

RL78/G1F

R01AN4273EC0100

Rev.1.00

Handy Vacuum Cleaner

Nov. 30, 2018

Introduction

This document describes a Renesas microcontroller RL78/G1F application for the handy vacuum cleaner.

Target Device

RL78/G1F

When applying the sample program covered in this document to another microcomputer, modify the program according to the specifications for the target microcomputer and conduct an extensive evaluation of the modified program.

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1. Description

1.1 Abstract

A vacuum cleaner, also known as a sweeper or Hoover, is a device that uses an air pump to create a partial vacuum to suck up dust and dirt, usually from floors and from other surfaces such as upholsteries and draperies.

Lightweight hand-held vacuum cleaners, powered from rechargeable batteries, are very popular for quick cleaning whenever you need it. They make cleaning easy, convenient, and effective.

The handy vacuum cleaner solution is based on Renesas multifunctional microcontroller RL78/G1F with enhanced functionality suitable for sensorless BLDC (Brushless Direct Current) motor control and battery monitor IC ISL94203. This system includes an inverter board, a motor, a temperature sensor, an analog switchboard, 6 batteries and a battery control board.

1.2 Specifications and Main Technical Parameters

Technical Parameters

- Operating Voltage: 18 V ~ 25.2 V (Li-ion 6 s)
- Rated Current: 4.6 A @ 50000 rpm with load
- Motor Model: SX-12998-00 (Max. 50000 rpm BLDCM)
- Air Flow: 260 L/min
- Wind Pressure: 8.4 kPa
- Battery Model: Panasonic NCR18650B (3400 mAh)

Specifications

- Motor Constitution: 3 phases / 2 poles / 3 slots
- Pole-pairs: 1 pp
- Motor BEMF: 0.3 V [V0-p] @ 1000 rpm
- Motor Mode: Standard: 30000 rpm
Power: 50000 rpm
- Protection: Undervoltage (19.8 V)
High voltage (25.2 V)
Current limited (13 A)
Step-out detection
Battery temperature (55°C)
Motor temperature (65°C)
- LED Display: Green: Power-on status / discharge status / full voltage
Red: Charge status / low voltage
- Operating Temperature: 0°C ~ 65°C
- Operating Humidity: 5 ~ 99% RH (No condensate water)

2. RL78/G1F Microcontroller

2.1 RL78/G1F Block Diagram

Figure 2.1 shows the block diagram of RL78/G1F (48-pin products).

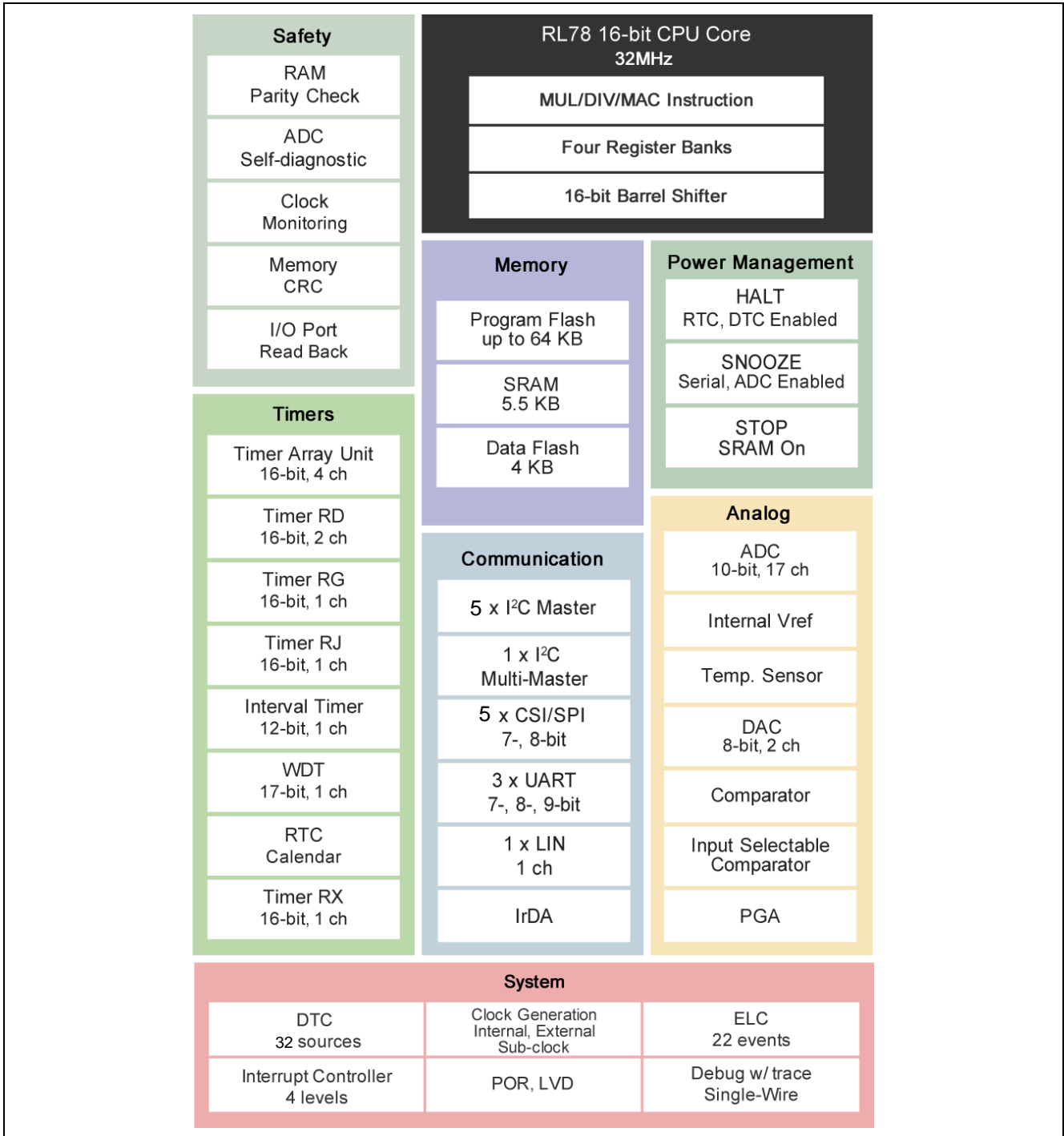


Figure 2.1 RL78/G1F (48-pin products) Block Diagram

2.2 Key Features

- Minimum instruction execution time: Can be changed from high speed (0.03125 μ s @ 32 MHz operation with high-speed on-chip oscillator) to ultra-low speed (30.5 μ s @ 32.768 kHz operation with subsystem clock)
- General-purpose registers: (8-bit register \times 8) \times 4 banks
- ROM: 64 KB, RAM: 5.5 KB, data flash: 4 KB
- Selectable high-speed on-chip oscillator clock: 64/48/32/24/16/12/8/6/4/3/2/1 MHz (TYP.)
- On-chip debug function
- On-chip selectable power-on-reset (POR) circuit
- On-chip voltage detector (LVD)
- On-chip watchdog timer (operable with the dedicated low-speed on-chip oscillator)
- On-chip key interrupt function: 6 key interrupt input pins
- On-chip clock output/buzzer output controller
- On-chip BCD (binary-coded decimal) correction circuit
- I/O port: 44
- Timer
 - 16-bit timer: 9 channels
 - 12-bit interval timer: 1 channel
- Serial interface
 - CSI: 5 channels
 - UART: 3 channels
 - Simplified I²C communication: 5 channels
 - Multi-master I²C communication: 1 channel
- 8/10-bit resolution A/D converter: 17 channels
- 8/10-bit resolution D/A converter: 2 channels
- Comparator: 2 channels
- PGA: 1 channel
- Data transfer controller (DTC)
- Event link controller (ELC)
- Standby function: HALT mode or STOP mode or SNOOZE mode
- Power supply voltage: $V_{DD} = 1.6$ to 5.5 V
- Operating ambient temperature: $T_A = -40$ to $+85^{\circ}\text{C}$

RL78/G1F microcontrollers are functionally upward-compatible with the RL78/G14 microcontrollers and have enhanced analog functionality. They are equipped with a built-in high slew rate PGA, high-speed multifunction comparator, and A/D and D/A converters. When RL78/G1F microcontrollers control sensorless BLDC motors, by using these analog functions and two timers capable of operating at 64 MHz, efficient initial rotor position detection and high-speed rotation using 120-degree conducting control can be achieved. They can also perform high-speed overcurrent detection and output cut-off without CPU intervention, so highly flexible motor control can be realized with a small number of parts.

