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RL78/G14

Sensorless Speed control of 120-degree conducting controlled permanent magnetic synchronous motor (Implementation)

Summary

This application note aims at explains sample programs driving a permanent magnetic synchronous motor in the 120-degree conducting method using the RL78/G14 microcontroller.

These control programs are only to be used as reference and Renesas Electronics Corporation does not guarantee the operations. Please use them after carrying out a thorough evaluation in a suitable environment.

Operation checking device

Operations of the control programs have been checked by using the following device.

- RL78/ G14 (R5F104LEAFB)

Target control programs

The target control programs of this application note are as follows.

RL78G14_MRSSK_SPM_LESS_120_CSP_CA_V100 (IDE：CS+ for CA,CX)

RL78G14_MRSSK_SPM_LESS_120_CSP_CC_V100 (IDE：CS+ for CC)

RL78G14_MRSSK_SPM_LESS_120_E2S_CC_V100 (IDE：e^2studio)

RL78/G14 Sensorless 120-degree conducting control program for
24V Motor Control Evaluation System and RL78/G14 CPU CARD

Reference

- RL78/G1G Group User’s Manual: Hardware (R01UH0186EJ0330)
- Application note: ‘120-degree conducting control of permanent magnetic synchronous motor: algorithm’ (R01AN2657EJ0120)
- Renesas Motor Workbench V.1.00 User’s Manual (R21UZ0004EJ0100)
- Renesas Solution Starter Kit 24V Motor Control Evaluation System for RX23T User’s Manual (R20UT3697EJ0110)
- RL78/G14 CPU card User’s Manual (R12UZ0023EJ0100)

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1. Overview

This application note explains how to implement the 120-degree conducting control programs of permanent magnetic synchronous motor (PMSM) using the RL78/G14 microcontroller. Note that this control programs use the algorithm described in the application note ‘120-degree conducting control of permanent magnetic synchronous motor: algorithm’.

1.1 Development environment

Table 1-1 and Table 1-2 show development environment of the control programs explained in this application note.

Table 1-1 Development Environment (H/W)

Microcontroller	Evaluation board	Motor
RL78/G14 (R5F104LEAFB)	24V inverter board (Note 1) RL78/G14 CPU Card (Note 2)	TG-55L-KA (Note 3)

Table 1-2 Development Environment (S/W)

CS+ version	Tool chain version
V4.00.00	CA78K0R V5.00.00.03
V6.00.00	CC-RL V1.04.00.00

e^{2}studio version	Tool chain version
5.4.0.018	CC-RL V1.04.00.00

For purchase and technical support contact, Sales representatives and dealers of Renesas Electronics Corporation.

Notes: 1. 24V inverter board (RTK0EM0006S01212BJ) is a product of Renesas Electronics Corporation.

2. RL78/G14 CPU Card (RTK0EML130C06000BJ) is a product of Renesas Electronics Corporation.

3. TG-55L-KA is a product of TSUKASA ELECTRIC.
TSUKASA ELECTRIC. (https://www.tsukasa-d.co.jp/en/)

2. System overview

Overview of this system is explained below.

2.1 Hardware configuration

The hardware configuration is shown below.

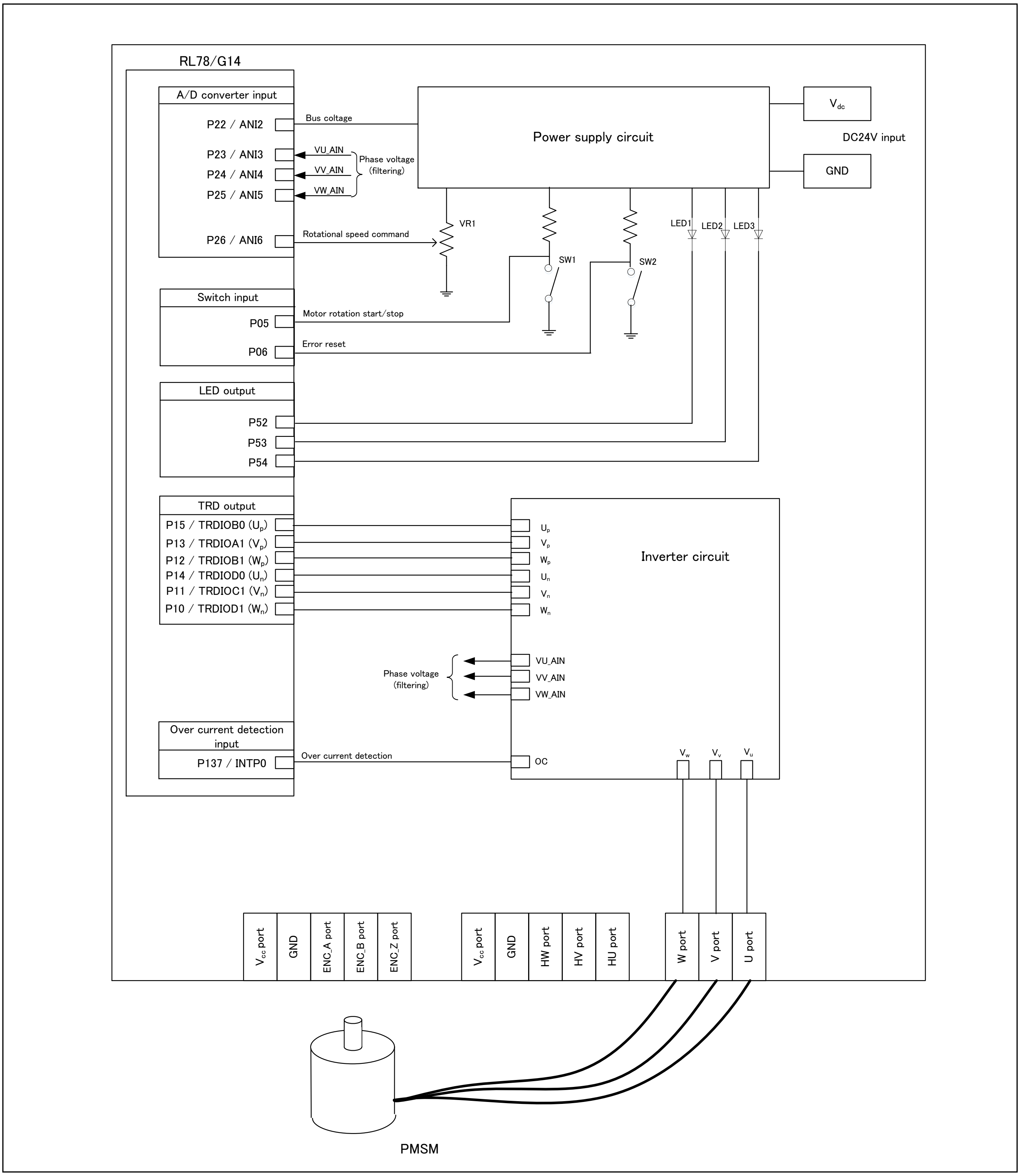


Figure 2-1 Hardware Configuration Diagram

2.2 Hardware specifications

2.2.1 User interface

Table 2-1 is a list of user interfaces of this system.

Table 2-1 User Interface

Item	Interface component	Function
Rotational speed	Variable resistance (VR1)	Rotational speed command value input (analog values)
START / STOP	Toggle switch (SW1)	Motor rotation start / stop command
ERROR RESET	Toggle switch (SW2)	Command of recovery from error status
LED1	Yellow green LED	- At the time of Motor rotation: ON - At the time of stop: OFF
LED2	Yellow green LED	- At the time of error detection: ON - At the time of normal operation: OFF
RESET	Push switch (RESET1)	System reset

Table 2-2 is a list of port interfaces of RL78/G14 microcontroller of this system.

Table 2-2 Port Interface

R5F104LEAFB Port name	Function
P22 / ANI2	Inverter bus voltage measurement
P26 / ANI6	For inputting rotational speed command values (analog values)
P05	START / STOP toggle switch
P06	ERROR RESET toggle switch
P52	LED1 ON / OFF control
P53	LED2 ON / OFF control
P23 / ANI3	U Phase voltage measurement (A/D)
P24 / ANI4	V Phase voltage measurement (A/D)
P25 / ANI5	W Phase voltage measurement (A/D)
P10 / TRDIOD1	PORT output / PWM output (W_n)
P11 / TRDIOC1	PORT output / PWM output (V_n)
P12 / TRDIOB1	PORT output / PWM output (W_p)
P13 / TRDIOA1	PORT output / PWM output (V_p)
P14 / TRDIOD0	PORT output / PWM output (U_n)
P15 / TRDIOB0	PORT output / PWM output (U_p)
P137 / INTP0	PWM emergency stop input at the time of overcurrent detection

2.2.2 Peripheral functions

Table 2-3 is a list of peripheral functions used in this system.

Table 2-3 List of Peripheral Functions

Peripheral Function	Purpose
A/D converter	- Rotational speed command value input - Inverter bus voltage measurement - Voltage of each phase U, V, and W measurement
Timer Array Unit (TAU)	- 1 [ms] interval timer - Free-running timer for rotational speed measurement
Timer RD (TRD)	Complementary PWM output
External Interrupt (INTP0)	Overcurrent detection

(1)A/D converter

The rotational speed command value input, U phase voltage (Vu), V phase voltage (Vv), W phase voltage (Vw), and inverter bus voltage (Vdc) are measured by using the A/D converter'.

The operation mode is set as below.

The channel selection mode: the select-mode.
The conversion operation mode: the one-shot conversion mode.

And software trigger is used.

(2) Timer Array Unit (TAU)

a. 1 [ms] interval timer

The channel 0 of Timer Array Unit (TAU) is used as 1 millisecond interval timer.

b. Free-running timer for measuring speed

The channel 1 of Timer Array Unit (TAU) is used as free-running timer for speed measurement.
Note that interrupt is not used.

(3) Timer RD (TRD)

Three-phase PWM output of chopping at the first 60 degrees with dead time (complementary) or without dead time (non-complementary) is performed using the Complementary PWM Mode. When detecting an overcurrent, the PWM output ports are set to high impedance output using the pulse output forced cutoff function.

(4) External interrupt (INTP0)

An overcurrent is detected by an external circuit.

2.3 Software structure

2.3.1 Software file structure

The folder and file configurations of the control programs are given below.

Table 2-4 Folder and File Configuration

Project	Folder	File	Content
RL78G14_MRSSK_SPM_LESS_120_CSP_CA_V100 RL78G14_MRSSK_SPM_LESS_120_CSP_CC_V100 RL78G14_MRSSK_SPM_LESS_120_E2S_CC_V100	inc	main.h	Main function, user interface control header
		mtr_common.h	Common definition header
		mtr_ctrl_mrssk.h	Board dependent processing part header
		mtr_ctrl_rl78g14.h	RL78/G1G dependent processing part header
		mtr_spm_less_120.h	Sensorless 120-degree conducting control dependent part header
		control_parameter.h	Control characteristic dependent processing part header
		motor_parameter.h	Motor characteristic dependent processing part header
		mtr_ctrl_rl78g1g_mrssk.h	RL78/G1G and board dependent processing part header
		mtr_feedback.h	Feedback control processing part header
		mtr_gmc.h	General motor control function part header
		mtr_driver_access.h	Driver access function on part header
		mtr_filter.h	Filters processing part header (not used)
	ics	Ics2_RL78G14_LE.lib	Library for GUI
		Ics2_RL78G14_Lx.h	Header for GUI
		RL78_vector.c	Interrupt processing part for GUI interface.
	prj	RL78G14_MRSSK_SPM_HALL_120_CSP_CA_V100.dr	Link directive file (Note1)
	lib	R_dsp_rl78_CA.lib	Digital signal controller library for CA tool-chain (Note2)
		R_dsp_rl78_CC.lib	Digital signal controller library for CC-RL tool-chain (Note2)
	src	main.c	Main function, user interface control
		mtr_ctrl_mrssk.c	Board dependent processing part
		mtr_ctrl_rl78g1g.c	RL78/G1G dependent processing part
		mtr_interrupt.c	Interrupt handler
		mtr_spm_less_120.c	Sensorless 120-degree conducting control dependent part
		mtr_ctrl_rl78g1g_mrssk.c	RL78/G1G and board dependent processing part
		mtr_feedback.c	Feedback control processing
		mtr_gmc.c	General motor control function
		mtr_driver_access.c	Driver access function
		mtr_filter.c	Filters processing (not used)

Notes: 1. Link directive file is included only in RL78G14_MRSSK_SPM_LESS_120_CSP_CA_V100.

2. R_dsp_rl78_CA.lib is included only in RL78G14_MRSSK_SPM_LESS_120_CSP_CA_V100. R_dsp_rl78_CC.lib is included in RL78G14_MRSSK_SPM_LESS_120_CSP_CC_V100 and RL78G14_MRSSK_SPM_LESS_120_E2S_CC_V100.

2.3.2 Module configuration

Figure 2-2 and Table 2-5 show module configuration of the control programs.

