

# Sensorless vector control for permanent magnetic synchronous motor - 1shunt current detection

For Renesas Flexible Motor Control Series

# Abstract

This application note describes the sample program for a permanent magnetic synchronous motor drive with sensorless vector control based on Renesas microcontroller. This application note also describes how to use the motor control development support tool, 'Renesas Motor Workbench'.

The targeted software for this application note is only to be used as reference purposes only and Renesas Electronics Corporation does not guarantee the operations. Please use this after carrying out a thorough evaluation in a suitable environment.

# **Operation checking device**

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

- RA6T2 (R7FA6T2BD3CFP)
- · RA6T3 (R7FA6T3BB3CFM)
- RA4T1 (R7FA4T1BB3CFM)
- · RA8T1 (R7FA8T1AHECBD)

# Target software

The following shows the target software for this application:

- · RA6T2\_MCILV1\_SPM\_LESS\_FOC\_1SHUNT\_E2S\_V111
- RA6T3\_MCILV1\_SPM\_LESS\_FOC\_1SHUNT\_E2S\_V101
- · RA4T1\_MCILV1\_SPM\_LESS\_FOC\_1SHUNT\_E2S\_V101
- RA8T1\_MCILV1\_SPM\_LESS\_FOC\_1SHUNT\_E2S\_V101



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# 1. Overview

This application note explains how to implement the sensorless vector control software that drives a permanent magnetic synchronous motor (PMSM) using the RA series microcontroller and how to use the motor control development support tool, 'Renesas Motor Workbench'.

Note that this software uses the 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.

# 2. Development environment

### 2.1 Test environments

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

Category	Product used
Microcontroller / CPU board	RA6T2 (R7FA6T2BD3CFP) / RTK0EMA270C00000BJ
product type	RA4T1 (R7FA4T1BB3CFM) / RTK0EMA430C00000BJ
	RA6T3(R7FA6T3BB3CFM) / RTK0EMA330C00000BJ
	RA8T1(R7FA8T1AHECBD) / RTK0EMA5K0C00000BJ
Inverter board	MCI-LV-1 / RTK0EM0000S04020BJ
Motor	R42BLD30L3
Sensor	None

#### **Table 2-1 Hardware Development Environment**

#### Table 2-2 Software Development Environment

e <sup>2</sup> studio version	FSP version	Toolchain version
e <sup>2</sup> studio : 2023-10	V5.1.0	GCC ARM Embedded : 10.3.1.20210824(RA6T2,RA6T3,RA4T1) 13.2.1.arm-13-7 (RA8T1)

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



# 2.2 Hardware configuration

# 2.2.1 Hardware configuration diagram

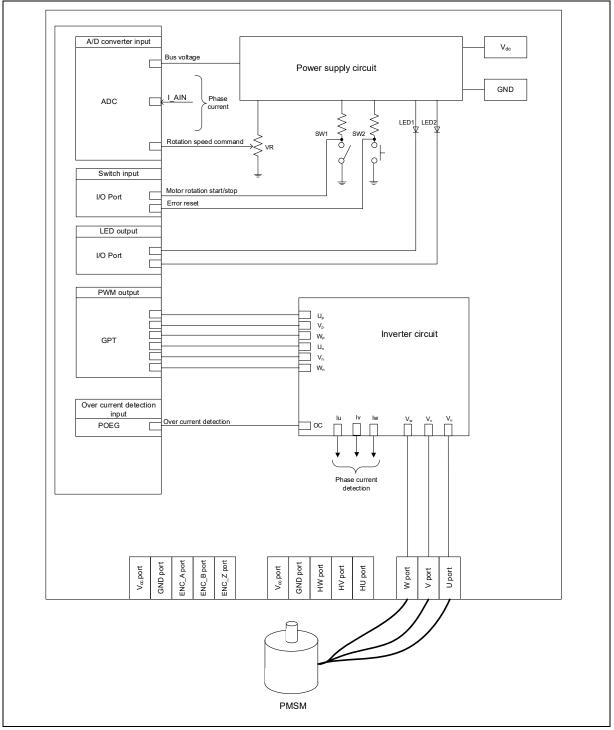


Figure 2-1 Hardware Configuration Diagram



# 2.2.2 Hardware modification details

Jumper pins need to be changed to use this system.

Please change the MCI-LV-1 connection of a jumper (JP8 and JP11) to connect 2-3 pins from 1-2 pins.

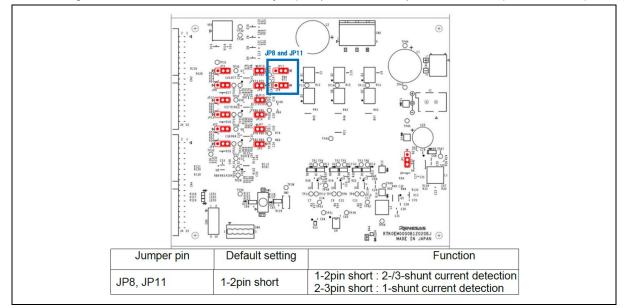


Figure 2-2 Change the connection of a jumper



# 2.2.3 Board User interface

Table 2-3 is lists of user interfaces of this system.

#### Table 2-3 Board user interface

ltem	Interface component	Function
Rotation position/speed	Volume (VR1)	Inputs the rotation position/speed command value (analog value).
START/STOP	Toggle switch (SW1)	Instructs start or stop of motor rotation.
ERROR RESET	Push switch (SW2)	Instructs recovery from an error state
LED1	Orange LED	On: The motor is rotating.
		Off: The motor is stopped.
LED2	Orange LED	On: An error was detected.
		Off: The system is operating normally.
LED3	Orange LED	Not used in this system
RESET	Push switch (RESET1)	System reset

List of port interfaces of this system is given in Table 2-4.

#### Table 2-4 Port interfaces

Function	RA6T2	RA4T1	RA6T3	RA8T1
Inverter bus voltage measurement	PA06 / AN006	P004 / AN004	P004 / AN004	P008 / AN008
For rotation speed command value input (analog value)	PB00 / AN008	P005 / AN005	P005 / AN005	P014 / AN007
START/STOP toggle switch (SW1)	PD04	P304	P304	PA15
ERROR RESET push switch (SW2)	PD07	P200	P200	PA13
LED1 ON/OFF control	PD01	P113	P113	PA12
LED2 ON/OFF control	PD02	P106	P106	PA14
Phase current measurement with 1shunt resistance	PA04 / AN004	P000 / AN000	P000 / AN000	PA04 / AN000
PWM output (U <sub>p</sub> )	PB04 / GTIOC4A	P409 / GTIOC1A	P409 / GTIOC1A	P115 / GTIOC5A
PWM output (V <sub>p</sub> )	PB06 / GTIOC5A	P103 / GTIOC2A	P103 / GTIOC2A	P113 / GTIOC2A
PWM output (W <sub>p</sub> )	PB08 / GTIOC6A	P111 / GTIOC3A	P111 / GTIOC3A	P300 / GTIOC3A
PWM output (U <sub>n</sub> )	PB05 / GTIOC4B	P408 / GTIOC1B	P408 / GTIOC1B	P609 / GTIOC5B
PWM output (V <sub>n</sub> )	PB07 / GTIOC5B	P102 / GTIOC2B	P102 / GTIOC2B	P114 / GTIOC2B
PWM output (Wn)	PB09 / GTIOC6B	P112 / GTIOC3B	P112 / GTIOC3B	P112 / GTIOC3B
PWM emergency stop input at the time of overcurrent detection	PC13 / GTETRGD	P104 / GTETRGB	P104 / GTETRGB	P613 / GTETRGA



## 2.2.4 Peripheral functions

List of the peripheral functions used in this system is given in Table 2-5.

Peripheral	Purpose	RA6T2	RA4T1	RA6T3	RA8T1
	Phase current measurement with 1shunt resistance	AN004	AN000	AN000	AN000
12-bit A/D Converter	Inverter bus voltage measurement	AN006	AN004	AN004	AN008
	For rotation speed command value input (analog value)	AN008	AN005	AN005	AN007
AGT	Speed control interval timer	AGT0	AGT0	AGT0	AGT0
	U phase PWM output	CH4	CN1	CN1	CN5
GPT	V phase PWM output	CH5	CN2	CN2	CN2
	W phase PWM output	CH6	CN3	CN3	CN3
POEG	PWM emergency stop input at the time of overcurrent detection	Group D	Group B	Group B	Group A

#### Table 2-5 List of the Peripheral Functions

#### 2.2.4.1 RA6T2

#### (1). 12-bit A/D Converter (ADC)

Phase current (with an 1shunt resistance), inverter bus voltage (Vdc) and rotation speed command (VR1) are measured in "Single scan mode" (use a hardware trigger).

Detection of the phase current uses FIFO function.

A/D conversion is implemented to be synchronized with carrier synchronized interrupt by using direct link function to GPT.

#### (2). Low Power Asynchronous General-Purpose Timer (AGT)

The AGT is used as 1 [ms] interval timer.

(3). General PWM Timer (GPT)

On the channel 4, 5, and 6, output with dead time is performed by using the Triangle-wave PWM mode 3.

#### (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 GTETRGD port is detected).

g_ioport I/O Port (r_ioport)	Motor Sensorless Vector	Control (rm_motor_sensorless)							g_poeg0 Port Output Enable for GPT (r_poeg
D	0								0
	Motor Speed Controller	(rm_motor_speed)	Motor Current Controller (rm_motor_	current)		1			
	٦		Ø						
	<ul> <li>g_timer3 Timer, Low-Power (r_agt)</li> </ul>	Add Position Module [Optional]	ADC and PWM Modulation (rm_motor)	r_driver)		•		g_motor_angle0 Motor     Angle and Speed	
	٩		٥					Estimation (rm_motor_estimate)	
				DC driver2 to t 1shunt [Option]	Three-Phase PWM (r_gpt_	_three_phase)			
			0	(	)				
					g_timer0 Timer, General PWM (r_gpt)	g_timer1 Timer, General PWM (r_gpt)	<ul> <li>g_timer2 Timer, General PWM (r_gpt)</li> </ul>		
				α		Ø	Ø		

#### Figure 2-3 Overall FSP Stacks diagram



g_adc0 ADC Driver c	n r_adc_b	
Settings Property		Value
API Info V Common		
	ter Checking	Default (BSP)
✓ Module g.	adc0 ADC Driver on r_adc_b	
✓ General		
✓ Mod	le	
Α	DC 0	Single Scan
Δ	DC 1	Single Scan
> ADC	Successive Approximation Time	
> Sync	hronous Operation	
> Calit	pration	
> Sam	pling State Table	
Nam	ne	g_adc0
> Clock C	onfiguration	
✓ Interrup	ots	
> Limi	ter Clip Priority	
> Con	version Error Priority	
> Ove	flow Priority	
> Calit	pration End Priority	
> Scar	End Priority	
> FIFC	Priorities	
Call	back	NULL
> Sample	and Hold	
> User Of		
> User Ga	in Table	
> Limiter	Clipping	

