RA Family

Vector control for magnetic synchronous motor with hall sensors - 1shunt current detection

For Motor Flexible Control Kit

Introduction

This application note aims for an explanation of vector control for permanent magnetic synchronous motor with hall sensors by using functions of RA6T2 microcontroller, and how to use the motor control development support tool, 'Renesas Motor Workbench'.

The target software of this application note is 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.

Target Device

Operations of the target software of this application note are checked by using the following device.

- RA6T2 (R7FA6T2BD3CFP)

Contents

1. Overview

This application note explains how to implement the vector control software that drives permanent magnetic synchronous motor (PMSM) with hall sensors using the RA6T2 microcontroller and how to use the motor control development support tool, 'Renesas Motor Workbench'

Note that this software uses the vector control algorithm described in the application note 'Sensorless vector control for permanent magnet synchronous motor (Algorithm)' (R01AN3786), so please refer to that for the details of the algorithm.

1.1 Development Environment

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

Table 1-1 Hardware development environment

Microcontroller	Evaluation board (Note 1)	Motor (Note 2)
RA6T2(R7FA6T2BD3CFP)	MCK-RA6T2 CPU board and inverter board	R42BLD30L3

Table 1-2 Software development environment

e2studio version	FSP version	Toolchain version
V2023-04	V4.4.0	GCC ARM Embedded : V10.3.1.20210824

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

Notes 1. Inverter board (RTK0EM0000B12020BJ) and CPU board (RTK0EMA270C00000BJ) are included in the kit products MCK-RA6T2 (RTK0EMA270S00020BJ), and it is a product of Renesas Electronics Corporation.

2. R42BLD30L3 is a product of MOONS' industry.
MOONS' industry (https://www.moonsindustries.com/en)

2. System Overview

Overview of this system is explained below.

2.1 Hardware Configuration

The hardware configuration is shown below.

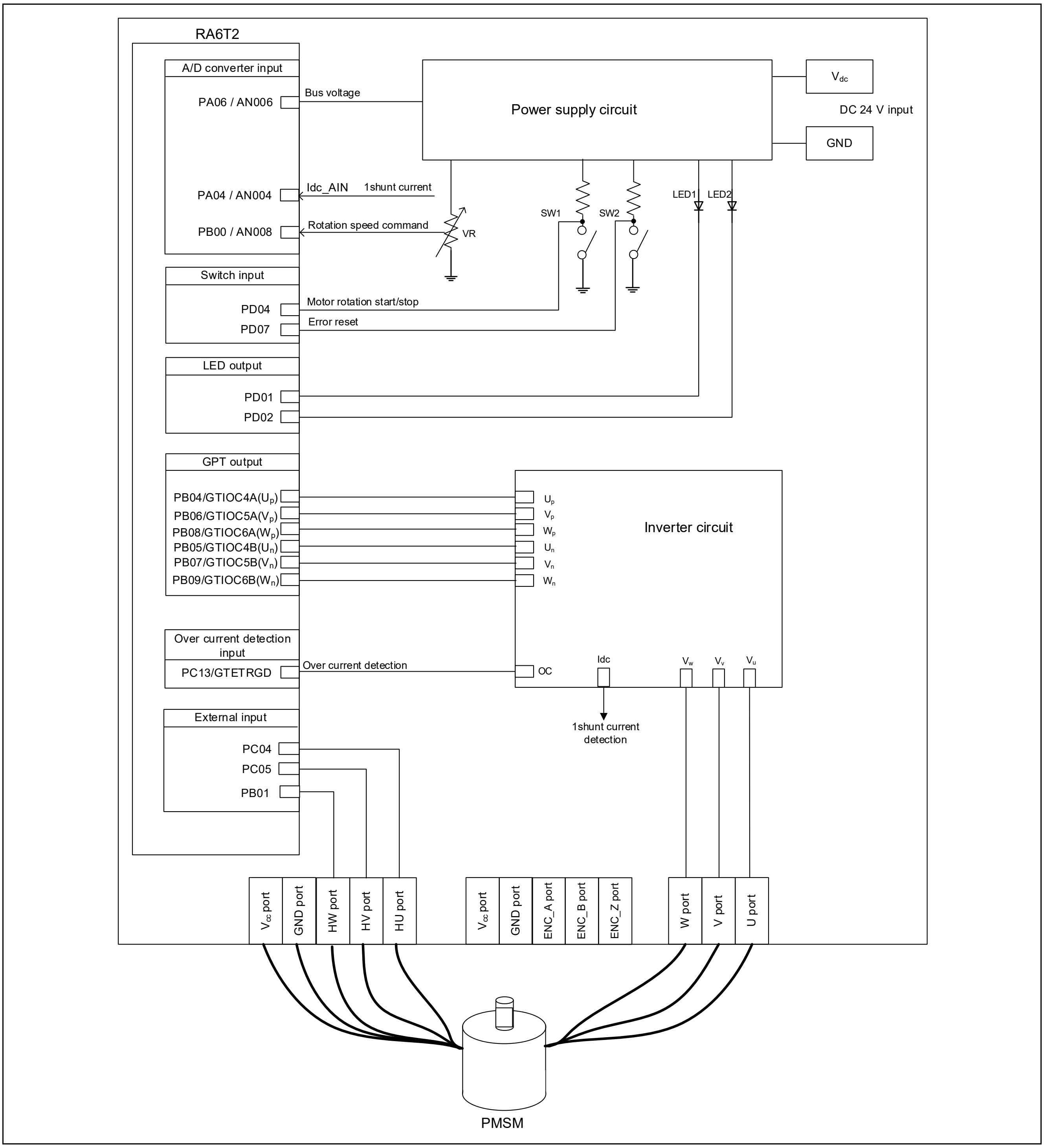
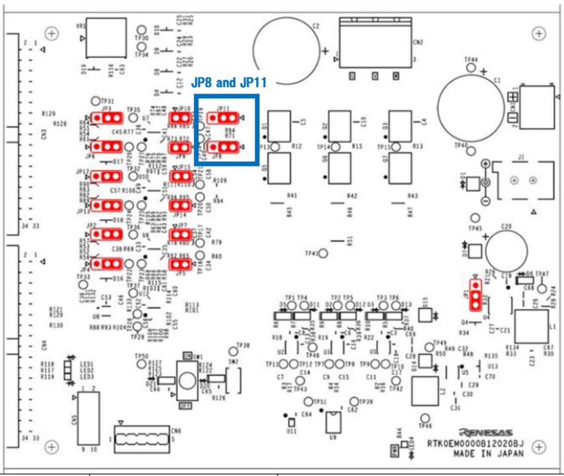


Figure 2-1 Hardware configuration diagram

2.2 Hardware Modification Details

Jumper pins need to be changed as below to use this system.

- Change connection of jumper pins
  (1) Change the connection of the jumper (JP8) to connect 2-3 pin from 1-2 pin.
  (2) Change the connection of the jumper (JP11) to connect 2-3 pin from 1-2 pin.



Jumper pin	Default setting	Function
JP8, JP11	1-2pin short	1-2pin short : 2-/3-shunt current detection 2-3pin short : 1-shunt current detection

Figure 2-2 Change the connection of jumper pins

2.3 Hardware Specifications

2.3.1 User interface

List of user interfaces of this system is given in Table 2-1.

Table 2-1 User interface on the inverter board

Item	Interface component	Function
Rotation speed command	Variable resistor (VR1)	Reference value of rotation speed input (analog value)
START/STOP	Toggle switch (SW1)	Motor rotation start/stop command
ERROR RESET	Push switch (SW2)	Command of recovery from error status
LED1	Orange LED	• At the time of motor rotation: ON • At the time of stop: OFF
LED2	Orange LED	• At the time of error detection: ON • At the time of normal operation: OFF

List of port interfaces of this system is given in Table 2-2.

Table 2-2 Port interfaces

R7FA6T2BD3CFP port name	Function
PA06 / AN006	Inverter bus voltage measurement
PB00 / AN008	For rotation speed command value input (analog value)
PD04	START/STOP toggle switch (SW1)
PD07	ERROR RESET push switch (SW2)
PD01	LED1 ON/OFF control
PD02	LED2 ON/OFF control
PA04 / AN004	Phase current measurement
PB04 / GTIOC4A	PWM output (Up)
PB06 / GTIOC5A	PWM output (Vp)
PB08 / GTIOC6A	PWM output (Wp)
PB05 / GTIOC4B	PWM output (Un)
PB07 / GTIOC5B	PWM output (Vn)
PB09 / GTIOC6B	PWM output (Wn)
PC04	U phase hall sensor input (HU)
PC05	V phase hall sensor input (HV)
PB01	W phase hall sensor input (HW)
PC13 / GTETRGD	PWM emergency stop input at the time of overcurrent detection

2.3.2 Peripheral functions

List of the peripheral functions used in this system is given in Table 2-3.

Table 2-3 List of the Peripheral Functions

Peripheral	Resource	Purpose
12-bit A/D Converter	AN004, AN006, AN008	• Rotational speed or position command input • Measure electric current with an 1shunt resistance • Measure inverter bus voltage
AGT	AGT0	500 [μs] interval timer
GPT	CH4, CH5, CH6	Complementary PWM outputs
POEG	Group D	Sets ports executing PWM output to high impedance state when an overcurrent is detected by external circuit.

(1) 12-bit A/D Converter (ADC12)
1shunt current, inverter bus voltage, and rotation speed command are measured in "Single scan mode" (use a hardware trigger). A/D conversion is implemented to be synchronized with carrier synchronized interrupt.

(2) Low Power Asynchronous General-Purpose Timer (AGT)
The AGT is used as 500 [μs] interval timer.

(3) General PWM Timer (GPT)
On the channel 4, 5 and 6, output with dead time is performed by using the complementary PWM Output Operating Mode.

(4) Port Output Enable for GPT (POEG)
The port executing PWM output are set to high impedance state when an overcurrent is detected (when a low level of the GTETRGB / GTETRGD pin is detected).

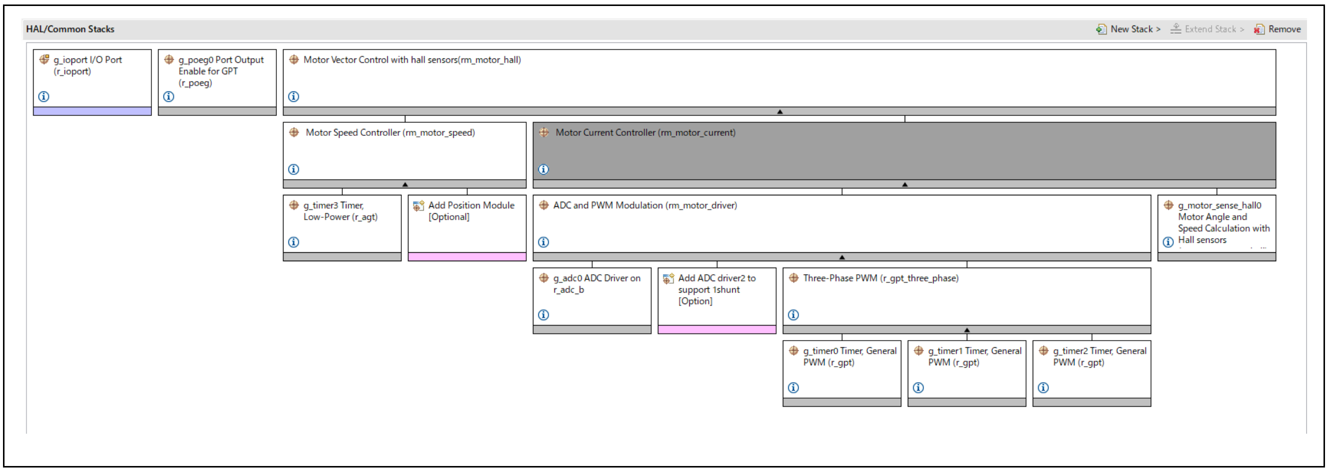
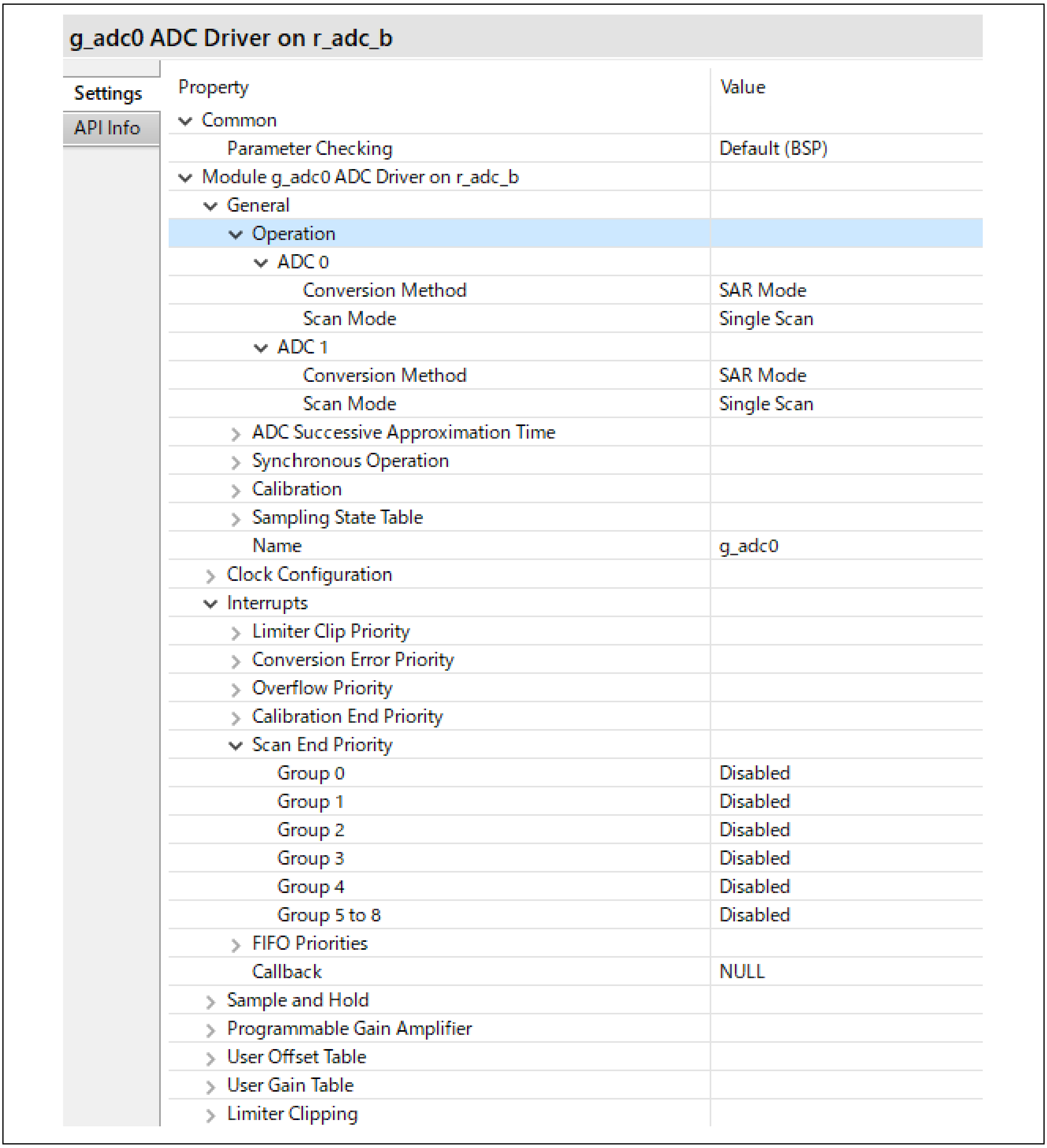


Figure 2-3 Overall FSP stacks diagram



g_adc0 ADC Driver on r_adc_b

Settings | API Info

Property	Value
Common	
Parameter Checking	Default (BSP)
Module g_adc0 ADC Driver on r_adc_b	
General	
Operation	
ADC 0	
Conversion Method	SAR Mode
Scan Mode	Single Scan
ADC 1	
Conversion Method	SAR Mode
Scan Mode	Single Scan
ADC Successive Approximation Time	
Synchronous Operation	
Calibration	
Sampling State Table	
Name	g_adc0
Clock Configuration	
Interrupts	
Limiter Clip Priority	
Conversion Error Priority	
Overflow Priority	
Calibration End Priority	
Scan End Priority	
Group 0	Disabled
Group 1	Disabled
Group 2	Disabled
Group 3	Disabled
Group 4	Disabled
Group 5 to 8	Disabled
FIFO Priorities	
Callback	NULL
Sample and Hold	
Programmable Gain Amplifier	
User Offset Table	
User Gain Table	
Limiter Clipping	

Figure 2-4 FSP Configuration of ADC driver [1/3]

g_adc0 ADC Driver on r_adc_b

Settings | API Info

Property	Value
Virtual Channel 0	
Scan Group	None
Channel Select	AN000
Sampling State Table ID	Sampling State Entry 0
Channel Gain Table	Disabled
Channel Offset Table	Disabled
Add/Average Mode	Disabled
Add/Average Count	1-time conversion (Normal Conversion)
Limit Clip Table Id	Disabled
Conversion Data Format Select	12-bit Data Format
Digital Filter Selection	Disabled
Virtual Channel 1	
Scan Group	None
Channel Select	AN002
Sampling State Table ID	Sampling State Entry 0
Channel Gain Table	Disabled
Channel Offset Table	Disabled
Add/Average Mode	Disabled
Add/Average Count	1-time conversion (Normal Conversion)
Limit Clip Table Id	Disabled
Conversion Data Format Select	12-bit Data Format
Digital Filter Selection	Disabled
Virtual Channel 2	
Scan Group	Scan Group 0
Channel Select	AN004
Sampling State Table ID	Sampling State Entry 0
Channel Gain Table	Disabled
Channel Offset Table	Disabled
Add/Average Mode	Disabled
Add/Average Count	1-time conversion (Normal Conversion)
Limit Clip Table Id	Disabled
Conversion Data Format Select	12-bit Data Format
Digital Filter Selection	Disabled
Virtual Channel 3	
Scan Group	Scan Group 1
Channel Select	AN006
Sampling State Table ID	Sampling State Entry 0
Channel Gain Table	Disabled
Channel Offset Table	Disabled
Add/Average Mode	Disabled
Add/Average Count	1-time conversion (Normal Conversion)
Limit Clip Table Id	Disabled
Conversion Data Format Select	12-bit Data Format
Digital Filter Selection	Disabled
Virtual Channel 4	
Scan Group	Scan Group 1
Channel Select	AN008
Sampling State Table ID	Sampling State Entry 0
Channel Gain Table	Disabled
Channel Offset Table	Disabled
Add/Average Mode	Disabled
Add/Average Count	1-time conversion (Normal Conversion)
Limit Clip Table Id	Disabled