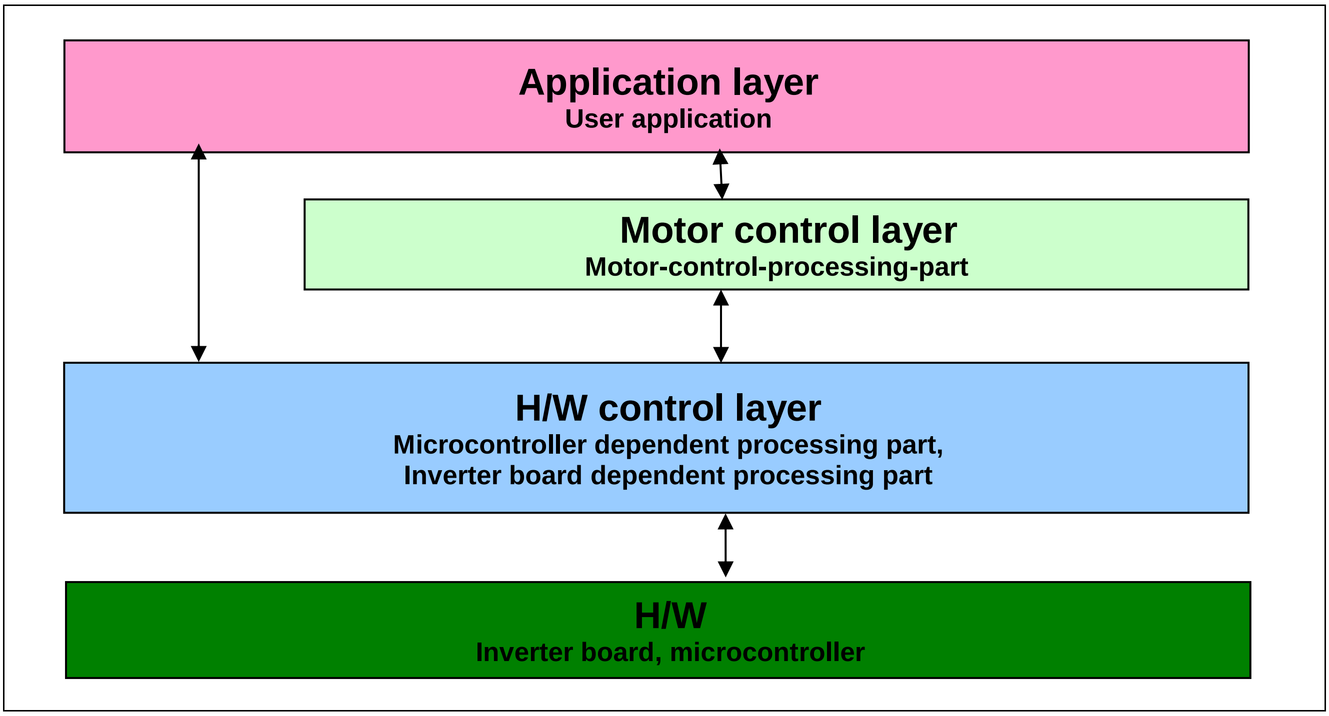


Figure 2-2 Module Configuration

Table 2-5 Module Configuration

Layers	File name
Application layer	main.c
Motor control layer	mtr_spm_less_120.c mtr_feedback.c mtr_gmc.c mtr_filter.c mtr_driver_access.c mtr_interrupt.c (Note)
H/W control layer	mtr_ctrl_rl78g14_mrssk.c mtr_ctrl_rl78g14.c mtr_ctrl_mrssk.c mtr_interrupt.c (Note)

Note: “mtr_interrupt.c” is belong to the motor control layer and H/W control layer.

2.4 Software specifications

Table 2-6 shows the basic software specification of this system. For details of 120-degree conducting control, refer to the application note ‘120-degree conducting control of permanent magnetic synchronous motor: algorithm’.

Table 2-6 Basic Specifications of Software

Item	Content	
Control method	120-degree conducting method (chopping at the first 60 degrees) (Complementary / Non-Complementary)	
Motor rotation start / stop	Determined depending on the level of SW1 (P05) (”Low”: rotation start “High”: stop) or input from Motor Control Development Support Tool. (Note)	
Position detection of rotor magnetic pole	Position detection by induced voltage with A/D converters. (by 60 degrees)	
Input voltage	DC24[V]	
Main clock frequency	CPU clock: f_{CLK} 32[MHz] TRD clock: f_{HOCO} 64[MHz]	
Carrier frequency (PWM)	20 [kHz]	
Dead time	2 [μs]	
Control cycle	Speed PI control: every 1 [ms]	
Rotational speed control range	1000 [rpm] to 2650 [rpm] Both CW and CCW are supported	
Optimization	CA	Standard optimization
	CC-RL	Perform Default optimization
ROM / RAM size	CA	ROM : 11.98 KB / RAM : 0.68 KB
	CC-RL	ROM : 10.48 KB / RAM : 0.69 KB
Processing stop for protection	- Disables the motor control signal output (six outputs), under any of the following conditions. 1. Inverter bus voltage exceeds 28 V (monitored per 1 [ms]) 2. Inverter bus voltage is less than 15 V (monitored per 1 [ms]) 3. Rotational speed exceeds 3500 rpm (monitored per 1 [ms]) 4. At the time of sensorless drive, zero-crossing is not detected for 50 [ms]. 5. Fault detection of virtual Hall sensor pattern (position information) - The ports executing PWM output are set to high impedance state when an overcurrent is detected by external circuit (low level edge input occurs in INTP0 port).	

Note: For more details, refer to 4. Motor Control Development Support Tool, ‘Renesas Motor Workbench’.

3. Descriptions of the control program

The target control programs of this application note are explained here.

3.1 Contents of control

3.1.1 Motor start/stop

The start and stop of the motor are controlled by input from Motor Control Development Support Tool or SW1.

A general-purpose port is assigned to SW1. The port is read within the main loop. When the port is at a “Low” level, it is determined that the start switch is being pressed. Conversely, when the level is switched to “High”, the program determines that the motor should be stopped.

Also, an analog input port is assigned to VR1. The input is A/D converted within the main loop to generate a rotational speed command value. When the command value is less than 1000 [rpm], the program determines that the motor should be stopped.

3.1.2 A/D Converter

(1) Motor rotational speed command value

The motor rotational speed command value can be set by A/D conversion of the VR1 output value (analog value). The A/D converted VR1 value is used as rotational speed command value, as shown below.

The maximum of the command value is set as the value from which maximum rotational speed is generated by the resolution of the A/D converter.

Table 3-1 Conversion Ratio of the Rotational Speed Command Value

Item	Conversion ratio (Command value: A/D conversion value)		Channel
Rotational speed command value	CW	0 rpm to 3072 rpm: 0200H to 03FFH	ANI6
	CCW	-3072 rpm to 0 rpm: 0000H to 01FFH	

(2) Inverter bus voltage

Inverter bus voltage is measured as given in Table 3-2. It is used for modulation factor calculation and over/under voltage detection. (When an abnormality is detected, PWM is stopped).

Table 3-2 Inverter Bus Voltage Conversion Ratio

Item	Conversion ratio (Inverter bus voltage: A/D conversion value)	Channel
Inverter bus voltage	0 V to 111 V: 0000H to 03FFH	ANI2

(3) U phase, V phase, and W phase voltage

The U, V, and W phase voltages are measured as shown in Table 3-3 and used for determining zero-crossing.

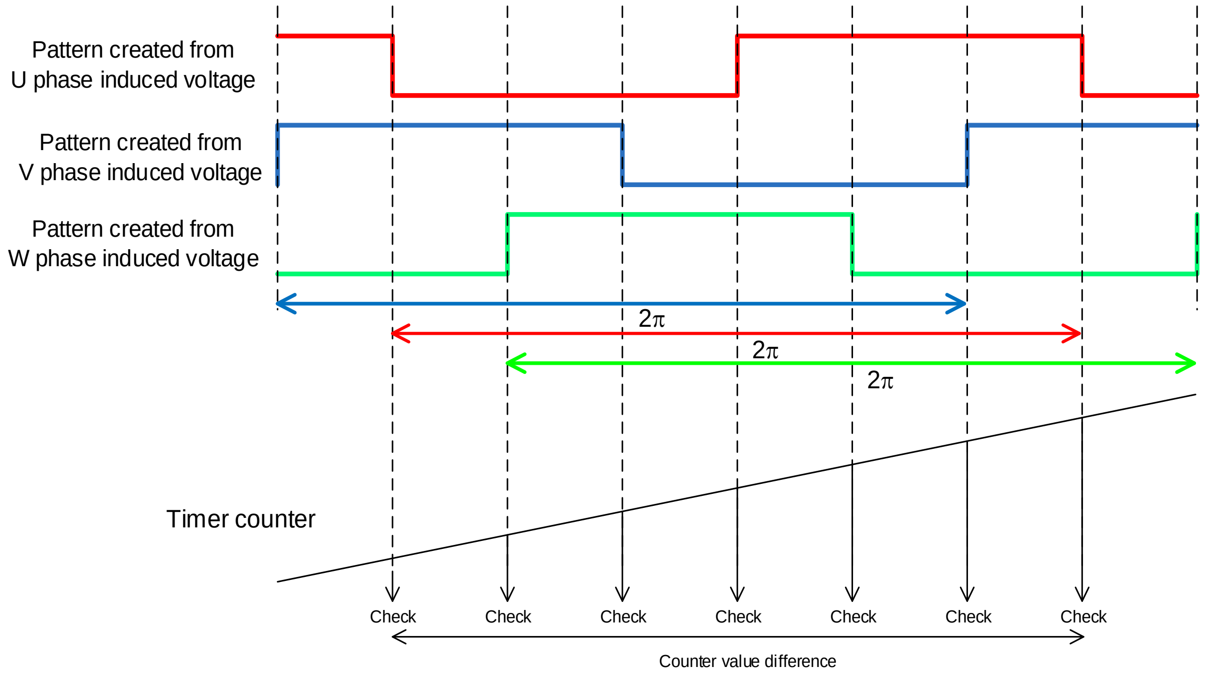
Table 3-3 Conversion Ratio of U, V, and W Phase Voltage

Item	Conversion ratio (U, V, and W phase voltage: A/D conversion value)	Channel
U, V, W phase voltage	0 V to 111 V: 0000H to 03FFH	ANI3, ANI4, ANI5

For more details of A/D conversion characteristics, refer to RL78/G14 User’s Manual: Hardware.

3.1.3 Speed control

In this system, the motor rotational speed is calculated from a difference of the current timer value and the timer value 2π [rad] before. The timer values are obtained when patterns are switched after zero-crossing detection, while having the timer of Timer Array Unit (TAU) channel 1 performed free running.



Motor rotational speed [rad/s] = (2π × frequency of timer) / (difference of timer counts)

Figure 3-1 Method of Calculation for Rotational Speed

The control program uses PI control for speed control. A voltage command value is calculated by the following formula of speed PI control.

$$v^* = \left(K_{P\omega} + \frac{K_{I\omega}}{s}\right)(\omega^* - \omega)$$

v^*: Voltage command value ω^*: Speed command value ω: Rotational speed

$K_{P\omega}$: Speed PI proportional gain $K_{I\omega}$: Speed PI integral gain S: Laplace operator

For more details of PI control, please refer to specialized books.

3.1.4 Voltage control by PWM

PWM control is used for controlling output voltage. The PWM control is a control method that continuously adjusts the average voltage by varying the duty of pulse, as shown in Figure 3-2.

$$\text{Duty} = \frac{T_{ON}}{T_{ON} + T_{OFF}} \times 100\ [\%]$$

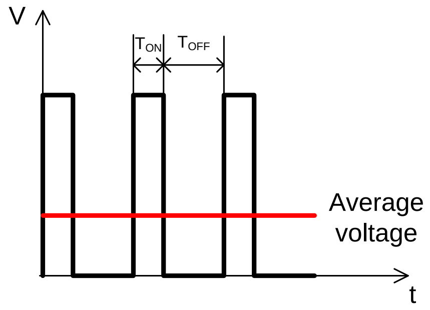


Figure 3-2 PWM Control

Modulation factor “m” is defined as follows.

$$m = \frac{V}{E}$$

m: Modulation factor *V*: Command value voltage *E*: Inverter bus voltage

This modulation factor is reflected in the setting value of the register that determines the PWM duty.

In the target control program, first-60-degree chopping is used to control the output voltage and speed. Figure 3-3 shows an example of motor control signal output waveforms at Non-complimentary first-60-degree chopping. Figure 3-4 shows an example of motor control signal output waveforms at Complimentary first-60-degree chopping.

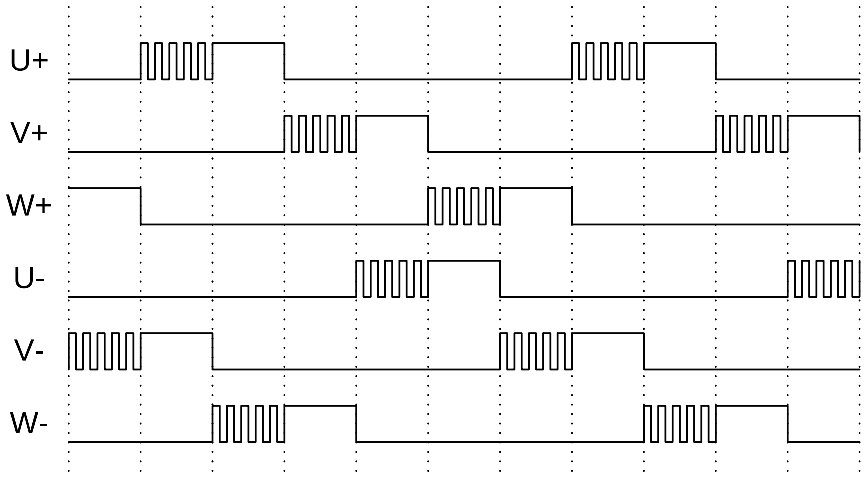


Figure 3-3 Non-complimentary first-60-degree Chopping

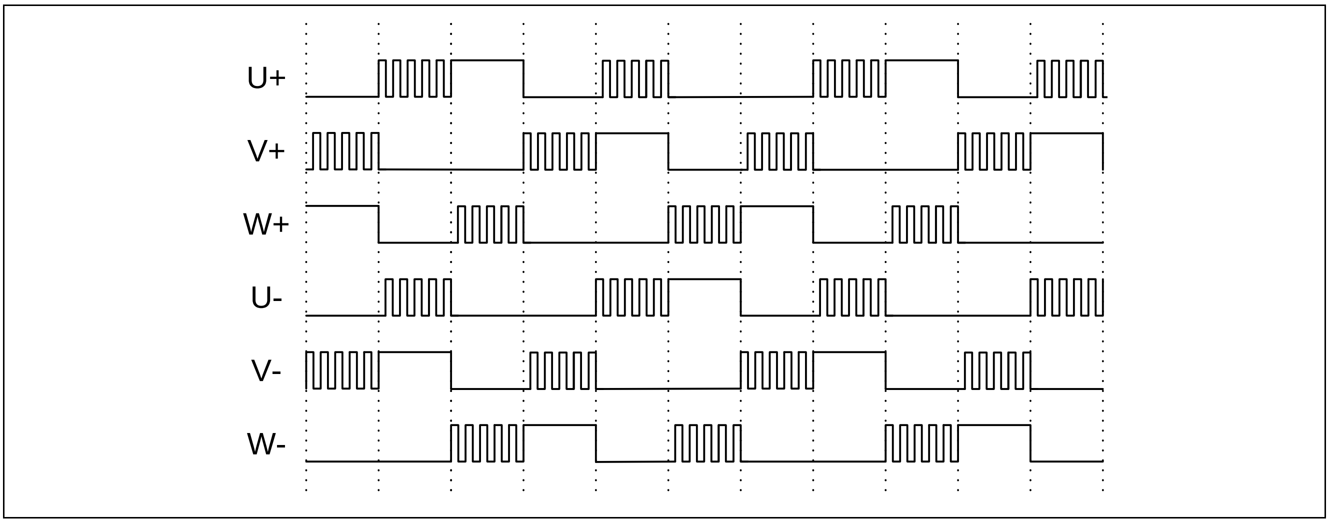


Figure 3-4 Complimentary first-60-degree Chopping

3.1.5 State transition

Figure 3-5 shows state transition diagrams of sensorless 120-degree conducting control software.