3. System Outline

3.1 Principle Introduction

The 120-degree BEMF (Back Electromotive Force) sensorless is controlled through sampling the BEMF waveform via hardware. By comparing the BEMF and the middle-point waveform through the RL78/G1F built-in comparator (CMP1), zero-cross of the BEMF can be detected. After a 30-degree software delay, the switching phase for the motor can be decided. To run the motor in high speed, all user operations are completed in main loop and all the interrupts are disabled. The RL78/G1F can also implement both the overcurrent detection and the PWM output forced cut-off function by using the built-in PGA, the comparator (CMP0), and the PWMOPA.

The ISL94203 monitors cell voltage, current and temperature. It converts the cell voltages, pack current and temperatures to 12-bit digital values to provide the overcurrent protection, the overvoltage protection, and the undervoltage protection. It also provides cell balance control and provides complete stand-alone battery pack operation.

Figure 3.1 shows the system block diagram. Figure 3.2 shows the picture of the whole system.

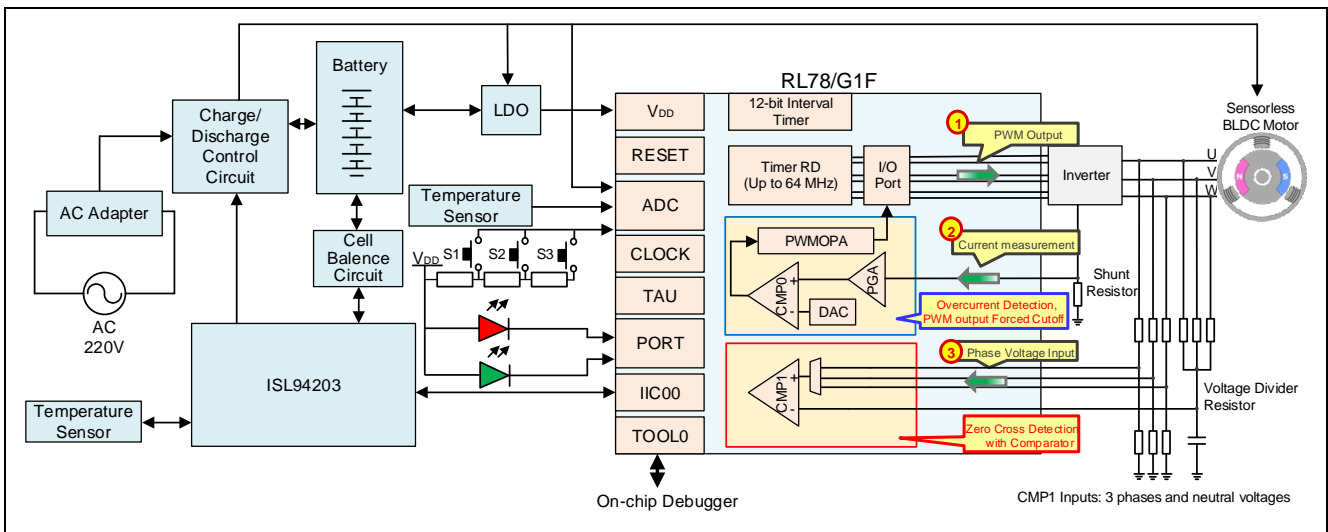


Figure 3.1 System Block Diagram

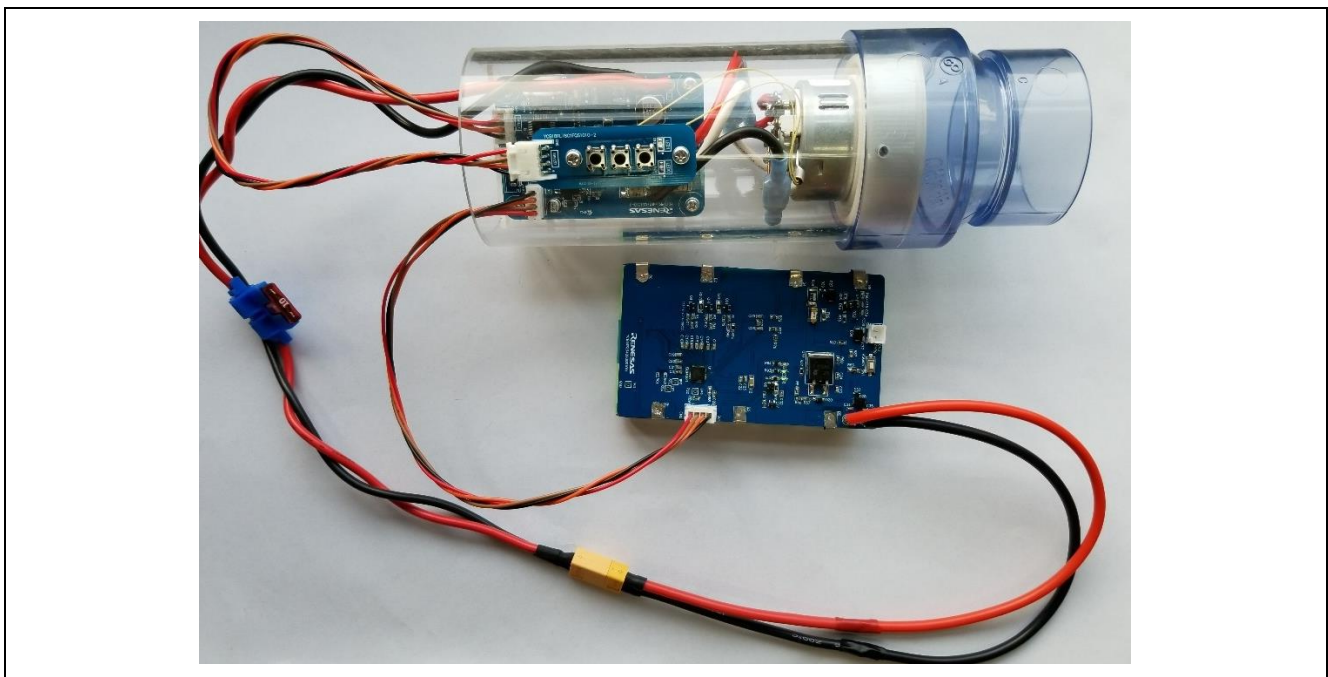


Figure 3.2 Whole System

3.1.1 Comparator Settings

The minus port of the comparator is middle-point input, and the plus port is BEMF value input. Every time after a 30-degree delay, one of the three BEMF voltages is selected according to the running steps of the motor.

Table 3.1 Comparator Selector Settings

Step	On-phase		Comparator Plus Input
Step 0	High: W	Low: V	VU
Step 1	High: W	Low: U	VV
Step 2	High: V	Low: U	VW
Step 3	High: V	Low: W	VU
Step 4	High: U	Low: W	VV
Step 5	High: U	Low: V	VW

3.1.2 Temperature Error Detection

The NTC thermistor is used in the motor temperature protection. In this solution, table checking is used to calculate the temperature.