Figure 2-5 FSP Configuration of ADC driver [2/3]

g_adc0 ADC Driver on r_adc_b

Settings | API Info

Property	Value
⌄ Scan Group 0	
› Self Diagnosis	
› External Trigger Enable	
› ELC Trigger Enable	
⌄ GPT Trigger Enable	
GPT Channel 0 Request A	☐
GPT Channel 1 Request A	☐
GPT Channel 2 Request A	☐
GPT Channel 3 Request A	☐
GPT Channel 4 Request A	☑
GPT Channel 5 Request A	☐
GPT Channel 6 Request A	☐
GPT Channel 7 Request A	☐
GPT Channel 8 Request A	☐
GPT Channel 9 Request A	☐
GPT Channel 0 Request B	☐
GPT Channel 1 Request B	☐
GPT Channel 2 Request B	☐
GPT Channel 3 Request B	☐
GPT Channel 4 Request B	☑
GPT Channel 5 Request B	☐
GPT Channel 6 Request B	☐
GPT Channel 7 Request B	☐
GPT Channel 8 Request B	☐
GPT Channel 9 Request B	☐
Enable	Enable
Converter Selection	ADC 0
Start Trigger Delay	0
Scan End Interrupt Enable	Disable
Limit Clip Interrupt Enable	Disable
FIFO Enable	Enable
FIFO Interrupt Enable	Disable
FIFO Interrupt Generation Level	0

g_adc0 ADC Driver on r_adc_b

Settings | API Info

Property	Value
⌄ Scan Group 1	
› Self Diagnosis	
› External Trigger Enable	
› ELC Trigger Enable	
⌄ GPT Trigger Enable	
GPT Channel 0 Request A	☐
GPT Channel 1 Request A	☐
GPT Channel 2 Request A	☐
GPT Channel 3 Request A	☐
GPT Channel 4 Request A	☐
GPT Channel 5 Request A	☑
GPT Channel 6 Request A	☐
GPT Channel 7 Request A	☐
GPT Channel 8 Request A	☐
GPT Channel 9 Request A	☐
GPT Channel 0 Request B	☐
GPT Channel 1 Request B	☐
GPT Channel 2 Request B	☐
GPT Channel 3 Request B	☐
GPT Channel 4 Request B	☐
GPT Channel 5 Request B	☐
GPT Channel 6 Request B	☐
GPT Channel 7 Request B	☐
GPT Channel 8 Request B	☐
GPT Channel 9 Request B	☐
Enable	Enable
Converter Selection	ADC 1
Start Trigger Delay	0
Scan End Interrupt Enable	Disable
Limit Clip Interrupt Enable	Disable
FIFO Enable	Disable
FIFO Interrupt Enable	Disable
FIFO Interrupt Generation Level	0

Figure 2-6 FSP Configuration of ADC driver [3/3]

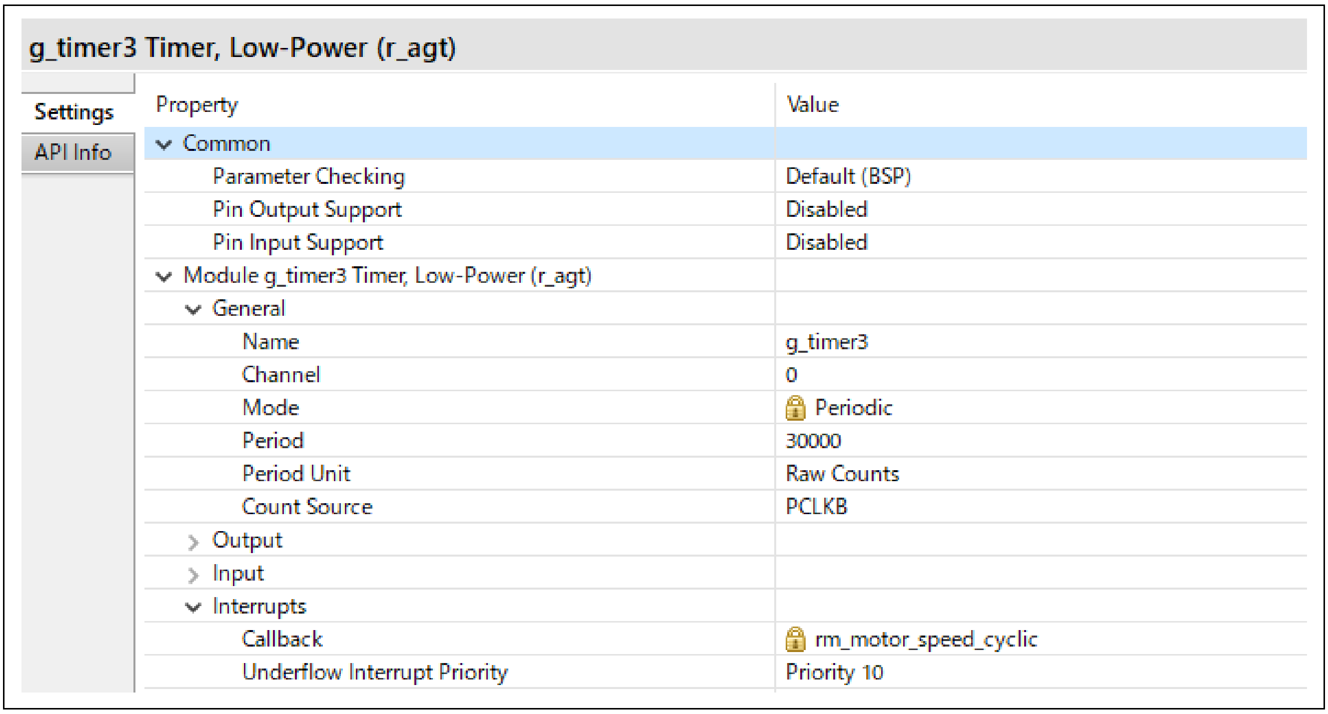


Figure 2-7 FSP Configuration of AGT driver

g_timer0 Timer, General PWM (r_gpt)

Settings
API Info

Property	Value
Common	
Parameter Checking	Default (BSP)
Pin Output Support	Enabled with Extra Features
Write Protect Enable	Disabled
Clock Source	PCLKD
Module g_timer0 Timer, General PWM (r_gpt)	
General	
Name	g_timer0
Channel	4
Mode	Triangle-Wave Asymmetric PWM (Mode 3)
Period	50
Period Unit	Microseconds
Output	
Custom Waveform	
Duty Cycle Percent (only applicable in PWM mode)	50
GTIOCA Output Enabled	True
GTIOCA Stop Level	Pin Level Low
GTIOCB Output Enabled	True
GTIOCB Stop Level	Pin Level High
Input	
Interrupts	
Extra Features	
Output Disable	
Output Disable POEG Trigger	
POEG Link	POEG Channel 3
GTIOCA Disable Setting	Set Hi Z
GTIOCB Disable Setting	Set Hi Z
ADC Trigger	
Start Event Trigger (Channels with GTINTAD only)	
Trigger Event A/D Converter Start Request A Durir	☑
Trigger Event A/D Converter Start Request A Durir	☐
Trigger Event A/D Converter Start Request B Durir	☑
Trigger Event A/D Converter Start Request B Durir	☐
Dead Time	
Dead Time Count Up (Raw Counts)	240
Dead Time Count Down (Raw Counts) (Channels witl	240
ADC Trigger (Channels with GTADTRA only)	
ADC A Compare Match (Raw Counts)	10
ADC Trigger (Channels with GTADTRB only)	
ADC B Compare Match (Raw Counts)	80
Interrupt Skipping (Channels with GTITC only)	
Extra Features	Enabled

Figure 2-8 FSP Configuration of GPT driver

g_poeg0 Port Output Enable for GPT (r_poeg)

Settings | API Info

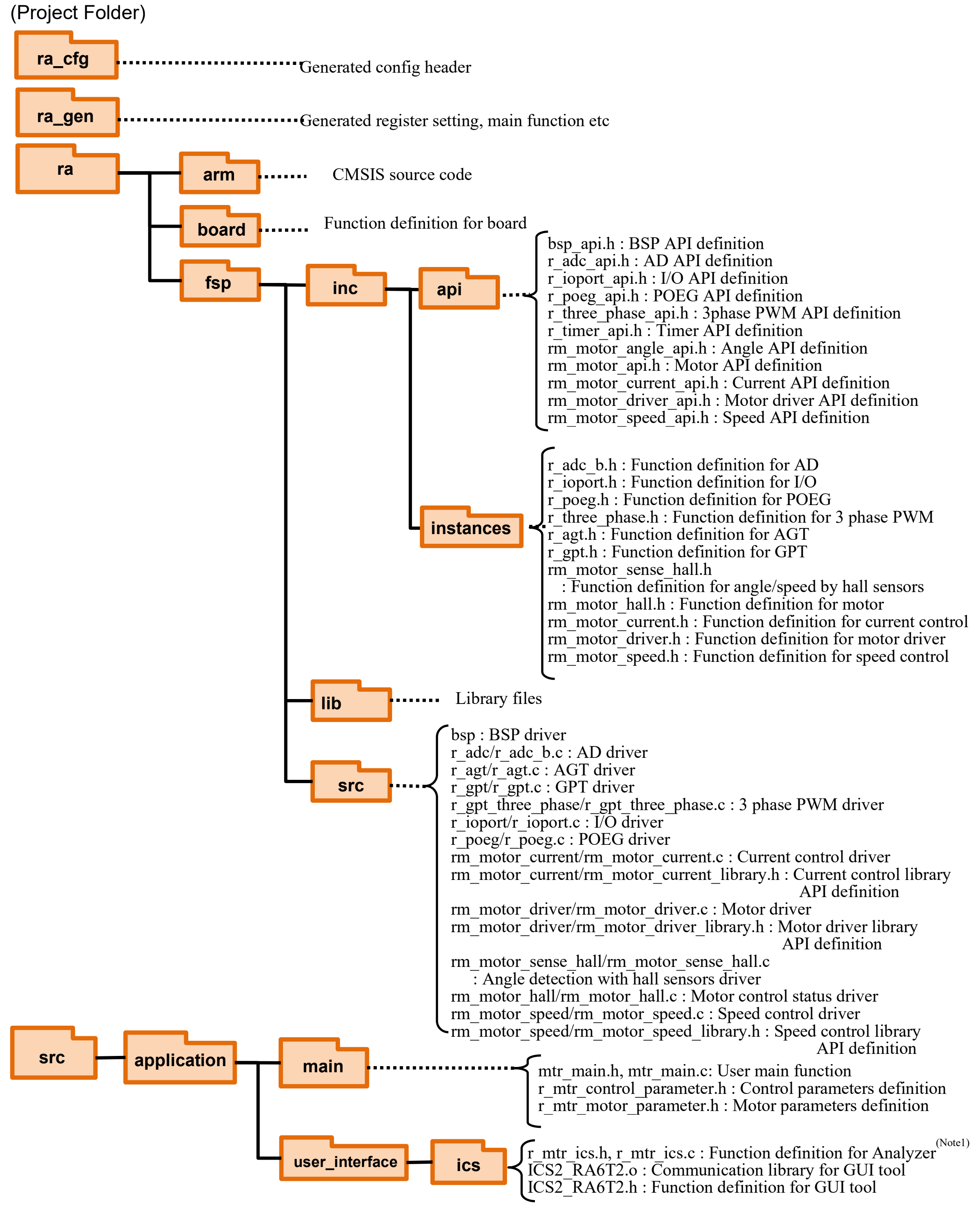
Property	Value
Common	
Parameter Checking	Default (BSP)
Module g_poeg0 Port Output Enable for GPT (r_poeg)	
General	
Trigger	
GTETRG Pin	☑
GPT Output Level	☐
Oscillation Stop	☐
ACMPHS0	☐
ACMPHS1	☐
ACMPHS2	☐
ACMPHS3	☐
Name	g_poeg0
Channel	3
Input	
GTETRG Polarity	Active Low
GTETRG Noise Filter	PCLKB/32
Interrupts	
Callback	g_poe_overcurrent
Interrupt Priority	Priority 0 (highest)

Figure 2-9 FSP Configuration of POEG driver

2.4 Software Configuration

2.4.1 Software file configuration

Folder and file configuration of the software is given below.



Note : Regarding the specification of Analyzer function in the motor control development support tool “Renesas Motor Workbench”, please refer to the chapter 4.4. The identifier “ics/ICS” (ICS is previous motor control development support tool “In Circuit Scope”) is attached to the name of folders, files, functions, variables related to “Renesas Motor Workbench”.

Figure 2-10 Folder and file configuration

2.4.2 Module configuration

Module configuration of the software is shown in Figure 2-11.

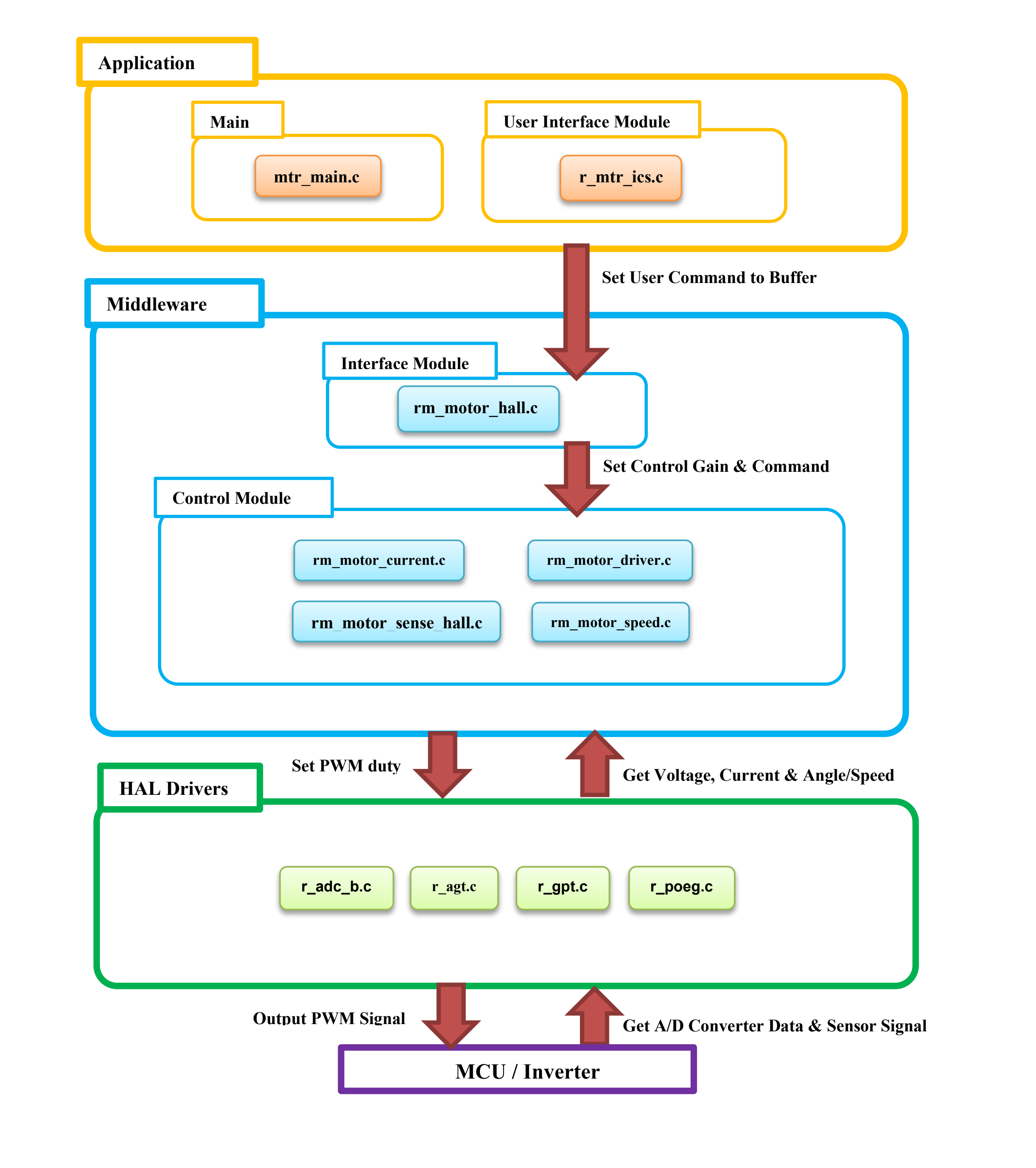


Figure 2-11 Module configuration

2.5 Software Specifications

Table 2-4 shows basic software specification of this system. For details of the vector control, refer to the application note ‘Sensorless vector control for permanent magnet synchronous motor (Algorithm)’ (R01AN3786).

Table 2-4 Basic Specifications of Vector Control with hall sensors Software

Item	Content	
Control method	Vector control	
Position detection method	Hall sensor	
Motor rotation start/stop	Determined depending on the level of SW1 or input from Renesas Motor Workbench	
Input voltage	DC 24 [V]	
Main clock frequency	240 [MHz]	
Carrier frequency (PWM)	20 [kHz] (Carrier period: 50 [μs])	
Dead time	2 [μs]	
Control period	Current control / Position and speed estimation: 50 [μs] (the carrier period) Speed control: 500 [μs]	
Rotation speed control range	CW: 0 [rpm] to 2400 [rpm] CCW: 0 [rpm] to 2400 [rpm]	
Natural frequency of each control system	Current control system : 300 [Hz] Speed control system : 5 [Hz] BEMF estimation system : 1000 [Hz] Position estimation system : 50 [Hz]	
Optimization setting of compiler	Optimization level	Optimize more(-O2) (default setting)
ROM/RAM size	ROM : 32.6KB RAM : 3.7KB	
Processing stop for protection	Disables the motor control signal output (six outputs), under any of the following conditions. 1. Instantaneous value of current of each phase exceeds 3.54(=1.67*sqrt(2)*1.5) [A] (monitored every 50 [μs]) 2. Inverter bus voltage exceeds 60 [V] (monitored every 50 [μs]) 3. Inverter bus voltage is less than 8 [V] (monitored every 50 [μs]) 4. Rotation speed exceeds 4500 [rpm] (monitored every 50 [μs]) When an external over current signal is detected (when a low level of the GTETRGD port is detected), the PWM output ports are set to high impedance state.	