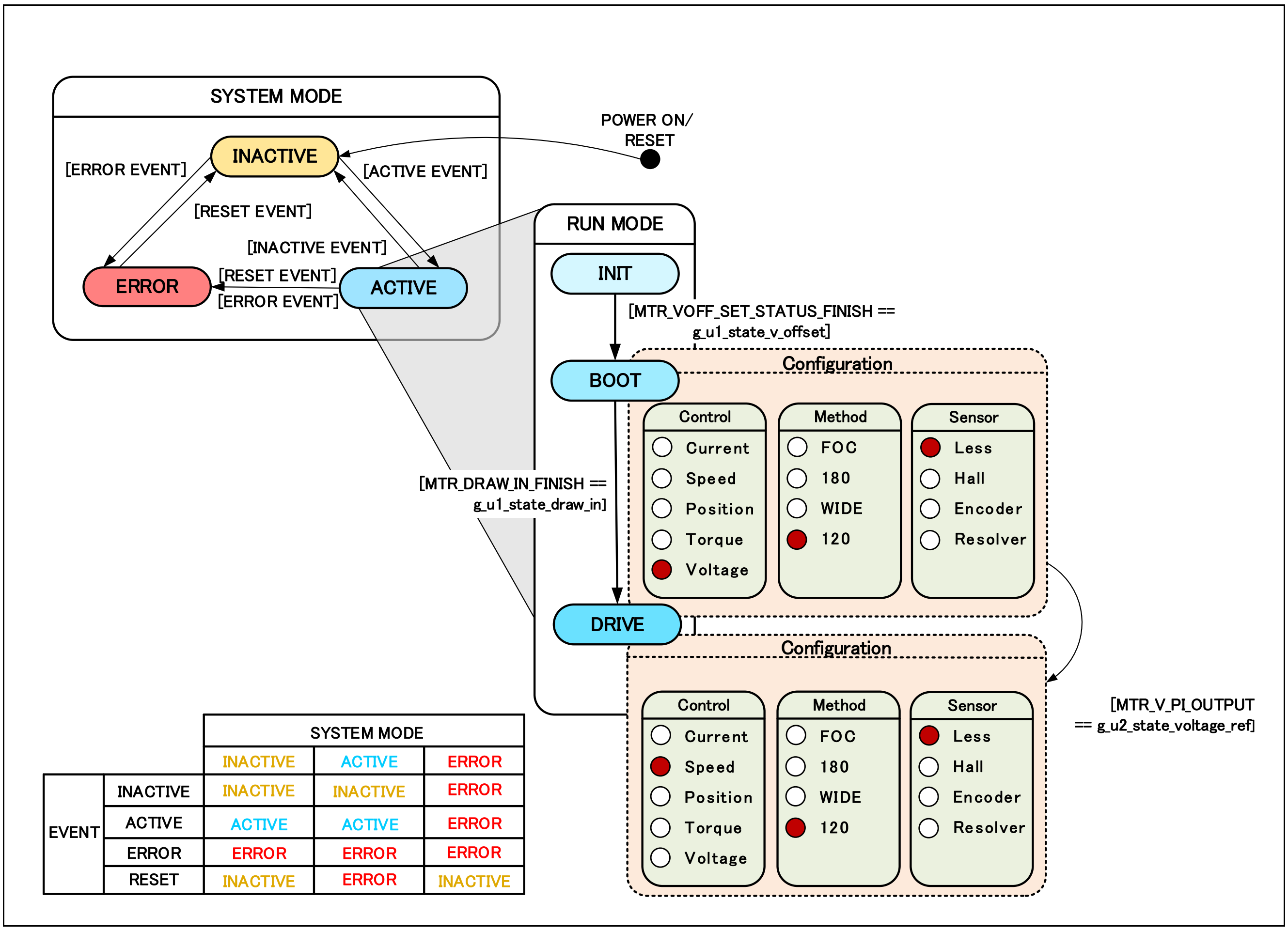


Figure 3-5 State Transition Diagram of Sensorless 120-degree Conducting Control Software

(1) SYSTEM MODE

"SYSTEM MODE" indicates the operating states of the system. The state transits on occurrence of each event (EVENT). "SYSTEM MODE" has 3 states that are motor drive stop (INACTIVE), motor drive (ACTIVE), and abnormal condition (ERROR).

(2) RUN MODE

"RUN MODE" indicates the condition of the motor control. "RUN MODE" transits sequentially as shown in Figure 3-5 when "SYSTEM MODE" is "ACTIVE".

(3) EVENT

When "EVENT" occurs in each "SYSTEM MODE", "SYSTEM MODE" changes as shown table in Figure 3-5, per that "EVENT".

Table 3-4 List of EVENT

EVENT name	Occurrence factor
INACTIVE	by user operation
ACTIVE	by user operation
ERROR	when the system detects an error
RESET	by user operation

3.1.6 Start-up method

In Sensorless 120-degree conducting control, the position of the magnetic poles (the rotor) is estimated every 60 degrees per the induced voltage which is generated the change of magnetic flux due to the rotation of the permanent magnet (rotor). However, the induced voltage is not generated when the rotor doesn't move. Therefore, it is impossible to estimate the position of the rotor at start-up, and enough rotational speed is necessary to estimate the position of the rotor (because the induced voltage cannot be caught without enough speed).

Therefore, as a start-up method, there is a method to lead the synchronous speed by generating a rotating magnetic field by forcibly switching conduction patterns regardless of position of the permanent magnet.

Figure 3-6 shows the start-up method in the control program. In "MTR_MODE_BOOT", the rotor is drawn in and the overcurrent at start-up is prevented.

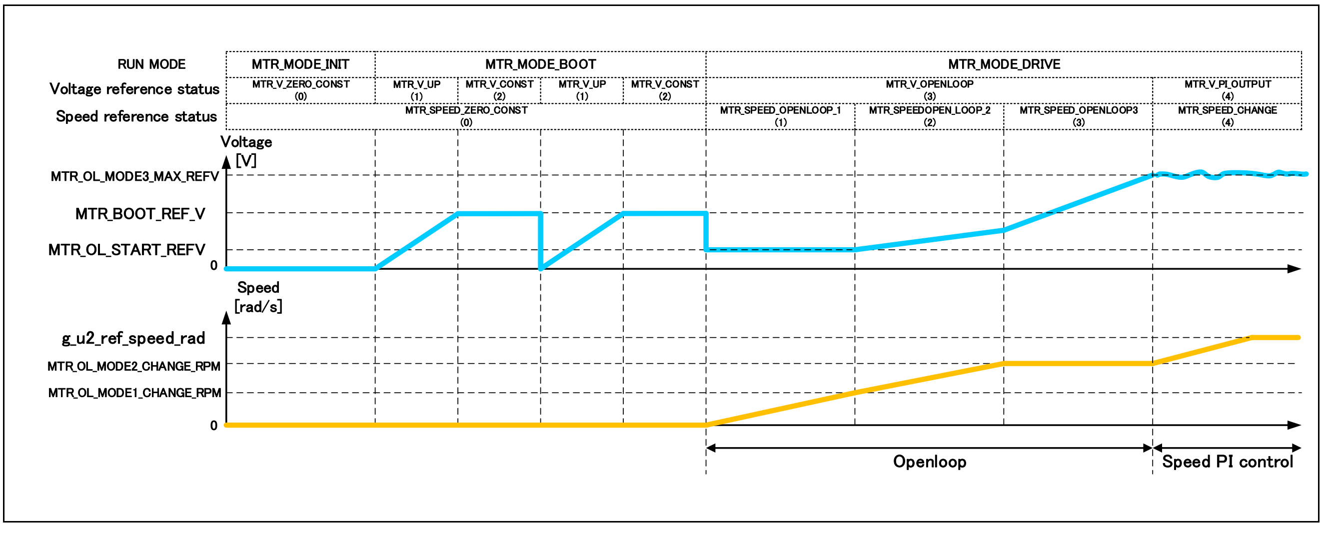


Figure 3-6 Start-up Method (Example)

3.1.7 System protection function

This system has the following types of error status and enables emergency stop functions in case of occurrence of respective error. Refer to エラー! 参照元が見つかりません。 for settings.

- Overcurrent error

High impedance output is made to the PWM output port in response to an emergency stop signal (overcurrent detection) from the hardware.

- Overvoltage error

The inverter bus voltage is monitored at the overvoltage monitoring cycle. When an over voltage is detected (when the voltage exceeds the limit), CPU performs an emergency stop. The threshold value of the overvoltage is set in consideration of the error of resistance value of the detection circuit.

- Low voltage error

The inverter bus voltage is monitored at the under voltage monitoring cycle. When an under voltage is detected (when the voltage lowers the limit), CPU performs an emergency stop. The threshold value of the low voltage is set in consideration of the error of resistance value of the detection circuit.

- Rotational speed error

The rotational speed is monitored at the rotational speed monitoring cycle. When the speed exceeds the limit, CPU performs an emergency stop.

- Timeout error of zero-cross detection

When no pattern switching is happened by zero-crossing during timeout period, CPU performs an emergency stop.

- Virtual Hall sensor pattern (position information) error

When an error is detected in virtual Hall sensor patterns (position information) generated from each of U, V, and W phase voltage, CPU performs an emergency stop.

Table 3-5 Setting Value of Each System Protection Function

Error name	**Threshold**	
Overvoltage error	Overvoltage limit [V]	28
	Monitoring cycle [ms]	1
Low voltage error	Under voltage limit [V]	15
	Monitoring cycle [ms]	1
Rotational speed error	Speed limit [rpm]	3500
	Monitoring cycle [ms]	1
Timeout error of zero-cross detection	Timeout value [ms]	50

3.2 Function specifications of 120-degree conducting control software

Multiple control functions are used in this control program. However, functions which are not used in this system are undescribed.

Table 3-6 List of Functions “main.c”

File name	Function name	Process overview
main.c	main Input: None Output: None	- Hardware initialization function call - User interface initialization function call - Initialization function call of the variables used in the main process - Waiting for stability of the bus voltage function call - Status transition and event execution function call - Main process ⇒ User interface call ⇒ Watchdog timer clear function call
	board_ui Input: None Output: None	- Motor status change - Determination of rotational speed command value
	ics_ui Input: None Output: None	Use “Motor RSSK Support Tool” - Motor status change - Determination of rotational speed command value - Determination of rotation direction
	software_init Input: None Output: None	Initialization of variables used in the main process

Table 3-7 List of Functions "mtr_ctrl_mrssk.c"

File name	Function name	Process overview
mtr_ctrl_mrssk.c	R_MTR_ChargeCapacitor Input: None Output: None	Wait for stability of the bus voltage
	get_vr1 Input: None Output: (uint16) u2_ad_data / A/D conversion result	VR1 status acquisition
	get_sw1 Input: None Output: (uint8) u1_temp / SW1 level	SW1 status acquisition
	get_sw2 Input: None Output: (uint8) u1_temp / SW2 level	SW2 status acquisition
	led1_on Input: None Output: None	Turning LED1 ON
	led2_on Input: None Output: None	Turning LED2 ON
	led3_on Input: None Output: None	Turning LED3 ON
	led1_off Input: None Output: None	Turning LED1 OFF
	led2_off Input: None Output: None	Turning LED2 OFF
	led3_off Input: None Output: None	Turning LED3 OFF

Table 3-8 List of Functions “mtr_ctrl_rl78g14.c”

File name	Function name	Process overview
mtr_ctrl_rl78g14.c	R_MTR_InitHardware Input: None Output: None	Initialization of the clock and peripheral functions
	mtr_init_clock Input: None Output: None	Initialization of clock
	mtr_init_tau Input: None Output: None	Initialization of the Timer Array Unit (TAU)
	mtr_init_intp Input: None Output: None	Initialization of external interrupt
	mtr_set_delaycount Input: (uint16) u2_delay_cnt / delay counts Output: None	Set delay counts for change pattern
	clear_wdt Input: None Output: None	Clear the watchdog timer (WDT)
	mtr_clear_oc_flag Input: None Output: None	Clear the high impedance state
	mtr_clear_trd0_imfa Input: None Output: None	Clear the Compare Match Timer A (IMFA)

Table 3-9 List of Functions “mtr_ctrl_rl78g14_mrssk.c”

File name	Function name	Process overview
mtr_ctrl_rl78g14_mrssk.c	mtr_init_trd Input: None Output: None	Initialization of Timer RD (TRD)
	mtr_init_ad_converter Input: None Output: None	Initialization of the A/D converter
	init_ui Input: None Output: None	Initialization of user interface
	mtr_ctrl_stop Input: None Output: None	Motor stop processing
	mtr_change_pattern Input: (uint8) u1_pattern / conduction pattern Output: None	- Change conduction pattern - Set PWM duty
	mtr_get_adc Input: (uint8) u1_ad_ch / target A/D conversion channel Output: (int16) s2_temp / A/D conversion value	Get A/D conversion value

Table 3-10 List of Functions "mtr_driver_access.c"

File name	Function name	Process overview
mtr_driver_access.c	R_MTR_SetSpeed Input: (uint16) u2_ref_speed / speed command value Output: None	Set the speed command value
	R_MTR_SetDir Input: (uint8) u1_dir / rotation direction Output: None	Set the rotation direction
	R_MTR_GetSpeed Input: None Output: (uint16) u2_speed_rpm / rotational speed	Obtain the calculated rotational speed
	R_MTR_GetDir Input: None Output: (uint8) g_u1_direction / rotation direction	Obtain the rotation direction
	R_MTR_GetStatus Input: None Output: (uint8) g_u1_mode_system / motor status	Obtain the motor status