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



ettings Property		Value
Pl Info Virtual Channel 2		
Scan Group		Scan Group 0
Channel Select		AN004
Sampling State	able ID	Sampling State Entry 0
Channel Gain Ta	ble	Disabled
Channel Offset	able	Disabled
Add/Average M	ode	Disabled
Add/Average Co	ount	1-time conversion (Normal Conversion)
Limit Clip Table	d	Disabled
Conversion Res	lution Format Select	12-bit Data Format
<ul> <li>Virtual Channel 3</li> </ul>		
Scan Group		Scan Group 1
Channel Select Sampling State Table ID		AN006
		Sampling State Entry 0
Channel Gain Ta	ble	Disabled
Channel Offset	able	Disabled
Add/Average M	ode	Disabled
Add/Average C	ount	1-time conversion (Normal Conversion)
Limit Clip Table	d	Disabled
Conversion Res	lution Format Select	12-bit Data Format
<ul> <li>Virtual Channel 4</li> </ul>		
Scan Group		Scan Group 1
Channel Select		AN008
Sampling State	able ID	Sampling State Entry 0
Channel Gain Ta	ble	Disabled
Channel Offset	able	Disabled
Add/Average M	ode	Disabled
Add/Average C	ount	1-time conversion (Normal Conversion)
Limit Clip Table	d	Disabled
Conversion Res	lution Format Select	12-bit Data Format

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



J_adc0 A	DC Driver on r_adc_b	
Settings	Property	Value
API Info	✓ Scan Groups	
APTIMO	✓ Scan Group 0	
	Self Diagnosis	
	> External Trigger Enable	
	> ELC Trigger Enable	
	<ul> <li>GPT Trigger Enable</li> </ul>	
	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
	✓ Scan Group 1	
	Self Diagnosis	
	> External Trigger Enable	
	> ELC Trigger Enable	
	> GPT Trigger Enable	
	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
	> Scan Group 2	

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



Settings	Property	Value
API Info	✓ Common	
AFTINO	Parameter Checking	Default (BSP)
	Pin Output Support	Disabled
	Pin Input Support	Disabled
	<ul> <li>Module g_timer3 Timer, Low-Power (r_agt)</li> </ul>	
	✓ General	
	Name	g_timer3
	Channel	0
	Mode	🔒 Periodic
	Period	60000
	Period Unit	Raw Counts
	Count Source	PCLKB
	> Output	
	> Input	
	✓ Interrupts	
	Callback	fm_motor_speed_cyclic
	Underflow Interrupt Priority	Priority 10

Figure 2-7 FSP Configuration of AGT Driver



j_timert	) Timer, General PWM (r_gpt)	
Settings	Property	Value
PI Info	✓ Common	
rinio	Parameter Checking	Default (BSP)
	Pin Output Support	Enabled with Extra Features
	Write Protect Enable	Disabled
	Clock Source	PCLKD
	<ul> <li>Module g_timer0 Timer, General PWM (r_gpt)</li> </ul>	
	✓ General	
	Name	g_timer0
	Channel	
	Mode	Triangle-Wave Asymmetric PWM (Mode 3
	Period	100
	Period Unit	A 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	1 True
	GTIOCB Stop Level	Pin Level High
	> Input	<u> </u>
	✓ Interrupts	
	Callback	rm_motor_driver_1shunt_cyclic
	Overflow/Crest Interrupt Priority	Priority 5
	Capture A Interrupt Priority	Disabled
	Capture B Interrupt Priority	Disabled
	Underflow/Trough Interrupt Priority	Disabled
	Extra Features	er e
	Output Disable	
	Output Disable POEG Trigger	
	POEG Link	POEG Channel 3
	GTIOCA Disable Setting	Set Hi Z
	GTIOCE Disable Setting	Set Hi Z
	<ul> <li>✓ ADC Trigger</li> </ul>	Sector 2
	Start Event Trigger (GPTE/GPTEH only)	
	Trigger Event A/D Converter Start Request A Durin	স
	Trigger Event A/D Converter Start Request A Durin	
	Trigger Event A/D Converter Start Request A Durin	
	Trigger Event A/D Converter Start Request B Durin	
	> Dead Time	1
	ADC Trigger (GPTE/GPTEH only)	
	<ul> <li>Interrupt Skipping (GPTE/GPTEH only)</li> </ul>	
	Extra Features	🔒 Enabled
	Pins	
	GTIOC4A	PB04
	GTIOC4B	PB05
		FDUD

Figure 2-8 FSP Configuration of GPT Driver



ettings	Property	Value
API Info	✓ Common	
d f line	Parameter Checking	Default (BSP)
	<ul> <li>Module g_poeg0 Port Output Enable for GPT (r_poeg)</li> </ul>	
	✓ General	
	> Trigger	
	Name	g_poeg0
	Channel	3
	✓ Input	
	GTETRG Polarity	Active Low
	GTETRG Noise Filter	PCLKB/128
	✓ Interrupts	
	Callback	g_poe_overcurrent
	Interrupt Priority	Priority 0 (highest)

Figure 2-9 FSP Configuration of POEG Driver



#### 2.2.4.2 RA4T1

#### (1). 12-bit A/D Converter (ADC12)

Phase current (with an 1shunt resistance), inverter bus voltage (Vdc) and rotation speed command (VR1) are measured in "Single scan mode" (use a hardware trigger).

Detection of the phase current uses FIFO function.

A/D conversion is implemented to be synchronized with carrier synchronized interrupt by using direct link function to GPT.

(2). Low Power Asynchronous General-Purpose Timer (AGT)

The AGT is used as 1 [ms] interval timer.

#### (3). General PWM Timer (GPT)

On the channel 1, 2, and 3, output with dead time is performed by using the Triangle-wave PWM mode 3. .

(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 port is detected).

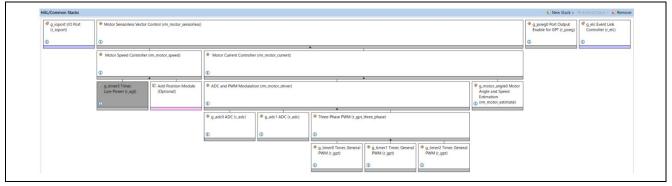


Figure 2-10 Overall FSP Stacks diagram



ADC (r_adc)	
Property	Value
✓ Common	
Parameter Checking	Default (BSP)
<ul> <li>Module g_adc0 ADC (r_adc)</li> </ul>	
✓ General	
Name	g_adc0
Unit	0
Resolution	🔒 12-Bit
Alignment	🔒 Right
Clear after read	On
Mode	Single Scan
Double-trigger	Enabled (extended mode)
> Input	
✓ Interrupts	
Normal/Group A Trigger	GPT1 AD TRIG A (A/D converter start request A
Group B Trigger	GPT1 AD TRIG B (A/D converter start request B)
Group Priority (Valid only in Group Scan Mode)	Group A cannot interrupt Group B
Callback	NULL
Scan End Interrupt Priority	Disabled
Scan End Group B Interrupt Priority	Disabled
Window Compare A Interrupt Priority	Disabled
Window Compare B Interrupt Priority	Disabled
> Extra	

Figure 2-11 FSP Configuration of ADC Driver [1/4]



# Sensorless vector control for permanent magnetic synchronous motor - 1shunt current detection

Property	Value
✓ Module g_adc0 ADC (r_adc)	
> General	
✓ Input	
<ul> <li>Channel Scan Mask (channel availability varies by MCU)</li> </ul>	
Channel 0	
Channel 1	
Channel 2	
Channel 3	
Channel 4	
Channel 5	
Channel 6	
Channel 7	
Channel 8	
Channel 9	
Channel 10	
Channel 11	
Channel 12	
Channel 13	
Channel 14	
Channel 15	
Channel 16	
Channel 17	
Channel 18	
Channel 19	
Channel 20	
Channel 21	
Channel 22	
Channel 23	
Channel 24	
Channel 25	
Channel 26	
Channel 27	
Temperature Sensor	
Voltage Sensor	
> Group B Scan Mask (channel availability varies by MCU)	
> Addition/Averaging Mask (channel availability varies by MCU and unit)	
> Sample and Hold	
> Window Compare	
Add/Average Count	Disabled
Reference Voltage control	S VREFH0/VREFH
> Interrupts	
> Extra	

Figure 2-12 FSP Configuration of ADC Driver [2/4]



Settings	Property	Value		
API Info	✓ Common			
a rano	Parameter Checking	Default (BSP)		
	<ul> <li>Module g_adc1 ADC (r_adc)</li> </ul>			
	✓ General			
	Name	g_adc1		
	Unit	0		
	Resolution	🚯 12-Bit		
	Alignment	🔒 Right		
	Clear after read	3 Off		
	Mode	Single Scan		
	Double-trigger	Disabled		
	> Input			
	✓ Interrupts			
	Normal/Group A Trigger	Software		
	Group B Trigger	Disabled		
	Group Priority (Valid only in Group Scan Mode)	Group A cannot interrupt Group B		
	Callback	NULL		
	Scan End Interrupt Priority	Disabled		
	Scan End Group B Interrupt Priority	Disabled		
	Window Compare A Interrupt Priority	Disabled		
	Window Compare B Interrupt Priority	Disabled		
	> Extra			

Figure 2-13 FSP Configuration of ADC Driver [3/4]



Settings	Property	Value
API Info	<ul> <li>Module g_adc1 ADC (r_adc)</li> </ul>	
- u i i iiio	> General	
	✓ Input	
	<ul> <li>Channel Scan Mask (channel availability varies by MCU)</li> </ul>	
	Channel 0	
	Channel 1	
	Channel 2	
	Channel 3	
	Channel 4	
	Channel 5	$\checkmark$
	Channel 6	
	Channel 7	
	Channel 8	
	Channel 9	
	Channel 10	
	Channel 11	
	Channel 12	
	Channel 13	
	Channel 14	
	Channel 15	
	Channel 16	
	Channel 17	
	Channel 18	
	Channel 19	
	Channel 20	
	Channel 21	
	Channel 22	
	Channel 23	
	Channel 24	
	Channel 25	
	Channel 26	
	Channel 27	
	Temperature Sensor	
	Voltage Sensor	
	> Group B Scan Mask (channel availability varies by MCU)	
	> Addition/Averaging Mask (channel availability varies by MCU and unit)	
	> Sample and Hold	
	> Window Compare	
	Add/Average Count	Disabled
	Reference Voltage control	C VREFH0/VREFH
	> Interrupts	
	> Extra	

Figure 2-14 FSP Configuration of ADC Driver [4/4]



g_timer	3 Timer, Low-Power (r_agt)	
Settings	Property	Value
API Info	✓ Common	
ATTING	Parameter Checking	Default (BSP)
	Pin Output Support	Disabled
	Pin Input Support	Disabled
	<ul> <li>Module g_timer3 Timer, Low-Power (r_agt)</li> </ul>	
	✓ General	
	Name	g_timer3
	Channel	0
	Mode	🔒 Periodic
	Period	1
	Period Unit	Milliseconds
	Count Source	PCLKB
	> Output	
	> Input	
	✓ Interrupts	
	Callback	fm_motor_speed_cyclic
	Underflow Interrupt Priority	Priority 10

Figure 2-15 FSP Configuration of AGT Driver



ettings	Property	Value
PI Info	✓ Common	
FILLIO	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	â 1
	Mode	Triangle-Wave Asymmetric PWM (Mode 3)
	Period	â 100
	Period Unit	Microseconds
	> Output	
	> Input	
	✓ Interrupts	
	Callback	rm_motor_driver_1shunt_cyclic
	Overflow/Crest Interrupt Priority	Priority 5
	Capture A Interrupt Priority	Disabled
	Capture B Interrupt Priority	Disabled
	Underflow/Trough Interrupt Priority	Disabled
	✓ Extra Features	
	✓ Output Disable	
	> Output Disable POEG Trigger	
	POEG Link	POEG Channel 1
	GTIOCA Disable Setting	Level Low
	GTIOCB Disable Setting	Level Low
	✓ ADC Trigger	
	<ul> <li>Start Event Trigger (Channels with GTINTAD only)</li> </ul>	
	Trigger Event A/D Converter Start Request A During Up Counting	<b>V</b>
	Trigger Event A/D Converter Start Request A During Down Counting	
	Trigger Event A/D Converter Start Request B During Up Counting	
	Trigger Event A/D Converter Start Request B During Down Counting	
	✓ Dead Time	
	Dead Time Count Up (Raw Counts)	â 200
	Dead Time Count Down (Raw Counts) (Channels with GTDVD only)	â 200
	✓ 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
	<ul> <li>Interrupt Skipping (Channels with GTITC only)</li> </ul>	
	Interrupt to Count	Trough (triangle)
	Interrupt Skip Count	1
	Skip ADC Events	None
	Extra Features	Enabled

Figure 2-16 FSP Configuration of GPT Driver



Settings	Property	Value
API Info	✓ Common	
	Parameter Checking	Default (BSP)
	<ul> <li>Module g_poeg0 Port Output Enable for GPT (r_poeg)</li> </ul>	
	✓ General	
	✓ Trigger	
	GTETRG Pin	<ul> <li>Image: A start of the start of</li></ul>
	GPT Output Level	
	Oscillation Stop	
	Name	g_poeg0
	Channel	1
	✓ Input	
	GTETRG Polarity	Active Low
	GTETRG Noise Filter	PCLKB/32
	✓ Interrupts	
	Callback	g_poe_overcurrent
	Interrupt Priority	Priority 0 (highest)

Figure 2-17 FSP Configuration of POEG Driver



#### 2.2.4.3 RA6T3

#### (1). 12-bit A/D Converter (ADC12)

Phase current (with an 1shunt resistance), inverter bus voltage (Vdc) and rotation speed command (VR1) are measured in "Single scan mode" (use a hardware trigger).