2.6 Interrupt Priority

Table 2-5 shows the interrupt and priorities used in this system.

Table 2-5 Interrupt priority

Interrupt level	Priority	Function
15	Min	
14		
13		
12		
11		
10		AGT0 INT 500 [us] interrupt handling
9		
8		
7		
6		
5		ADC0 ADI0 A/D conversion complete interrupt
4		
3		
2		
1		
0	Max	POEG3 EVENT Over current error interrupt

Allocations

Interrupt	Event	ISR
0	POEG3 EVENT (Port Output disable interrupt D)	poeg_event_isr
1	AGT0 INT (AGT interrupt)	agt_int_isr
2	GPT4 COUNTER OVERFLOW (Overflow)	gpt_counter_overflow_isr

Figure 2-12 FSP interrupts configuration

3. Descriptions of Control Program

The target software of this application note is 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 Renesas Motor Workbench or SW1.

SW1 is assigned to a general-purpose port. 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 software determines that the motor should be stopped.

3.1.2 A/D converter

(1) Motor rotation speed reference

The motor rotation speed reference can be set by Renesas Motor Workbench input or A/D conversion of the VR1 output value (analog value). The A/D converted VR value is used as rotation speed command value, as shown below.

Table 3-1 Conversion ratio of the rotation speed reference

Item	Conversion ratio (reference : A/D conversion value)		Channel
Rotation speed reference	CW	0 [rpm] to 2400[rpm] : 0800H to 0FFFH	AN008
	CCW	0 [rpm] to 2400[rpm] : 07FFH to 0000H	

(2) Inverter bus voltage

It is used for modulation factor calculation and over-voltage/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 73.26 [V] : 0000H to 0FFFH	AN006

(3) 1shunt current

1shunt current is measured as shown in Table 3-3 and used for vector control.

Table 3-3 Conversion ratio of 1shunt current

Item	Conversion ratio (1shunt current : A/D conversion value)	Channel
1shunt current	-8.25 [A] to 8.25 [A] : 0000H to 0FFFH (*Note) Current＝(3.3V－1.65V)÷(0.01Ohm×20)＝8.25A	AN004

Note: For more details of A/D conversion characteristics, refer to "RA6T2 Group User's Manual: Hardware".

3.1.3 Modulation

The target software of this application note uses pulse width modulation (hereinafter called PWM) to generate the input voltage to the motor. And the PWM waveform is generated by the triangular wave comparison method.

- Triangular wave comparison method
  The triangular wave comparison method is used to output the voltage command value. By this method, the pulse width of the output voltage can be determined by comparing the carrier waveform (triangular wave) and voltage command value waveform. The voltage command value of the pseudo sinusoidal wave can be output by turning the switch on or off when the voltage command value is larger or smaller than the carrier wave respectively.

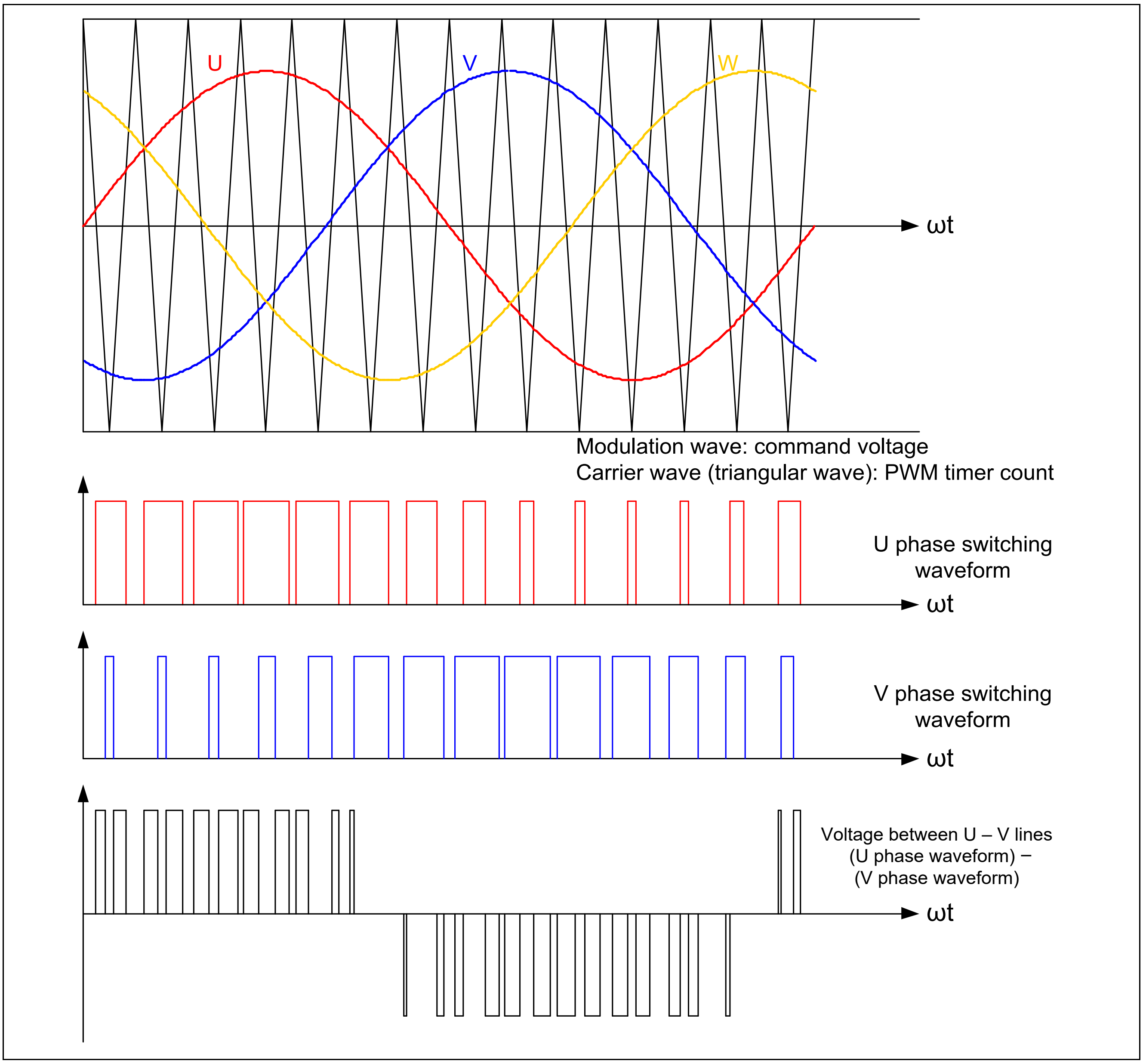


Figure 3-1 Conceptual diagram of triangular wave comparison method

As shown in the Figure 3-2 Definition of duty, ratio of the output voltage pulse to the carrier wave is called duty.

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

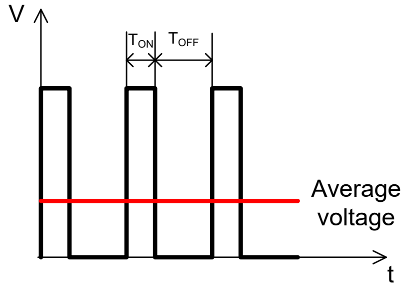


Figure 3-2 Definition of duty

Modulation factor “m” is defined as follows.

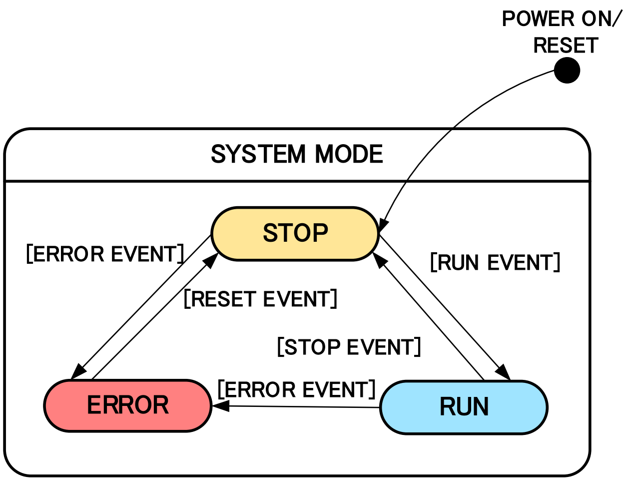
$$m = \frac{V}{E}$$

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

A requested control can be performed by setting this modulation factor to the register which determines PWM duty.

3.1.4 State transition

Figure 3-3 is a state transition diagram of the vector control with hall sensors software. In the target software of this application note, the software state is managed by “SYSTEM MODE”.



		MODE		
		STOP	RUN	ERROR
EVENT	STOP	STOP	STOP	ERROR
	RUN	RUN	RUN	ERROR
	ERROR	ERROR	ERROR	ERROR
	RESET	STOP	RUN	STOP

Figure 3-3 State Transition diagram of vector control with hall sensors 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) EVENT
When “EVENT” occurs in each “SYSTEM MODE”, “SYSTEM MODE” changes as shown the table in Figure 3-3, according to that “EVENT”. The occurrence factors of each event are shown below.

Table 3-4 List of EVENT

EVENT name	Occurrence factor
STOP	by user operation
RUN	by user operation
ERROR	when the system detects an error
RESET	by user operation

3.1.5 Estimation of rotor angle and rotational speed

3.1.5.1 Estimation of rotational speed

The rotational speed is estimated by below algorithm.

At every carrier interrupt (50μsec), hall sensors input signal are read. and the change in hall signal pattern is detected. Time for rotation by 60-degree electrical angle (period between each hall signal pattern change) is measured by counting the number of carrier interrupt.

Period of 60 degree (electrical) = Number of carrier interrupt * Period of carrier interrupt [50μsec]

From this equation, rotational speed (electrical) can be calculated.

Rotational speed (electrical) [rad/sec] = (2π * 60/360) / Period of 60-degree (electrical) [μsec]

However, if only one period of hall sensor signal change is used, there is a possibility of an error due to the tolerance of hall signal. Therefore, in this implementation, summation of last 6 periods of hall sensor signal changes is used to estimate the rotational speed.

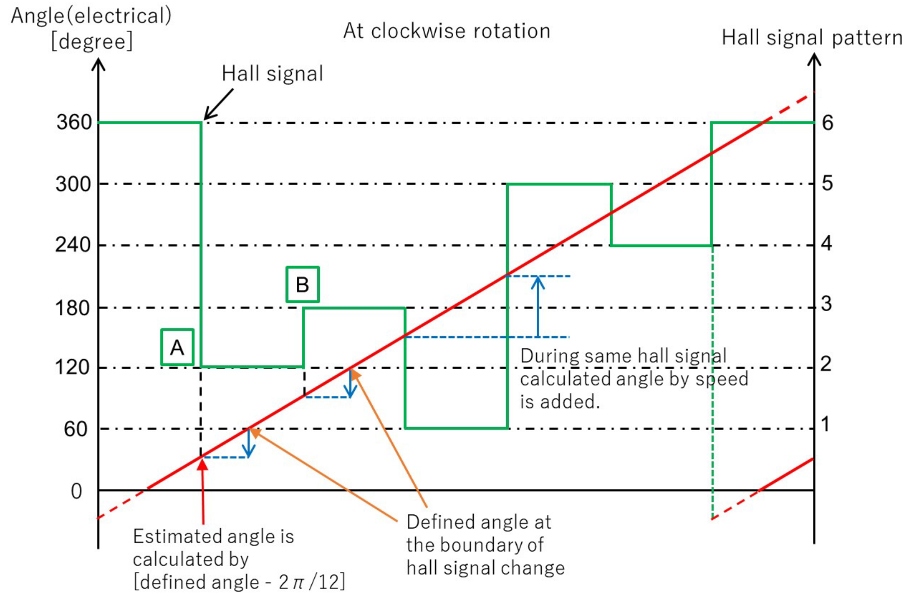
Rotational speed (electrical) [rad/sec] = 2π / Period of 360-degree (6 * 60-degree) (electrical) [μsec]

3.1.5.2 Estimation of rotor angle

The rotor angle is estimated by below information.

(A) The direction of rotation
(B) The estimated rotational speed

The direction of rotation is detected by the hall sensor signal pattern. The hall sensor signal pattern is unique in each rotation direction, therefore, the direction of rotation can be detected by comparison between current and last hall signal pattern.



	CW	CCW
Hall signal pattern	6 -> 2 -> 3 -> 1 -> 5 -> 4	6 -> 4 -> 5 -> 1 -> 3 -> 2

Figure 3-4 Estimation of rotor angle (at clockwise rotation)

At the point A in Figure 3-4, the hall signal changes 6 to 2. Therefore, the direction of rotation can be detected as clockwise. At this point A, the rotor angle is set as below.

Rotor angle [rad] = 2π * (60*1)/360 + internal angle [rad] + offset [rad]

Internal angle means fixed angle at the boundary of hall signal change. It is defined as “-2π/12” at clockwise rotation, as “2π/12” at counterclockwise rotation. At each carrier interrupt, the difference of angle calculated with the rotational speed is added at clockwise, decreased at counterclockwise.
The difference is limited -2π/12 to 2π/12 with consideration about an error and speed change.

- At clockwise rotation
  Internal angle in same hall signal [rad]
  = Defined value (-2π/12) + estimated speed [rad/sec] * carrier interrupt period(50μsec) * Number of carrier interrupt

- At counterclockwise rotation
  Internal angle in same hall signal [rad]
  = Defined value (2π/12) – estimated speed [rad/sec] * carrier interrupt period(50μsec) * Number of carrier interrupt

At each case, calculated angle is limited from -2π/12 to 2π/12.

At the point B in Figure 3-4, the rotor angle is set as below.

Rotor angle [rad] = 2π * (60*2)/360 + internal angle [rad] + offset [rad]

At the boundary of hall signal change, the rotor angle is estimated with 60-degree definition angle. (At next boundary, 120 is changed to 180.)

Offset value is set by user with an evaluation of each motor characteristics. (mainly the tolerance of hall signal sensor.)

3.1.6 Start-up method

Figure 3-5 shows startup control of vector control software. Each mode is controlled by flags managing each reference of the d-axis current, q-axis current, and speed.

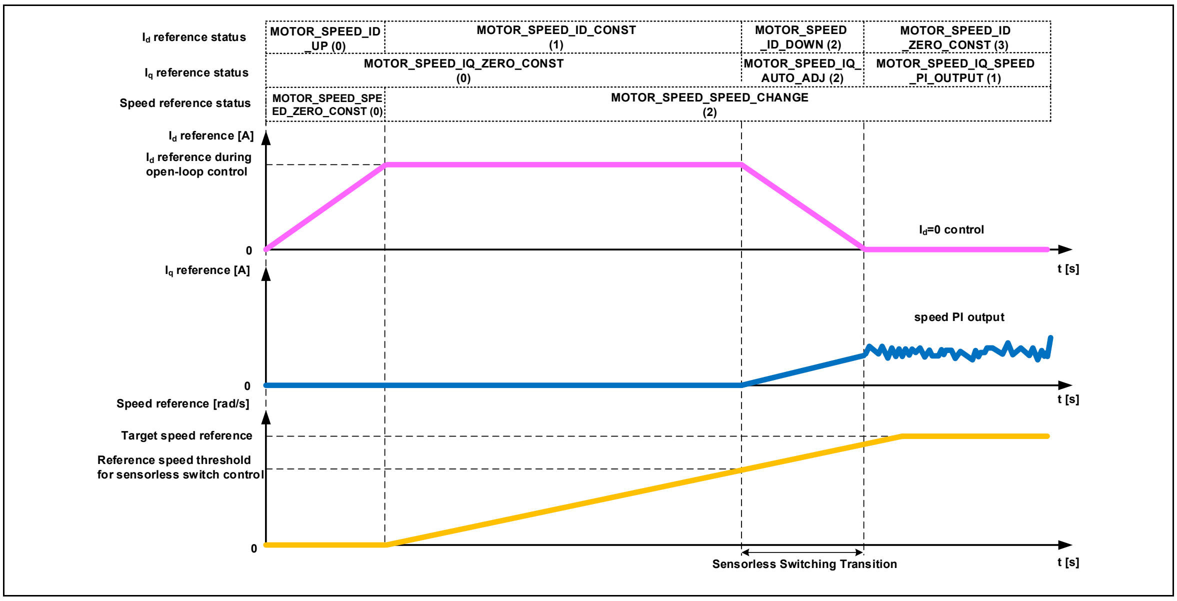


Figure 3-5 Startup control of vector control software

3.1.7 System protection function

This control software has the following error status and executes emergency stop functions in case of occurrence of respective errors. Table 3-5 shows each software threshold for the system protection function.

- Over current error
  The PWM output ports are set to high impedance state in response to an emergency stop signal (over current detection) from the hardware.
  In addition, U, V, and W phase currents are monitored in over current monitoring cycle. When an over current (when the current exceeds the over current limit) is detected, the CPU executes emergency stop (software detection).

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

- Low voltage error
  The inverter bus voltage is monitored in low-voltage monitoring cycle. The CPU performs emergency stop when low voltage (when voltage falls below the limit) is detected. Here, the low voltage limit is set in consideration of the error of resistance value of the detect circuit.

- Over speed error
  The rotation speed is monitored in rotation speed monitoring cycle. The CPU performs emergency stop when the speed is over the limit.

Table 3-5 Setting values of the system protection function

Error name	Threshold	
Over current error	Over current limit [A]	3.54
	Monitoring cycle [µs]	50
Over voltage error	Over voltage limit [V]	60
	Monitoring cycle [µs]	50
Low voltage error	Low voltage limit [V]	8
	Monitoring cycle [µs]	50
Over speed error	Speed limit [rpm]	4500
	Monitoring cycle [µs]	50

3.1.8 Method to measure currents with 1shunt resistance

This section describes the method to measure currents with a single shunt resistance, which is used in the sample program.