Table 3-11 List of Functions "mtr_feedback.c"

File name	Function name	Process overview
mtr_feedback.c	mtr_pi_ctrl Input: (MTR_PI_CTRL*) pi_ctrl / PI control structure Output: (int16) s2_ref / PI control output value	PI control

Table 3-12 List of Functions "mtr_gmc.c"

File name	Function name	Process overview
mtr_gmc.c	mtr_get_vdc Input: None Output: (int16) s2_temp / the bus voltage value	Obtain the bus voltage
	mtr_check_over_voltage_error Input: (int16) s2_vdc / bus voltage value (int16) s2_limit_voltage / over voltage limit Output: (uint16) u2_temp0 / over voltage error flag (when error happens)	Check over voltage error
	mtr_check_under_voltage_error Input: (int16) s2_vdc / bus voltage value (int16) s2_limit_voltage / under voltage limit Output: (uint16) u2_temp0 / under voltage error flag (when error happens)	Check low voltage error
	mtr_check_over_speed_error Input: (uint16) u2_speed_rad / rotational speed (uint16) u2_speed_limit / speed limit Output: (uint16) u2_temp0 / over speed error flag (when error happens)	Check over speed error
	mtr_get_duty Input: (volatile int16) s2_v_ref / reference voltage (volatile int16) s2_vdc_ad / bus voltage A/D conversion value Output: (int16) s2_temp / rate of PWM duty	Calculate PWM duty
	mtr_generate_pattern Input: (uint16) u2_vu_ad / U phase voltage A/D conversion value (uint16) u2_vv_ad / V phase voltage A/D conversion value (uint16) u2_vw_ad / W phase voltage A/D conversion value (uint16) u2_vn_ad / 3 phase average A/D conversion value Output: (uint8) u1_temp / pseudo Hall sensor pattern	Generate pseudo Hall sensor pattern
	mtr_check_timeout_error Input: (uint16) u2_cnt_timeout / counter of timeout (uint16) u2_timeout_limit / timeout limit Output: (uint16) u2_temp0 / flag of timeout error (when error happens)	Check timeout error

Table 3-13 List of Functions “mtr_interrupt.c”

File name	Function name	Process overview
mtr_interrupt.c	mtr_oc_intp0_interrupt Input: None Output: None	Overcurrent detection process (Hardware detection) - Disable INTP0 interrupt servicing - Event processing selection function call (Generate error event) - Changing the motor status (Set the flag of error about overcurrent)
	mtr_carrier_interrupt Input: None Output: None	Calling every 50 [μs] - Measure invertor bus voltage - Measure voltage of each phase and cancel offset - Calculate pseudo center voltage - Detect zero-cross - Calculate the rotational speed - Set delay to change pattern - Change pattern per pseudo Hall pattern call - Drive process for open loop call
	mtr_1ms_interrupt Input: None Output: None	Calling every 1 [ms] - Run mode management ⇒Setting speed reference ⇒Setting voltage reference ⇒Setting PWM duty - Error check function call - Motor stop detection function call
	mtr_delay_interrupt Input: None Output: None	Delayed change pattern from zero-cross - Stop delay counter - Clear interrupt information - Change pattern according to pseudo Hall pattern

Table 3-14 List of Functions "mtr_spm_less_120.c" [1/2]

File name	Function name	Process overview
mtr_spm_less_120.c	R_MTR_InitSequence Input: None Output: None	Initialization of the sequence process
	R_MTR_ExecEvent Input: (uint8) u1_event / occurred event Output: None	- Change the status - Call an appropriate process execution function for the occurred event
	mtr_act_active Input: (uint8) u1_state / motor status Output: (uint8) u1_state / motor status	Enable PWM output
	mtr_act_inactive Input: (uint8) u1_state / motor status Output: (uint8) u1_state / motor status	Disable PWM output
	mtr_act_none Input: (uint8) u1_state / motor status Output: (uint8) u1_state / motor status	No process is performed.
	mtr_act_reset Input: (uint8) u1_state / motor status Output: (uint8) u1_state / motor status	Global variables initialization
	mtr_act_error Input: (uint8) u1_state / motor status Output: (uint8) u1_state / motor status	Call motor control stop function
	mtr_ol_signal_set Input: None Output: (uint8) u1_pattern / forced conduction pattern	Set conduction pattern at open loop mode
	mtr_pattern_set Input: (uint8) u1_pattern / conduction pattern Output: None	- Clear counter for timeout error - Set conduction pattern
	mtr_speed_calc Input: None Output: None	Speed calculation process with a detection of zero-cross
	mtr_start_init Input: None Output: None	Initialize the variables required at motor start-up
	mtr_error_check Input: None Output: None	Error monitoring
	mtr_wait_motorstop Input: None Output: None	Check motor stop
	mtr_drive_openloop Input: None Output: None	Change pattern forcedly at open loop
	mtr_set_voltage_ref Input: None Output: None	Set reference voltage
	mtr_set_speed_ref Input: None Output: None	Set reference speed
	mtr_measure_voltage_offset Input: None Output: None	- Measure the offset of voltage - Cancel the offset of voltage

Table 3-15 List of Functions “mtr_spm_less_120.c” [2/2]

File name	Function name	Process overview
mtr_spm_less_120.c	mtr_draw_in_signal_set Input: None Output: None	Set the conduction pattern at draw in the rotor
	mtr_set_angle_shift Input: None Output: None	Calculate the counts for phase shift based on the detection of zero-cross
	mtr_check_pattern Input: None Output: None	Check the validity of zero-cross which is detected
	mtr_set_variables Input: None Output: None	Set motor variables according to control layer
	mtr_pattern_first60 Input: (uint8) u1_pattern / conduction pattern Output: None	Set voltage pattern non-complementary first 60 degree PWM
	mtr_pattern_first60_comp Input: (uint8) u1_pattern / conduction pattern Output: None	Set voltage pattern complementary first 60 degree PWM

3.3 List of variables of sensorless 120-degree conducting control software

Lists of variables used in this control program are given below. However, note that the local variables are not mentioned.

In the control programs in this application note use fixed-point calculation. Therefore, some variables are already established with fixed-point calculation. Bits number in fractional part of fixed-point number is expressed in the Q format. For example, a "Q3" number has 3 fractional bits. "Qn" number is indicated on "Scale" column in below table.

Table 3-16 List of variables [1/4]

Variable name	Type	Scale	Content	Remarks
g_u2_max_speed_rpm	uint16	—	Rotational speed command maximum value	Mechanical angle [rpm]
g_u2_min_speed_rpm	uint16	—	Rotational speed command minimum value	Mechanical angle [rpm]
g_u2_margin_min_speed_rpm	uint16	—	Rotational speed command minimum value for motor stop	Mechanical angle [rpm]
g_u2_ref_speed_rpm	uint16	—	User setting rotational speed	Mechanical angle [rpm]
g_u1_rot_dir	uint8	—	User setting rotation direction	0: CW 1: CCW
g_u1_motor_status	uint8	—	User motor status management	0: Stop 1: Rotating 2: Error
g_u1_reset_req	uint8	—	Reset request flag	0: Turning SW2 ON in error status 1: Turning SW2 OFF in error status
g_u1_sw1_cnt	uint8	—	SW1 determination counter	Chattering removal
g_u1_sw2_cnt	uint8	—	SW2 determination counter	Chattering removal
g_u1_stop_req	uint8	—	VR1 stop command flag	
g_s2_sw_userif	int16	—	User interface switch	0: ICS user interface use (default) 1: Board user interface use
g_s2_mode_system	int16	—	System mode	
g_s2_enable_write	int16	—	Variable for ICS UI	
g_u2_speed_rpm	uint16	—	Current speed value	Mechanical angle [rpm]
st_ics_input	MTR_ICS_INPUT	—	ICS input structure	
g_s2_v_ref	int16	Q7	Voltage command value	Speed PI control output value [V]
g_s2_vdc_ad	int16	Q7	Inverter bus voltage A/D value	[V]
g_u2_pwm_duty	uint16	—	PWM duty	
g_u2_ref_speed_rad	uint16	Q3	Speed reference (user selected) value	Electrical angle [rad/s]
g_u2_speed_rad	uint16	Q3	Measured rotational speed	Electrical angle [rad/s]
g_s2_speed_lpf_k	int16	Q14	Speed LPF parameter	
st_speed	MTR_PI_CTRL	—	Structure for speed PI control	
g_u2_vu_ad	uint16	—	U phase voltage A/D value	
g_u2_vv_ad	uint16	—	V phase voltage A/D value	
g_u2_vw_ad	uint16	—	W phase voltage A/D value	
g_u2_vn_ad	uint16	—	Three-phase voltage average A/D value	
g_u2_cnt_ol_ctrl	uint16	—	Counter for open-loop process	
g_u1_trig_enable_write	uint8	—	Enable flag to reflect input data to internal data	
g_u1_cnt_ics	uint8	—	Decimation counter to communicate with ICS	

Table 3-17 List of variables [2/4]

Variable name	Type	Scale	Content	Remarks
st_ics_input_buff	MTR_ICS_INPUT	–	Structure for Input data buffer from ICS	
g_u2_run_mode	uint16	–	Operation mode management	0x00: Initialize mode 0x01: Boot mode 0x02: Drive mode 0x03: Analysis mode 0x04: Tune mode
g_u2_error_status	uint16	–	Error status management	0x00: None error 0x01: Overcurrent error 0x02: Over voltage error 0x04: Over speed error 0x08: Hall signal time out error 0x10: BEMF time out error 0x20: Hall pattern error 0x40: BEMF pattern error 0x80: Under voltage error 0xFF: Undefined error
g_u1_mode_system	uint8	–	State management	0x00: Inactive mode 0x01: Active mode 0x02: Error mode
g_u1_state_v_offset	uint8	–	State management of voltage offset process	0x00: None 0x01: Measure with PWM off 0x02: Measure with PWM on 0x03: Finish measurement (Reflect offset value)
g_u1_state_draw_in	uint8	–	State management of draw-in at start-up	0x00: None 0x01: Draw-in 1st time 0x02: Draw-in 2nd time 0x03: Finish
g_u2_state_voltage_ref	uint16	–	State management of voltage setting	0: Voltage zero 1: Increase voltage 2: Voltage constant 3: Open loop 4: PI output
g_u2_state_speed_ref	uint16	–	State management of speed setting	0: Speed zero 1: Open loop mode1 2: Open loop mode2 3: Open loop mode3 4: Speed controlled
g_u2_sensor_conf	uint16	–	Sensor configuration	0x01: Sensorless 0x02: Hall sensor 0x04: Encoder 0x08: Resolver
g_u2_method_conf	uint16	–	Control method configuration	0x00: FOC (Fields Oriented Control) 0x01: 180 degree control 0x02: Wide angle electricity control 0x03: 120 degree control

Table 3-18 List of variables [3/4]

Variable name	Type	Scale	Content	Remarks
g_u2_ctrl_conf	uint16	—	Control configuration	0x01: Current control 0x02: Speed control 0x04: Position control 0x08: Torque control 0x10: Voltage control
g_u1_cnt_speed_pi	uint8	—	Decimation counter for speed PI control function call	
g_u1_flg_wait_stop	uint8	—	Flag to wait motor rotation stop	0x00: motor stopped 0x01: waiting motor stop
g_u1_flag_charge_cap	uint8	—	Flag of finish capacitor charge	
g_u2_ref_speed_rad_ctrl	uint16	Q3	Speed command value	Electrical angle [rad/s]
g_s2_kp_speed	int16	Q16	Speed PI control proportional gain	
g_s2_ki_speed	int16	Q22	Speed PI control integral gain	
g_s2_lim_v	int16	Q7	Limit of speed PI control	[V]
g_s4_ilim_v	int32	Q26	Limit for integral part of speed PI control	[V]
g_s2_limit_speed_change	int16	Q3	Increase step of speed command	Electrical angle [rad/s]
g_s2_ol_freq	int16	—	Frequency of open loop	[Hz]
g_u2_cnt_zerocross	uint16	—	Counter to start speed calculation	
g_s2_ol_speed_rpm	int16	—	Speed of open loop	Mechanical angle [rpm]
g_u2_cnt_ol_pattern_set	uint16	—	Counter for open loop	
g_s2_ol_start_rpm	int16	—	Start speed of open loop	Mechanical angle [rpm]
g_s2_ol_mode1_change_rpm	int16	—	Change speed of open loop mode1	Mechanical angle [rpm]
g_s2_ol_mode2_change_rpm	int16	—	Change speed of open loop mode2	Mechanical angle [rpm]
g_s2_ol_start_refv	int16	Q7	Reference voltage of start open loop	[V]
g_s2_ol_mode1_rate_rpm	int16	—	Increase step of speed at open loop mode1	Mechanical angle [rpm]
g_s2_ol_mode2_rate_refv	int16	Q7	Increase step of voltage at open loop mode2	[V]
g_s2_ol_mode2_rate_rpm	int16	—	Increase step of speed at open loop mode2	Mechanical angle [rpm]
g_s2_ol_mode3_rate_refv	int16	Q7	Increase step of voltage at open loop mode3	[V]
g_s2_ol_mode3_max_refv	int16	Q7	Maximum voltage of open loop3	[V]
g_s2_ol_start_freq	int16	—	Start frequency of open loop	[Hz]
g_s2_ol_mode1_change_freq	int16	—	Change frequency of open loop mode1	[Hz]
g_s2_ol_mode2_change_freq	int16	—	Change frequency of open loop mode2	[Hz]
g_u2_cnt_draw_in	uint16	—	Counter for draw-in	
g_s2_boot_ref_v	int16	Q7	Voltage reference at draw-in	[V]
g_u2_v_up_time	uint16	—	Time to increase voltage step at draw-in	
g_s2_v_up_step	int16	—	Voltage step at draw-in	
g_u2_v_const_period	uint16	—	Period of constant voltage at draw-in	[ms]
g_u1_bemf_signal	uint8	—	Pseudo Hall pattern generated	
g_u1_pre_bemf_signal	uint8	—	Previous Hall pattern generated	
g_u1_v_pattern	uint8	—	Conduction pattern	
g_u1_flg_pattern_change	uint8	—	Zero-cross detection flag	
g_u2_cnt_timeout	uint16	—	Counter for timeout	
g_u1_direction	uint8	—	Rotation direction	CW: 0 CCW: 1
g_u2_motor_pp	uint16	—	Motor pole pairs	