Detection of the phase current uses FIFO function.

A/D conversion is implemented to be synchronized with carrier synchronized interrupt by using direct link function to GPT.

(2). Low Power Asynchronous General-Purpose Timer (AGT)

The AGT is used as 1 [ms] interval timer.

#### (3). General PWM Timer (GPT)

On the channel 1, 2, and 3, output with dead time is performed by using the Triangle-wave PWM mode 3. .

(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 port is detected).

g_ioport I/O Port (r_ioport)	Motor Sensorless Vector	r Control (rm_motor_sensorless)							g_poeg0 Port Output Enable for GPT (r_poeg)     (	<ul> <li>g_elc Event Link Controller (r_elc)</li> <li>Image: Controller (r_elc)</li> </ul>
	Motor Speed Controlle	r (rm_motor_speed)	Motor Current Control	er (rm_motor_current)						
	tr g_timer3 Timer, Low-Power (r_agt)	Add Position Module [Optional]	<ul> <li>ADC and PWM Modular</li> <li>O</li> </ul>	tion (rm_motor_driver)				<ul> <li>g_motor_angle0 Motor</li> <li>Angle and Speed</li> <li>Estimation</li> <li>(m_motor_estimate)</li> </ul>		
			f g_adc0 ADC (r_adc)	g_adc1 ADC (r_adc)	Three-Phase PWM (r_gpt	three_phase)				
					g_timer0 Timer, General     PWM (r_gpt)	g_timer1 Timer, General     PWM (r_gpt)	g_timer2 Timer, General     PWM (r_gpt)			

Figure 2-18 Overall FSP Stacks diagram



ADC (r_adc)	
Property	Value
✓ Common	
Parameter Checking	Default (BSP)
<ul> <li>Module g_adc0 ADC (r_adc)</li> </ul>	
✓ General	
Name	g_adc0
Unit	0
Resolution	🔒 12-Bit
Alignment	🔒 Right
Clear after read	On
Mode	Single Scan
Double-trigger	Enabled (extended mode)
> Input	
✓ Interrupts	
Normal/Group A Trigger	GPT1 AD TRIG A (A/D converter start request A
Group B Trigger	GPT1 AD TRIG B (A/D converter start request B
Group Priority (Valid only in Group Scan Mode)	Group A cannot interrupt Group B
Callback	NULL
Scan End Interrupt Priority	Disabled
Scan End Group B Interrupt Priority	Disabled
Window Compare A Interrupt Priority	Disabled
Window Compare B Interrupt Priority	Disabled
> Extra	

Figure 2-19 FSP Configuration of ADC Driver [1/4]



# Sensorless vector control for permanent magnetic synchronous motor - 1shunt current detection

Property	Value
✓ Module g_adc0 ADC (r_adc)	
> General	
✓ Input	
<ul> <li>Channel Scan Mask (channel availability varies by MCU)</li> </ul>	
Channel 0	
Channel 1	
Channel 2	
Channel 3	
Channel 4	
Channel 5	
Channel 6	
Channel 7	
Channel 8	
Channel 9	
Channel 10	
Channel 11	
Channel 12	
Channel 13	
Channel 14	
Channel 15	
Channel 16	
Channel 17	
Channel 18	
Channel 19	
Channel 20	
Channel 21	
Channel 22	
Channel 23	
Channel 24	
Channel 25	
Channel 26	
Channel 27	
Temperature Sensor	
Voltage Sensor	
> Group B Scan Mask (channel availability varies by MCU)	
> Addition/Averaging Mask (channel availability varies by MCU a	and unit)
> Sample and Hold	
> Window Compare	
Add/Average Count	Disabled
Reference Voltage control	VREFH0/VREFH
> Interrupts	

Figure 2-20 FSP Configuration of ADC Driver [2/4]



Settings	Property	Value	
API Info	✓ Common		
u runo	Parameter Checking	Default (BSP)	
	<ul> <li>Module g_adc1 ADC (r_adc)</li> </ul>		
	✓ General		
	Name	g_adc1	
	Unit	0	
	Resolution	🙆 12-Bit	
	Alignment	🔒 Right	
	Clear after read	G Off	
	Mode	Single Scan	
	Double-trigger	Disabled	
	> Input		
	✓ Interrupts		
	Normal/Group A Trigger	Software	
	Group B Trigger	Disabled	
	Group Priority (Valid only in Group Scan Mode)	Group A cannot interrupt Group B	
	Callback	NULL	
	Scan End Interrupt Priority	Disabled	
	Scan End Group B Interrupt Priority	Disabled	
	Window Compare A Interrupt Priority	Disabled	
	Window Compare B Interrupt Priority	Disabled	
	> Extra		

Figure 2-21 FSP Configuration of ADC Driver [3/4]



Settings	Property	Value
API Info	<ul> <li>Module g_adc1 ADC (r_adc)</li> </ul>	
a third	> General	
	✓ Input	
	<ul> <li>Channel Scan Mask (channel availability varies by MCU)</li> </ul>	
	Channel 0	
	Channel 1	
	Channel 2	
	Channel 3	
	Channel 4	
	Channel 5	<ul> <li>Image: A start of the start of</li></ul>
	Channel 6	
	Channel 7	
	Channel 8	
	Channel 9	
	Channel 10	
	Channel 11	
	Channel 12	
	Channel 13	
	Channel 14	
	Channel 15	
	Channel 16	
	Channel 17	
	Channel 18	
	Channel 19	
	Channel 20	
	Channel 21	
	Channel 22	
	Channel 23	
	Channel 24	
	Channel 25	
	Channel 26	
	Channel 27	
	Temperature Sensor	
	Voltage Sensor	
	> Group B Scan Mask (channel availability varies by MCU)	
	> Addition/Averaging Mask (channel availability varies by MCU and unit)	
	> Sample and Hold	
	> Window Compare	
	Add/Average Count	Disabled
	Reference Voltage control	S VREFH0/VREFH
	> Interrupts	
	> Extra	

Figure 2-22 FSP Configuration of ADC Driver [4/4]



g_timer	3 Timer, Low-Power (r_agt)	
Settings	Property	Value
API Info	✓ Common	
ATTING	Parameter Checking	Default (BSP)
	Pin Output Support	Disabled
	Pin Input Support	Disabled
	<ul> <li>Module g_timer3 Timer, Low-Power (r_agt)</li> </ul>	
	✓ General	
	Name	g_timer3
	Channel	0
	Mode	🔒 Periodic
	Period	1
	Period Unit	Milliseconds
	Count Source	PCLKB
	> Output	
	> Input	
	✓ Interrupts	
	Callback	fm_motor_speed_cyclic
	Underflow Interrupt Priority	Priority 10

Figure 2-23 FSP Configuration of AGT Driver



ettings	Property	Value
PI Info	✓ Common	
FTINO	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	â 1
	Mode	G Triangle-Wave Asymmetric PWM (Mode 3)
	Period	â 100
	Period Unit	Microseconds
	> Output	
	> Input	
	✓ Interrupts	
	Callback	rm_motor_driver_1shunt_cyclic
	Overflow/Crest Interrupt Priority	Priority 5
	Capture A Interrupt Priority	Disabled
	Capture B Interrupt Priority	Disabled
	Underflow/Trough Interrupt Priority	Disabled
	✓ Extra Features	
	✓ Output Disable	
	> Output Disable POEG Trigger	
	POEG Link	POEG Channel 1
	GTIOCA Disable Setting	Level Low
	GTIOCB Disable Setting	Level Low
	✓ ADC Trigger	
	<ul> <li>Start Event Trigger (Channels with GTINTAD only)</li> </ul>	
	Trigger Event A/D Converter Start Request A During Up Counting	
	Trigger Event A/D Converter Start Request A During Down Counting	
	Trigger Event A/D Converter Start Request B During Up Counting	
	Trigger Event A/D Converter Start Request B During Down Counting	
	✓ Dead Time	
	Dead Time Count Up (Raw Counts)	â 200
	Dead Time Count Down (Raw Counts) (Channels with GTDVD only)	🔒 200
	<ul> <li>ADC Trigger (Channels with GTADTRA only)</li> </ul>	
	ADC A Compare Match (Raw Counts)	10
	✓ ADC Trigger (Channels with GTADTRB only)	
	ADC B Compare Match (Raw Counts)	80
	<ul> <li>Interrupt Skipping (Channels with GTITC only)</li> </ul>	
	Interrupt to Count	Trough (triangle)
	Interrupt Skip Count	1
	Skip ADC Events	None
	Extra Features	Enabled

Figure 2-24 FSP Configuration of GPT Driver



Settings	Property	Value
API Info	✓ Common	
	Parameter Checking	Default (BSP)
	<ul> <li>Module g_poeg0 Port Output Enable for GPT (r_poeg)</li> </ul>	
	✓ General	
	✓ Trigger	
	GTETRG Pin	<ul> <li>Image: A start of the start of</li></ul>
	GPT Output Level	
	Oscillation Stop	
	Name	g_poeg0
	Channel	1
	✓ Input	
	GTETRG Polarity	Active Low
	GTETRG Noise Filter	PCLKB/32
	✓ Interrupts	
	Callback	g_poe_overcurrent
	Interrupt Priority	Priority 0 (highest)

Figure 2-25 FSP Configuration of POEG Driver



#### 2.2.4.4 RA8T1

#### (1). 12-bit A/D Converter (ADC12)

Phase current (with an 1shunt resistance), inverter bus voltage (Vdc) and rotation speed command (VR1) are measured in "Single scan mode" (use a hardware trigger).

Detection of the phase current uses FIFO function.

A/D conversion is implemented to be synchronized with carrier synchronized interrupt by using direct link function to GPT.

#### (2). Low Power Asynchronous General-Purpose Timer (AGT)

The AGT is used as 1 [ms] interval timer.

#### (3). General PWM Timer (GPT)

On the channel 5, 2, and 3, output with dead time is performed by using the Triangle-wave PWM mode 3.