Table 3.2 Temperature Calculation (°C)

	0	1	2	3	4	5	6	7	8	9
0	-19	-19	-19	-19	-19	-19	-19	-19	-19	-19
1	-19	-19	-18	-17	-15	-14	-12	-11	-10	-9
2	-8	-7	-6	-5	-4	-3	-2	-1	-1	0
3	1	2	3	4	5	6	6	7	8	9
4	9	10	10	11	11	12	13	13	14	15
5	16	16	17	18	18	19	20	20	21	22
6	22	23	24	24	25	26	27	27	28	29
7	30	30	31	32	32	33	34	35	36	37
8	37	38	39	40	41	41	42	43	44	45
9	46	47	48	49	50	51	52	54	55	56
10	58	59	60	61	63	65	66	68	70	72
11	74	76	79	81	83	85	88	93	97	100
12	100	100	100	100	100	100	100	100		

The A/D of the RL78/G1F is 10-bit resolution, and we can calculate the temperature by using the first 7 bits data of the A/D value. Which means:

$$\text{Temp} = \text{Table}[\text{ADCR} \gg 9]$$

For example, when ADCR >> 9 is 112, we can get the Temp value from row 11 and column 2.

From the table above, we can see the temperature that can be tested is between -20 and 100°C.

3.1.3 Speed Control

In BEMF Mode, the duty is calculated by speed control.

As the control interval is not constant, the variable factor for control loop comes to be necessary here.

$$\text{Duty} += k * \Delta\text{Speed}$$

$$k = k1 / \text{SpeedEst}$$

Here,

SpeedEst is the estimation speed.

The formula means the control factor is inversely proportional to the speed.

The estimation speed is calculated by detecting the timing between zero-cross points.

$$\text{SpeedAct} = 60 / (\text{Cnt} * 3 * \text{Tfreq})$$

$$\text{SpeedEst} += k2 * (\text{SpeedAct} - \text{SpeedEst})$$

Here,

Cnt is the timing of 120-degree detected between two zero-cross points.

Tfreq is the time of 1 Cnt (1 us)

3.1.4 BEMF Control Algorithm

The 120-degree BEMF sensorless is controlled through sampling the BEMF waveform by hardware.

By comparing the BEMF and the middle-point waveform through the RL78/G1F built-in comparator, the zero-cross of the BEMF can be detected. After a 30-degree software delay, the switching phase for the motor can be decided.

To run the motor in high speed, all control software must be completed inside the main loop and all interrupts must be disabled.

3.1.5 Fast Deceleration Function

The system comes to Stop Mode from BEMF Mode by pressing the switch. To decelerate the motor in a short time, all the low-arms of the inverter are turned on to shorten the phase of the motor. When the motor is decelerating, the input value will not be checked until it is totally stopped (about 1 second).

3.1.6 LED Display

Table 3.3 lists the LED display specifications.

Table 3.3 LED Display Specifications

LED Display	Description
Green LED is ON	The system powers on when the batteries are fully charged.
Green LED blinks	Every 1 second: The system powers on when the batteries are not fully charged. Every 0.4 seconds: The motor is working.
Red LED is ON	The batteries are being charged.
Red LED blinks	Any error occurs.

The red LED blinks every 0.4 seconds (ON/OFF = 0.2 seconds) when an error occurs. The count value of the red LED blinking means the error number.

Figure 3.3 shows the error display of the red LED.



Figure 3.3 Error Display of Red LED

To confirm the error number, users only need to count how many times the red LED blinks after resting 2 seconds.

Here lists the error numbers for each error.

Table 3.4 Error Numbers

Error Flag	Error Contents	Error Level	Error Number
FLAG_ERROR_MOTOR_TEMP	Motor temperature error	65°C	1
FLAG_ERROR_VDC_LOW	Battery low voltage	19.8 V	4
FLAG_ERROR_STEP_OUT	Step-out error	-	16

3.2 Peripheral Functions to be Used

Table 3.5 lists the peripheral functions to be used and their usages.

Table 3.5 Peripheral Functions to be Used

Peripheral Function	Usage
Timer RD	Complementary PWM output
PGA	Overcurrent detection
Comparator 0 (CMP0)	
10-bit A/D Converter	Detection of the motor temperature, the battery temperature, the battery voltage Analog switch input
Comparator 1 (CMP1)	Detection of the zero-cross at U/V/W phase
12-bit Interval Timer	Time counter for entering standby mode A/D hardware trigger in standby mode
Timer Array Unit 0	TAU00: Delay timer TAU02: Free running timer for the rotational speed measurement / step-out error check
Serial Array Unit IIC	Communicate with the ISL94203

3.3 Pins to be Used

Table 3.6 lists the pins to be used and their functions.

Table 3.6 Pins to be Used

Pin Name	Description
P15/TRDIOB0	PORT output / PWM output (UP)
P13/TRDIOA1	PORT output / PWM output (VP)
P12/TRDIOB1	PORT output / PWM output (WP)
P14/TRDIOD0	PORT output / PWM output (UN)
P11/TRDIOC1	PORT output / PWM output (VN)
P10/TRDIOD1	PORT output / PWM output (WN)
P00/ANI17/IVCMP10	Pseudo center voltage input
P01/ANI16/IVCMP11	U phase zero-cross compare
ANI0/AVREFP/IVCMP12	V phase zero-cross compare
ANI1/AVREFM/IVCMP13	W phase zero-cross compare
P22/ANI2/PGAI/IVCMP0	PWM emergency stop input at the time of overcurrent detection
P23/ANI3/PGAGND	
P24/ANI4	Motor temperature detection
P25/ANI5	Battery temperature detection
P26/ANI6	Analog switch input
P27/ANI7	Battery voltage detection
P71	Control the green LED
P70	Control the red LED
P50/SDA00	IIC communication with the ISL94203
P30/SCL00	
P40/TOOL0	On-chip debug
P125/RESET	Hardware reset
V _{SS}	Ground
V _{DD}	Power supply voltage

3.4 Operating Instructions

- (1) The system enters a power on state when the power pack is connected to the motor control board. The RL78/G1F is then initialized and sends battery control data to the ISL94203 before entering Stop Mode.
- (2) If the S1 (switch) is pressed, the system will enter Stop Mode and the motor will stop running. The green LED will blink every 1 second if the batteries are not fully charged. Or the green LED will turn ON if the batteries are fully charged.
- (3) If the S2 (switch) is pressed, the system will enter Standard Mode and the motor will run at 30000 rpm. The green LED will blink every 0.4 seconds.
- (4) If the S3 (switch) is pressed, the system will enter Power Mode and the motor will run at 50000 rpm. The green LED will blink every 0.4 seconds.
- (5) If there is no operation for 40 seconds and the batteries are not in charging status, the RL78/G1F will enter Standby Mode and the green LED and the red LED will turn OFF.
- (6) If the batteries become low voltage, the red LED will start to blink, and the motor will not work.
- (7) When the batteries are being charged, the red LED turns ON.
- (8) When the batteries are fully charged, the green LED turns ON.

4. Hardware

Once the pack power output plug on the battery control board is connected to the power input plug on the motor control board, the system powers on. The RL78/G1F communicates with the ISL94203 through the IIC to get the battery status. TH2 (W), TH3 (V), TH4 (U) are connected to the sensorless BLDC motor to drive it. The NTC thermistor in the motor temperature sensor interface is screwed to the motor. The RL78/G1F can detect the temperature of the motor in real time. If the temperature exceeds 65°C, the motor will stop.

Figure 4.1 shows the picture of the motor control board. Figure 4.2 shows the picture of the battery control board.