Table 3-19 List of variables [4/4]

Variable name	Type	Scale	Content	Remarks
g_u2_bemf_timer_cnt	uint16	—	Free run timer count	
g_u2_pre_bemf_timer_cnt	uint16	—	Previous free run timer count	
g_u2_timer_cnt_sum	uint16	—	Sum of free runt timer count as 2π	
g_u2_timer_cnt_buf[6]	uint16	—	Free run timer count buffer for 6 times	
g_u1_timer_cnt_num	uint8	—	Counter for g_u2_timer_cnt_buf	
g_u2_bemf_delay	uint16	—	Delay counts for change pattern from the zero-cross detected	
g_s2_angle_shift_adjust	int16	—	Adjustment value for delay from zero-cross detected	
g_u2_cnt_carrier	uint16	—	Carrier cycle interruption counter	
g_u2_pre_cnt_carrier	uint16	—	Previous carrier interruption counter value	
g_u1_v_pattern_num	uint8	—	Control number for forced conduction pattern at open loop	
g_u1_v_pattern_open[2][7]	uint8	—	Array of forced conduction patterns at open loop	
g_u2_offset_calc_time	uint16	—	Counts for measurement of voltage offset	
g_u2_offset_calc_cnt	uint16	—	Counter for measurement of voltage offset	
g_u2_offset_vu	uint16	—	Voltage offset value of U phase at PWM on	
g_u2_offset_vv	uint16	—	Voltage offset value of V phase at PWM on	
g_u2_offset_vw	uint16	—	Voltage offset value of W phase at PWM on	
g_u2_offset_off_vu	uint16	—	Voltage offset value of U phase at PWM off	
g_u2_offset_off_vv	uint16	—	Voltage offset value of V phase at PWM off	
g_u2_offset_off_vw	uint16	—	Voltage offset value of W phase at PWM off	
g_u2_sum_vu_ad	uint16	—	Sum of voltage offset value of U phase	
g_u2_sum_vv_ad	uint16	—	Sum of voltage offset value of V phase	
g_u2_sum_vw_ad	uint16	—	Sum of voltage offset value of W phase	
g_u4_inv_offset_calc	uint32	—	Variable to calculate voltage offset	Inverse of g_u2_offset_calc_time

3.4 List of sensorless 120-degree conducting control software structure

Lists of structure used in this control program are given below.

Table 3-20 List of structure

Structure	Member	Type	Scale	Content	Remarks
MTR_PI_CTRL	s2_err	int16	Q3	Error	
	s2_kp	int16	Q16	PI control proportional gain	
	s2_ki	int16	Q22	PI control integral gain	
	s4_refi	int32	Q7	Integral output value	
	s4_ilimit	int32	Q26	Integral output limit	
MTR_ICS_INPUT	u2_ref_speed	uint16	－	Reference speed	Mechanical angle [rpm]
	s2_direction	int16	－	Rotation direction	0：CW 1：CCW
	u2_motor_pp	uint16	－	Number of pole pairs	
	s2_kp_speed	int16	Q16	Speed PI control proportional gain	
	s2_ki_speed	int16	Q22	Speed PI control Integral gain	
	s2_speed_lpf_k	int16	Q14	Speed LPF parameter	
	s2_limit_speed_change	int16	Q3	Step of speed command at PI control	Electrical angle [rad/s]
	s2_ol_start_rpm	int16	－	Start speed of open loop	Mechanical angle [rpm]
	s2_ol_mode1_change_rpm	int16	－	Change speed of open loop mode1	Mechanical angle [rpm]
	s2_ol_mode2_change_rpm	int16	－	Change speed of open loop mode1	Mechanical angle [rpm]
	s2_ol_start_refv	int16	Q7	Voltage reference of open loop at start-up	[V]
	s2_ol_mode1_rate_rpm	int16	－	Increase step of speed at open loop mode1	Mechanical angle [rpm]
	s2_ol_mode2_rate_refv	int16	Q7	Increase step of voltage at open loop mode2	[V]
	s2_ol_mode2_rate_rpm	int16	－	Increase step of speed at open loop mode2	Mechanical angle [rpm]
	s2_ol_mode3_rate_refv	int16	Q7	Increase step of voltage at open loop mode3	[V]
	s2_ol_mode3_max_refv	int16	Q7	Maximum voltage of open loop3	[V]
	u2_v_up_period	uint16	－	Time to increase voltage step at draw-in	
	u2_v_const_period	uint16	－	Period of constant voltage at draw-in	
	s2_angle_shift_adjust	int16	－	Adjustment value for delay from zero-cross detected by A/D converters	

3.5 Macro definitions of sensorless 120-degree conducting control software

Lists of macro definitions used in this control program are given below.

Table 3-21 List of Macro definitions "motor_parameter.h"

File name	Macro name	Definition value	Remarks
motor_parameter.h	MP_POLE_PAIRS	2	Number of pole pairs
	MP_MAGNETIC_FLUX	0.02159f	Flux [Wb] (not used)
	MP_RESISTANCE	6.447f	Resistance [Ω] (not used)
	MP_D_INDUCTANCE	0.0045f	d-axis Inductance [H] (not used)
	MP_Q_INDUCTANCE	0.0045f	q-axis Inductance [H] (not used)

Table 3-22 List of Macro definitions "control_parameter.h"

File name	Macro name	Definition value	Remarks
control_parameter.h	CP_OFFSET_CALC_TIME	10000	Counts for measurement of voltage offset
	CP_BOOT_REF_V	5.0f * 0x80	Voltage reference at draw-in [V]
	CP_V_UP_TIME	180	Time to increase voltage step at draw-in [ms]
	CP_V_CONST_TIME	180	Period of constant voltage at draw-in [ms]
	CP_MAX_SPEED_RPM	2650	Maximum of rotational speed command Mechanical angle [rpm]
	CP_MIN_SPEED_RPM	1000	Minimum of rotational speed command Mechanical angle [rpm]
	CP_LIMIT_SPEED_CHANGE	0.30f * 0x08	Step to increase speed reference Electrical angle [rad/s]
	CP_OL_START_RPM	140	Speed of open loop at start-up Mechanical angle [rpm]
	CP_OL_MODE1_CHANGE_RPM	300	Speed to change open loop mode1 Mechanical angle [rpm]
	CP_OL_MODE2_CHANGE_RPM	800	Speed to change open loop mode2 Mechanical angle [rpm]
	CP_OL_START_REFV	5.5f * 0x80	Voltage reference of open loop at start-up [V]
	CP_OL_MODE1_RATE_RPM	6	Increase step of speed at open loop mode1 [rpm/control period]
	CP_OL_MODE2_RATE_REFV	0.01f * 0x80	Increase step of voltage at open loop mode2 [V]
	CP_OL_MODE2_RATE_RPM	9	Increase step of speed at open loop mode2 [rpm/control period]
	CP_OL_MODE3_RATE_REFV	0.01f * 0x80	Increase step of voltage at open loop mode3 [V]
	CP_OL_MODE3_MAX_REFV	6.20f * 0x80	Maximum voltage of open loop [V]
	CP_SPEED_PI_KP	0.0180f * 0xFFFF	Proportional gain
	CP_SPEED_PI_KI	0.0006f * 0x400000	Integral gain
	CP_SPEED_LPF_K	1.0f * 0x40	Speed LPF parameter
	MTR_FIRST60	0	Non-Complementary First 60 degree PWM
	MTR_FIRST60_COMP	1	Complementary First 60 degree PWM (default)

Table 3-23 List of Macro definitions "main.h"

File name	Macro name	Definition value	Remarks
main.h	M_CW	0	Rotation direction
	M_CCW	1	
	VOFFSET_MEASURE_CNT	CP_OFFSET_CALC_TIME	Counts for measurement of voltage offset [ms]
	BOOT_REF_V	CP_BOOT_REF_V	Voltage reference at draw-in [V]
	V_UP_PERIOD	CP_V_UP_TIME	Time to increase voltage step at draw-in [ms]
	V_CONST_PERIOD	CP_V_CONST_TIME	Period of constant voltage at draw-in [ms]
	MAX_SPEED	CP_MAX_SPEED_RPM	Maximum of rotational speed command Mechanical angle [rpm]
	MIN_SPEED	CP_MIN_SPEED_RPM	Minimum of rotational speed command Mechanical angle [rpm]
	MARGIN_SPEED	50.0f	Rotational speed command minimum value creation constants for stop Mechanical angle [rpm]
	MARGIN_MIN_SPEED	MIN_SPEED - MARGIN_SPEED	Minimum of rotational speed to control motor stop Mechanical angle [rpm]
	OL_START_RPM	CP_OL_START_RPM	Speed of open loop at start-up Mechanical angle [rpm]
	OL_MODE1_CHANGE_RPM	CP_OL_MODE1_CHANGE_RPM	Speed to change open loop mode1 Mechanical angle [rpm]
	OL_MODE2_CHANGE_RPM	CP_OL_MODE2_CHANGE_RPM	Speed to change open loop mode2 Mechanical angle [rpm]
	OL_START_REFV	(int16) CP_OL_START_REFV	Voltage reference of open loop at start-up [V]
	OL_MODE1_RATE_RPM	CP_OL_MODE1_RATE_RPM	Increase step of speed at open loop mode1 [rpm/control period]
	OL_MODE2_RATE_REFV	(int16) CP_OL_MODE2_RATE_REFV	Increase step of voltage at open loop mode2 [V]
	OL_MODE2_RATE_RPM	CP_OL_MODE2_RATE_RPM	Increase step of speed at open loop mode2 [rpm/control period]
	OL_MODE3_RATE_REFV	(int16) CP_OL_MODE3_RATE_REFV	Increase step of voltage at open loop mode3 [V]
	OL_MODE3_MAX_REFV	(int16) CP_OL_MODE3_MAX_REFV	Maximum voltage of open loop [V]
	LIMIT_SPEED_CHANGE	(int16) CP_LIMIT_SPEED_CHANGE	Step to increase speed reference Electrical angle [rad/s]
	SPEED_PI_KP	(int16) CP_SPEED_PI_KP	Speed proportional gain
	SPEED_PI_KI	(int16) CP_SPEED_PI_KI	Speed Integral gain
	SPEED_LPF_K	(int16) CP_SPEED_LPF_K	Speed LPF parameter
	SW_ON	0	Active in case of "Low"
	SW_OFF	1	
	CHATTERING_CNT	10	Counts to remove chattering
	VR1_SCALING	(MAX_SPEED + 500) / 0x200	Speed command value creation constant
	ADJUST_OFFSET	0x1FF	Speed command value offset adjustment constant
	POLE_PAIR	MP_POLE_PAIRS	Pole pairs
	REQ_CLR	0	Clear VR1 stop command flag
	REQ_SET	1	Set VR1 stop command flag

Table 3-24 List of Macro definitions “mtr_ctrl_rl78g14.h”

File name	Macro name	Definition value		Remarks
mtr_ctrl_rl78g14.h	PARITYCTL_BIT	CA	RPECTL.7	Set enable RAM parity error detection
		CC-RL	RPECTL_bit.no7	

Table 3-25 List of Macro definitions “mtr_ctrl_rl78g1g_mrssk.h” [1/2]

File name	Macro name	Definition value				Remarks
mtr_ctrl_rl78g1g_mrssk.h	MTR_PWM_TIMER_FREQ	64.0f				PWM timer count frequency [MHz]
	MTR_CARRIER_FREQ	20.0f				Carrier frequency [kHz]
	MTR_DEADTIME	2000				Dead time [ns]
	MTR_DEADTIME_SET	(int16)(MTR_DEADTIME * MTR_PWM_TIMER_FREQ / 1000)				Dead time setting value
	MTR_CARRIER_SET	(MTR_PWM_TIMER_FREQ * 1000 / MTR_CARRIER_FREQ / 2) + MTR_DEADTIME_SET - 2				Carrier setting value
	MTR_HALF_CARRIER_SET	MTR_CARRIER_SET / 2				Half of “MTR_CARRIER_SET”
	MTR_NDT_CARRIER_SET	MTR_CARRIER_SET - MTR_DEADTIME_SET				
	MTR_PORT_UP	CA	P1.5	CC-RL	P1_bit.no5	U phase (positive phase) output port
	MTR_PORT_UN		P1.4		P1_bit.no4	U phase (negative phase) output port
	MTR_PORT_VP		P1.3		P1_bit.no3	V phase (positive phase) output port
	MTR_PORT_VN		P1.1		P1_bit.no1	V phase (negative phase) output port
	MTR_PORT_WP		P1.2		P1_bit.no2	W phase (positive phase) output port
	MTR_PORT_WN		P1.0		P1_bit.no0	W phase (negative phase) output port
	MTR_PORT_SW1		P0.5		P0_bit.no5	SW1 input port
	MTR_PORT_SW2		P0.6		P0_bit.no6	SW2 input port
	MTR_PORT_LED1		P5.2		P5_bit.no2	LED1 output port
	MTR_PORT_LED2		P5.3		P5_bit.no3	LED2 output port
	MTR_PORT_LED3		P5.4		P5_bit.no4	LED3 output port
	MTR_LED_ON	0				LED active in case of “Low”
	MTR_LED_OFF	1				
	MTR_INPUT_V	(int16) 24 * 0x80				input DC voltage [V] (scale: Q7)
	MTR_MCU_ON_V	(int16) MTR_INPUT_V * 0.8				MCU power on voltage (scale: Q7)
	MTR_VDC_SCALING	3555				Calculate parameter for scaling invertor bus voltage from A/D converted value (scale: Q7)
	MTR_RECIVDC_SCALING	64				Reciprocal value of MTR_VDC_SCALING (scale: Q7)
	MTR_OVERVOLTAGE_LIMIT	(int16) 28 * 0x80				High voltage limit [V]
	MTR_UNDERVOLTAGE_LIMIT	(int16) 15 * 0x80				Low voltage limit [V]
	MTR_TAU1_CNT	TCR01				Counter register of Free-run timer to measure rotational speed

Table 3-26 List of Macro definitions “mtr_ctrl_rl78g1g_mrssk.h” [2/2]