3.1.8.1 Timing of measuring currents with 1shunt resistance

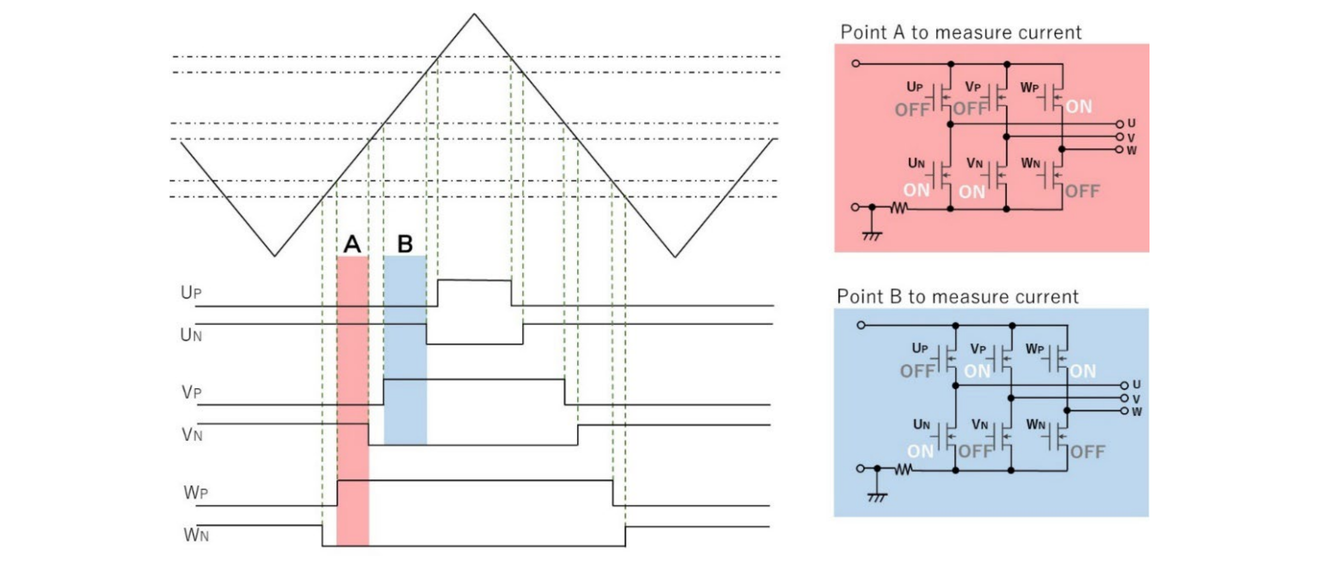


Figure 3-6 Waveform of complementary PWM (in case of duty pattern W>V>U)

In this program, a GPT unit is used to control with 3-phase PWM output with dead time in the complementary PWM mode. Figure 3-6 shows the complementary PWM waveforms in case of duty pattern W>V>U.

At the point A in the figure, only W phase upper arm is ON as shown in the red rectangle in right side. In this case, the current which flows through the 1shunt resistance (Idc) is same as the current flows in W phase (Iw).

At the point B in the figure, only U phase low arm is ON as shown in the blue rectangle. In this case, the current which flows through the 1shunt resistance (Idc) is same as the current flows in U phase (Iu).

The remained V phase current can be calculated as Iv=-Iu-Iw by the first theory of Kirchhoff using these phase currents.

Therefore, the three phase currents can be measured with the value of the current flowing through 1shunt resistance at the point A and B in the figure.

The example shown in Figure 3-6 is the case where the duty pattern W>V>U. There are six duty patterns depending on change in PWM output. The currents which are measured at the point A and B vary in relation to the phases according to the duty pattern, so it is necessary to assign calculated currents to each phase. Since the duty patterns are already known at the duty settings, it is possible to switch the assignment of the calculated currents to each phase.

Table 3-6 Relation between duty pattern and phase current

Duty pattern	Point A	Point B
W > V > U	Iw	-Iu
W > U > V	Iw	-Iv
V > W > U	Iv	-Iu
V > U > W	Iv	-Iw
U > W > V	Iu	-Iv
U > V > W	Iu	-Iw

3.1.8.2 1shunt resistance current measurement method using RA6T2 function

When measuring the current with one shunt resistor as shown in 3.1.8.1, it is necessary to control the conversion timing of the A/D converter according to the PWM duty setting. In the sample software, this is controlled by A/D conversion start request function with compare match of registers GTADTRA/GTADTRB of the RA6T2 GPT module and the GTCNT counter.

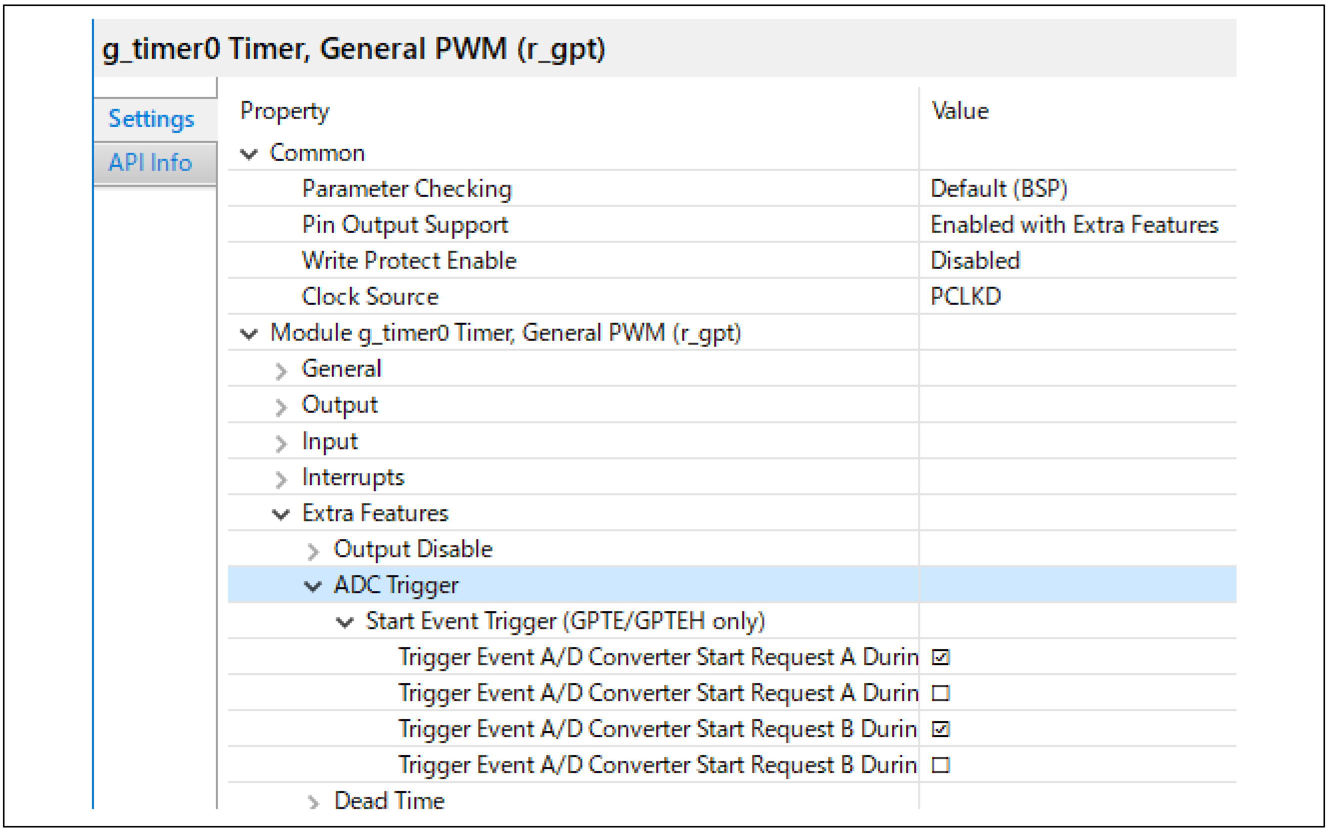


Figure 3-7 GPT ADC trigger setting

3.1.8.3 Duty adjustment

If the timing as shown in 3.1.8.1 can be secured, the current can be detected by one shunt resistor, but sufficient time for A/D conversion cannot be secured depending on some PWM duty setting conditions during operation. Therefore, the current value cannot be obtained correctly in such a case. The following two measures are implemented for the conditions where timing cannot be secured.

(1) When the switching timings of the two phases are close to each other
When the switching timings of the two phases are close to each other and the time for A/D conversion cannot be secured, the PWM duty is not changed, and the phase switching timing to be switched later is shifted backward by the time required for A/D conversion in order to secure it.

(2) When timing shift is not possible
When the PWM switching timing is shifted as described above, if the duty is wide and reaches the end of carrier cycle, the timing cannot be shifted. In such a case, the modulation factor is close to 1, so the modulation factor is limited so that the PWM switching timing is at the end of the carrier cycle.

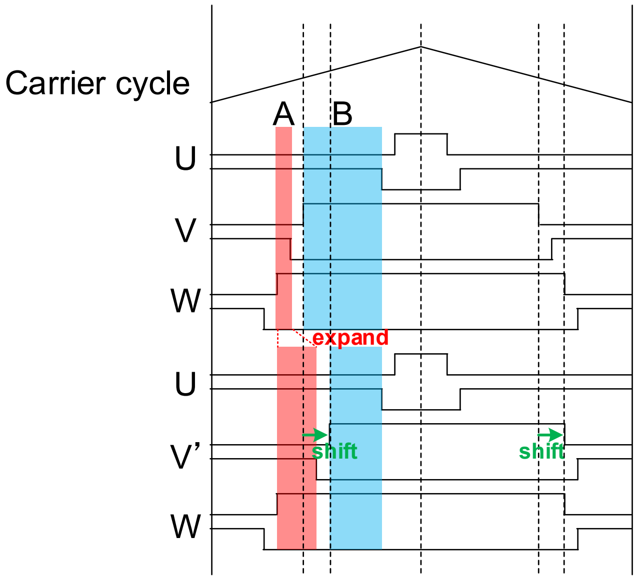


Figure 3-8 Duty adjustment

3.1.9 AD triggers

Figure 3-9 shows the timing of AD triggers and scan groups.

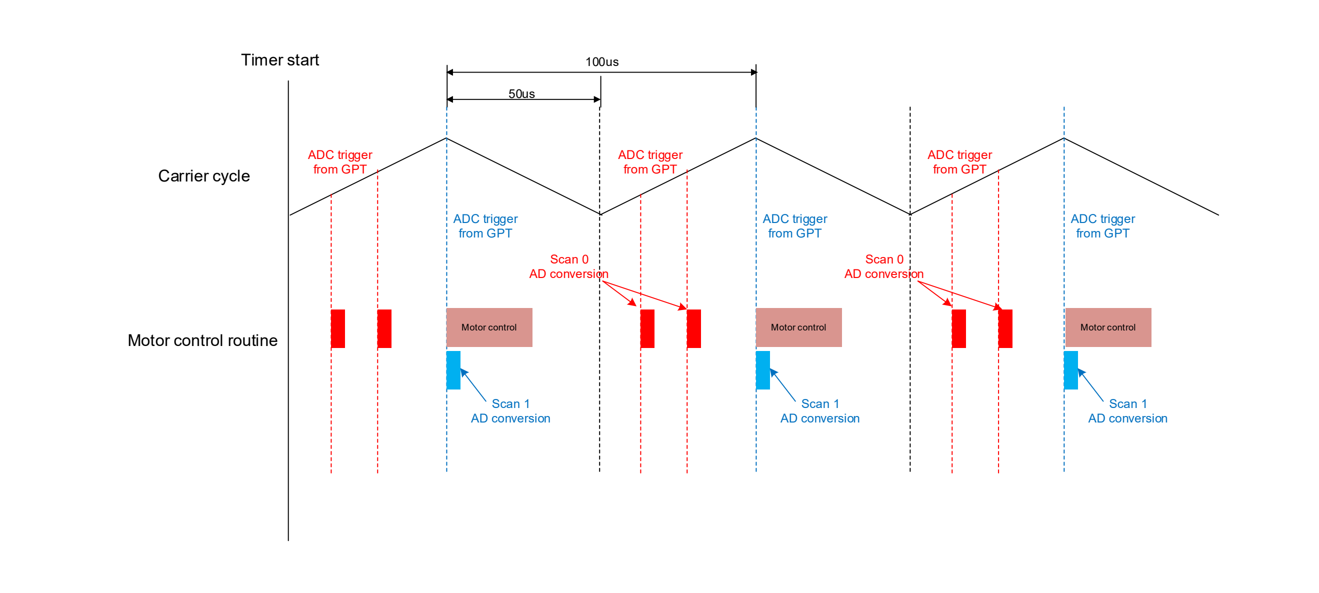


Figure 3-9 AD trigger timing

3.2 Function Specifications of Vector Control with Hall Sensor Software

The control process of the target software of this application note is mainly consisted of 50[μs] period interrupt (carrier interrupt) and 500[μs] period interrupt. As following Figure 3-10, the control process in the red broken line part is executed every 50[μs] cycle, and the control process in the blue broken line part is executed every 500[μs] cycle.

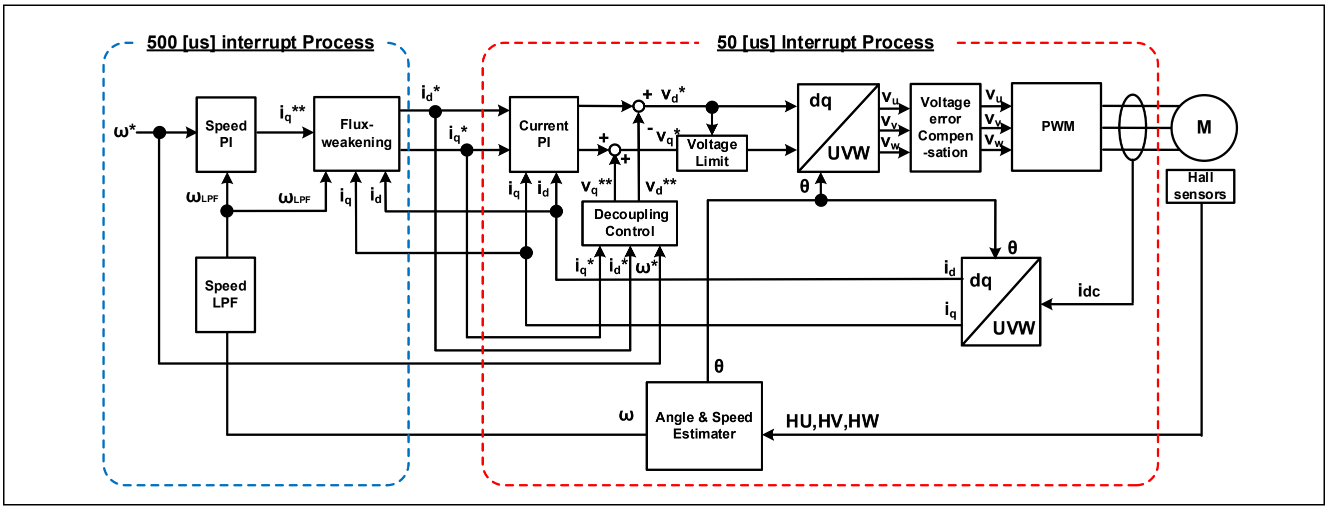


Figure 3-10 Block diagram of vector control with hall sensors

This chapter shows the specification of 2 interrupt functions and functions executed in each interrupt cycle. In following tables, only primary functions of the vector control with hall sensors are listed. Regarding the specification of functions not listed in the following tables, refer to source codes.

Table 3-7 List of functions executed in 50 [μs] period interrupt (1/4)

File name	Function name	Process overview
mtr_main.c	mtr_callback_event Input : (motor_hall_callback_args_t *) p_args / Callback argument Output : None	Vector control with hall sensors callback function
rm_motor_hall.c	rm_motor_hall_current_callback Input : (motor_current_callback_args_t *) p_args / Callback argument Output : None	Set the speed control output to the current control input
	RM_MOTOR_HALL_ErrorCheck Input : (motor_ctrl_t * const) p_ctrl / Pointer to control structure (uint16_t * const) p_error / Pointer to get occurred error Output : fsp_err_t / Execution result	Check the occurrence of error
	rm_motor_hall_copy_speed_current Input : (motor_speed_output_t *) st_output / Speed control output (motor_current_input_t *) st_input / Current control input Output : None	Copy speed output data to current input data
rm_motor_driver.c	rm_motor_driver_cyclic Input : : (adc_callback_args_t *) p_args / Callback argument Output : None	Motor driver callback function
	rm_motor_driver_current_get Input : (motor_driver_instance_ctrl_t *) p_ctrl / Motor driver module instance Output : None	Get A/D converted data (phase current & main line voltage)
	RM_MOTOR_DRIVER_FlagCurrentOffsetGet Input : (motor_driver_ctrl_t * const) p_ctrl / Pointer to control structure (uint8_t * const) p_flag_offset / Flag of finish current offset detection Output : fsp_err_t / Execution result	Measure current offset values
	RM_MOTOR_DRIVER_PhaseVoltageSet Input : (motor_driver_ctrl_t * const) p_ctrl / Pointer to control structure (float const) u_voltage / U phase voltage (float const) v_voltage / V phase voltage (float const) w_voltage / W phase voltage Output : fsp_err_t / Execution result	Set phase voltage data to calculate PWM duty
	rm_motor_driver_modulation Input : (motor_driver_instance_ctrl_t *) p_ctrl / Pointer to motor driver instance Output : None	Perform PWM modulation

Table 3-8 List of functions executed in 50 [μs] period interrupt (2/4)

File name	Function name	Process overview
rm_motor_driver.c	rm_motor_driver_mod_run Input : (motor_driver_instance_ctrl_t *) p_ctrl / Pointer to motor driver instance (const float *) p_f4_v_in / Pointer to 3-phase input voltage (float *) p_f4_duty_out / Where to store the 3-phase output duty cycle Output : None	Calculates duty cycle from input 3-phase voltage (bipolar)
	rm_motor_driver_set_uvw_duty Input : (motor_driver_instance_ctrl_t *) p_ctrl / Pointer to motor driver instance (float) f_duty_u / The duty cycle of phase-U (float) f_duty_v / The duty cycle of phase-V (float) f_duty_w / The duty cycle of phase-W Output : None	PWM duty setting
	RM_MOTOR_DRIVER_CurrentGet Input : (motor_driver_ctrl_t * const) p_ctrl / Pointer to control strucrure (motor_driver_current_get_t * const) p_current_get / Pointer to get data structure Output : fsp_err_t / Execution result	Get calculated phase current, Vdc, and Va_max data
rm_motor_current.c	rm_motor_current_cyclic Input : (motor_driver_callback_args_t *) p_args / Callback argument Output : None	Current control cycle operation
	RM_MOTOR_CURRENT_ParameterSet Input : (motor_current_ctrl_t * const) p_ctrl / Pointer to control structure (motor_current_input_current_t const * const) p_st_input / Pointer to input current structure Output : fsp_err_t / Execution result	Set (input) parameter data
	RM_MOTOR_CURRENT_CurrentSet Input : (motor_current_ctrl_t * const) p_ctrl / Pointer to control structure (motor_current_input_current_t const * const) p_st_current / Pointer to input current structure (motor_current_input_voltage_t const * const) p_st_voltage / Pointer to input voltage structure Output : fsp_err_t / Execution result	Set d/q-axis current & voltage data
	RM_MOTOR_CURRENT_CurrentGet Input : (motor_current_ctrl_t * const) p_ctrl / Pointer to control structure (float * const) p_id / Pointer to get d-axis current (float * const) p_iq / Pointer to get q-axis current Output : fsp_err_t / Execution result	Get d/q-axis current
	motor_current_transform_uvw_dq_abs Input : (const float) f_angle / rotor angle (const float *) f_uvw / Pointer to the UVW-phase array in [U,V,W] format (float *) f_dq / where to store the [d,q] formatted array on dq coordinates Output : None	Coordinate transform UVW to dq (absolute transform)