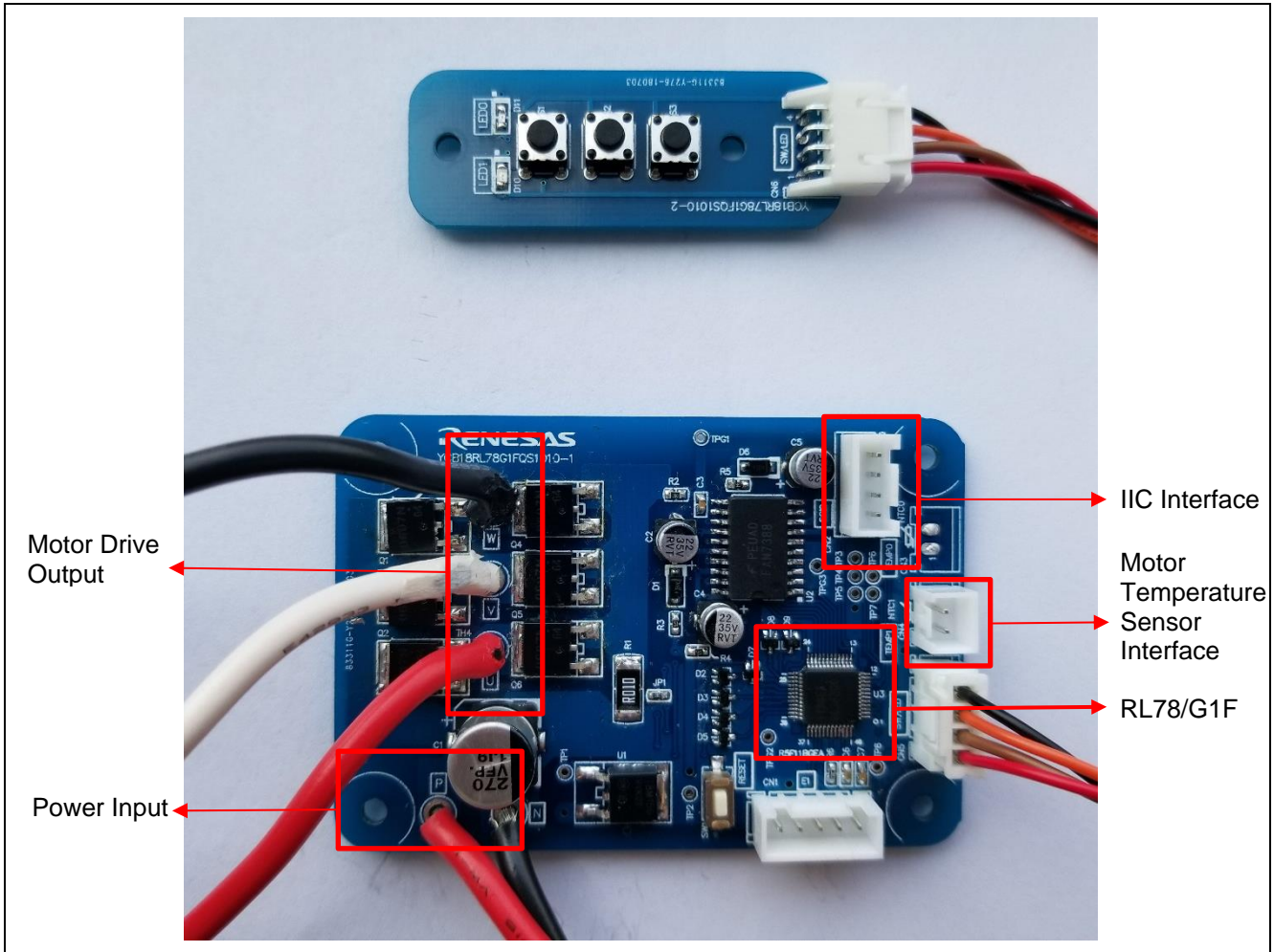


Figure 4.1 Motor Control Board

4.1 Cell Balance Circuit

Figure 4.3 shows the schematic of the cell balance circuit.

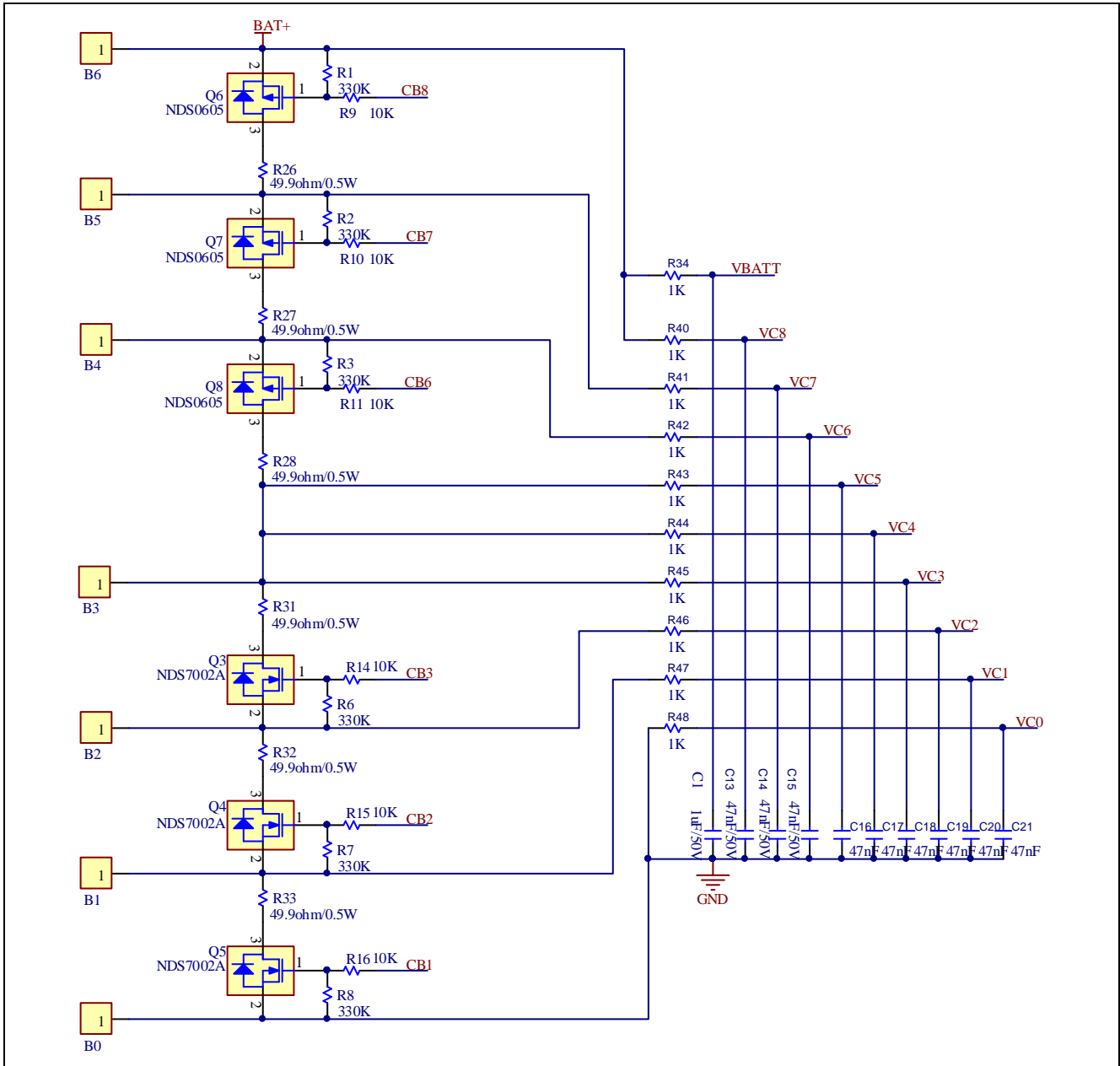


Figure 4.3 Cell Balance Circuit

The ISL94203 can monitor the voltage of each section of up to 8 batteries via the VC0 to VC8 ports. In this application, 6 batteries are used, and the connection circuit is shown as above. The cell balance during charging and discharging is realized through controlling the NMOS transistor and PMOS transistor's conduction or cut-off by the CB1 to CB8 ports.

4.2 Charge/Discharge Circuit

Figure 4.4 shows the schematic of the charge/discharge circuit.

