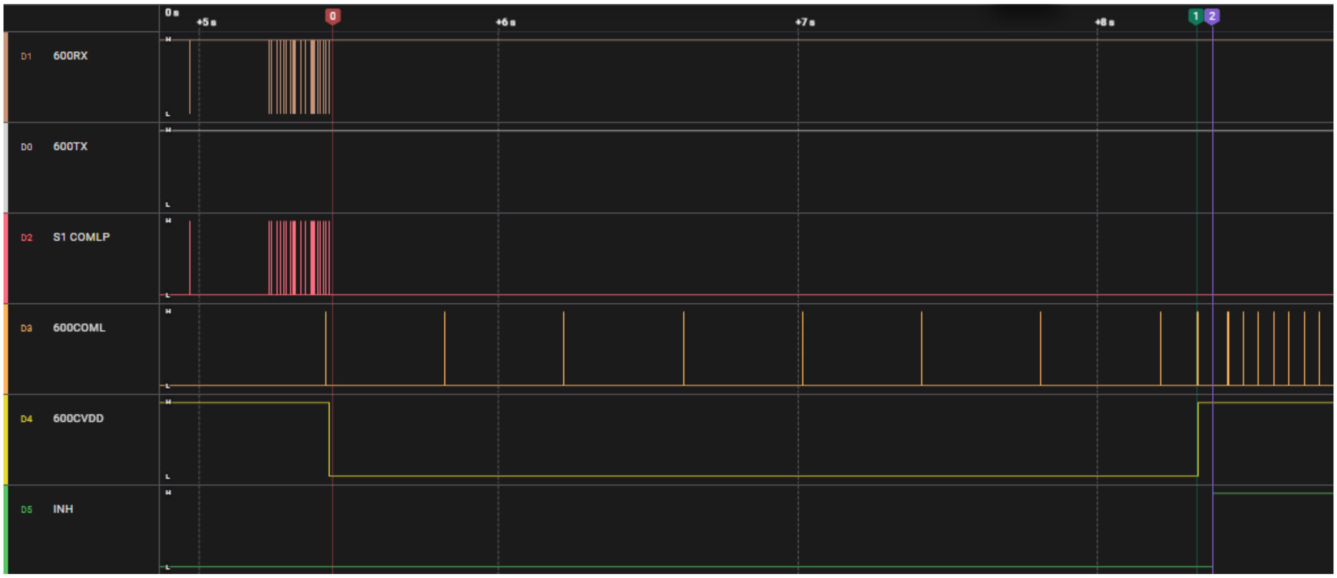

Figure 3-4. Logic Analyzer Data for Reverse Wake-up Implemented with BQ79600 Operating in Shutdown Mode

It can be observed that,

1. At time t_0, the BQ79616 enters Sleep mode, the BQ79600 enters Shutdown mode, and CVDD is pulled low.
2. Before time t_1, the BQ79616 transmits a Heartbeat tone to the subsequent chips every 400ms.
3. At time t_1, an OVUVOTUT or Heartbeat tone fail fault is artificially injected. At this moment, after detecting the fault, the BQ79616 immediately begins transmitting a Fault tone.
4. Upon receiving the Fault tone, the BQ79600 enters VALIDATE mode and awaits the second Fault tone.
5. At time t_2, the BQ79600 receives the second Fault tone, and INH is pulled high.

Figure 3-5. Enlarged View of Logic Analyzer Data

4 Summary

This article shows how the BMS consisting of the BQ79600 and BQ79616 implements reverse wakeup. The operational logic for the two chips to realize reverse wake-up is explained respectively. Meanwhile, the specific configuration flows and corresponding test results are provided. Engineers wishing to utilize the reverse wake-up of the BQ79600 and BQ79616 can implement the reverse wake-up function by slightly modifying the configuration program accordingly after understanding its principle.

5 References

1. BQ79600-Q1 datasheet, Automotive SPI/UART Communication Interface with Automatic Host Wake-Up Feature and Functional Safety Compliance
2. BQ79616-Q1 datasheet, Functional Safety Compliant Automotive 16-Channel Series Battery Monitor