Table 3-9 List of functions executed in 50 [μs] period interrupt (3/4)

File name	Function name	Process overview
rm_motor_current.c	motor_current_angle_cyclic Input : (motor_current_instance_t *) p_instance / Pointer to current control module control instance Output : None	Angle/Speed process in cyclic process of current control
	RM_MOTOR_CURRENT_SpeedPhaseSet Input : (motor_current_ctrl_t * const) p_ctrl / Pointer to control structure (float const) speed / Rotational speed (float const) phase / Rotor phase Output : fsp_err_t / Execution result	Set current speed and rotor phase data
	RM_MOTOR_CURRENT_CurrentReferenceSet Input : (motor_current_ctrl_t * const) p_ctrl / Pointer to control structure (float const) id_reference / id (float const) iq_reference / iq Output : fsp_err_t / Execution result	Set current reference data
	RM_MOTOR_CURRENT_PhaseVoltageGet Input : (motor_current_ctrl_t * const) p_ctrl / Pointer to control structure (motor_current_get_voltage_t * const) p_voltage / Pointer to get voltages Output : fsp_err_t / Execution result	Get the set phase voltage
	motor_current_pi_calculation Input : (motor_current_instance_ctrl_t *) p_ctrl / Pointer to the FOC current control structure Output : None	Calculates the output voltage vector from current vector command and actual current vector
	motor_current_pi_control Input : (motor_current_pi_params_t *) pi_ctrl / Pointer to the PI control structure Output : float / PI control output value	PI control
	motor_current_limit_abs Input : (float) f4_value / Target value (float) f4_limit_value / Limit Output : float / Limited value	Limit with absolute value
	motor_current_decoupling Input : (motor_current_instance_ctrl_t *) p_ctrl / Pointer to the FOC current control instance (float) f_speed_rad / Rotation speed (const motor_current_motor_parameter_t *) p_mtr / Pointer to the motor parameter data structure Output : None	Decoupling control
	motor_current_voltage_limit Input : (motor_current_instance_ctrl_t *) p_ctrl / Pointer to the FOC current control structure Output : None	Limit voltage vector

Table 3-10 List of functions executed in 50 [μs] period interrupt (4/4)

File name	Function name	Process overview
rm_motor_current.c	motor_current_transform_dq_uvw_abs Input : (const float) f_angle / Rotor angle (const float *) f_dq / Pointer to the dq-axis value array in [D,Q] format (float *) f_uvw / Where to store the [U,V,W] formatted 3-phase quantities array Output : None	Coordinate transform dq to UVW 3-phase (absolute transform)
librm_motor_current.a	rm_motor_voltage_error_compensation_main Input : (motor_currnt_voltage_compensation_t *) st_volt_comp / Voltage error compensation data (float *) p_f4_v_array / Reference voltage (float *) p_f4_i_array / Reference current (float) f4_vdc / Bus voltage Output : None	Voltage error compensation
rm_motor_sense_hall.c	RM_MOTOR_SENSE_HALL_FlagPiCtrlSet Input : (motor_angle_ctrl_t * const) p_ctrl / Pointer to control structure (uint32_t const) flag_pi / Flag of PI control runs Output : fsp_err_t / Execution result	Set the flag of PI Control runs
	RM_MOTOR_SENSE_HALL_AngleSpeedGet Input : (motor_angle_ctrl_t * const) p_ctrl / Pointer to control structure (float * const) p_angle / Memory address to get rotor angle data (float * const) p_speed / Memory address to get rotational speed data (float * const) p_phase_err / Memory address to get phase (angle) error data Output : fsp_err_t / Execution result	Gets the current rotor's angle and rotation speed. (phase error data is invalid.)
r_gpt_three_phase.c	R_GPT_THREE_PHASE_DutyCycleSet Input : (three_phase_ctrl_t * const) p_ctrl / Control block set in @ref three_phase_api_t::open call for this timer (three_phase_duty_cycle_t * const) p_duty_cycle / Duty cycle values for all three timer channels Output : fsp_err_t / Execution result	Sets duty cycle for all three timers.

Table 3-11 List of functions executed in 500[μs] period interrupt (1/2)

File name	Function name	Process overview
mtr_main.c	mtr_callback_event Input : (motor_hall_callback_args_t *) p_args / Callback argument Output : None	Vector control with hall sensors callback function
	get_vr1 Input : None Output : uint16_t / Conversion value	Get VR1 A/D conversion value
rm_motor_current.c	RM_MOTOR_CURRENT_ParameterGet Input : (motor_current_ctrl_t * const) p_ctrl / Pointer to control structure (motor_current_output_t const * const) p_st_output / Pointer to output current data structure Output : fsp_err_t / Execution result	Get speed control input data from current control
rm_motor_hall.c	rm_motor_hall_speed_callback Input : (motor_speed_callback_args_t *) p_args / Callback argument Output : None	Speed control callback function
	rm_motor_hall_copy_current_speed Input : (motor_current_output_t *) st_output / Pointer to structure of current control output (motor_speed_input_t *) st_input / Pointer to structure of speed control input Output : None	Copy current output data to speed input data
rm_motor_speed.c	rm_motor_speed_cyclic Input : (timer_callback_args_t *) p_args / Callback argument Output : None	Cyclic process of speed control (Call at timer interrupt)
	RM_MOTOR_SPEED_ParameterSet Input : (motor_speed_ctrl_t * const) p_ctrl / Pointer to control structure (motor_speed_input_t const * const) p_st_input / Pointer to structure of input parameters Output : fsp_err_t / Execution result	Set speed Input parameters
	RM_MOTOR_SPEED_SpeedControl Input : (motor_speed_ctrl_t * const) p_ctrl / Pointer to control structure Output : fsp_err_t / Execution result	Calculates the d/q-axis current reference. (Main process of speed control)
	rm_motor_speed_set_speed_ref Input : (motor_speed_instance_ctrl_t *) p_ctrl / Pointer to the FOC data instance Output : float / Speed reference	Updates the speed reference
	rm_motor_speed_set_iq_ref Input : (motor_speed_instance_ctrl_t *) p_ctrl / Pointer to the control instance Output : float / Iq reference	Updates the q-axis current reference
	rm_motor_speed_set_id_ref Input : (motor_speed_instance_ctrl_t *) p_ctrl / The pointer to the control instance Output : float / Id reference	Updates the d-axis current reference
	RM_MOTOR_SPEED_ParameterGet Input : (motor_speed_ctrl_t * const) p_ctrl / Pointer to control instance (motor_speed_output_t * const) p_st_output / Pointer to get speed control parameters Output : fsp_err_t / Execution result	Get speed control output parameters

Table 3-12 List of functions executed in 500[μs] period interrupt (2/2)

File name	Function name	Process overview
librm_motor_speed.a	rm_motor_speed_first_order_lpf Input : (motor_speed_lpf_t *) p_lpf / First order LPF structure (float) f_input / Input data Output : float / Filtered data	First Order LPF
	rm_motor_speed_fluxwkn_set_vamax Input : (motor_speed_flux_weakening_t *) p_fluxwkn / Pointer to flux weakening structure (float) f4_va_max / maximum magnitude of voltage vector Output : None	Sets the maximum magnitude of voltage vector
	rm_motor_speed_fluxwkn_run Input : (motor_speed_flux_weakening_t *) p_fluxwkn / Pointer to flux weakening structure (float) f4_speed_rad / Electrical speed of motor (const float *) p_f4_idq / Pointer to the measured current vector in format d/q (float *) p_f4_idq_ref / Pointer to the reference current vector in format d/q Output : None	Executes the flux-weakening module

3.3 Contents of Control

3.3.1 Configuration Options

The configuration options of the vector control with hall sensors module for motor can be configured using the RA Configurator. The changed options are automatically reflected to common_data.c/h and hal_data.c/h files when generating code. The option names and setting values are listed in the Table 3-13 shown as follows.

Table 3-13 Configuration options for motor_hall module

Configuration Options (rm_motor_hall.h)	
Options	**Description**
Limit of over current (A) Initial : 1.67	When a phase current exceeds this value, PWM output ports are set to off.
Limit of over voltage (V) Initial : 60.0	When an inverter voltage exceeds this value, PWM output ports are set to off.
Limit of over speed (rpm) Initial : 4500.0	When a rotation speed exceeds this value, PWM output ports are set to off.
Limit of over speed (rpm) Initial : 8.0	When an inverter voltage becomes below this value, PWM output ports are set to off.

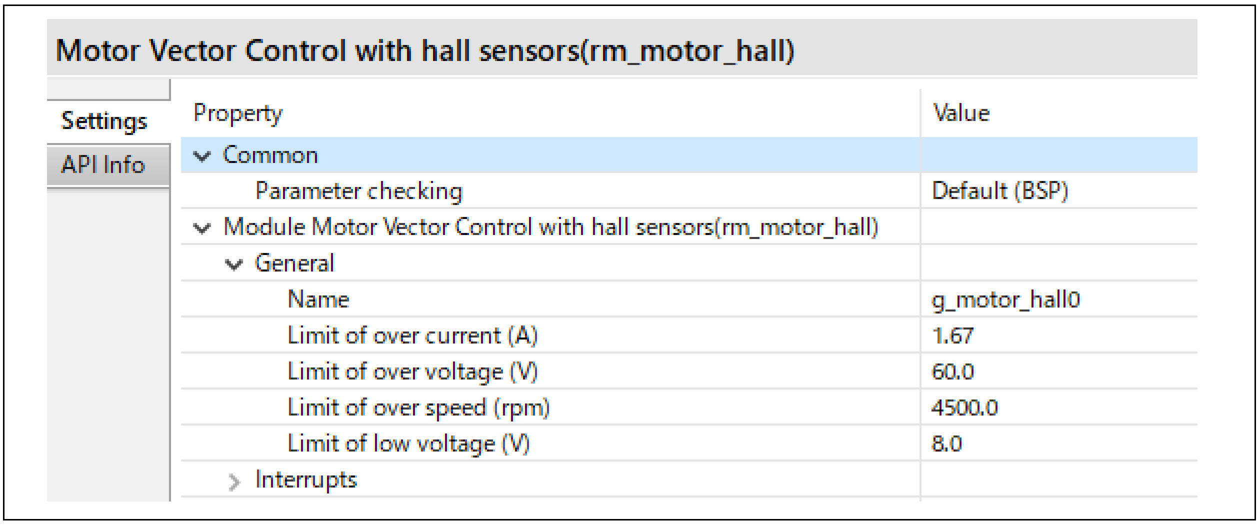


Figure 3-11 FSP configuration of motor vector control with hall sensors

3.3.2 Configuration Options for included modules

The vector control with hall sensors module includes below modules.

- Current Module
- Speed Module
- Angle Module
- Driver Module

And also these included modules have each configuration parameters as same as the vector control with hall sensors module. The option names and setting values are listed in the tables shown as follows.

Table 3-14 Configuration options for current control

Configuration Options (rm_motor_current.h)	
Options	**Description**
Voltage error compensation Initial : Enable	Selects whether to “enable” or “disable” voltage error compensation.
Shunt type Initial : 1shunt	Selects how many shunt resistances to use current detection.
Motor Parameter | Pole pairs Initial : 4	Pole pairs of target motor.
Motor Parameter | Resistance (ohm) Initial : 1.3	Resistance of motor [ohm].
Motor Parameter | Inductance of d-axis (H) Initial : 0.013	D-axis inductance [H].
Motor Parameter | Inductance of q-axis (H) Initial : 0.013	Q-axis inductance [H].
Motor Parameter | Permanent magnetic flux (Wb) Initial : 0.01119	Magnetic flux [Wb].
Motor Parameter | Rotor inertia (kgm^2) Initial : 0.000003666	Rotor inertia [kgm^2].
Design Parameter | Current PI loop omega Initial : 300.0	Current PI control omega parameter [Hz].
Design Parameter | Current PI loop zeta Initial : 1.0	Current PI control zeta parameter.

Motor Current Controller (rm_motor_current)

Settings | API Info

Property	Value
Common	
Parameter Checking	Default (BSP)
Module Motor Current Controller (rm_motor_current)	
General	
Name	g_motor_current0
Sensor type	Hall
Shunt type	1 shunt
Current control decimation	0
PWM carrier frequency (kHz)	20.0
Input voltage (V)	24.0
Sample delay compensation	Enable
Voltage error compensation	Enable
Voltage error compensation table of voltage 1	0.477
Voltage error compensation table of voltage 2	0.742
Voltage error compensation table of voltage 3	0.892
Voltage error compensation table of voltage 4	0.979
Voltage error compensation table of voltage 5	1.009
Voltage error compensation table of current 1	0.021
Voltage error compensation table of current 2	0.034
Voltage error compensation table of current 3	0.064
Voltage error compensation table of current 4	0.158
Voltage error compensation table of current 5	0.400
Interrupts	
Callback	rm_motor_hall_current_callback
Design Parameter	
Current PI loop omega (Hz)	300.0
Current PI loop zeta	1.0F
Motor Parameter	
Pole pairs	4
Resistance (ohm)	1.3
Inductance of d-axis (H)	0.0013
Inductance of q-axis (H)	0.0013
Permanent magnetic flux (Wb)	0.01119
Rotor inertia (kgm^2)	0.000003666

Figure 3-12 FSP configuration of motor current controller

Table 3-15 Configuration options for speed control [1/2]

Configuration Options (rm_motor_speed.h)	
Options	**Description**
Speed control period (sec) Initial : 0.0005	The period of speed control process [sec].
Step of speed climbing (rpm) Initial : 0.5	The step of speed fluctuation [rpm]. Program controls speed by this step at acceleration and deceleration.
Maximum rotational speed (rpm) Initial : 2400.0	Maximum rotational speed [rpm]
Speed LPF omega Initial : 10.0	Speed LPF parameter omega [Hz].
Speed at Id climbing (rpm) Initial : 400	The threshold speed to control d-axis current increase [rad/s]. Program increases d-axis current at start up the motor rotation until the speed reaches this value.
Limit of q-axis current (A) Initial : 1.67	Limit of q-axis current [A].
Step of speed feedback at open-loop Initial : 0.2	Rate of reference speed for feedback speed limiter at Open-Loop.
Flux weakening Initial : Disable	Select enable/disable of flux weakening control at high speed.

Table 3-16 Configuration options for speed control [2/2]

Configuration Options (rm_motor_speed.h)	
Options	**Description**
Open-Loop | Step of d-axis current climbing Initial : 0.3	The d-axis current reference ramping up rate [A/msec].
Open-Loop | Step of d-axis current descending Initial : 0.3	The d-axis current reference ramping down rate [A/msec].
Open-Loop | Step of q-axis current descending ratio Initial : 1.0	The q-axis current reference ramping down proportion to reference before open-loop [A/msec].
Open-Loop | Reference of d-axis current Initial : 0.3	The d-axis current reference in open-loop drive [A].
Open-Loop | Threshold of speed control descending Initial : 500.0	The speed threshold [rad/s] to ramp down the d-axis current [rpm].
Open-Loop | Threshold of speed control climbing Initial : 400.0	The speed threshold [rad/s] to ramp up the d-axis current [rpm].
Open-Loop | Period between open-loop to BEMF (sec) Initial : 0.025	Time to switch open-loop to sensor-less [sec]
Design parameter | Speed PI loop omega Initial : 5.0	Speed PI Control parameter omega. [Hz]
Design parameter | Speed PI loop zeta Initial : 1.0	Speed PI Control parameter zeta.
Motor Parameter | Pole pairs Initial : 4	Pole pairs of target motor.
Motor Parameter | Resistance (ohm) Initial : 1.3	Resistance of motor [ohm]
Motor Parameter | Inductance of d-axis (H) Initial : 0.0013	D-axis inductance [H].
Motor Parameter | Inductance of q-axis (H) Initial : 0.0013	Q-axis inductance [H].
Motor Parameter | Permanent magnetic flux (Wb) Initial : 0.01119	Magnetic flux [Wb].
Motor Parameter | Rotor inertia (kgm^2) Initial : 0.000003666	Rotor inertia [kgm^2].