#### (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 GTETRGA port is detected).

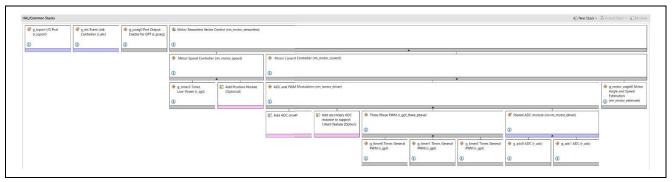


Figure 2-26 Overall FSP Stacks diagram

0 ADC (r_adc)	
property	Value
✓ Common	
Parameter Checking	Default (BSP)
<ul> <li>Module g_adc0 ADC (r_adc)</li> </ul>	
✓ General	
Name	g_adc0
Unit	0
Resolution	🔒 12-Bit
Alignment	🔒 Right
Clear after read	On
Mode	Single Scan
Double-trigger	Enabled (extended mode)
> Input	
✓ Interrupts	
Normal/Group A Trigger	GPT1 AD TRIG A (A/D converter start request A)
Group B Trigger	GPT1 AD TRIG B (A/D converter start request B)
Group Priority (Valid only in Group Scan Mode)	Group A cannot interrupt Group B
Callback	NULL
Scan End Interrupt Priority	Disabled
Scan End Group B Interrupt Priority	Disabled
Window Compare A Interrupt Priority	Disabled
Window Compare B Interrupt Priority	Disabled
> Extra	

Figure 2-27 FSP Configuration of ADC Driver [1/4]



Settings	Property	Value
API Info	✓ Module g_adc0 ADC (r_adc)	
AFTIMO	> General	
	✓ Input	
	<ul> <li>Channel Scan Mask (channel availability varies by MCU)</li> </ul>	
	Channel 0	<ul> <li>Image: A start of the start of</li></ul>
	Channel 1	
	Channel 2	
	Channel 3	
	Channel 4	
	Channel 5	
	Channel 6	
	Channel 7	
	Channel 8	
	Channel 9	
	Channel 10	
	Channel 11	
	Channel 12	
	Channel 13	
	Channel 14	
	Channel 15	
	Channel 16	
	Channel 17	
	Channel 18	
	Channel 19	
	Channel 20	
	Channel 21	
	Channel 22	
	Channel 23	
	Channel 24	
	Channel 25	
	Channel 26	
	Channel 27	
	Temperature Sensor	
	Voltage Sensor	
	> Group B Scan Mask (channel availability varies by MCU)	
	> Addition/Averaging Mask (channel availability varies by MCU and unit)	
	> Sample and Hold	
	> Window Compare	
	Add/Average Count	Disabled
	Reference Voltage control	VREFH0/VREFH
	> Interrupts	

Figure 2-28 FSP Configuration of ADC Driver [2/4]



	Drawarts	Value
Settings	Property	value
API Info	✓ Common	
	Parameter Checking	Default (BSP)
	<ul> <li>Module g_adc1 ADC (r_adc)</li> </ul>	
	✓ General	
	Name	g_adc1
	Unit	0
	Resolution	🕯 12-Bit
	Alignment	🔒 Right
	Clear after read	G Off
	Mode	Single Scan
	Double-trigger	Disabled
	> Input	
	✓ Interrupts	
	Normal/Group A Trigger	Software
	Group B Trigger	Disabled
	Group Priority (Valid only in Group Scan Mode)	Group A cannot interrupt Group B
	Callback	NULL
	Scan End Interrupt Priority	Disabled
	Scan End Group B Interrupt Priority	Disabled
	Window Compare A Interrupt Priority	Disabled
	Window Compare B Interrupt Priority	Disabled
	> Extra	

Figure 2-29 FSP Configuration of ADC Driver [3/4]

g_adc1 A	ADC (r_adc)	
Settings	Property	Value
API Info	✓ Module g_adc1 ADC (r_adc)	
ATTINO	> General	
	✓ Input	
	<ul> <li>Channel Scan Mask (channel availability varies by MCU)</li> </ul>	
	Channel 0	
	Channel 1	
	Channel 2	
	Channel 3	
	Channel 4	~
	Channel 5	<ul> <li>Image: A start of the start of</li></ul>
	Channel 6	
	Channel 7	
	Channel 8	
	Channel 9	
	Channel 10	
	Channel 11	
	Channel 12	
	Channel 13	
	Channel 14	
	Channel 15	
	Channel 16	
	Channel 17	
	Channel 18	
	Channel 19	
	Channel 20	
	Channel 21	
	Channel 22	
	Channel 23	
	Channel 24	
	Channel 25	
	Channel 26	
	Channel 27	
	Temperature Sensor	
	Voltage Sensor	
	> Group B Scan Mask (channel availability varies by MCU)	
	> Addition/Averaging Mask (channel availability varies by MCU and unit)	
	> Sample and Hold	
	> Window Compare	
	Add/Average Count	Disabled
	Reference Voltage control	SVREFH0/VREFH
	> Interrupts	
	> Extra	

Figure 2-30 FSP Configuration of ADC Driver [4/4]



Settings	Property	Value
API Info	✓ Common	
	Parameter Checking	Default (BSP)
	Pin Output Support	Disabled
	Pin Input Support	Disabled
	✓ Module g_timer3 Timer, Low-Power (r_agt)	
	✓ General	
	Name	g_timer3
	Channel	0
	Mode	🔞 Periodic
	Period	1
	Period Unit	Milliseconds
	Count Source	PCLKB
	> Output	
	> Input	
	✓ Interrupts	
	Callback	rm_motor_speed_cyclic
	Underflow Interrupt Priority	Priority 10

Figure 2-31 FSP Configuration of AGT Driver

attinas	Property	Value
ettings	✓ Common	TOTOL:
PI Info	Parameter Checking	Default (BSP)
	Pin Output Support	Enabled with Extra Features
	Write Protect Enable	Disabled
	Clock Source	PCLKD
		PCLKD
	Module g_timer0 Timer, General PWM (r_gpt)     General	
		a timero
	Name Channel	g_timer0
	Mode	
		Triangle-Wave Asymmetric PWM (Mode 3)
	Period	<b>1</b> 00
	Period Unit	G Microseconds
	> Output	
	> Input	
	✓ Interrupts	
	Callback	rm_motor_driver_1shunt_cyclic
	Overflow/Crest Interrupt Priority	Priority 5
	Capture A Interrupt Priority	Disabled
	Capture B Interrupt Priority	Disabled
	Underflow/Trough Interrupt Priority	Disabled
	✓ Extra Features	
	✓ Output Disable	
	> Output Disable POEG Trigger	
	POEG Link	POEG Channel 1
	GTIOCA Disable Setting	Level Low
	GTIOCB Disable Setting	Level Low
	✓ ADC Trigger	
	<ul> <li>Start Event Trigger (Channels with GTINTAD only)</li> </ul>	
	Trigger Event A/D Converter Start Request A During Up Counting	
	Trigger Event A/D Converter Start Request A During Down Counting	
	Trigger Event A/D Converter Start Request B During Up Counting	
	Trigger Event A/D Converter Start Request B During Down Counting	
	✓ Dead Time	
	Dead Time Count Up (Raw Counts)	â 200
	Dead Time Count Down (Raw Counts) (Channels with GTDVD only)	<b>a</b> 200
	<ul> <li>ADC Trigger (Channels with GTADTRA only)</li> </ul>	
	ADC A Compare Match (Raw Counts)	10
	<ul> <li>ADC Trigger (Channels with GTADTRB only)</li> </ul>	
	ADC B Compare Match (Raw Counts)	80
	<ul> <li>Interrupt Skipping (Channels with GTITC only)</li> </ul>	
	Interrupt to Count	Trough (triangle)
	Interrupt Skip Count	1
	Skip ADC Events	None
	Extra Features	G Enabled

Figure 2-32 FSP Configuration of GPT Driver



Propert	ies 🗙 📑	🏣 🍸 🗔 🛷 🕴 🗖 🗖
g_poeg0	Port Output Enable for GPT (r_poeg)	
Settings	Property	Value
-	✓ Common	
API Info	Parameter Checking	Default (BSP)
	✓ Module g_poeg0 Port Output Enable for GPT (r_poeg)	
	✓ General	
	✓ Trigger	
	GTETRG Pin	$\checkmark$
	GPT Output Level	
	Oscillation Stop	
	ACMPHS0	
	ACMPHS1	
	Name	g_poeg0
	Channel	0
	✓ Input	
	GTETRG Polarity	Active Low
	GTETRG Noise Filter	PCLKB/32
	✓ Interrupts	
	Callback	g_poe_overcurrent
	Interrupt Priority	Priority 0 (highest)

Figure 2-33 FSP Configuration of POEG Driver



# 2.3 Software configuration

# 2.3.1 Software file configuration

Folder and file configuration of the software is given below.

# Table 2-6 File and folder configuration[1/2]

Folder	Subfolder	File	Remarks
ra_cfg			Generated config header
ra_gen			Generated register setting, main
			function etc. CMSIS source code
ra	arm		
	board		Function definition for board
	fsp/inc/api	bsp_api.h	BSP API definition
		r_adc_api.h	AD API definition
		r_elc_api.h(Only RA4T1, RA6T3 and RA8T1)	ELC API definition
		r_ioport_api.h	I/O API definition
		r_poeg_api.h	POEG API definition
		r_three_phase_api.h	3phase PWM API definition
		r_timer_api.h	Timer API definition
		r_transfer_api.h	Transfer API definition
		rm_motor_angle_api.h	Angle API definition
		rm_motor_api.h	Motor API definition
		rm_motor_current_api.h	Current API definition
		rm_motor_driver_api.h	Motor driver API definition
		rm_motor_position_api.h	Position API definition
		rm_motor_speed_api.h	Speed API definition
	fsp/inc/instances	r_adc_b.h(RA6T2)	Function definition for AD
		r_adc.h(RA4T1,RA6T3 and RA8T1)	
		r_agt.h	Function definition for AGT
		r_elc.h(Only RA4T1, RA6T3 and RA8T1)	Function definition for ELC
		r_gpt_three_phase.h	Function definition for 3 Phase
			PWM
		r_gpt.h	Function definition for GPT
		r_ioport.h	Function definition for I/O
		r_poeg.h	Function definition for POEG
		rm_motor_current.h	Function definition for current control
		rm_motor_driver.h	Function definition for motor driver
		rm_motor_estimate.h	Function definition for angle estimate
		rm_motor_sensorless.h	Function definition for Sensorless
		rm motor speed.h	Function definition for Speed



Folder	Subfolder	File	Remarks
ra	fsp/lib		Library files
	fsp/src	bsp	BSP driver
		r_adc_b/r_adc_b.c(RA6T2)	AD driver
		r_adc/r_adc.c(RA4T1,RA6T3 and RA8T1)	
		r_agt/r_agt.c	AGT driver
		r_elc/r_elc.c(Only RA4T1, RA6T3 and RA8T1)	ELC driver
		r_gpt/r_gpt.c	GPT driver
		r_gpt_three_phase/ r_gpt_three_phase.c	3 phase PWM driver
		r_ioport/r_ioport.c	I/O driver
		r_poeg/r_poeg.c	POEG driver
		rm_motor_current/rm_motor_current.c	Current control driver
		rm_motor_current/rm_motor_current_library.h	Current control library API
			definition
		rm_motor_driver/rm_motor_driver.c	Motor driver
		rm_motor_estimate.c	Angle estimate driver
		rm_motor_estimate_library.h	Angle estimate library API definition
		rm_motor_sensorless.c	Sensorless driver
		rm_motor_speed/rm_motor_speed.c	Speed control driver
		rm_motor_speed/rm_motor_speed_library.h	Speed control library API definition
src	application/main	mtr_main.h , mtr_main.c	User main function
		r_mtr_control_parameter.h	Control parameters
			definition
		r_mtr_motor_parameter.h	Motor parameters definition
	application/user_interface/ics	r_mtr_ics.h , r_mtr_ics.c	Function definition for
			Analyzer
		ICS2_RA6T2.h , ICS2_RA4T1.h ,	Function definition for GUI
		ICS2_RA6T3.h , ICS2_RA8T1.h	tool
		ICS2_RA6T2.o , ICS2_RA4T1.o ,	Communication library for
		ICS2_RA6T3.o , ICS2_RA8T1.o	GUI tool

# Table 2-7 File and folder configuration[2/2]



# 2.3.2 Module configuration

Module configuration of the software is described below.