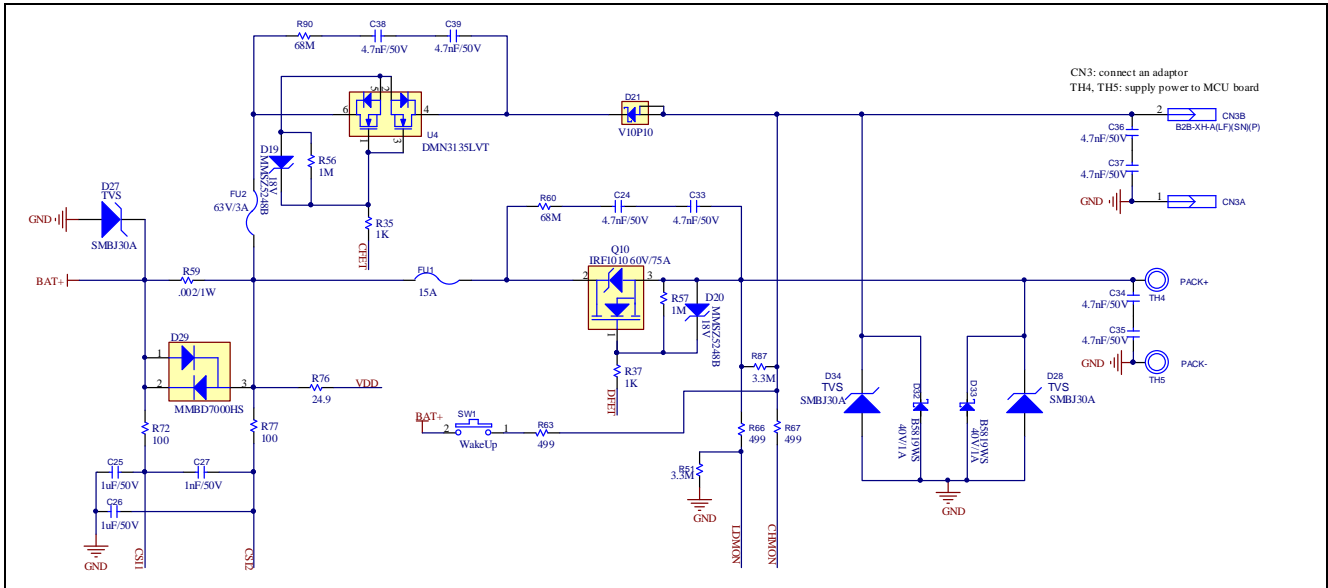


Figure 4.4 Charge/Discharge Circuit

The charge port (CFET) and the discharge port (DFET) are used to control the MOSFET product to complete the charging and discharging paths respectively.

The DMN3135LVT, along with 2 series NMOS transistors is used to prevent discharging at the charge port. The IRF1010 is an N-channel power MOSFET with current conduction capability of 84 A, fast switching speed, low on-state resistance, breakdown voltage rating of 60 V, which is good enough for the 25.2 V, 13 A system in this application.

4.3 Motor Control Circuit

Figure 4.5 shows the schematic of the motor control circuit.

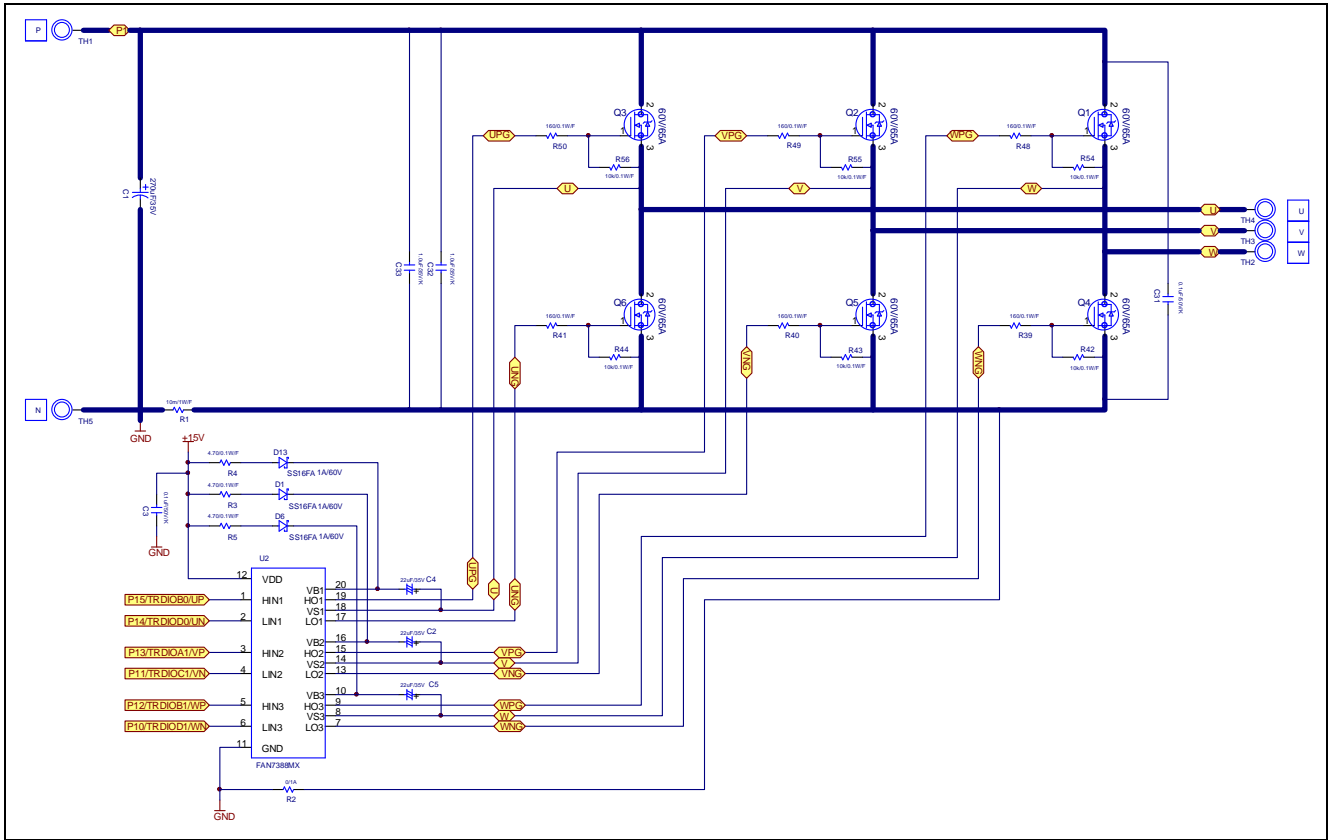


Figure 4.5 Motor Control Circuit

FAN7388 is a monolithic three half-bridge gate-drive IC, which drives 6 IGBTs operating at 19.8 V ~ 25.2 V with high-speed. It is suitable for this application in the motor drive system.

4.4 Zero-cross Detection Circuit

Figure 4.6 shows the schematic of the zero-cross detection circuit.