Motor Speed Controller (rm_motor_speed)

Settings | API Info

Property	Value
Common	
Parameter Checking	Default (BSP)
Postion Support	Disabled
Module Motor Speed Controller (rm_motor_speed)	
General	
Name	g_motor_speed0
Speed control period (sec)	0.0005
Step of speed climbing (rpm)	0.5
Maximum rotational speed (rpm)	2400.0
Speed LPF omega	10.0
Speed at Id climbing (rpm)	400
Limit of q-axis current (A)	1.67
Step of speed feedback at open-loop	0.2
Natural frequency	100.0
Open-loop damping	Enable
Flux weakening	Disable
Torque compensation for sensorless transition	Disable
Speed observer	Enable
Selection of speed observer	Disturbance
Control method	PID
Control type	Hall
Open-Loop	
Step of d-axis current climbing	0.3
Step of d-axis current descending	0.3
Step of q-axis current descending ratio	1.0
Reference of d-axis current	0.3
Threshold of speed control descending	500
Threshold of speed control climbing	400
Period between open-loop to BEMF (sec)	0.025
Phase error(degree) to decide sensor-less switch timing	10
Design parameter	
Speed PI loop omega	5.0
Speed PI loop zeta	1.0
Estimated d-axis HPF omega	2.5
Open-loop damping zeta	1.0
Cutoff frequency of phase error LPF	10.0
Speed observer omega	200.0
Speed observer zeta	1.0
Motor Parameter	
Pole pairs	4
Resistance (ohm)	1.3
Inductance of d-axis (H)	0.0013
Inductance of q-axis (H)	0.0013
Permanent magnetic flux (Wb)	0.01119
Rotor inertia (kgm^2)	0.000003666
Interrupts	
Callback	rm_motor_hall_speed_callback
Input data	(g_motor_hall0_ctrl.st_speed_input)
Output data	(g_motor_hall0_ctrl.st_speed_output)

Figure 3-13 FSP configuration of motor speed controller

Table 3-17 Configuration options for angle and speed with hall sensors

Configuration Options (rm_motor_sense_hall.h)	
Options	**Description**
PMW Carrier Frequency (kHz) Initial : 20.0	Carrier Frequency [kHz]
Correction parameter of rotor angle Initial : 0.4	Angle correction value
Default counts of carrier interrupt Initial : 1000	Number of carrier interrupt measurements
Maximum counts of one rotation Initial : 5000	Maximum number of measurements between Hall sensor signals

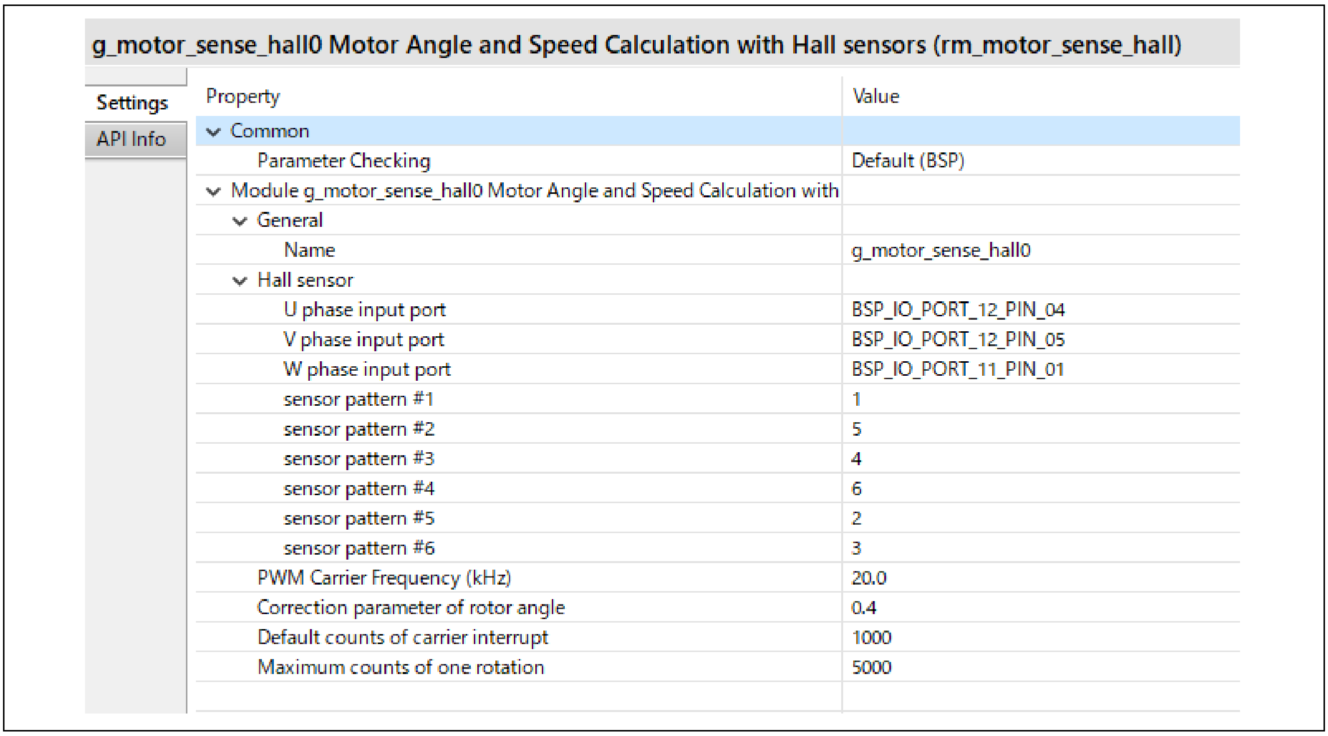


Figure 3-14 FSP configuration of motor angle driver

Table 3-18 Configuration options for driver access

Configuration Options (rm_motor_driver.h)	
Options	**Description**
PWM timer frequency (MHz) Initial : 120	PWM Timer Clock Frequency [MHz]
PWM carrier period (micro seconds) Initial : 50	PWM Carrier Period [Micro seconds]
Dead time (raw counts) Initial : 240	PWM Dead time [raw counts]
Current range (A) Initial : 16.5	Measurement Range of Electric current [A]
Voltage range (V) Initial : 73.26	Measurement Range of Inverter Voltage [V]
Counts for current offset measurement Initial : 500	Counts of measurement the offset of A/D conversion at electric current input.
Shunt type Initial : 1shunt	Selects how many shunt resistances to use current detection.
A/D conversion channel for U phase current Initial : 4	A/D channel for U-phase current
A/D conversion channel for main line voltage Initial : 6	A/D channel for main line voltage
Input voltage Initial : 24.0	Range of input for main line voltage
Resolution of A/D conversion Initial : 0xFFF	Resolution of A/D conversion Please set the same value with ADC module setting.
Offset of A/D conversion for current Initial : 0x7FF	Offset level of A/D conversion input for current. Please set according to the circuit.
Conversion level of A/D conversion for voltage Initial : 1.0	Conversion level of A/D conversion for voltage Please set when the CPU main voltage is different.
GTIOCA stop level Initial : Pin level Low	Output level of upper arm at stop status
GTIOCB stop level Initial : Pin level High	Output level of lower arm at stop status
Maximum duty Initial : 0.9375	Maximum duty of PWM Maximum duty except dead time.

ADC and PWM Modulation (rm_motor_driver)

Settings | API Info

Property	Value
Common	
Parameter Checking	Default (BSP)
ADC_B Support	Enabled
Module ADC and PWM Modulation (rm_motor_driver)	
General	
Name	g_motor_driver0
Shunt type	1 shunt
Modulation method	SVPWM
PWM output port UP	0
PWM output port UN	0
PWM output port VP	0
PWM output port VN	0
PWM output port WP	0
PWM output port WN	0
PWM Timer Frequency (MHz)	120
PWM Carrier Period (Microseconds)	50
Dead Time (Raw Counts)	240
Current Range (A)	16.5
Voltage Range (V)	73.26
Counts for current offset measurement	500
A/D conversion channel for U Phase current	4
A/D conversion channel for W Phase current	0
A/D conversion channel for Main Line Voltage	6
A/D conversion channel for V Phase current	2
A/D conversion channel for sin signal	27
A/D conversion channel for cos signal	28
Adjustment value to current A/D	0.0
Minimum difference of PWM duty	480
Adjustment delay of A/D conversion	120
Input Voltage (V)	24.0
Resolution of A/D conversion	0xFFF
Offset of A/D conversion for current	0x7FF
Conversion level of A/D conversion for voltage	1.0
GTIOCA Stop Level	Pin Level Low
GTIOCB Stop Level	Pin Level High
Modulation	
Maximum Duty	0.9375
Interrupts	
Callback	rm_motor_current_cyclic

Figure 3-15 FSP configuration of ADC and PWM modulation driver

3.4 Control Flowcharts

3.4.1 Main process

Figure 3-16 Main process flowchart

3.4.2 50 [μs] period interrupt (carrier synchronized Interrupt) process

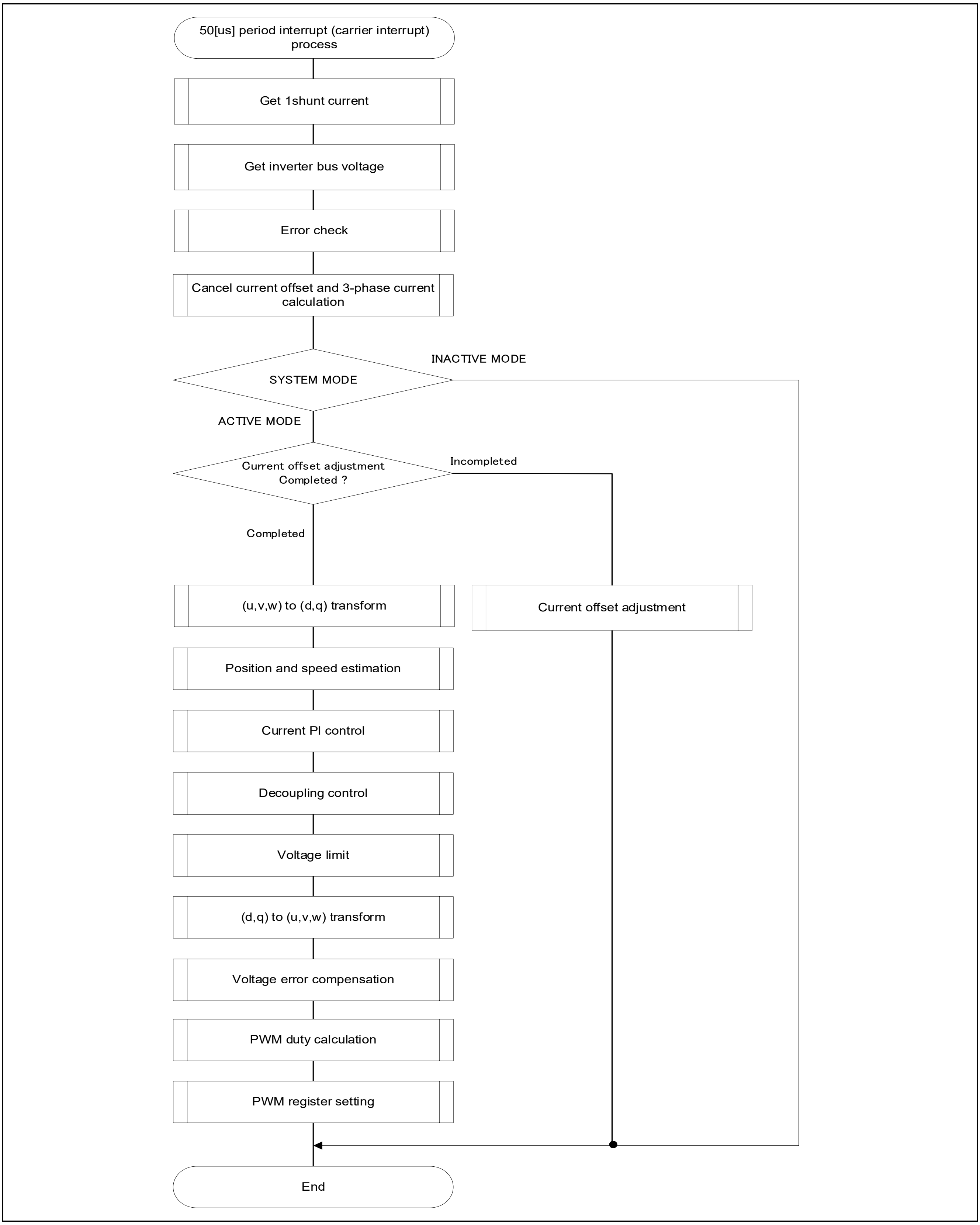


Figure 3-17 50 [μs] period interrupt (carrier interrupt) process flowchart

3.4.3 500 [μs] period interrupt process

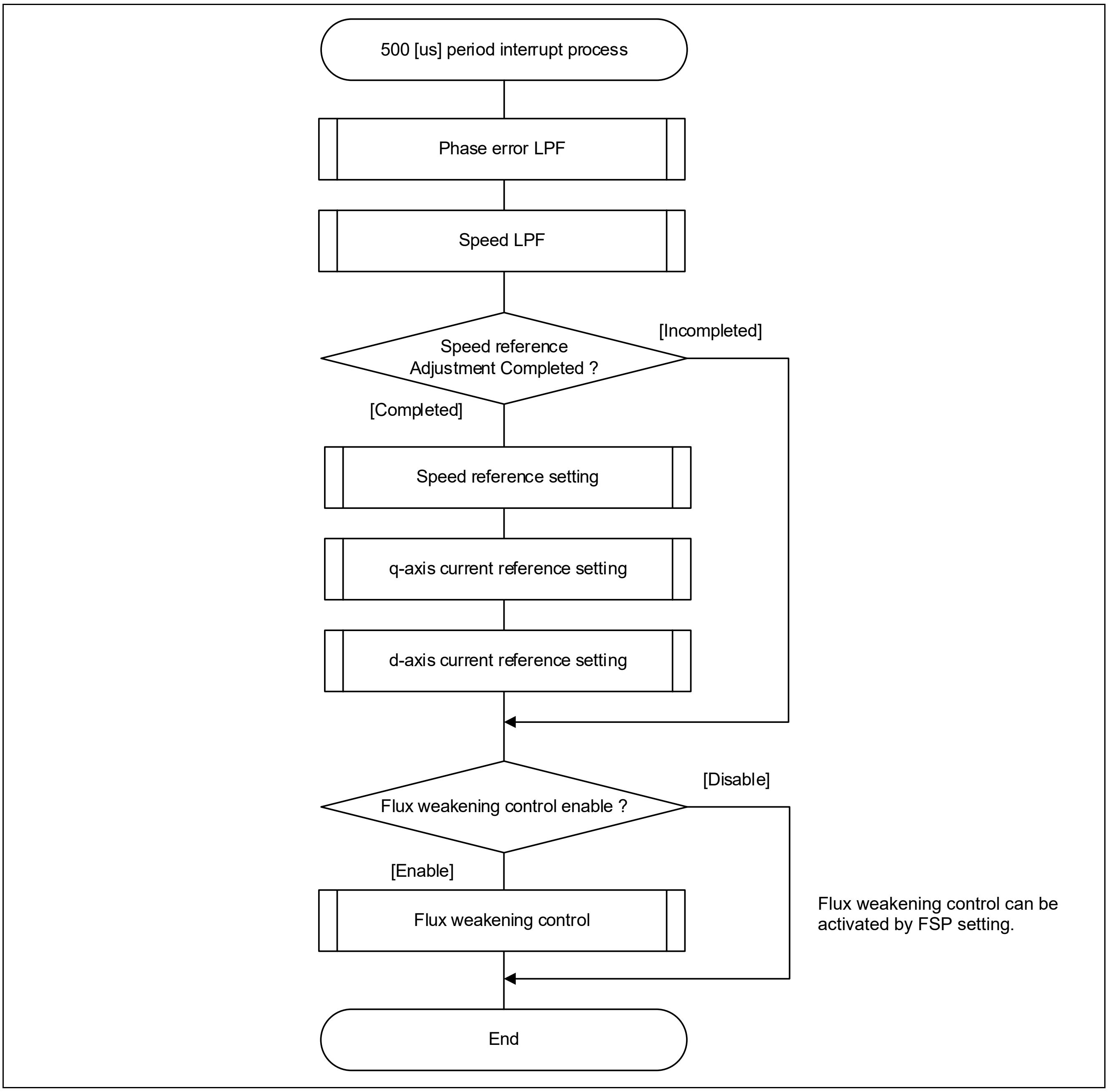


Figure 3-18 500 [μs] period interrupt process flowchart

3.4.4 Over current detection interrupt process

The over current detection interrupt occurs when GTETRGD pin detects an output short circuit. Therefore, when this interrupt process is executed, PWM output pins are already in high-impedance state and the output to the motor is stopped.

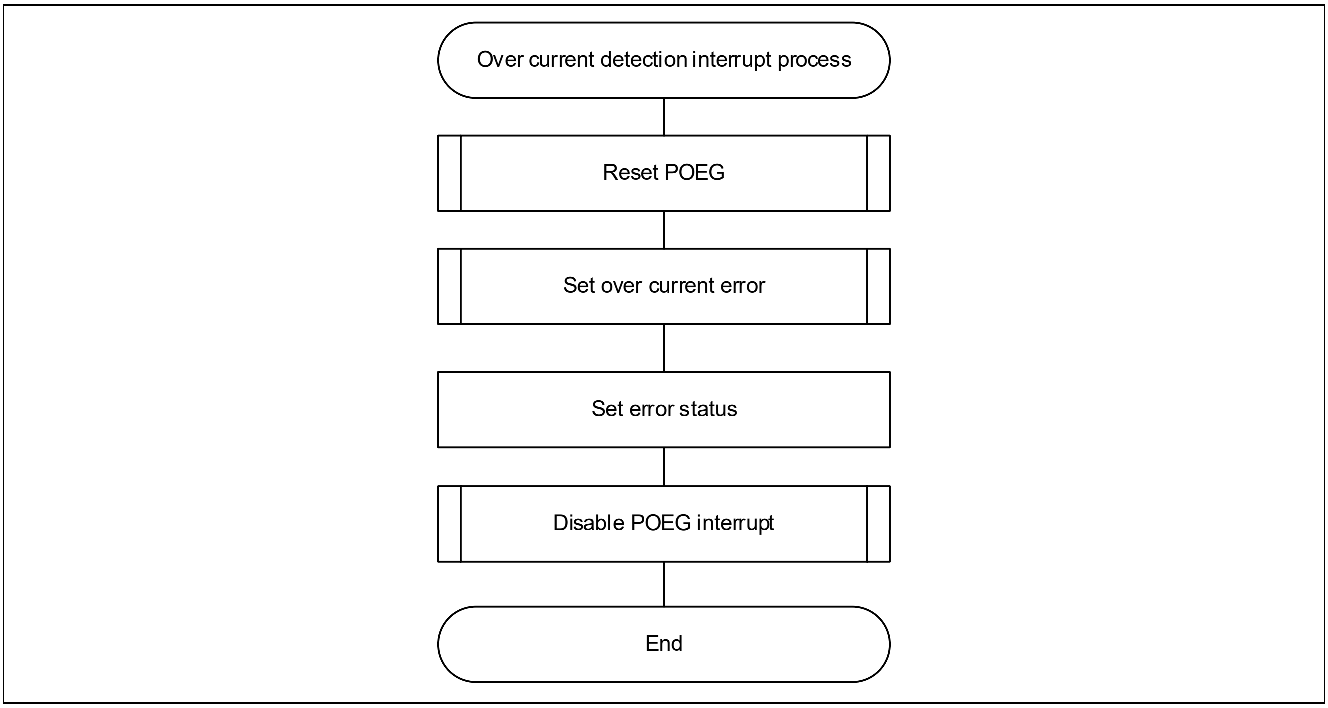


Figure 3-19 Over current detection interrupt process flowchart

4. Project Operation Overview

4.1 Importing the Demo Project

The sample application provided with this document may be imported into e²studio using the steps in this section.