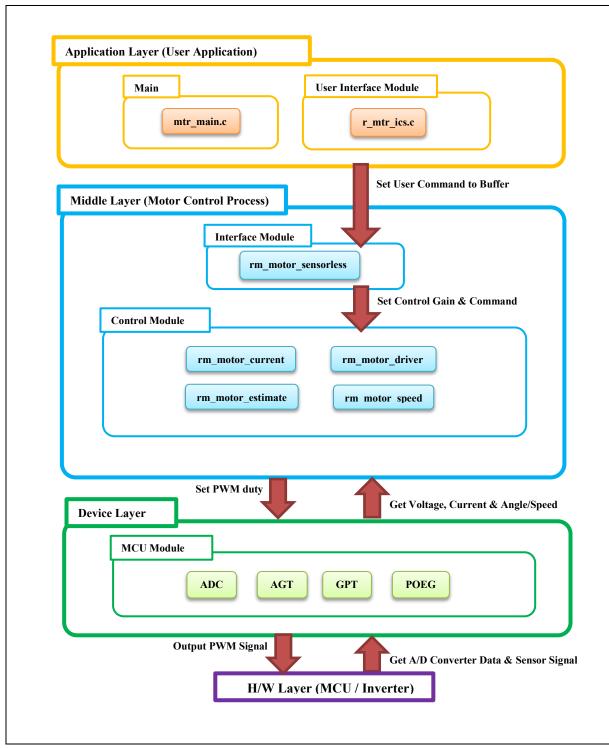


Figure 2-34 Module Configuration



# 2.4 Software specifications

Table 2-8 shows basic software specification of this system. For details of the sensorless vector control, refer to the application note 'Sensorless vector control for permanent magnet synchronous motor (Algorithm)' (R01AN3786).

Item	Content				
Control method	Vector control				
Position detection method	Sensorless				
Motor rotation start/stop	SW1 input or input from 'Renesas Motor Workbench'				
Input voltage	DC 24 [V]				
Main clock frequency	RA6T2: 240 [MHz]				
	RA6T3: 200 [MHz]				
	RA4T1: 100 [MHz]				
	RA8T1: 480 [MHz]				
Carrier frequency (PWM)	10 [kHz] (Carrier period: 100 [	JS])			
Dead time	2 [µs]				
Current control period	RA6T2: 100 [µs]				
	RA6T3: 100 [µs]				
	RA4T1: 200 [µs]				
	RA8T1: 100 [µs]				
Speed control period	RA6T2: 1000 [µs]				
	RA6T3: 1000 [µs]				
	RA4T1: 2000 [µs]				
	RA8T1: 1000 [µs]				
Rotation speed control	CW: 0 [rpm] to 2400 [rpm]				
range	CCW: 0 [rpm] to 2400 [rpm]				
	However, 500 [rpm] or less is driven by a speed open loop.				
Natural frequency	Current control system : 300 [H	Hz]			
of each control system	Speed control system : 5 [Hz]				
	BEMF estimation system : 100	0 [Hz]			
	Position estimation system : 50	) [Hz]			
Optimization setting	Optimization level	Optimize more(-O2) (default setting)			
of compiler					
Processing stop for	Disables the motor control signal output (six outputs), under any of the following conditions.				
protection	1. Instantaneous value of current of any phase exceeds 3.54(=1.67*sqrt (2)*1.5) [A]				
(monitored in current control period)		. ,			
	-	eds 60 [V] (monitored in current control period)			
	-	ss than 8 [V] (monitored in current control period)			
	4. Rotation speed exceeds	4500 [rpm] (monitored in current control period)			
	When an external over current	signal is detected (when a low level is detected), the PWM output			
	ports are set to high impedance state.				

Table 2-8 Basic Specifications of Sensorless	Vector Control Software



# 2.5 Interrupt Priority

Table 2-9 shows the interrupt and priorities used in this system.

#### Table 2-9 Interrupt priority

Interrupt level	Priority	function
15	Min	
14		
13		
12		
11		
10		AGT0 INT
		Speed control Interrupt
9		
8		
7		
6		
5		GPT4 COUNTER OVERFLOW(RA6T2)
		GPT1 COUNTER OVERFLOW (RA4T1,RA6T3)
		GPT5 COUNTER OVERFLOW (RA8T1)
		GPT overflow Interrupt
4		
3		
2		
1		
0		POEG3 EVENT(RA6T2) POEG1 EVENT(RA4T1,RA6T3)
	Мах	POEG0 EVENT(RA8T1)
	Max	Over current error interrupt

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

#### Figure 2-35 RA6T2 FSP Interrupts Configuration

Allocations		
Interrupt	Event	ISR
0	AGT0 INT (AGT interrupt)	agt_int_isr
1	GPT1 COUNTER OVERFLOW (Overflow)	gpt_counter_overflow_isr
2	POEG1 EVENT (Port Output disable interrupt B)	poeg_event_isr

#### Figure 2-36 RA4T1/RA6T3 FSP Interrupts Configuration

Allocations		
Interrupt	Event	ISR
0	POEG0 EVENT (Port Output disable interrupt A)	poeg_event_isr
1	AGT1 INT (AGT interrupt)	agt_int_isr
2	GPT2 COUNTER OVERFLOW (Overflow)	gpt_counter_overflow_isr

#### Figure 2-37 RA8T1 FSP Interrupts Configuration



# 3. Descriptions of the control program

The target software of this application note is explained here.

# 3.1 Contents of control

# 3.1.1 Motor start/stop

Starting and stopping of the motor are controlled by input from 'Renesas Motor Workbench' or SW1.

A general-purpose port is assigned to SW1 and based upon its level the motor operation is controlled.

"High" level  $\rightarrow$  Motor Start

"Low" level  $\rightarrow$  Motor Stop

#### 3.1.2 A/D Converter

#### (1) Motor rotation speed reference

The rotation speed command value of the motor is determined from the input from 'Renesas Motor Workbench' or the output value (analog value) of VR1. Rotation speed command value from VR1 is measured as shown in the table below.

#### Table 3-1 Conversion Ratio of the Rotation Speed Reference

ltem	Conversion ratio (r	Channel	
Rotation speed	CW	0 rpm to 2400 rpm: 0800H to 0FFFH	AN008
reference	CCW	0 rpm to 2400 rpm: 07FFH to 0000H	ANOUG

#### (2) Inverter bus voltage

Inverter bus voltage is measured as shown in the table below. It is used for calculation of modulation rate and detection of overvoltage and low voltage (PWM stops in case of abnormality).

#### 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) Phase current with 1shunt resitance

The phase currents are measured as shown in Table 3-3 and used for vector control.

#### **Table 3-3 Conversion Ratio of Phase Current**

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



# 3.1.3 Modulation (current control module)

A modulated voltage can be output to improve the efficiency of voltage usage. The modulation operation is set from the API of the current control module.

#### (a) Sine wave modulation (MOD\_METHOD\_SPWM)

The modulation factor m is defined as follows.

$$m = \frac{V}{E}$$
m:Modulation ratio V:Reference voltage E:Inverter input voltage

#### (b) Space Vector Modulation (MOD\_METHOD\_SVPWM) \*

In vector control of a permanent magnet synchronous motor, generally, the desired voltage command value of each phase is generated sinusoidally. However, if the generated value is used as-is for the modulation wave for PWM generation, voltage utilization as applied to the motor (in terms of line voltage) is limited to a maximum of 86.7% with respect to inverter bus voltage. As such, as shown in the following expression, the average of the maximum and minimum values is calculated for the voltage command value of each phase, and the value obtained by subtracting the average from the voltage command value of each phase is used as the modulation wave. As a result, the maximum amplitude of the modulation wave is multiplied by  $\sqrt{3}/2$ , while voltage utilization becomes 100% and line voltage is unchanged.

$$\begin{pmatrix} V'_{u} \\ V'_{v} \\ V'_{w} \end{pmatrix} = \begin{pmatrix} V_{u} \\ V_{v} \\ V_{w} \end{pmatrix} + \Delta V \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}$$
  
$$\therefore \Delta V = -\frac{V_{max} + V_{min}}{2} , V_{max} = max\{V_{u}, V_{v}, V_{w}\} , V_{min} = min\{V_{u}, V_{v}, V_{w}\}$$
  
$$V_{u}, V_{v}, V_{w}: \text{ Command values of U-, V-, and W-phases}$$
  
$$V'_{u}, V'_{v}, V'_{w}: \text{ Command values of U-, V-, and W-phases for PWM generation (modulation wave)}$$

The modulation factor m is defined as follows.

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

m:Modulation ratio \$V'\$ :Reference phase voltage for PWM E:Inverter input voltage



# 3.1.4 State transition

Figure **3-1** is a state transition diagram of the sensorless vector control software. In the target software of this application note, the software state is managed by "SYSTEM MODE". Motor 1 and 2 are controlled in the same method.

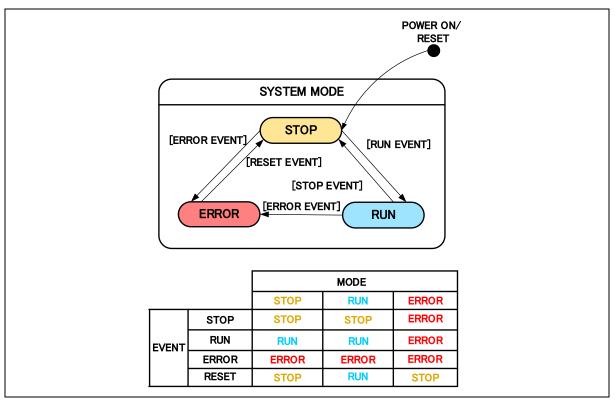


Figure 3-1 State Transition Diagram of Sensorless Vector Control Software

#### (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). EVENT

When "EVENT" occurs in each "SYSTEM MODE", "SYSTEM MODE" changes as shown the table in Table 3-4, 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 Start-up method

Figure **3-2** shows startup control of sensorless vector control software. Each mode is controlled by flags managing each reference of the d-axis current, q-axis current, and speed.

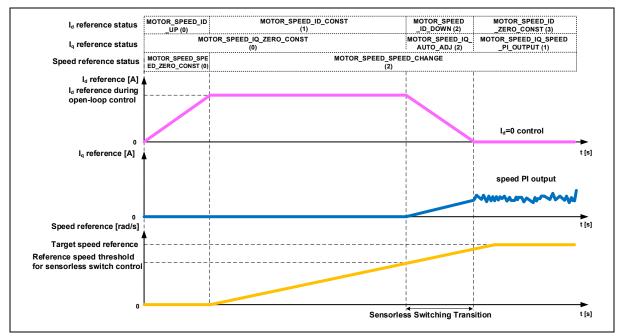


Figure 3-2 Startup Control of Sensorless Vector Control Software



#### 3.1.6 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

There are two kind of overcurrent protection.

Hardware OCP: When emergency stop signal from the hardware is detected, PWM output ports are automatically set to high impedance output (without software intervention).

Software OCP: U, V, and W phase currents are monitored in over current monitoring cycle. When an over current is detected, the CPU executes emergency stop.