File name	Macro name	Definition value	Remarks
mtr_ctrl_rl78g1g _mrssk.h	MTR_ADCCH_VR1	6	A/D Converter channel of VR1
	MTR_ADCCH_VDC	2	A/D Converter channel of inverter bus voltage
	MTR_ADCCH_VU	3	A/D Converter channel of U phase voltage
	MTR_ADCCH_VV	4	A/D Converter channel of V phase voltage
	MTR_ADCCH_VW	5	A/D Converter channel of W phase voltage
	MTR_OC_HW_FLG	TRDSHUTS	Forced cutoff flag
	MTR_OC_INTP_MASK	PMK0	INTP0 interrupt mask flag
	MTR_DISABLE_OC_INTR	1	Disable interrupt service

Table 3-27 List of Macro definitions “mtr_spm_less_120.h” [1/4]

File name	Macro name	Definition value	Remarks
mtr_spm_less_120.h	MTR_POLE_PAIRS	MP_POLE_PAIRS	Motor Pole pairs
	MTR_TWOPI	2 * 3.14159265f	2π
	MTR_RPM_RAD	13726	Calculate parameter for [rpm]→[rad/s] (scale: Q3)
	MTR_RAD_RPM	4889	Calculate parameter for [rad/s]→[rpm] (scale: Q12)
	MTR_SPEED_LIMIT_RPM	3500	Speed limit Mechanical angle [rpm]
	MTR_SPEED_LIMIT	MTR_SPEED_LIMIT_RPM * MTR_TWOPI / 60	Speed limit Electrical angle [rad/s]
	MTR_SPEED_PI_DECIMATION	0	Number of interrupt decimation times for speed PI control
	MTR_SPEED_PI_KP	(int16) CP_SPEED_PI_KP	Speed PI proportional gain
	MTR_SPEED_PI_KI	(int16) CP_SPEED_PI_KI	Speed PI Integral gain
	MTR_SPEED_PI_LIMIT_V	24 * 0x80	Voltage PI control output limit [V] (scale: Q7)
	MTR_SPEED_PI_I_LIMIT_V	24 * 0x80 * 0x80000	Voltage PI control output limit [V] Integral part (for calculation) (scale: Q12)
	MTR_SPEED_CALC_BASE	767	Calculate parameter to translate the timer counter to rotational speed [rad/s] (scale: Q3)
	MTR_CNT_START_CALC	30	Wait speed measurement still zero-cross is detected become this counts
	MTR_SPEED_LPF_K	(int16) CP_SPEED_LPF_K	Speed LPF parameter
	MTR_LIMIT_SPEED_CHANGE	CP_LIMIT_SPEED_CHANGE	Step to increase speed reference Electrical angle [rad/s]
	MTR_MAX_DRIVE_V	(int16) 22 * 0x80	Maximum command voltage [V] (scale: Q7)
	MTR_MIN_DRIVE_V	(int16) 0.01 * 0x80	Minimum command voltage [V] (scale: Q7)
	MTR_MAX_BOOT_V	8.0 * 0x80	Maximum command voltage at draw-in [V] (scale: Q7)
	MTR_TIMEOUT_CNT	50	Timeout limit [ms]
	MTR_STOP_BEMF	122	Value to judge motor stopped
	MTR_SHIFT_ADJUST	0	Value of angle shift adjusting
	MTR_OL_CTRL_PERIOD	15	Control period of open loop [ms]
	MTR_OL_START_RPM	CP_OL_START_RPM	Speed of open loop at start-up Mechanical angle [rpm]
	MTR_OL_MODE1_CHANGE_RPM	CP_OL_MODE1_CHANGE_RPM	Speed to change open loop mode1 Mechanical angle [rpm]
	MTR_OL_MODE2_CHANGE_RPM	CP_OL_MODE2_CHANGE_RPM	Speed to change open loop mode2 Mechanical angle [rpm]
	MTR_OL_START_REFV	(int16) CP_OL_START_REFV	Voltage reference of open loop at start-up [V]
	MTR_OL_MODE1_RATE_RPM	CP_OL_MODE1_RATE_RPM	Increase step of speed at open loop mode1 [rpm/control period]
	MTR_OL_MODE2_RATE_REFV	(int16) CP_OL_MODE2_RATE_REFV	Increase step of voltage at open loop mode2 [V]
	MTR_OL_MODE2_RATE_RPM	CP_OL_MODE2_RATE_RPM	Increase step of speed at open loop mode2 [rpm/control period]

Table 3-28 List of Macro definitions “mtr_spm_less_120.h” [2/4]

File name	Macro name	Definition value	Remarks
mtr_spm_less_120.h	MTR_OL_MODE3_RATE_REFV	(int16) CP_OL_MODE3_RATE_REFV	Increase step of voltage at open loop mode3 [V]
	MTR_OL_MODE3_MAX_REFV	(int16) CP_OL_MODE3_MAX_REFV	Maximum voltage of open loop [V]
	MTR_OL_FREQ_CALC	MTR_CARRIER_FREQ * 60000/6	Calculate parameter to translate [rpm] to [Hz]
	MTR_OL_START_FREQ	(int16) MTR_OL_FREQ_CALC/MTR_POLE_PAIRS / MTR_OL_START_RPM	Frequency for start-up [Hz]
	MTR_OL_MODE1_CHANGE_FREQ	(int16) MTR_OL_FREQ_CALC/MTR_POLE_PAIRS / MTR_OL_MODE1_CHANGE_RPM	Frequency to change open loop mode1 [Hz]
	MTR_OL_MODE2_CHANGE_FREQ	(int16) MTR_OL_FREQ_CALC/MTR_POLE_PAIRS / MTR_OL_MODE2_CHANGE_RPM	Frequency to change open loop mode2 [Hz]
	MTR_DELAY_VALUE_MIN	20	Minimum value of delay from zero-cross
	MTR_PATTERN_CW_V_U	2	CW pseudo Hall sensor pattern
	MTR_PATTERN_CW_W_U	3	
	MTR_PATTERN_CW_W_V	1	
	MTR_PATTERN_CW_U_V	5	
	MTR_PATTERN_CW_U_W	4	
	MTR_PATTERN_CW_V_W	6	
	MTR_PATTERN_CCW_V_U	3	CCW pseudo Hall sensor pattern
	MTR_PATTERN_CCW_V_W	2	
	MTR_PATTERN_CCW_U_W	6	
	MTR_PATTERN_CCW_U_V	4	
	MTR_PATTERN_CCW_W_V	5	
	MTR_PATTERN_CCW_W_U	1	
	MTR_PATTERN_ERROR	0	Conduction pattern
	MTR_UP_PWM_VN_ON	1	
	MTR_UP_PWM_WN_ON	2	
	MTR_VP_PWM_UN_ON	3	
	MTR_VP_PWM_WN_ON	4	
	MTR_WP_PWM_UN_ON	5	
	MTR_WP_PWM_VN_ON	6	
	MTR_UP_ON_VN_PWM	7	
	MTR_UP_ON_WN_PWM	8	
	MTR_VP_ON_UN_PWM	9	
	MTR_VP_ON_WN_PWM	10	
	MTR_WP_ON_UN_PWM	11	
	MTR_WP_ON_VN_PWM	12	
	MTR_U_PWM_VN_ON	13	
	MTR_U_PWM_WN_ON	14	
	MTR_V_PWM_UN_ON	15	
	MTR_V_PWM_WN_ON	16	
	MTR_W_PWM_UN_ON	17	
	MTR_W_PWM_VN_ON	18	
	MTR_UP_ON_V_PWM	19	
	MTR_UP_ON_W_PWM	20	

Table 3-29 List of Macro definitions "mtr_spm_less_120.h" [3/4]

File name	Macro name	Definition value	Remarks
mtr_spm_less_120.h	MTR_VP_ON_U_PWM	21	Conduction pattern
	MTR_VP_ON_W_PWM	22	
	MTR_WP_ON_U_PWM	23	
	MTR_WP_ON_V_PWM	24	
	MTR_OFFSET_CALC_TIME	CP_OFFSET_CALC_TIME	Time to calculate voltage offset [ms]
	MTR_BOOT_REF_V	CP_BOOT_REF_V	Voltage reference at draw-in [V]
	MTR_V_UP_PERIOD	CP_V_UP_TIME	Time to increase voltage step at draw-in [ms]
	MTR_V_UP_STEP	(int16) MTR_BOOT_REF_V / MTR_V_UP_PERIOD	Increase step of voltage at draw-in
	MTR_V_CONST_TIME	CP_V_CONST_TIME	Period of constant voltage at draw-in [ms]
	MTR_CW	0	Rotation direction
	MTR_CCW	1	
	MTR_FLG_CLR	0	Constant for flag management
	MTR_FLG_SET	1	
	MTR_ICS_DECIMATION	5	Number of function call decimation times for ICS
	MTR_MODE_INACTIVE	0x00	Inactive mode
	MTR_MODE_ACTIVE	0x01	Active mode
	MTR_MODE_ERROR	0x02	Error mode
	MTR_SIZE_STATE	3	State size
	MTR_EVENT_INACTIVE	0x00	Inactive event
	MTR_EVENT_ACTIVE	0x01	Active event
	MTR_EVENT_ERROR	0x02	Error event
	MTR_EVENT_RESET	0x03	Reset event
	MTR_SIZE_EVENT	4	Event size
	MTR_MODE_INIT	0x00	Initialize mode
	MTR_MODE_BOOT	0x01	Boot mode
	MTR_MODE_DRIVE	0x02	Drive mode
	MTR_MODE_ANALYSIS	0x03	Analysis mode
	MTR_MODE_TUNE	0x04	Tune mode
	MTR_SENSOR_LESS	0x01	Sensorless
	MTR_SENSOR_HALL	0x02	Hall sensor
	MTR_SENSOR_ENCD	0x04	Encoder
	MTR_SENSOR_RESO	0x08	Resolver
	MTR_METHOD_FOC	0x00	Fields oriented control
	MTR_METHOD_180	0x01	180 degree control
	MTR_METHOD_WIDE	0x02	Wide angle electricity control
	MTR_METHOD_120	0x03	120 degree control
	MTR_CONTROL_CURRENT	0x01	Current control
	MTR_CONTROL_SPEED	0x02	Speed control
	MTR_CONTROL_POSITION	0x04	Position control
	MTR_CONTROL_TORQUE	0x08	Torque control
	MTR_CONTROL_VOLTAGE	0x10	Voltage control

Table 3-30 List of Macro definitions "mtr_spm_less_120.h" [4/4]

File name	Macro name	Definition value	Remarks
mtr_spm_less_120.h	MTR_ERROR_NONE	0x00	No error
	MTR_ERROR_OVER_CURRENT	0x01	Overcurrent error
	MTR_ERROR_OVER_VOLTAGE	0x02	Over voltage error
	MTR_ERROR_OVER_SPEED	0x04	Over speed error
	MTR_ERROR_HALL_TIMEOUT	0x08	Hall timeout error
	MTR_ERROR_BEMF_TIMEOUT	0x10	BEMF timeout error
	MTR_ERROR_HALL_PATTERN	0x20	Hall pattern error
	MTR_ERROR_BEMF_PATTERN	0x40	BEMF pattern error
	MTR_ERROR_UNDER_VOLTAGE	0x80	Under voltage error
	MTR_ERROR_UNKNOWN	0xff	Unknown error
	MTR_DRAW_IN_NONE	0	initial state (not work)
	MTR_DRAW_IN_1ST	1	draw-in the 1st initial position
	MTR_DRAW_IN_2ND	2	draw-in the 2nd initial position
	MTR_DRAW_IN_FINISH	3	draw-in finished
	MTR_V_ZERO_CONST	0	zero voltage constant
	MTR_V_UP	1	increase of voltage
	MTR_V_CONST	2	voltage constant
	MTR_V_OPENLOOP	3	Open-loop voltage setting mode
	MTR_V_PI_OUTPUT	4	Speed PI output voltage setting mode
	MTR_SPEED_ZERO_CONST	0	Speed zero constant
	MTR_SPEED_OPENLOOP_1	1	Open loop MODE1
	MTR_SPEED_OPENLOOP_2	2	Open loop MODE2
	MTR_SPEED_OPENLOOP_3	3	Open loop MODE3
	MTR_SPEED_CHANGE	4	Speed changing
	MTR_VOFFSET_STATUS_NONE	0	The measurement of voltage offset doesn't work
	MTR_VOFFSET_STATUS_MEASURE_OFF	1	Measure voltage offset with PWM off
	MTR_VOFFSET_STATUS_MEASURE_ON	2	Measure voltage offset with PWM on
	MTR_VOFFSET_STATUS_FINISH	3	Finish the measurement of voltage offset