(1) Select File → Import

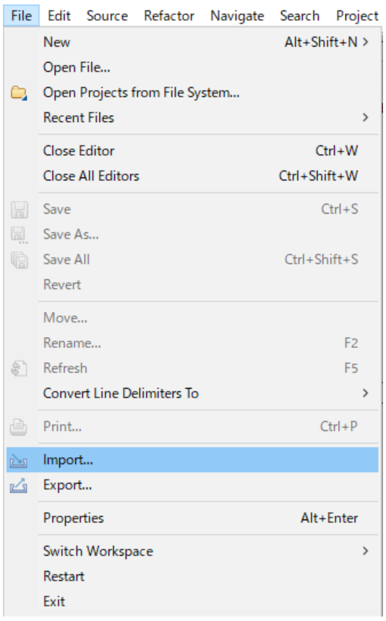


Figure 4-1 File menu

(2) Select "Existing Projects into Workspace".

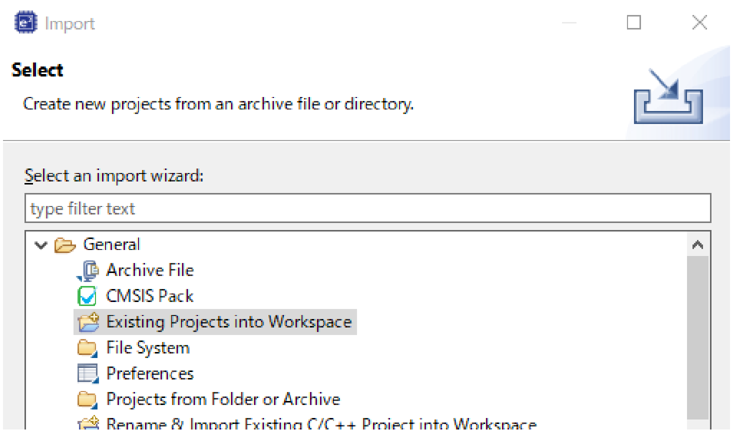


Figure 4-2 Import wizard selection

(3) Click “Browse…” button and select the demo project. Click Finish button and the demo project is imported.

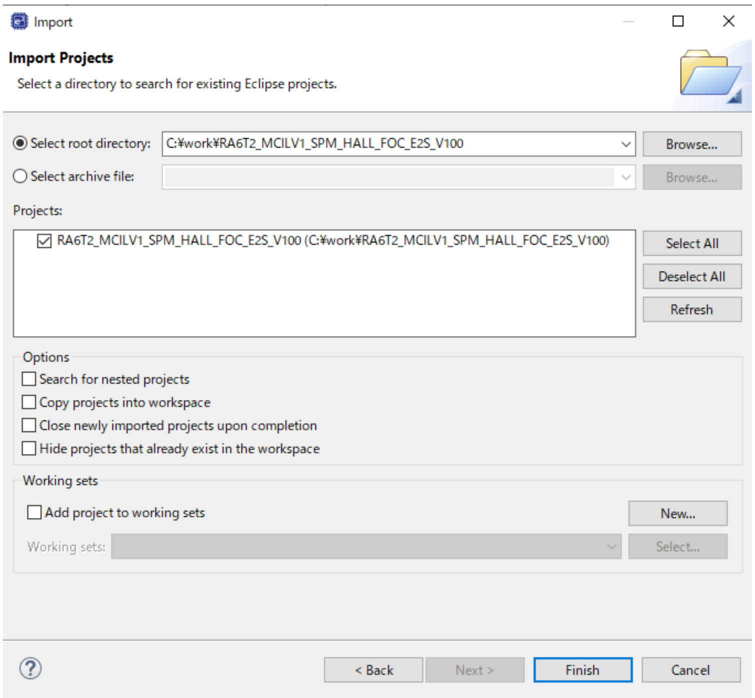


Figure 4-3 Import projects

4.2 Building and Debugging

Refer to the "e2studio User’s Manual : Quick Start Guide (R20UT5210)”.

4.3 Quick Start

When executing the sample code only in the evaluation environment without using Renesas motor workbench, the Quick Start Sample Project can be executed with the following procedure.

(1) After turning on stabilized power supply or executing reset, LED1, and LED2 on the inverter board are both off and the motor stops.

(2) IF the toggle switch (SW1) on the inverter board is turned on, the motor starts to rotate. Every time the toggle switch (SW1) is changed, motor rotation starts/stops alternately. If the motor rotates normally, LED1 is on. However, if LED2 on the inverter board is also on, error is occurring.

(3) In order to change the direction of the motor rotation, adjust it with the variable resistor (VR) on the inverter board.

- Turn the variable resistor (VR) right: Motor rotates clockwise
- Turn the variable resistor (VR) left: Motor rotates counterclockwise

(4) If error occurs, LED2 on the inverter board lighten, and the motor rotation stops. To restore, the toggle switch (SW1) on the inverter board needs to be turned off, then the switch (SW2) to be pushed and released.

(5) In order to stop the operation check, turn off the output of the stabilized power supply after making sure that the motor rotation has already stopped.

4.4 Motor Control Development Support Tool 'Renesas Motor Workbench'

4.4.1 Overview

In the target software of this application note, the motor control development support tool "Renesas Motor Workbench" is used as a user interface (rotating/stop motor, set rotation speed reference, etc). Please refer to 'Renesas Motor Workbench User's Manual' for usage and more details.

You can find 'Renesas Motor Workbench' on Renesas Electronics Corporation website.

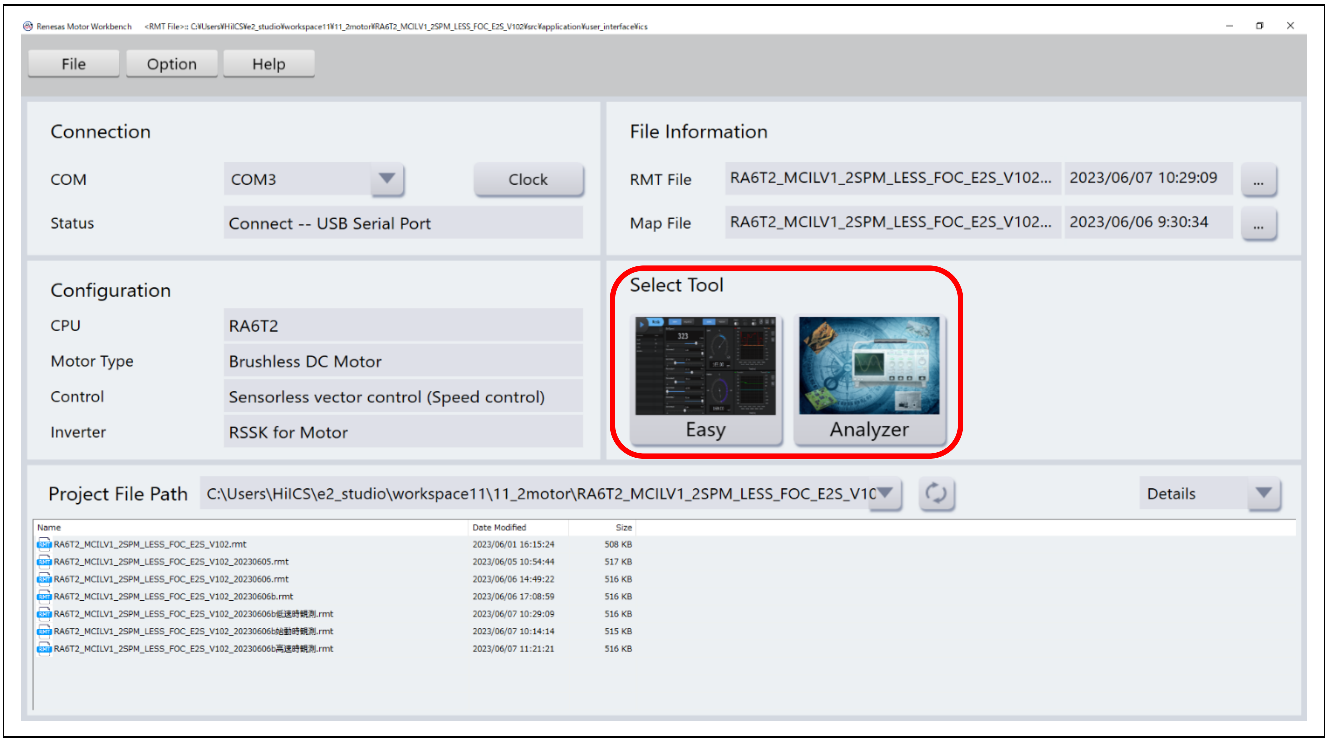
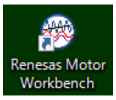


Figure 4-4 Renesas Motor Workbench – appearance

- Set up for "Renesas Motor Workbench"

(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]/src/application/user_interface/ics/'.
(3) Use the 'Connection' [COM] select menu to choose the COM port.
(4) Click the Analyzer button of Select Tool to activate Analyzer function.
(5) Please refer to '4.4.2 Easy function operation example4.4.4 Operation example for Analyzer' for motor driving operation.

4.4.2 Easy function operation example

The following is an example of operating the motor using the Easy function.

- Change the user interface to use Renesas Motor Workbench
  (1) Turn on "RMW UI"

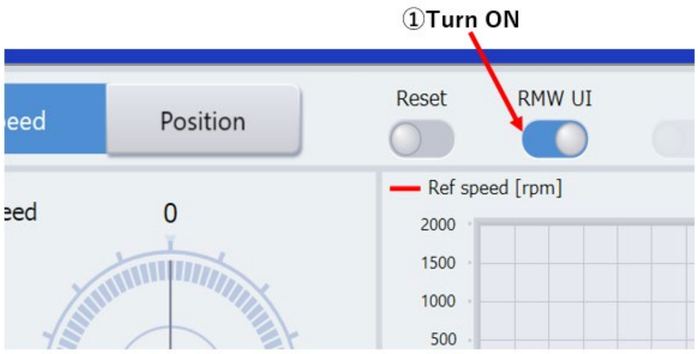


Figure 4-5 Procedure for changing to use Renesas Motor Workbench

- Run the motor
  (1) Press the “Run” button
  (2) Set the reference speed using the “Ref speed” slider.

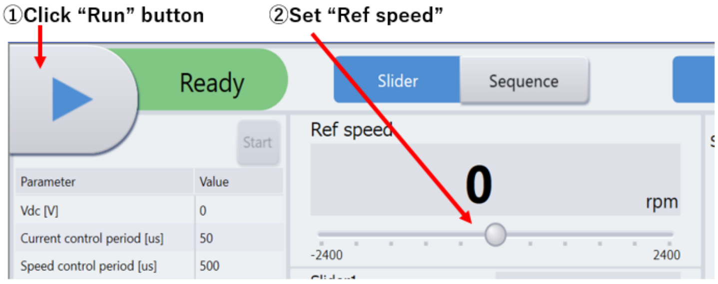


Figure 4-6 Motor rotation procedure

- Stop the motor
  (1) Press the “Stop” button.

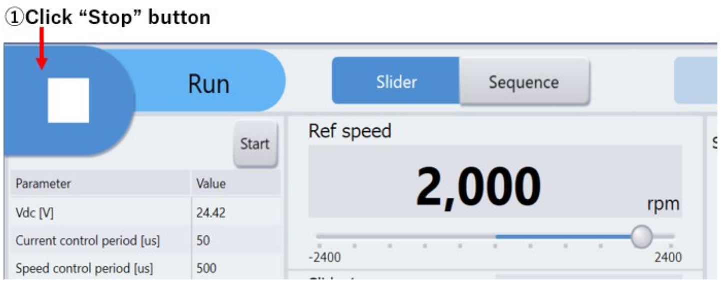


Figure 4-7 Motor stop procedure

- Processing when it stops (error)
  (1) Turn on "Reset" button.
  (2) Turn off “Reset” button

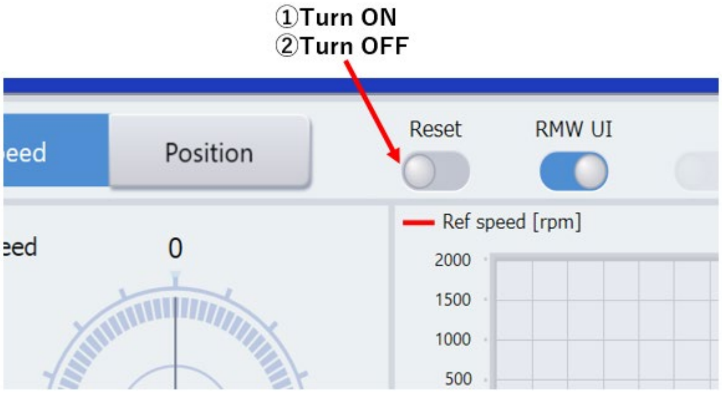


Figure 4-8 Error clearing procedure

4.4.3 List of variables for Analyzer function

Table 4-1 is a list of variables for Analyzer. These variables are reflected to the corresponding variables when the same values as g_u1_enable_write are written to com_u1_enable_write. However, note that variables with (*) do not depend on com_u1_enable_write.

Table 4-1 List of variables for Analyzer

Variable name	Type	Content
com_u1_sw_userif (*)	uint8_t	User interface switch 0: Analyzer use 1: Board user interface use (default)
com_u1_mode_system1(*)	uint8_t	State management 0: Stop mode 1: Run mode 3: Reset
com_f4_ref_speed_rpm	float	Speed reference (mechanical angle) [rpm]
com_u2_mtr_pp	uint16_t	Number of pole pairs
com_f4_mtr_r	float	Resistance [Ω]
com_f4_mtr_ld	float	d-axis Inductance [H]
com_f4_mtr_lq	float	q-axis Inductance [H]
com_f4_mtr_m	float	Magnetic Flux [Wb]
com_f4_mtr_j	float	Inertia [kgm^2]
com_f4_current_omega	float	Natural frequency of current control system [Hz]
com_f4_current_zeta	float	Damping ratio of current control system
com_f4_speed_omega	float	Natural frequency of speed control system [Hz]
com_f4_speed_zeta	float	Damping ratio of speed control system
com_f4_ref_id	float	d-axis current reference in open loop mode [A]
com_f4_ol_id_up_step	float	d-axis current reference ramping up rate
com_f4_ol_id_down_step	float	d-axis current reference ramping down rate
com_f4_id_down_speed_rpm	float	Speed when start to subtract d-axis current reference (mechanical angle) [rpm]
com_f4_id_up_speed_rpm	float	Speed when start to add d-axis current reference (mechanical angle) [rpm]
com_f4_max_speed_rpm	float	Maximum speed value (mechanical angle) [rpm]
com_f4_overspeed_limit_rpm	float	Speed limit (mechanical angle) [rpm]
com_f4_overcurrent_limit	float	Over current limit [A]
com_f4_iq_limit	float	q-axis current limit [A]
com_f4_limit_speed_change	float	Change speed limit (electrical angle) [rad/s]
com_u1_enable_write	uint8_t	Enabled to rewriting variables (rewritten when the same values as g_u1_enable_write are written)

4.4.4 Operation example for Analyzer

Following example shows motor driving operation using Analyzer. Operation is using “Control Window” as shown in Figure 4-9. Regarding specification of “Control Window”, refer to ‘Renesas Motor Workbench User’s Manual’.

- Change the user interface to Renesas Motor Workbench
  (1) Confirm the check-boxes of column [W?] for ‘com_u1_sw_userif’ marks.
  (2) Input ‘0’ in the [Write] box of ‘com_u1_sw_userif’.
  (3) Click the ‘Write’ button.

- Drive the motor
  (1) The [W?] check boxes contain checkmarks for “com_u1_mode_system”,“com_f4_ref_speed_rpm”, “com_u1_enable_write”
  (2) Type a reference speed value in the [Write] box of “com_f4_ref_speed_rpm”.
  (3) Click the “Write” button.
  (4) Click the “Read” button. Confirm the [Read] box of “com_f4_ref_speed_rpm” , ”g_u1_enable_write”.
  (5) Enter the value of “g_u1_enable_write” in the [Write] box of “com_u1_enable_write”.
  (6) Enter “1” in the [Write] box of “com_u1_mode_system”.
  (7) Click the “Write” button.

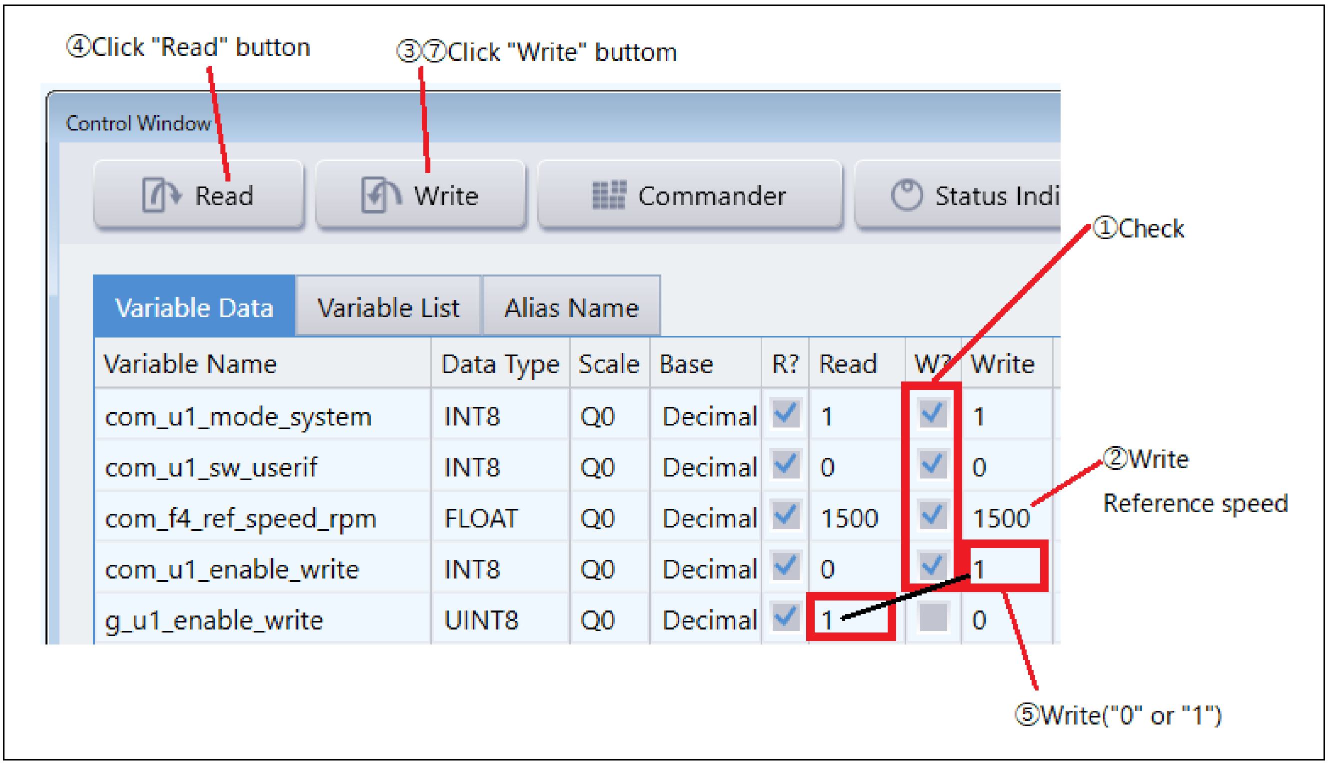


Figure 4-9 Procedure - Drive the motor

- Stop the motor
  (1) Enter “0” in the [Write] box of “com_u1_mode_system”.
  (2) Click the “Write” button.