#### - 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. When this error occurs, the CPU performs emergency stop in the side of the motor in which the error occurred.

#### - 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. When this error occurs, the CPU performs emergency stop in the side of the motor in which the error occurred.

#### - 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. When this error occurs, the CPU performs emergency stop in the side of the motor in which the error occurred.

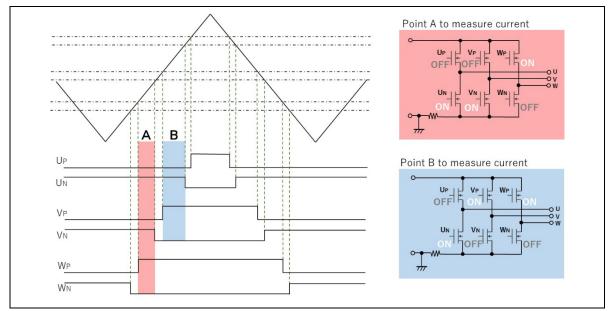
Error name	Threshold		Monitoring cycle
Over current error	Over current limit [A]	3.54	Current control
Over voltage error	Over voltage limit [V]	60	Current control
Low voltage error	Low voltage limit [V]	8	Current control
Over speed error	Speed limit [rpm]	4500	Current control

#### **Table 3-5 Setting Values of the System Protection Function**



## 3.1.7 The method to measure phase currents with an 1shunt resistance

In the chapter, the method to measure phase currents using in this software is explained.



## 3.1.7.1 The timing of measure phase currents



In this program, Triangle-wave PWM mode 3 is used to generate PWM wave with dead time by GPT unit. Figure **3-3** shows the wave form of PWM 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 that case, the current which flows in the 1shunt resistance is same as current flows in W phase.

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

The remained V phase current can be calculated with these phase currents by the first theory of Kirchhoff.

Therefore, the three phase currents can be measured with measurement of point A and B.

The case which is shown in Figure **3-3** is the duty pattern W>V>U. Six duty pattern will be performed with each phase PWM output. The currents which be measured in point A and B changes according to duty pattern, so it is necessary to assign calculated currents to each phase. The assignment is possible, because each phase relations can be known at each PWM duty calculation.

#### Table 3-6 Relation between Duty pattern and phase current

Duty pattern	Point A	Point B
W > V > U	lw	-lu
W > U > V	lw	-lv
V > W > U	lv	-lu
V > U > W	lv	-lw
U > W > V	lu	-lv
U > V > W	lu	-lw



#### 3.1.7.2 Shunt resistance current measurement method using RA6T2 function

When measuring the current with one shunt resistor as shown in 3.1.7.1, 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 realized by GTADTRA of RA6T2 GPT module and A / D conversion start request function by compare match of GTADTRB register and GTCNT counter.

Settings	Property	Value
API Info	✓ Common	
AFTIMO	Parameter Checking	Default (BSP)
	Pin Output Support	Enabled with Extra Features
	Write Protect Enable	Disabled
	Clock Source	PCLKD
	<ul> <li>Module g_timer0 Timer, General PWM (r_gpt)</li> </ul>	
	✓ General	
	Name	g_timer0
	Channel	â 4
	Mode	Triangle-Wave Asymmetric PWM (Mode 3)
	Period	â 100
	Period Unit	G 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	
	Callback	rm_motor_driver_1shunt_cyclic
	Overflow/Crest Interrupt Priority	Priority 8
	Capture A Interrupt Priority	Disabled
	Capture B Interrupt Priority	Disabled
	Underflow/Trough Interrupt Priority	Disabled
	✓ Extra Features	
	> Output Disable	
	✓ ADC Trigger	
	<ul> <li>Start Event Trigger (GPTE/GPTEH only)</li> </ul>	
	Trigger Event A/D Converter Start Request A Dur	
	Trigger Event A/D Converter Start Request A Dur	
	Trigger Event A/D Converter Start Request B Durin	
	Trigger Event A/D Converter Start Request B Dur	
	> Dead Time	
	> ADC Trigger (GPTE/GPTEH only)	
	> Interrupt Skipping (GPTE/GPTEH only)	
	Extra Features	🔒 Enabled

Figure 3-4 GPT ADC trigger setting



## 3.1.7.3 Duty adjustment

If the timing as shown in 3.1.7.1 can be secured, the current can be detected by one shunt resistor, but sufficient time for A / D conversion cannot be secured depending on the PWM duty setting conditions during operation. Therefore, the current value cannot be obtained correctly. 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 required for A / D conversion. The conversion time is secured by shifting only.

#### (2) When timing shift is not possible

If the PWM switching timing is delayed as described above, the duty is wide, and if the end of the PWM carrier cycle is reached, the timing cannot be delayed. 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.

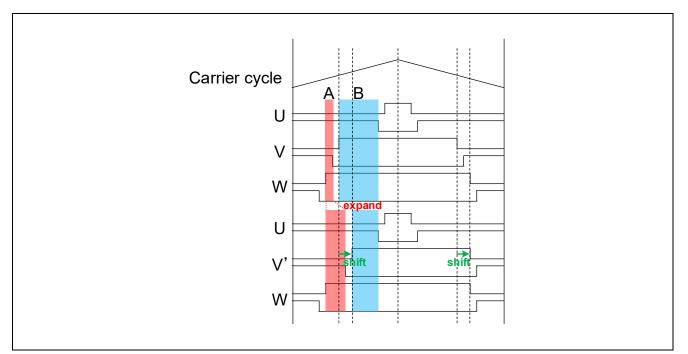


Figure 3-5 Duty adjustment



# 3.1.8 AD triggers

Shows the timing of AD triggers and scan groups.

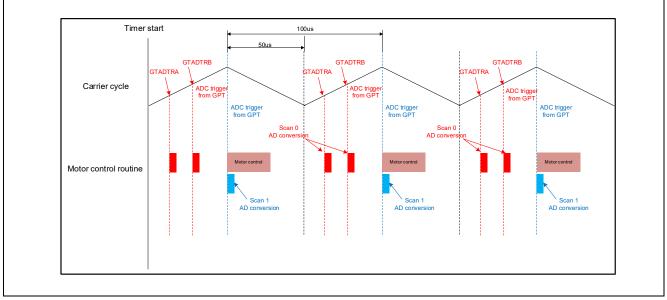


Figure 3-6 AD trigger timing



# 3.2 Function specifications of sensorless vector control software

The block diagram of sensorless vector control is shown below.

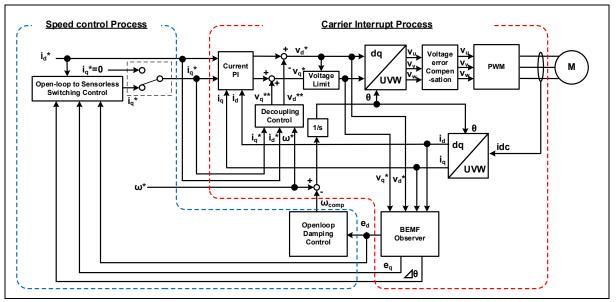


Figure 3-7 Block Diagram of Sensorless Vector Control (Openloop Control)

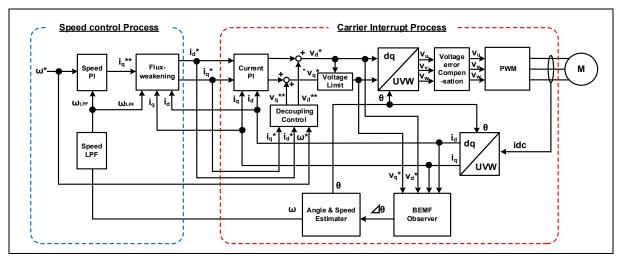


Figure 3-8 Block Diagram of Sensorless Vector Control (Sensorless Control)



File name	Function name	Process overview
mtr_main.c	mtr_callback_event Input : (motor_callback_args_t *) p_args / Callback argument Output : None	Sensorless control callback function
	rm_motor_sensorless_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_sensorless.c	RM_MOTOR_SENSORLESS_ErrorCheck Input : (motor_ctrl_t * const) p_ctrl / Pointer to control structure. (uint16_t * const) p_error / Pointer to get occured error Output : fsp_err_t / Execution result	Check the occurrence of Error.
	rm_motor_sensorless_copy_speed_current Input : (motor_speed_output_t *) st_output / Pointer to the structure of Speed Control output (motor_current_input_t *) st_input / Pointer to the structure of Current Control input Output :None	Copy speed output data to current input data
rm_motor_driver.c	rm_motor_driver_1shunt_cyclic Input : ((timer_callback_args_t *) p_args / Callback argument Output :None	Motor driver callback function
	rm_motor_driver_1shunt_current_get Input : (motor_driver_instance_ctrl_t *) p_ctrl / The pointer to the motor driver module instance Output :None	Get A/D converted data (Phase Current with 1shunt resistance & 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.

#### Table 3-7 List of Functions Executed in Current Control Period Interrupt (1/4)



File name	Function name	Process overview
	rm_motor_driver_1shunt_modulation Input : (motor_driver_instance_ctrl_t *) p_ctrl / The pointer to the motor driver module instance Output :None	Perform PWM modulation (included duty pattern judgement)
	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 the 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.c	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 : fsp_err_t / Execution result	PWM duty setting
	RM_MOTOR_DRIVER_CurrentGet Input : (motor_driver_ctrl_t * const) p_ctrl / Pointer to control structure (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 & 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_t const * const) p_st_input / Pointer to input data 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 / the pointer to the UVW-phase array in [U,V,W] format (float *) f_dq / where to store the [d,q] formated array on dq coordinates Output :None	Coordinate transform UVW to dq (absolute transform)

#### Table 3-8 List of Functions Executed in Current Control Period Interrupt (2/4)



#### Table 3-9 List of Functions Executed in Current Control Period Interrupt (3/4)

File name	Function name	Process overview
	motor_current_angle_cyclic Input : (motor_current_instance_t *) p_instance / The 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 & rotor phase Data.
	RM_MOTOR_CURRENT_CurrentReferenceSet Input : (motor_current_ctrl_t * const) p_ctrl / Pointer to control structure (float const) id_reference / D-axis current Reference (float const) iq_reference / Q-axis current Reference 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	Gets the set phase voltage.
rm_motor_current.c	motor_current_pi_calculation Input : (motor_current_instance_ctrl_t *) p_ctrl / The 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 / The 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
	<pre>motor_current_decoupling Input : (motor_current_instance_ctrl_t *) p_ctrl / The pointer to the FOC current control instance (float) f_speed_rad / The electrical speed (const motor_current_motor_parameter_t *) p_mtr / The pointer to the motor parameter data structure Output :None</pre>	Decoupling control
	motor_current_voltage_limit Input : (motor_current_instance_ctrl_t *) p_ctrl / The pointer to the FOC current control structure Output :None	Limit voltage vector