3.6 Control flows (flow charts)

3.6.1 Main process

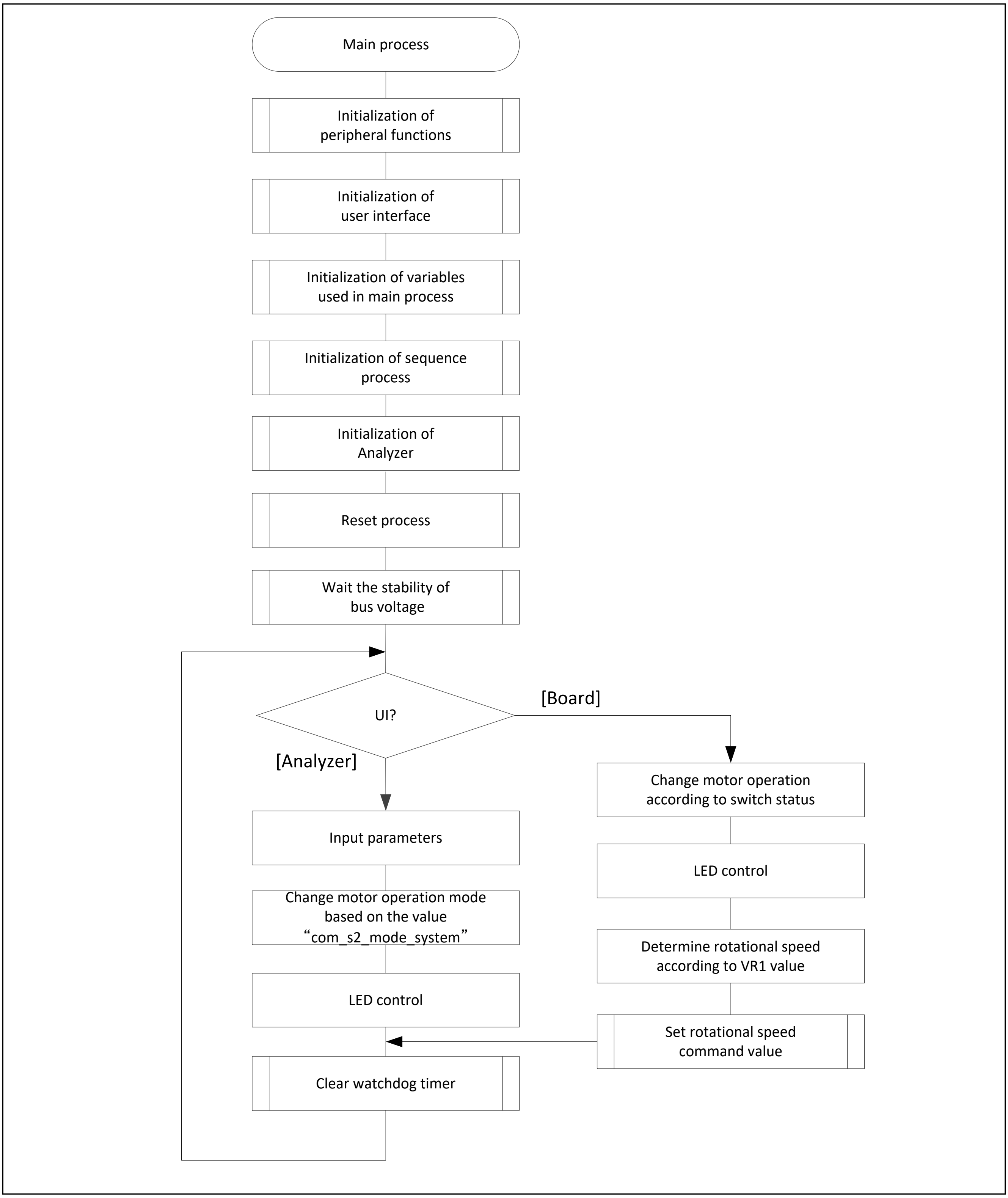


Figure 3-7 Main Process Flowchart

3.6.2 Carrier cycle interrupt handling

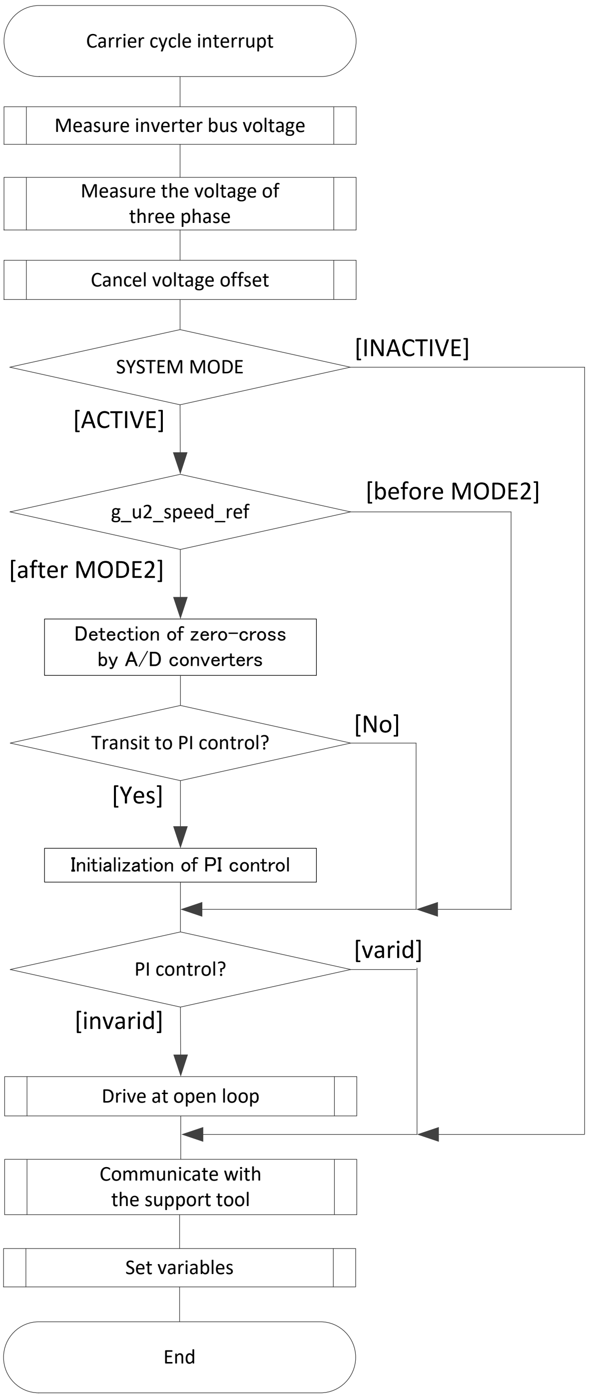


Figure 3-8 50 [μs] Cycle Interrupt Handling (Sensorless 120-degree control)

3.6.3 1 [ms] interrupt handling

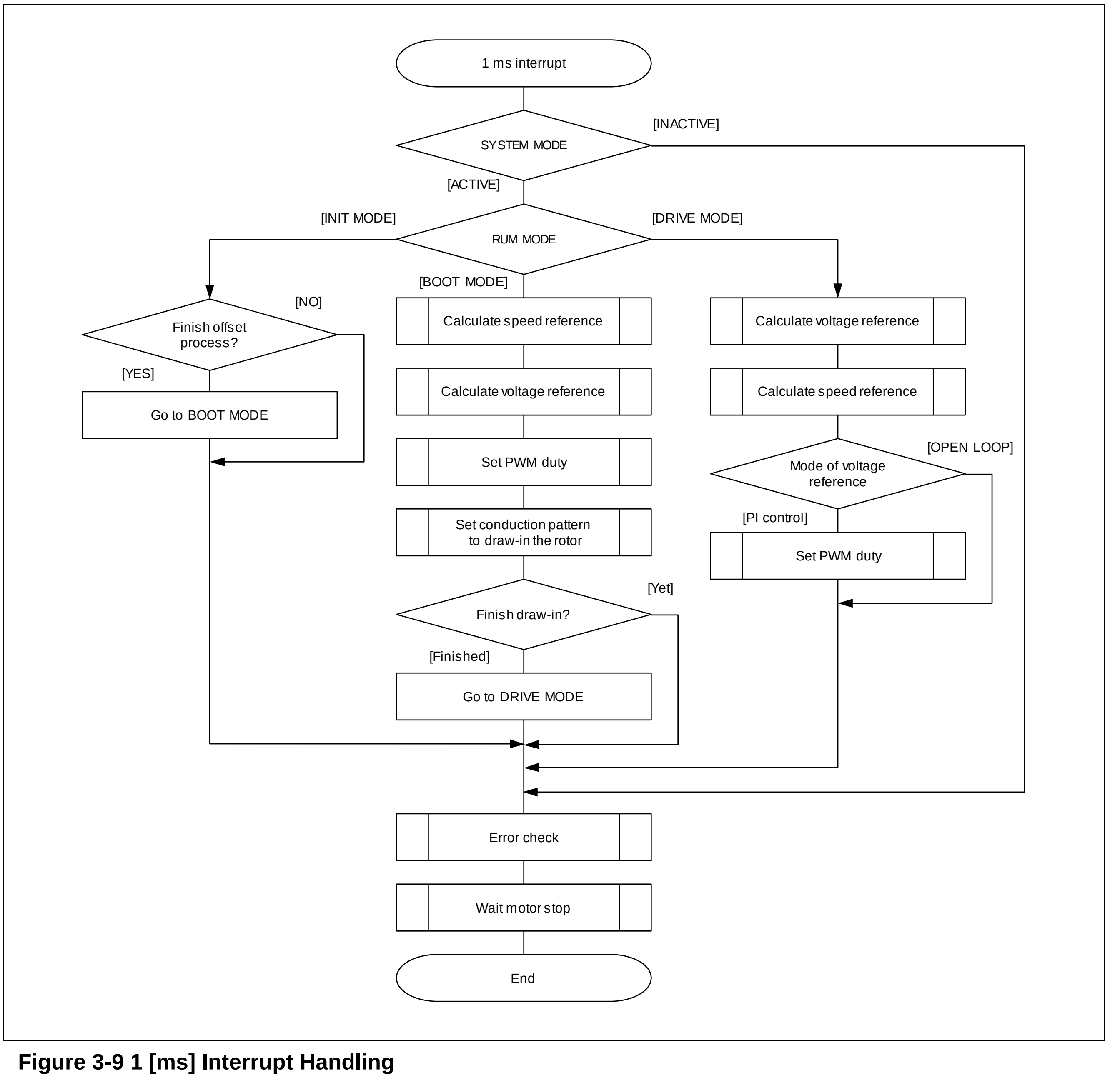


Figure 3-9 1 [ms] Interrupt Handling

3.6.4 Overcurrent interrupt handling

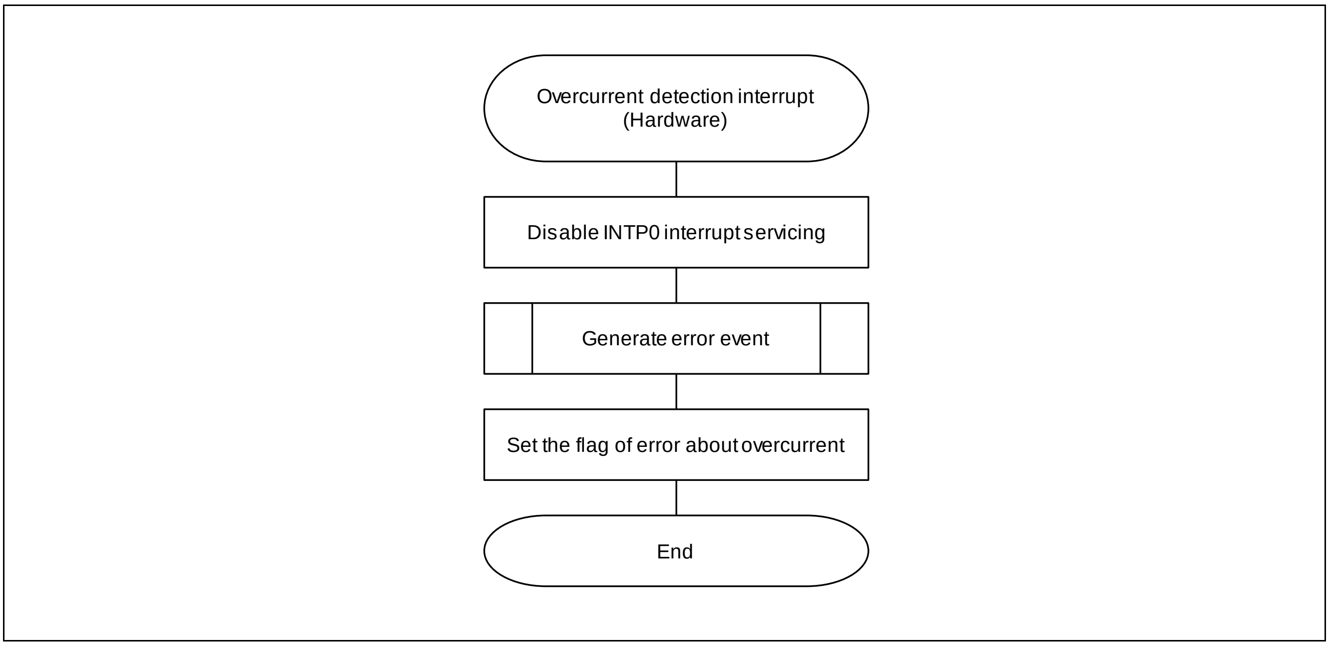


Figure 3-10 Overcurrent detection process (Hardware detection)

3.6.5 Delay interrupt handling

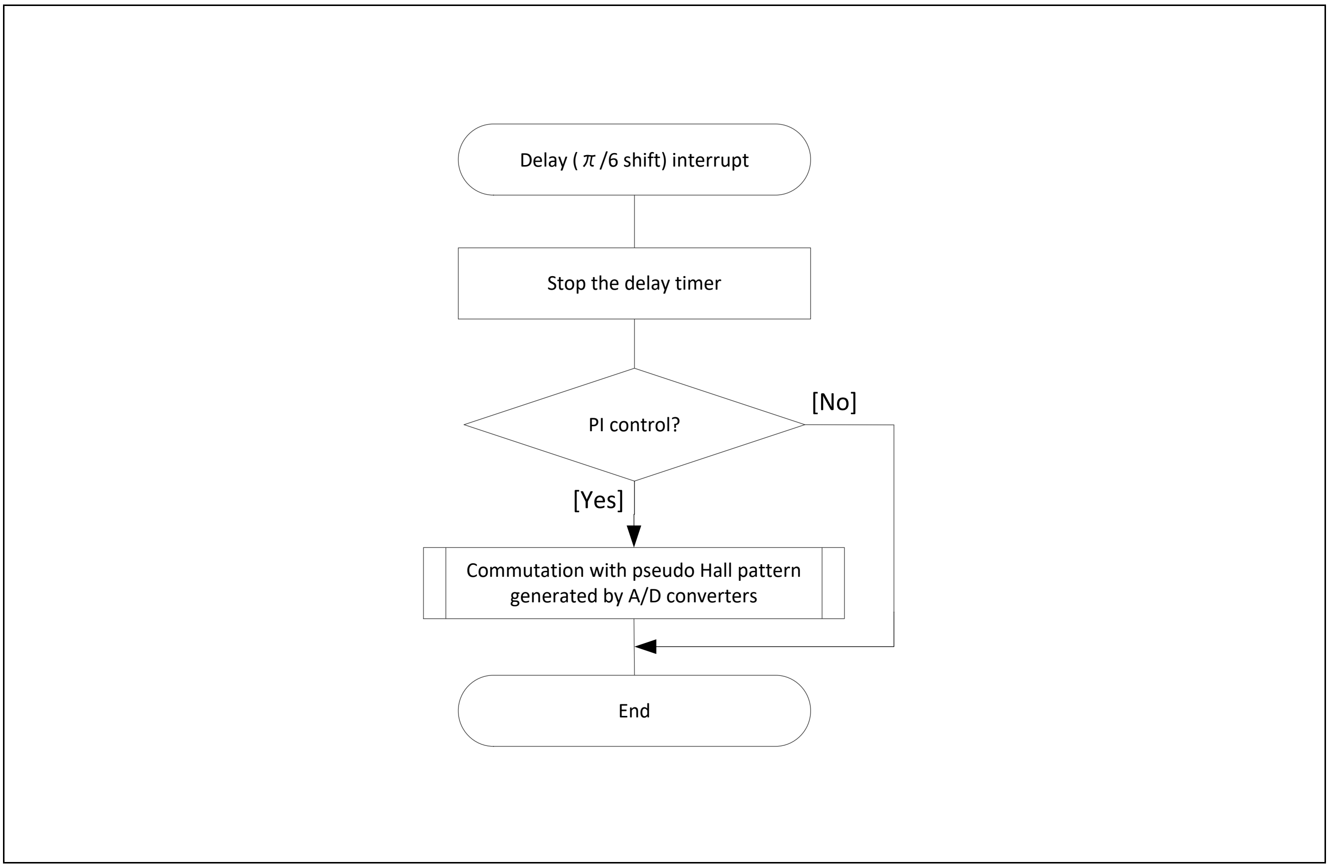


Figure 3-11 Delay Interrupt Handling

4. Motor Control Development Support Tool, ‘Renesas Motor Workbench’

4.1 Overview

In the target sample programs described in this application note, user interfaces (rotating/stop command, rotation speed command, etc.) based on the motor control development support tool, ’Renesas Motor Workbench’ can be used. Please refer to ‘Renesas Motor Workbench V.1.00 User’s Manual’ for usage and more details. You can find ‘Renesas Motor Workbench’ on Renesas Electronics Corporation website.