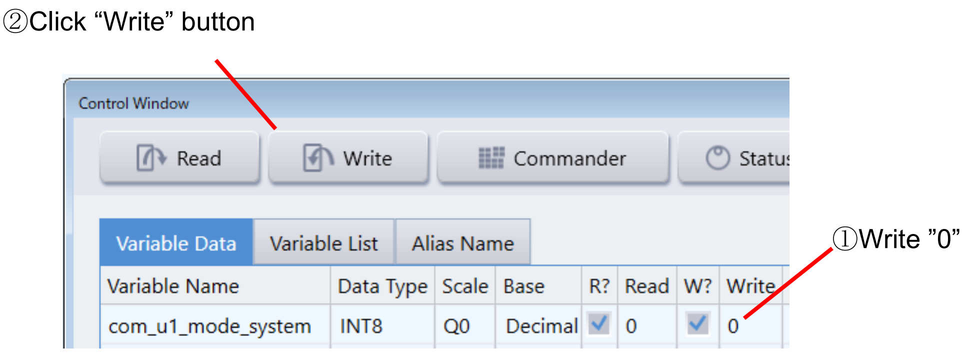


Figure 4-10 Procedure - Stop the motor

- Error cancel operation
  (1) Enter “3” in the [Write] box of “com_u1_mode_system”.
  (2) Click the “Write” button.

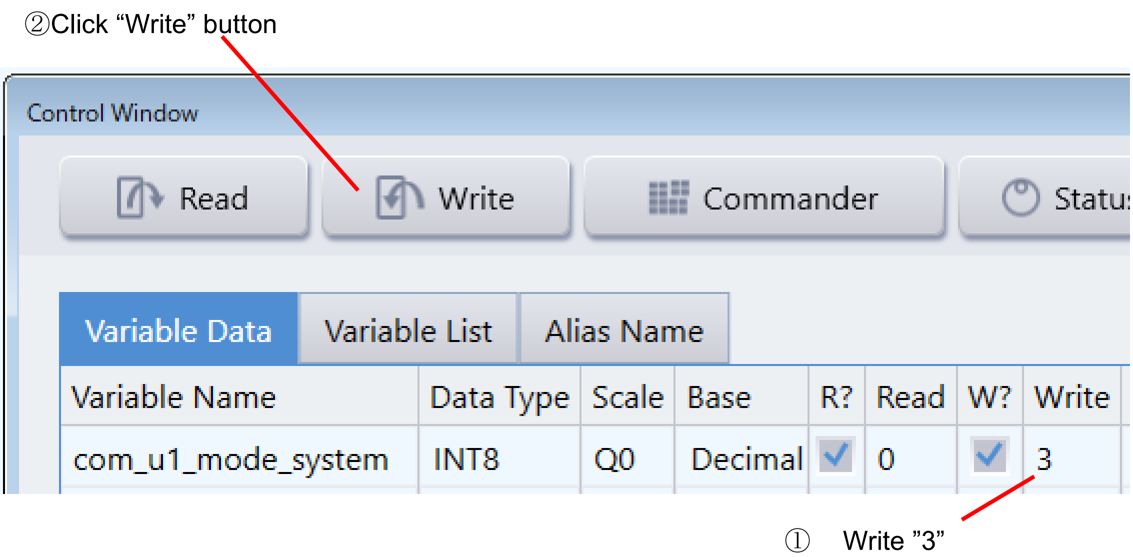


Figure 4-11 Procedure - Error cancel operation

4.4.5 Example of changing communication speed

The procedure for changing the communication speed of Renesas Motor Workbench with the sample software is shown below. See the Renesas Motor Workbench User's Manual for the values to change.

- Change the communication speed setting of the sample software (when the required communication rate is 10 Mbps)
  (1) Change the value of ICS_BRR in r_mtr_ics.h to 1.
  (2) Change the value of MTR_ICS_DECIMATION in r_mtr_ics.h to 1.

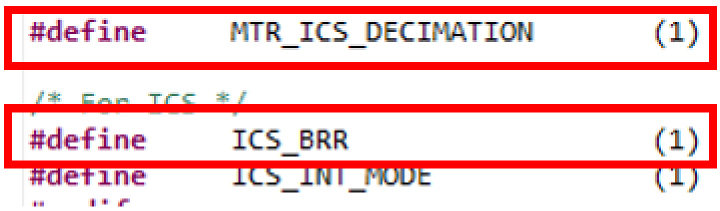


Figure 4-12 Modification of r_mtr_ics.h

- Change the communication speed setting of Renesas Motor Workbench to connect
  (1) Press the Clock button on the Main Window to change the value to 80,000,000
  This value was calculated by multiplying the default 8,000,000 by 10 because the UART communication baud rate was changed from 1Mbps to 10Mbps.
  (2) Select the COM of the connected kit in the COM of Connection

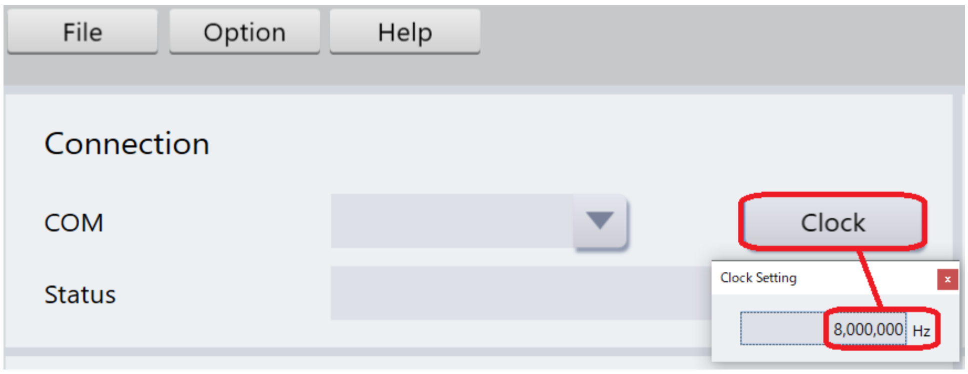


Figure 4-13 Clock frequency setting

If the connection fails, repeat the procedure for reconnecting after resetting the communication board.

4.4.6 How to use the built-in communication library

The procedure for connecting to Renesas Motor Workbench using the built-in communication library without using the communication board with the sample software is shown below.

- Connection between PC and CPU board
  Connect the CPU board and PC via a USB / serial conversion board, etc.

- Preparing a project for built-in communication (example of 921600bps)
  (1) Cancel the registration of ICS2_RA6T2.o

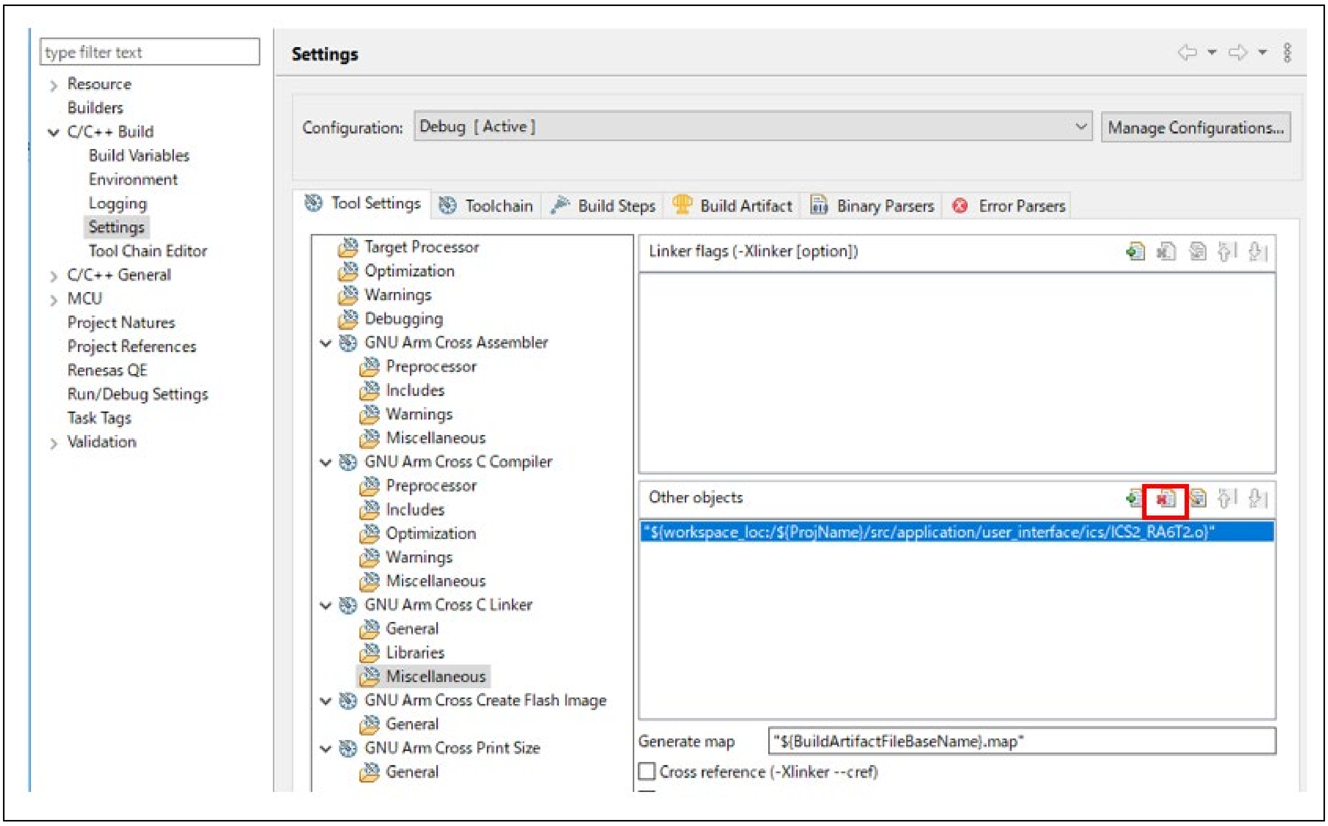


Figure 4-14 Unregister ICS2_RA6T2.o

(2) Register ICS2_RA6T2_Built_in.o

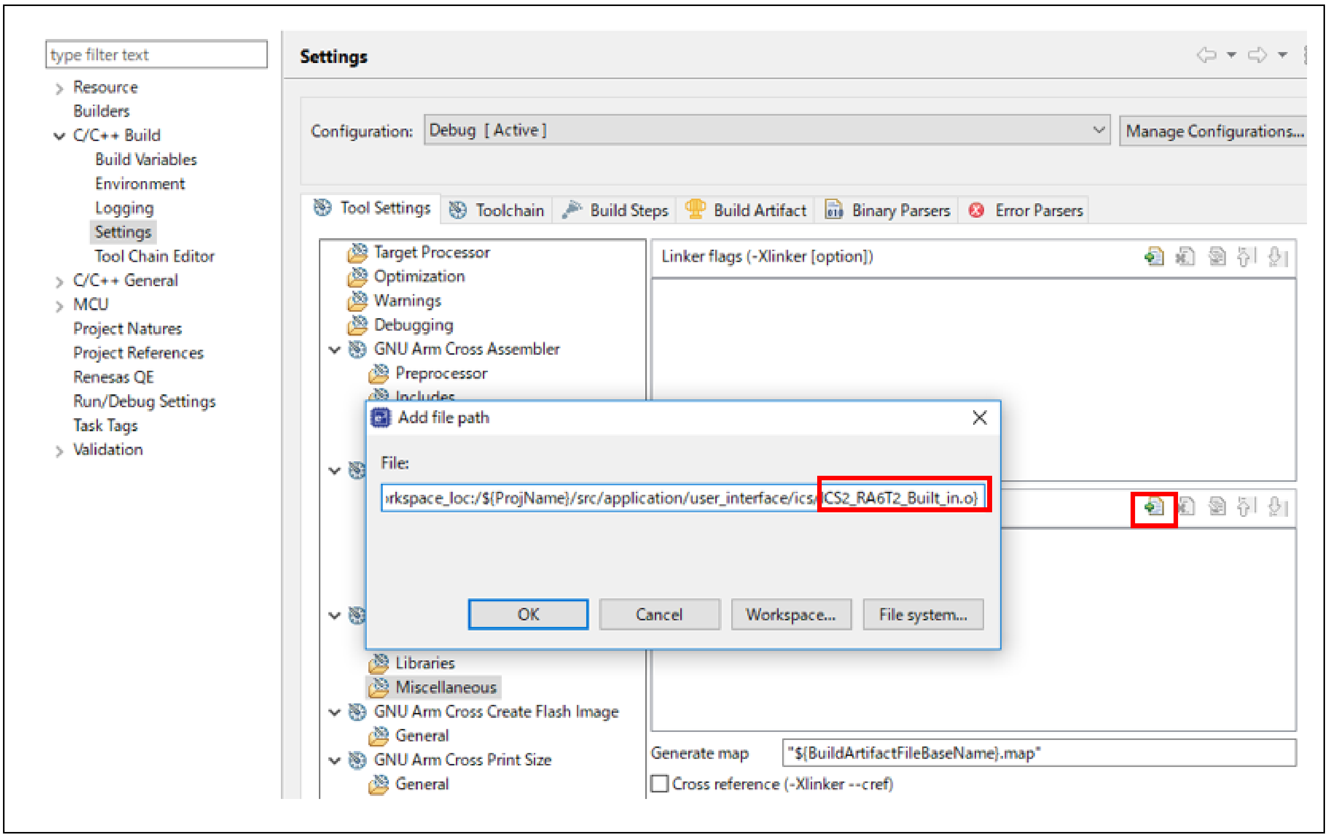


Figure 4-15 Register ICS2_RA6T2_Built_in.o

(3) Change the value of USE_BUILT_IN in r_mtr_ics.h to 1.

```
#define     USE_BUILT_IN             (1)

#if USE_BUILT_IN
#define     MTR_ICS_DECIMATION       (1)

/* For ICS */
#define     ICS_BRR                  (21)
#define     ICS_INT_MODE             (1)
```

Figure 4-16 Modification of r_mtr_ics.h

- Change the communication baud rate setting of Renesas Motor Workbench to connect
  (1) Change the value to 921,600 with Baud rate Dialog from the Option menu of the Main Window.
  (2) Select the COM port of the connected kit in the COM of Connection.

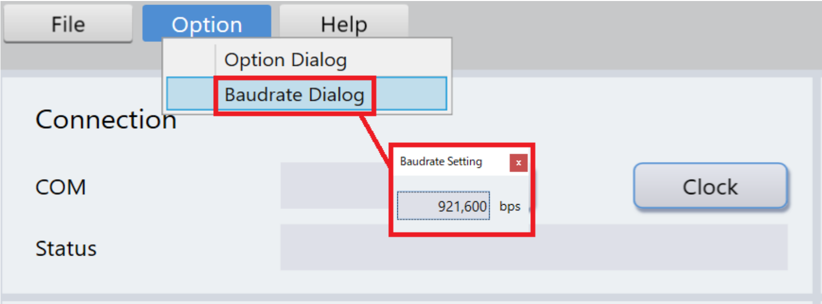


Figure 4-17 Baud rate setting

5. Reference Documents

- RA6T2 Group User's Manual: Hardware (R01UH0951)
- Renesas Flexible Software Package User's manual
  (PDF version : R11UM0155, Web version : RA Flexible Software Package Documentation)
- Application note: 'Sensorless vector control for permanent magnet synchronous motor (Algorithm)' (R01AN3786)
- Renesas Motor Workbench User's Manual (R21UZ0004)
- MCK-RA6T2 User's Manual (R12UZ0091)

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Aug.04.23	—	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. Precaution against Electrostatic Discharge (ESD)

   A strong electrical field, when exposed to a CMOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop the generation of static electricity as much as possible, and quickly dissipate it when it occurs. Environmental control must be adequate. When it is dry, a humidifier should be used. This is recommended to avoid using insulators that can easily build up static electricity. Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work benches and floors must be grounded. The operator must also be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions must be taken for printed circuit boards with mounted semiconductor devices.
2. Processing at power-on

   The state of the product is undefined at the time 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 time 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 time 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 time when power is supplied until the power reaches the level at which resetting is specified.
3. Input of signal during power-off state

   Do not input signals or an I/O pull-up power supply while the device is powered off. The current injection that results from input of such a signal or I/O pull-up power supply may cause malfunction and the abnormal current that passes in the device at this time may cause degradation of internal elements. Follow the guideline for input signal during power-off state as described in your product documentation.
4. 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 the 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.
5. Clock signals

   After applying a reset, only release the reset line after the operating clock signal becomes stable. When switching the clock signal during program execution, wait until the target clock signal is 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. Additionally, 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.
6. Voltage application waveform at input pin

   Waveform distortion due to input noise or a reflected wave may cause malfunction. If the input of the CMOS device stays in the area between V_{IL} (Max.) and V_{IH} (Min.) due to noise, for example, the device may malfunction. Take care to prevent chattering noise from entering the device when the input level is fixed, and also in the transition period when the input level passes through the area between V_{IL} (Max.) and V_{IH} (Min.).
7. Prohibition of access to reserved addresses

   Access to reserved addresses is prohibited. The reserved addresses are provided for possible future expansion of functions. Do not access these addresses as the correct operation of the LSI is not guaranteed.
8. Differences between products

   Before changing from one product to another, for example to a product with a different part number, confirm that the change will not lead to problems. The characteristics of a microprocessing unit or microcontroller unit products in the same group but having a different part number might differ in terms of 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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Contact information

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