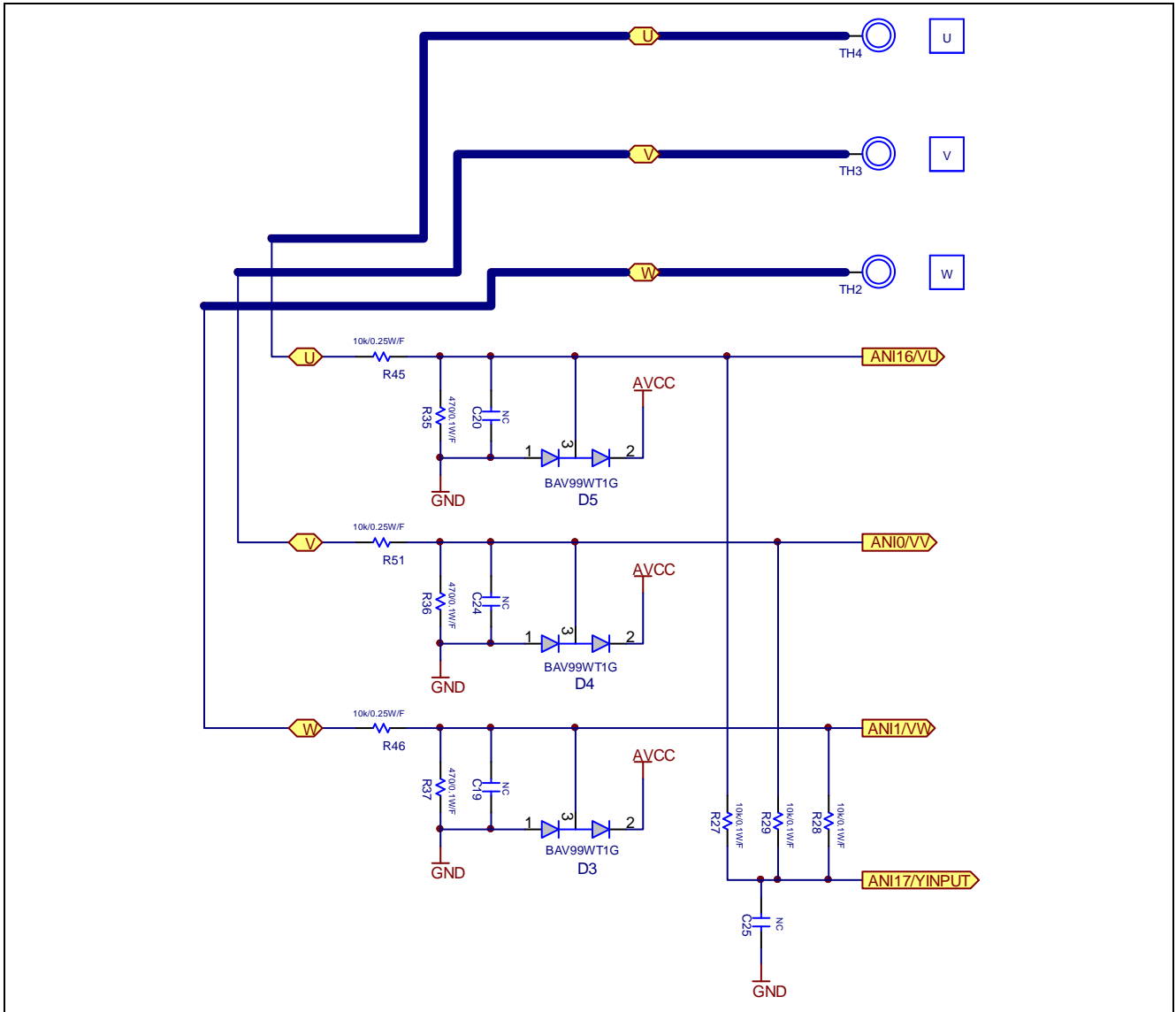


Figure 4.6 Zero-cross Detection Circuit

By comparing the voltage of the cut-off phase and the middle-point through the RL78/G1F built-in comparator, the zero-cross of the BEMF can be detected.

5. Software

5.1 Integrated Development Environment

The sample code described in this chapter has been checked under the conditions listed in the table below.

Table 5.1 Operation Check Conditions

Item	Description
Microcontroller used	RL78/G1F (R5F11BGE)
Operating frequency	High-speed on-chip oscillator (HOCO) clock: 64 MHz CPU/peripheral hardware clock: 32 MHz Low-speed on-chip oscillator clock: 15 kHz
Operating voltage	5.0 V (can run on a voltage range of 2.7 V to 5.5 V) LVD: Interrupt & reset mode Rising edge: 4.06 V (3.98 V ~ 4.14 V) Falling edge: 3.98 V (3.90 V ~ 4.06 V)
Integrated development environment (CS+)	CS+ V6.00.00 from Renesas Electronics Corp.
C compiler (CS+)	CC-RL V1.05.00 from Renesas Electronics Corp.
Integrated development environment (e ² studio)	e ² studio V6.0.0 from Renesas Electronics Corp.
C compiler (e ² studio)	CC-RL V1.05.00 from Renesas Electronics Corp.

5.2 Option Byte

Table 5.2 summarizes the settings of the option bytes.

Table 5.2 Option Byte Settings

Address	Value	Description
000C0H/010C0H	01101110B	Watchdog timer counter operation disabled (counting stopped after reset)
000C1H/010C1H	01110010B	LVD: Interrupt & reset mode Rising edge: 4.06 V (3.98 V ~ 4.14 V) Falling edge: 3.98 V (3.90 V ~ 4.06 V)
000C2H/010C2H	11111000B	HS mode, f_{HOCO} : 64 MHz CPU clock f_{CLK} : 32 MHz
000C3H/010C3H	10000101B	Enables on-chip debugging

5.3 Operation Outline

5.3.1 Operating Mode

The tasks of the whole system are listed as below: Reset, Stop Mode, Standard Mode, Power Mode, Standby Mode and Error Mode.

Figure 5.1 shows the block diagram for the tasks transition.