File name	Function name	Process overview
rm_motor_current.c	<pre>motor_current_transform_dq_uvw_abs Input : (const float) f_angle / Rotor angle (const float *) f_dq / The pointer to the dq-axis value array in [D,Q] format f_uvw / Where to store the [U,V,W] formated 3-phase quantities array (float *) Output :None</pre>	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_ESTIMATE_FlagPiCtrlSet Input : (motor_angle_ctrl_t * const) p_ctrl / Pointer to control structure (uint32_t const) flag_pi / The flag of PI control runs Output : fsp_err_t / Execution result	Set the flag of PI Control runs.
rm_motor_estimate.c	RM_MOTOR_ESTIMATE_SpeedSet Input : (motor_angle_ctrl_t * const) p_ctrl / Pointer to control structure (float const) speed_ctrl / Control reference of rotational speed (float const) damp_speed / Damping rotational speed Output : fsp_err_t / Execution result	Set Speed Information
	RM_MOTOR_ESTIMATE_CurrentSet         Input : (motor_angle_ctrl_t * const) p_ctrl / Pointer to control structure         (motor_angle_current_t * const) p_st_current / Pointer to current         structure         (motor_angle_voltage_reference_t * const) p_st_voltage / Pointer to         voltage Reference structure         Output : fsp_err_t / Execution result	Set d/q-axis Current Data & Voltage Reference.
	RM_MOTOR_ESTIMATE_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.
	RM_MOTOR_ESTIMATE_EstimatedComponentGet Input : (motor_angle_ctrl_t * const) p_ctrl / Pointer to control structure (float * const) p_ed / Memory address to get estimated d-axis component (float * const) p_eq / Memory address to get estimated q-axis component Output : fsp_err_t / Execution result	Gets estimated d/q-axis component.
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 3-10 List of Functions Executed in Current Control Period Interrupt (4/4)



File name	Function name	Process overview
	mtr_callback_event	Sensorless control
	Input : (motor_callback_args_t *)	callback function
	/ Callback argument	
mtr_main.c	Output :None	
	get_vr1	Get VR1 A/D conversion
	Input :None	value
	Output : uint16_t / conversion value	
	RM_MOTOR_CURRENT_ParameterGet	Get speed control input
	Input : (motor_current_ctrl_t * const) p_ctrl / Pointer to control	data from current contro
rm motor ourrent o	structure	
rm_motor_current.c	(motor_current_output _t * const) p_st_output / Pointer to output data	
	structure	
	Output : fsp_err_t / Execution result	
	rm_motor_sensorless_speed_callback	Speed control callback
	Input : (motor_speed_callback_args_t *) p_args / Callback argument	function
	Output :None	
	rm_motor_sensorless_copy_current_speed	Copy current output data
rm_motor_sensorless.c	Input : (motor_current_output_t *) st_output / Pointer to the structure	to speed input data
	of Current Control output	
	(motor_speed_input_t *) st_input / Pointer to the structure of Speed	
	Control input	
	Output :None	
	rm motor speed cyclic	Cyclic process of Speed
	Input : (timer_callback_args_t *) p_args/ Callback argument	Control (Call at timer
	Output :None	interrupt)
	RM_MOTOR_SPEED_ParameterSet	Set speed Input
	Input : (motor_speed_ctrl_t * const) p_ctrl / Pointer to control	parameters
	structure	
	(motor_speed_input_t const * const) p_st_input / Pointer to structure	
	to input parameters	
	Output : fsp_err_t / Execution result	
	RM_MOTOR_SPEED_SpeedControl	Calculates the d/q-axis
	Input : (motor_speed_ctrl_t * const) p_ctrl / Pointer to control	current reference.(Main
	structure	process of Speed
	Output : fsp_err_t / Execution result	Control)
	rm motor speed set speed ref	Updates the speed
	Input : (motor_speed_instance_ctrl_t *) p_ctrl / The pointer to the	reference
rm_motor_speed.c	FOC data instance	
	Output : float / Speed reference	
	rm motor speed set iq ref	Updates the q-axis
	Input : (motor_speed_instance_ctrl_t *) p_ctrl / The pointer to the ctrl	current reference
	instance	
	Output : float / lq reference	
	rm motor speed set id ref	Updates the d-axis
	Input : (motor_speed_instance_ctrl_t *) p_ctrl / The pointer to the ctrl	current reference
	instance	
	Output : float / ld reference	
	RM_MOTOR_SPEED_ParameterGet	Get speed control output
	Input : (motor_speed_ctrl_t * const) p_ctrl / The pointer to the ctrl	parameters
	instance	
	(motor_speed_output_t * const) p_st_output / Pointer to get speed	
	control parameters	

#### Table 3-11 List of Functions Executed in Speed Control Interrupt(1/2)



Function name	Process overview
rm_motor_speed_first_order_lpf Input : (motor_speed_lpf_t *) p_lpf / First order LPF structure (float) f4_omega / Natural frequency (float) f4_ctrl_period / Control period Output : None	First Order LPF
rm_motor_speed_fluxwkn_set_vamax Input : (motor_speed_flux_weakening_t *) p_fluxwkn / The 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 / The pointer to flux weakening structure (float) f4_speed_rad / The electrical speed of motor (const float *) p_f4_idq / The pointer to the measured current vector in format d/q (float *) p_f4_idq_ref / The pointer to the reference current vector in format d/q	Executes the flux- weakening module
	<pre>rm_motor_speed_first_order_lpf Input : (motor_speed_lpf_t *) p_lpf / First order LPF structure (float) f4_omega / Natural frequency (float) f4_ctrl_period / Control period Output : None rm_motor_speed_fluxwkn_set_vamax Input : (motor_speed_flux_weakening_t *) p_fluxwkn / The pointer to flux weakening structure (float) f4_va_max / maximum magnitude of voltage vector Output :None rm_motor_speed_fluxwkn_run Input : (motor_speed_flux_weakening_t *) p_fluxwkn / The pointer to flux weakening structure (float) f4_speed_flux_weakening_t *) p_fluxwkn / The pointer to flux weakening structure (float) f4_speed_rad / The electrical speed of motor (const float *) p_f4_idq / The pointer to the measured current vector in format d/q (float *) p_f4_idq_ref / The pointer to the reference current vector in</pre>



# 3.3 Contents of control

# 3.3.1 Configuration Options

The configuration options of the sensorless vector control module for motor can be configured using the RA Configurator. The changed options are automatically reflected to the hal\_data.c when generating code. The option names and setting values are listed in the Table 3-13 shown as follows.

Table 3-13 Co	nfiguration	Options	(rm_	_motor_	_sensorless.h)
---------------	-------------	---------	------	---------	----------------

Options	Description
Limit of over current (A)	When a phase current exceeds this value, PWM output ports are set to off.
Limit of over voltage (V)	When an inverter voltage exceeds this value, PWM output ports are set to off.
Limit of over speed (rpm)	When a rotation speed exceeds this value, PWM output ports are set to off.
Limit of low voltage (V)	When an inverter voltage becomes below this value, PWM output ports are set to off.

Table 3-14 Configuration Options initial value(rm\_motor\_sensorless.h)

Options	RA6T2	RA4T1	RA6T3	RA8T1
Limit of over current (A)	1.67	1.67	1.67	1.67
Limit of over voltage (V)	60.0	60.0	60.0	60.0
Limit of over speed (rpm)	4500.0	4500.0	4500.0	4500.0
Limit of low voltage (V)	8.0	8.0	8.0	8.0

# 3.3.2 Configuration Options for included modules

The sensorless vector control module for motor includes below modules.

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

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



#### Table 3-15 Configuration Options for Current Control

Configuration Options (rm_motor_current.h)	
Options	Description
General   Shunt type	Selects how many shunt resistances to use current detection.
General   Current control decimation	Counts of decimation about carrier interrupt
General   PWM carrier frequency (kHz)	PWM carrier frequency [kHz]
General   Input voltage (V)	Input voltage [V]
General   Sample delay compensation	Selects whether to "enable" or "disable" sample delay compensation
General   Period magnification value	Period magnification value for sampling delay compensation.
General   Voltage error compensation	Selects whether to "enable" or "disable" voltage error compensation.
General   Voltage error compensation table of voltage 1	Table of voltage error compensation about voltage #1
General   Voltage error compensation table of voltage 2	Table of voltage error compensation about voltage #2
General   Voltage error compensation table of voltage 3	Table of voltage error compensation about voltage #3
General   Voltage error compensation table of voltage 4	Table of voltage error compensation about voltage #4
General   Voltage error compensation table of voltage 5	Table of voltage error compensation about voltage #5
General   Voltage error compensation table of current 1	Table of voltage error compensation about current #1
General   Voltage error compensation table of current 2	Table of voltage error compensation about current #2
General   Voltage error compensation table of current 3	Table of voltage error compensation about current #3
General   Voltage error compensation table of current 4	Table of voltage error compensation about current #4
General   Voltage error compensation table of current 5	Table of voltage error compensation about current #5
Design Parameter   Current PI loop omega	Current PI control omega parameter [Hz].
Design Parameter   Current PI loop zeta	Current PI control zeta parameter.
Motor Parameter   Pole pairs	Pole pairs of target motor.
Motor Parameter   Resistance (ohm)	Resistance of motor [ohm].
Motor Parameter   Inductance of d-axis (H)	D-axis inductance [H].
Motor Parameter   Inductance of q-axis (H)	Q-axis inductance [H].
Motor Parameter   Permanent magnetic flux (Wb)	Magnetic flux [Wb].
Motor Parameter   Rotor inertia (kgm^2)	Rotor inertia [kgm^2].



#### Table 3-16 Configuration Options initial value(rm\_motor\_current.h)

Options	RA6T2	RA4T1	RA6T3	RA8T1
General   Shunt type	1shunt	1shunt	1shunt	1shunt
General   Current control decimation	0	1	0	0
General   PWM carrier frequency (kHz)	10.0	10.0	10.0	10.0
General   Input voltage (V)	24.0	24.0	24.0	24.0
General   Sample delay	Disable	Disable	Disable	Disable
compensation	Disable	Disable	Disable	Disable
General   Period magnification value	1.5	1.5	1.5	1.5
General   Voltage error	Enable	Enable	Enable	Enable
compensation	LINDIC	LINADIC	LINDIC	LINADIC
General   Voltage error	0.477	0.477	0.477	0.477
compensation table of voltage 1	0.477	0.477	0.477	0.477
General   Voltage error	0.742	0.742	0.742	0.742
compensation table of voltage 2	0.1.12	0.1.12	0.1.12	0.1 12
General   Voltage error	0.892	0.892	0.892	0.892
compensation table of voltage 3				
General   Voltage error	0.979	0.979	0.979	0.979
compensation table of voltage 4				
General   Voltage error	1.009	1.009	1.009	1.009
compensation table of voltage 5				
General   Voltage error	0.021	0.021	0.021	0.021
compensation table of current 1				
General   Voltage error	0.034	0.034	0.034	0.034
compensation table of current 2				
General   Voltage error	0.064	0.064	0.064	0.064
compensation table of current 3				
General   Voltage error	0.158	0.158	0.158	0.158
compensation table of current 4	0.400	0.400	0.400	0.400
General   Voltage error	0.400	0.400	0.400	0.400
compensation table of current 5	200.0	200.0	200.0	200.0
Design Parameter   Current PI loop	300.0	300.0	300.0	300.0
omega Design Parameter   Current PI loop	1.0	1.0	1.0	1.0
zeta	1.0	1.0	1.0	1.0
Motor Parameter   Pole pairs	4	4	4	4
	1.3	1.3	1.3	1.3
Motor Parameter   Resistance (ohm)				
Motor Parameter   Inductance of d-	0.0013	0.0013	0.0013	0.0013
axis (H) Motor Parameter   Inductance of q-	0.0013	0.0013	0.0013	0.0013
axis (H)	0.0013	0.0013	0.0013	0.0013
Motor Parameter   Permanent	0.01119	0.01119	0.01119	0.01119
magnetic flux (Wb)	0.01113	0.01113	0.01113	0.01113
Motor Parameter   Rotor inertia	0.000003666	0.000003666	0.000003666	0.000003666
(kgm^2)	0.0000000000000000000000000000000000000	0.0000000000000000000000000000000000000	0.0000000000000000000000000000000000000	5.000000000