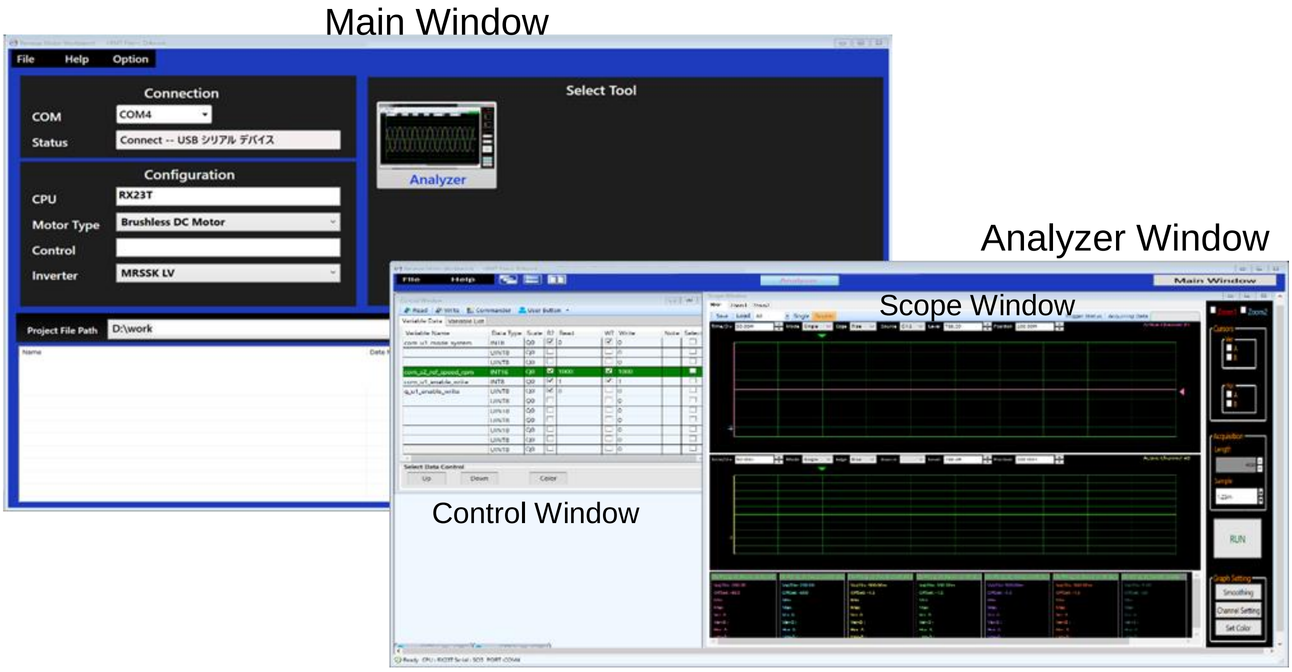
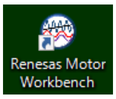


Figure 4-1 Motor RSSK Support Tool – Appearance

Set up for Motor control development support tool

(1) Start ‘Renesas Motor Workbench’ by clicking this icon. 

(2) Drop down menu [File] → [Open RMT File(O)].

And select RMT file in ‘[Project Folder]/ics/’.

(3) Use the ‘Connection’ COM select menu to choose the COM port for Motor RSSK.

(4) Click the ‘Analyzer’ icon in right side of Main Window. (Then, “Analyzer Window” will be displayed.)

(5) Please refer to ‘4.3 Operation Example for Analyzer’ for motor driving operation.

4.2 List of variables for Analyzer

Table 4-1 is a list of variables for Analyzer. These variable values are reflected to the protect variables when the same values as g_s2_enable_write are written to com_s2_enable_write. However, note that variables with (*) do not depend on com_s2_enable_write.

In the sample programs in this application note use fixed-point calculation. Therefore, some variables are already established with fixed-point calculation. Bits number in fractional part of fixed-point number is expressed in the Q format. For example, a "Q3" number has 3 fractional bits. "Qn" number is indicated on "Scale" column in below table.

When referring to variables with fixed-point number, it is possible to display the value without scaling by choosing same "Qn" in "Control Window".

Table 4-1 List of Variables for Analyzer [1/2]

Variable name	Type	Scale	Content	Remarks ([ ]: reflection variable name)
com_s2_sw_userif (*)	int16		User interface switch 0: Analyzer use (default) 1: Board user interface use	【g_s2_sw_userif】
com_s2_mode_system(*)	int16		State management 0: Stop mode 1: Run mode 2: Error mode 3: Reset	【g_s2_mode_system】
com_s2_direction	int16		Rotation direction 0: CW 1: CCW	【g_u1_direction】
com_u2_ref_speed_rpm	uint16		Speed command value (mechanical angle) [rpm]	【g_u2_ref_speed_rad】
com_u2_mortor_pp	uint16		Number of pole pairs	【g_u2_mortor_pp】
com_s2_kp_speed	int16	Q16	Speed PI control proportional gain	【g_s2_kp_speed】
com_s2_ki_speed	int16	Q22	Speed PI control integral gain	【g_s2_ki_speed】
com_s2_speed_lpf_k	int16	Q14	Speed LPF parameter	【g_s2_speed_lpf_k】
com_s2_limit_speed_change	int16	Q3	Step to increase speed reference Electrical angle [rad/s]	【g_s2_limit_speed_change】
com_s2_ol_start_rpm	int16		Speed of open loop at start-up Mechanical angle [rpm]	【g_s2_ol_start_rpm】
com _s2_ol_mode1_change_rpm	int16		Speed to change open loop mode1 Mechanical angle [rpm]	【g_s2_ol_mode1_change_rpm 】
com _s2_ol_mode2_change_rpm	int16		Speed to change open loop mode2 Mechanical angle [rpm]	【g_s2_ol_mode2_change_rpm 】
com _s2_ol_start_refv	int16	Q7	Voltage reference of open loop at start-up [V]	【g_s2_ol_start_refv】
com _s2_ol_mode1_rate_rpm	int16		Increase step of speed at open loop mode1 [rpm/control period]	【g_s2_ol_mode1_rate_rpm】
com _s2_ol_mode2_rate_refv	int16	Q7	Increase step of voltage at open loop mode2 [rpm/control period]	【g_s2_ol_mode2_rate_refv】
com _s2_ol_mode2_rate_rpm	int16		Increase step of speed at open loop mode2 [rpm/control period]	【g_s2_ol_mode2_rate_rpm】
com _s2_ol_mode3_rate_refv	int16	Q7	Increase step of voltage at open loop mode3 [rpm/control period]	【g_s2_ol_mode3_rate_refv】
com _s2_ol_mode3_max_refv	int16	Q7	Maximum voltage of open loop [V]	【g_s2_ol_mode3_max_refv】

Table 4-2 List of Variables for Analyzer [2/2]

Variable name	Type	Scale	Content	Remarks ([ ]: reflection variable name)
com_s2_boot_ref_v	int16	Q7	Voltage reference at draw-in	【g_s2_boot_ref_v】
com_u2_v_up_period	uint16		Time to increase voltage step at draw-in	【g_s2_v_up_step】
com_u2_v_const_period	uint16		Period of constant voltage at draw-in	【g_u2_v_const_period】
com_s2_angle_shift_adjust	int16		Adjustment value for delay from zero-cross detected by A/D converters	【g_s2_angle_shift_adjust】
com_s2_enable_write	int16		Enable to rewriting variables	

4.3 Operation Example for Analyzer

Show an example below that motor driving operation using Analyzer. Operation is using “Control Window”. Refer to ‘Renesas Motor Workbench V.1.00 User’s Manual’ for “Control Window”.

- Driving the motor
  (1) The [W?] check boxes contain checkmarks for “com_s2_mode_system”,“com_s2_ref_speed_rpm”, “com_s2_enable_write”
  (2) Type a reference speed value in the [Write] box of “com_s2_ref_speed_rpm”.
  (3) Click the “Write” button.
  (4) Click the “Read” button. Confirm the [Read] box of “com_s2_ref_speed_rpm”,”g_s2_enable_write”.
  (5) Type a same value of “g_s2_enable_write” in the [Write] box of “com_s2_ref_speed_rpm”.
  (6) Type a value of “1” in the [Write] box of “com_s2_mode_system”.
  (7) Click the “Write” button.

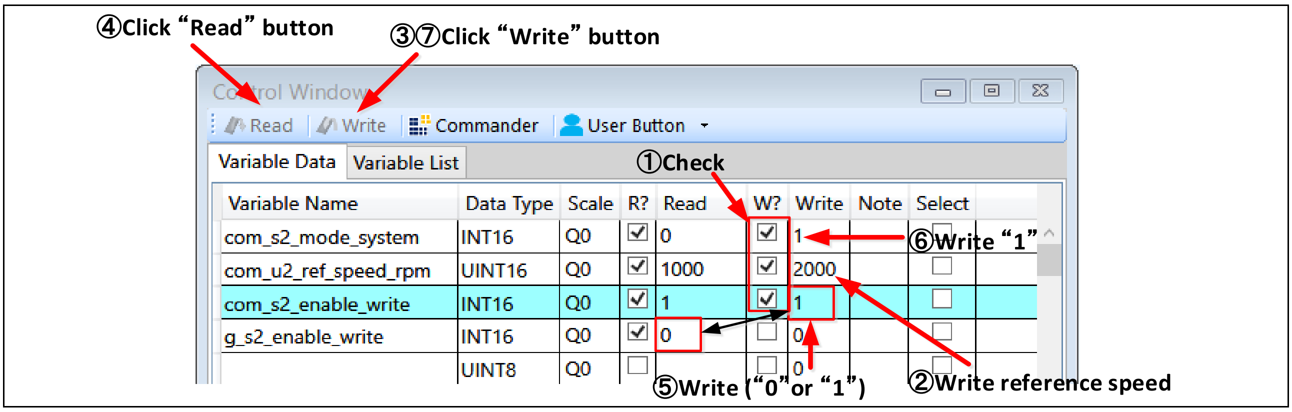


Figure 4-2 Procedure - Driving the motor

- Stop the motor
  (1) Type a value of “0” in the [Write] box of “com_s2_mode_system”
  (2) Click the “Write” button.

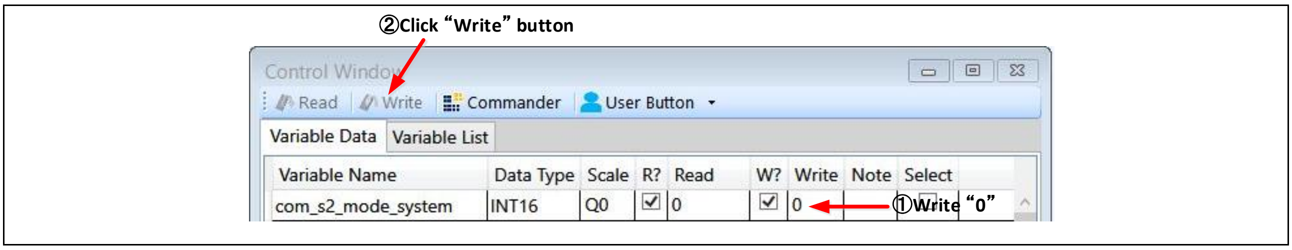


Figure 4-3 Procedure - Stop the motor

- Error cancel operation
  (1) Type a value of “3” in the [Write] box of “com_s2_mode_system”
  (2) Click the “Write” button.

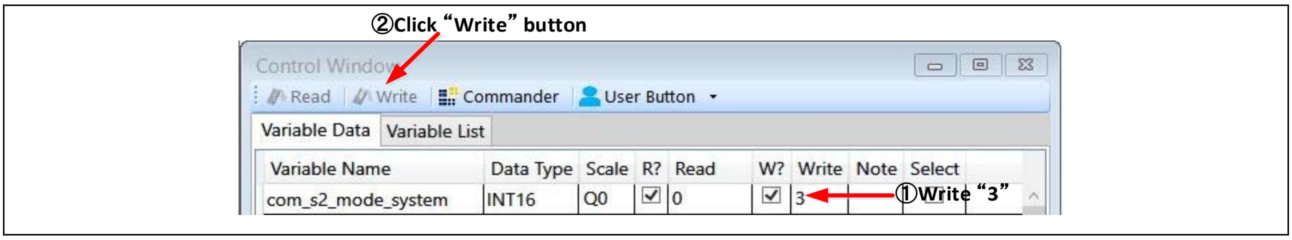


Figure 4-4 Procedure - Error cancel operation

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Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Oct.02.2017	—	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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