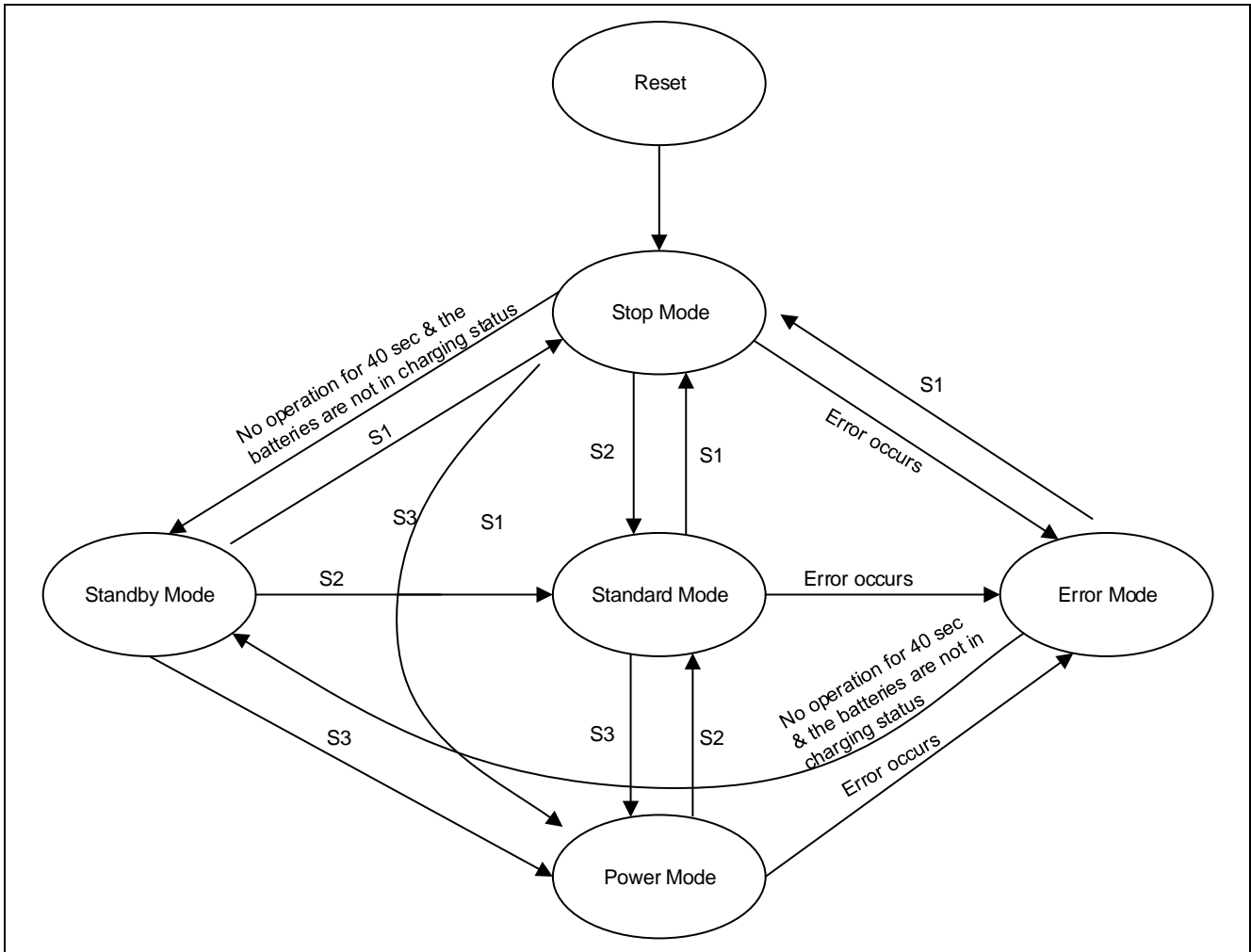


Figure 5.1 Tasks Transition Block Diagram

(1) Reset

The system enters a power on state when the power pack is connected to the motor control board. The RL78/G1F is then initialized (f_{HOCO} is 64 MHz used as input clock for the timer RD. f_{MAIN} is 32 MHz supplying input clock to other peripheral functions) and sends battery control data to the ISL94203 before entering Stop Mode.

(2) Stop Mode

After initialization or the S1 is pressed, the system enters Stop Mode. The green LED will blink every 1 second if the batteries are not fully charged or the green LED will turn ON if the batteries are fully charged. The motor stops running in this mode. The variables are initialized. The A/D sampling and the mode judgement are in operation.

The red LED will turn ON while the batteries are charging.

(3) Standard Mode

When the S2 is pressed, the system enters Standard Mode and the motor runs at 30000 rpm. The green LED will blink every 0.4 seconds. The A/D sampling and the mode judgement are in operation.

(4) Power Mode

When the S3 is pressed, the system enters Power Mode and the motor runs at 50000 rpm. The green LED will blink every 0.4 seconds. The A/D sampling and the mode judgement are in operation.

(5) Standby Mode (STOP mode & SNOOZE mode)

When there is no operation for 40 seconds and the batteries are not in charging status, the system enters Standby Mode. The green LED and the red LED turn OFF.

f_{IL} is used as the input clock for the 12-bit interval timer, which triggers A/D conversion every 0.2 seconds to make the system enter SNOOZE mode. Once a switch is pressed, an A/D interrupt will occur to make the system exit STOP Mode.

(6) Error Mode

When an error occurs, the system enters Error Mode, including the motor temperature error, the battery low voltage error and the step-out error. If an error occurs, the red LED will blink. The A/D sampling and the mode judgement are in operation.

5.3.2 Run Mode

When in Standard Mode and Power Mode, the motor firstly runs in Open Loop Mode with a constant duty for several control cycles, then the mode will change into BEMF Mode.

Figure 5.2 shows the diagram for run mode.

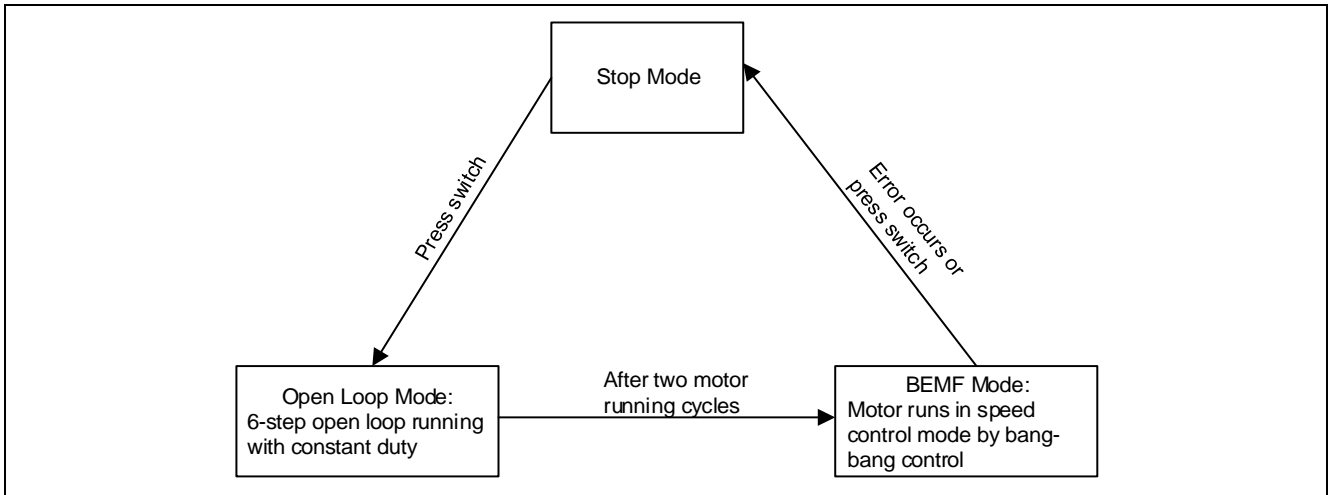


Figure 5.2 Run Mode Diagram

(1) Open Loop Mode

In Open Loop Mode, the PWM duty setting value starts from 180 ($180/1600 = 0.11$). After two cycles of the motor, the mode changes to BEMF Mode and the RL78/G1F detects the zero-cross point.

(2) BEMF Mode

In BEMF Mode, the motor runs in speed control mode by bang-bang control.

5.4 Flow Chart

Figure 5.3 and figure 5.4 show the flowcharts for the main processing routine.

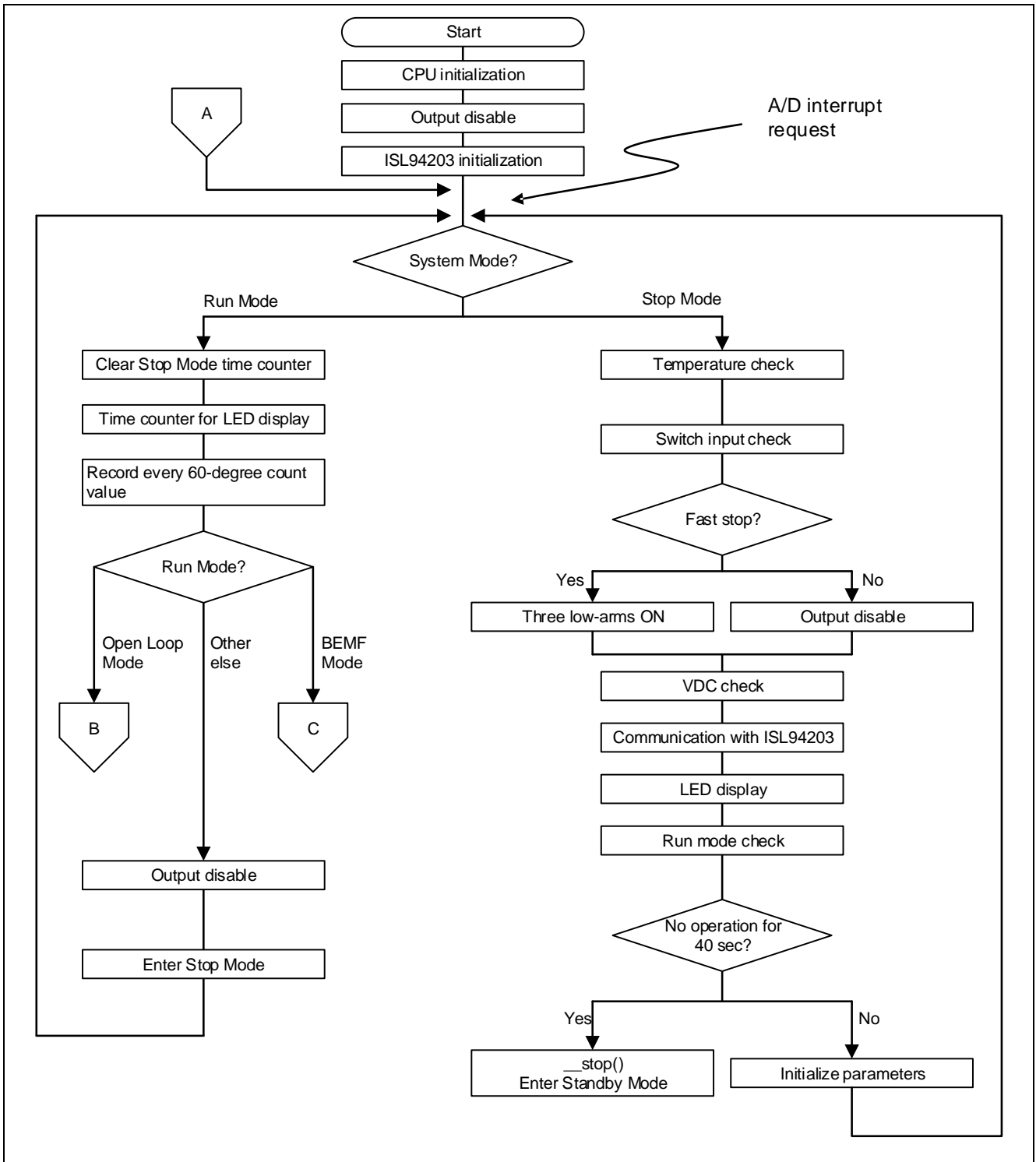


Figure 5.3 Main Processing (1/2)

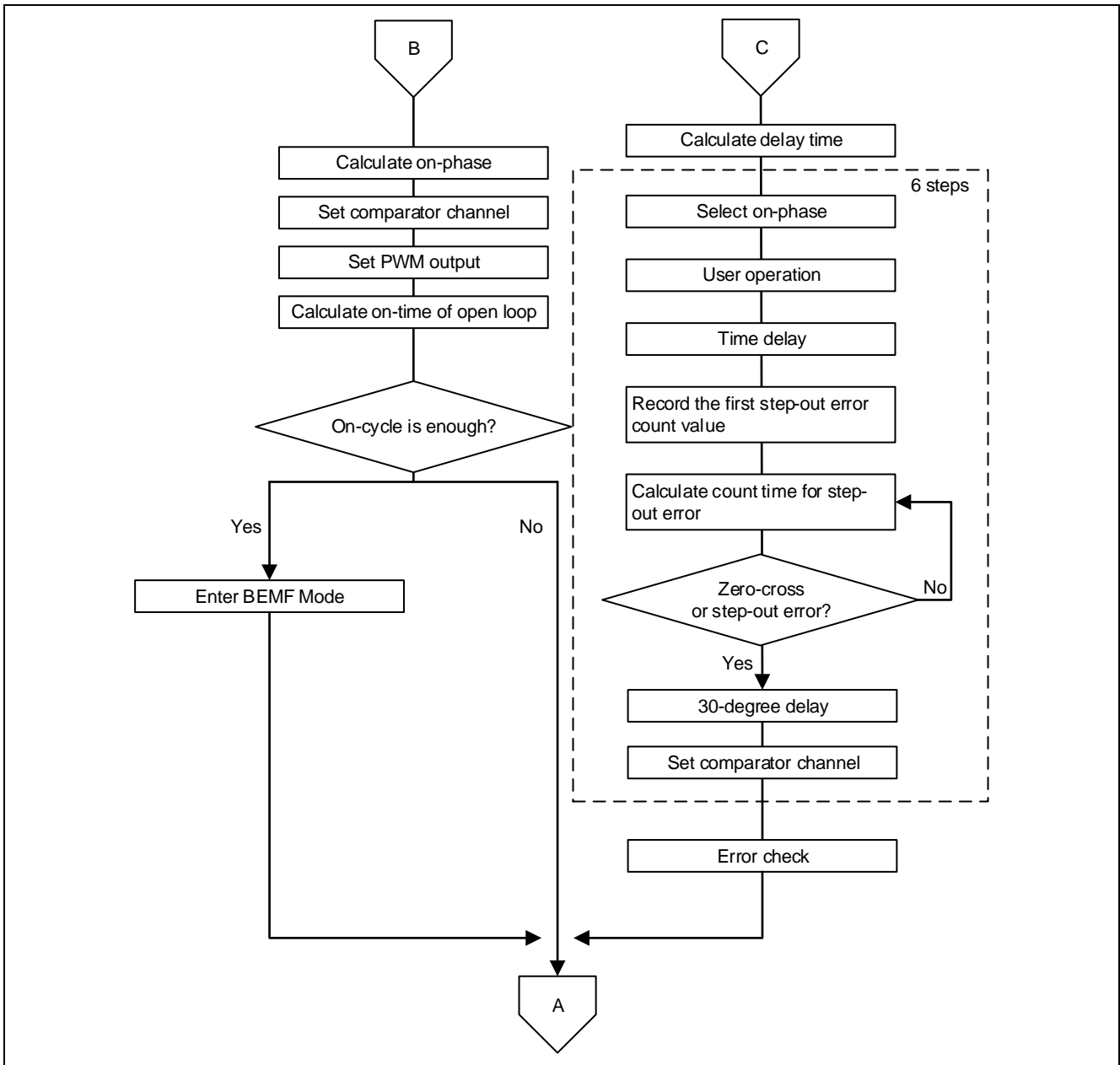


Figure 5.4 Main Processing (2/2)

As the time delay module uses an infinite loop to calculate the time correctly, there's almost no time for another operation when the motor is running.

The only way to lower the time bandwidth requirements is to shorten the first time delay before checking the zero-cross. As there are 6 steps in the motor running cycle, the user operations software can be separated into 6 parts.

Here lists the actual user operations used in the handy vacuum cleaner demo.

Table 5.3 User Operations

No.	Step	User Operation
1	Step 0	No user operation
2	Step 1	Switch input check Run mode check Set speed reference
3	Step 2	Calculate speed value
4	Step 3	Thermistor value detection Temperature error check
5	Step 4	Speed control (calculate duty reference)
6	Step 5	VDC check VDC error check LED display

6. Sample Code

The sample code is available on the Renesas Electronics Website.

7. Reference Documents

RL78/G1F User's Manual: Hardware (R01UH0516)

RL78 Family User's Manual: Software (R01US0015)

(The latest versions of the documents are available on the Renesas Electronics Website.)

Technical Updates/Technical News

(The latest information can be downloaded from the Renesas Electronics Website.)

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Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Nov. 30, 2018	—	First edition issued

General Precautions in the Handling of Microprocessing Unit and Microcontroller Unit Products

The following usage notes are applicable to all Microprocessing unit and Microcontroller unit products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Handling of Unused Pins

Handle unused pins in accordance with the directions given under Handling of Unused Pins in the manual.

- 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.

2. Processing at Power-on

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.

3. Prohibition of Access to Reserved Addresses

Access to reserved addresses is prohibited.

- The reserved addresses are provided for the possible future expansion of functions. Do not access these addresses; the correct operation of LSI is not guaranteed if they are accessed.

4. Clock Signals

After applying a reset, only release the reset line after the operating clock signal has become stable. When switching the clock signal during program execution, wait until the target clock signal has stabilized.

- When the clock signal is generated with an external resonator (or from an external oscillator) during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Moreover, when switching to a clock signal produced with an external resonator (or by an external oscillator) while program execution is in progress, wait until the target clock signal is stable.

5. Differences between Products

Before changing from one product to another, i.e. to a product with a different part number, confirm that the change will not lead to problems.

- The characteristics of Microprocessing unit or Microcontroller unit products in the same group but having a different part number may differ in terms of the internal memory capacity, layout pattern, and other factors, which can affect the ranges of electrical characteristics, such as characteristic values, operating margins, immunity to noise, and amount of radiated noise. When changing to a product with a different part number, implement a system-evaluation test for the given product.

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