# Table 3-17 Configuration Options for Speed Control

Options         Description           Common   Position support         Support position control           General   Step of speed control period (sec)         The period of speed control process [sec].           General   Step of speed climbing (rpm)         The step of speed fluctuation [rpm]. Program controls speed by this step at acceleration and deceleration.           General   Maximum rotational speed (rpm)         Maximum rotational speed (rpm)           General   Speed LPF omega         Speed LPF parameter omega [Hz].           General   Step of speed fleedback at open-loop         Copen-Loop.           General   Open-loop damping         Select enable/disable of flux weakening control at Open-Loop.           General   Torque compensation for select enable/disable of speed observer         Select enable/disable of speed observer process           General   Selection of speed observer         Select enable/disable of speed observer           General   Selection of speed observer         Select the position control method.           Open-Loop   Step of d-axis current climbing         The d-axis current reference ramping down proportion to reference before open-loop [A/msec].           Open-Loop   Step of d-axis current         The d-axis current reference in open-loop drive [A].           Open-Loop   Step of d-axis current         The d-axis current reference in open-loop drive [A].           Open-Loop   Step of d-axis current         The d-axis current reference in open-loop drive [A].	Configuration Options (rm_motor_speed.	
Common   Position support         Support position control           General   Speed control period (sec)         The period of speed control process [sec].           General   Step of speed climbing (rpm)         Speed by this step at acceleration and deceleration.           General   Maximum rotational speed (rpm)         Maximum rotational speed [rpm]           General   Maximum rotational speed (rpm)         Maximum rotational speed [rpm]           General   Maximum rotational speed (rpm)         Maximum rotational speed [rpm]           General   Natural frequency         Natural frequency for disturbance speed observer.           General   Natural frequency         Natural frequency for disturbance speed observer.           General   Natural frequency         Natural frequency for disturbance speed observer.           General   Control method         Select enable/disable of full weakening control at Open-Loop.           General   Speed observer         Select enable/disable of speed observer process           General   Speed observer         Select enable/disable of speed observer           General   Control method         Select enable/disable of speed observer           General   Speed d-axis current climbing         The d-axis current reference ramping down rate [A/msec].           Open-Loop   Step of d-axis current         The d-axis current reference ramping down rate [A/msec].           Open-Loop   Inreshold of speed control         The speed threshold		•
General         Speed control period (sec)         The period of speed functuation (process [sec].           General         [Step of speed climbing (rpm)         The step of speed fluctuation (prm]. Program controls speed fluctuation (speed fluctuation (speed fluctuation).           General         [Step of speed PF ormega         Speed LPF parameter momga [Hz].           General         [Step of speed fledback at open-loop.         Rate of reference speed for feedback speed limiter at Open-Loop.           General         [Step of speed observer.         Select enable/disable of damping control at Open-Loop.           General         [Pon-loop damping         Select enable/disable of flux weakening control at Open-Loop.           General         [Pon-loop damping         Select enable/disable of speed observer.           General         [Step of d-axis current form Open-Loop to PI control.         General           General         [Step of d-axis current climbing         The d-axis current reference ramping up rate [A/msec].           General         [Step of d-axis current         The d-axis current reference ramping down rate [A/msec].           General         [Step of d-axis current         The d-axis current reference ramping up rate [A/msec].           General         [Step of d-axis current         The d-axis current reference ramping down rate [A/msec].           General         [Step of d-axis current         The d-axis current reference rampi		
General   Step of speed climbing (rpm)         The step of speed fluctuation [rpm]. Program controls speed by this step at acceleration and deceleration.           General   Maximum rotational speed (rpm)         Maximum rotational speed [rpm]           General   Control of speed DeP ornega         Speed LPF prameter ornega [Hz].           General   Step of speed feedback at open-loop.         Rate of reference speed for feedback speed limiter at Open-Loop.           General   Natural frequency         Natural frequency for disturbance speed observer.           General   Natural frequency         Natural frequency for disturbance speed observer.           General   Torque compensation for select enable/disable of fux weakening control at high speed.         Select enable/disable of speed observer process           General   Step of axis current climbing         Select the method of speed observer         Select the position control method.           General   Step of a-axis current climbing         The d-axis current reference ramping down rate [A/msec].           Open-Loop   Step of a-axis current         The d-axis current reference ramping down the d-axis current [A].           Open-Loop   Step of a-axis current         The d-axis current reference in open-loop drive [A].           Open-Loop   Threshold of speed control         The g-axis current reference in open-loop drive [A].           Open-Loop   Threshold of speed control         The speed threshold [rad/s] to ramp down the d-axis current [rpm].           Open-Loop   Period		
General   Maximum rotational speed (rpm)         Maximum rotational speed (rpm)           General   Limit of q-axis current (A)         Limit of q-axis current [A].           General   Limit of q-axis current (A)         Limit of q-axis current [A].           General   Natural frequency         Natural frequency for disturbance speed observer.           General   Natural frequency         Natural frequency for disturbance speed observer.           General   Netweakening         Select enable/disable of flaw weakening control at high speed.           General   Speed observer         Select enable/disable of speed observer process           General   Speed observer         Select the method of speed observer           General   Selection of speed observer         Select the position control method.           General   Speed dobserver         Select the position control method.           General   Speed dobserver         Select the position control method.           Open-Loop   Step of d-axis current         The d-axis current reference ramping down rate [A/mscc].           Open-Loop   Step of d-axis current         The d-axis current reference ramping down the d-axis current [rpm].           Open-Loop   Nareshold of speed control drighes speed threshold [rad/s] to ramp up the d-axis current [rpm].           Open-Loop   Phreshold of speed control drime switch upen-loop damping and design.           Open-Loop   Phreshold of speed Phop geta Speed Pl Control parameter omega. <tr< td=""><td></td><td>The step of speed fluctuation [rpm]. Program controls</td></tr<>		The step of speed fluctuation [rpm]. Program controls
General         Speed LPF parameter omega [Hz].           General         Step of speed feedback at open- loop         Limit of q-axis current [A].           General         Netural frequency         Natural frequency for disturbance speed observer.           General         Open-loop.         Select enable/disable of damping control at Open-Loop.           General         Natural frequency         Natural frequency for disturbance speed observer.           General         Flux weakening         Select enable/disable of flux weakening control at Npen-Loop to PI control.           General         Speed observer         Select enable/disable of speed observer process           General         Speed observer         Select the position control method.           Open-Loop         Step of d-axis current climbing         The d-axis current reference ramping up rate [A/msec].           Open-Loop         Step of d-axis current         The d-axis current reference ramping down proportion to reference before open-loop [A/msec].           Open-Loop         Threshold (rad/s) to ramp down the d-axis current [mm].         Open-Loop [A/msec].           Open-Loop         Threshold of speed observer to decide sensor-less [sec].         The d-axis current reference in open-loop drive [A].           Open-Loop         Threshold of speed control         The speed threshold [rad/s] to ramp down the d-axis current [mm].           Open-Loop         Th	General   Maximum rotational speed (rpm)	
General   Limit of q-axis current (A)         Limit of q-axis current [A].           General   Step of speed feedback at open- loop         Rate of reference speed for feedback speed limiter at Open-Loop.           General   Natural frequency         Natural frequency for disturbance speed observer.           General   Flux weakening         Select enable/disable of famping control at Open-Loop.           General   Torque compensation for sensorless transition         Select enable/disable of speed observer           General   Selection of speed observer         Select the method of speed observer process           General   Selection of speed observer         Select the position control method.           Open-Loop   Step of d-axis current climbing         The d-axis current reference ramping down rate [A/msec].           Open-Loop   Step of d-axis current         The d-axis current reference ramping down proportion to descending ratio           Open-Loop   Reference of d-axis current         The d-axis current reference in open-loop drive [A].           Open-Loop   Neference of d-axis current         The d-axis current reference in open-loop drive [A].           Open-Loop   Threshold of speed control climbing         The speed threshold [rad/s] to ramp down the d-axis current [rpm].           Open-Loop   Phreshold of speed control climbing         The speed threshold [rad/s] to ramp down the d-axis current [rpm].           Open-Loop   Phreshold of speed control climbing         The speed threshold [rad/s] to ramp down the d-axis cur		
General   Step of speed feedback at open- loop         Rate of reference speed for feedback speed limiter at Open-Loop.           General   Natural frequency         Natural frequency for disturbance speed observer.           General   Flux weakening         Select enable/disable of damping control at Open-Loop.           General   Torque compensation for sensorless transition         Select enable/disable of soft switching at the transition from Open-Loop to P1 control.           General   Speed observer         Select the method of speed observer process           General   Speed observer         Select the position control method.           Open-Loop   Step of d-axis current climbing         The d-axis current reference ramping down rate [A/msec].           Open-Loop   Step of d-axis current         The d-axis current reference ramping down proportion to reference before open-loop [A/msec].           Open-Loop   Step of q-axis current         The d-axis current reference in open-loop drive [A].           Open-Loop   Threshold of speed control descending         The q-axis current reference in open-loop drive [A].           Open-Loop   Threshold of speed control dimbing         The speed threshold [rad/s] to ramp up the d-axis current [rpm].           Open-Loop   Threshold of speed control design parameter   Speed P1 loop omega         Speed P1 Control parameter omega.           Design parameter   Speed P1 loop omega         Speed P1 Control parameter zeta.           Design parameter   Open-loop damping and esign.         Speed P1	· · · · · · · · · · · · · · · · · · ·	
General         Natural frequency         Natural frequency for disturbance speed observer.           General         Open-loop damping         Select enable/disable of damping control at Open-Loop.           General         Flux weakening         Select enable/disable of flux weakening control at high speed.           General         Speed observer         Select enable/disable of soft switching at the transition from Open-Loop to PI control.           General         Speed observer         Select enable/disable of speed observer process           General         Control method         Select the method of speed observer           General         Control method         Select the position control method.           Open-Loop         Step of d-axis current climbing         The d-axis current reference ramping down proportion to reference open-loop [Atep of d-axis current           Open-Loop         Step of q-axis current         The q-axis current reference in open-loop drive [A].           Open-Loop         Reference of d-axis current         The speed threshold [rad/s] to ramp up the d-axis current [rpm].           Open-Loop         Presold of speed control         The speed threshold [rad/s] to ramp up the d-axis current [rpm].           Open-Loop         Presold of speed control         The speed threshold [rad/s] to ramp up the d-axis current [rpm].           Open-Loop         Presold of speed control         The speed threshold [rad/s] to ramp up t		
General         Open-loop damping         Select enable/disable of damping control at Open-Loop.           General   Flux weakening         Select enable/disable of flux weakening control at high speed.           General   Speed observer         Select enable/disable of speed observer process           General   Speed observer         Select enable/disable of speed observer process           General   Speed observer         Select the method of speed observer           General   Speed observer         Select the position control method.           Open-Loop   Step of d-axis current climbing         The d-axis current reference ramping down rate [A/msec].           Open-Loop   Step of d-axis current         The d-axis current reference ramping down proportion to reference before open-loop [A/msec].           Open-Loop   Threshold of speed control current [rpm].         The speed threshold [rad/s] to ramp down the d-axis current [rpm].           Open-Loop   Threshold of speed control [rpm].         The speed threshold [rad/s] to ramp up the d-axis current [rpm].           Open-Loop   Preiod between open-loop to BLMF (sec)         The speed threshold [rad/s] to ramp up the d-axis current [rpm].           Open-Loop   Preiod between open-loop to BLMF (sec)         Time to switch open-loop to sensor-less [sec].           Design parameter   Speed PI loop omega         Speed PI Control parameter omega.           Design parameter   Speed PI loop omega         Speed PI Control parameter omega.           Design		
General   Flux weakening         Select enable/disable of flux weakening control at high speed.           General   Torque compensation for sensorless transition         Select enable/disable of soft switching at the transition from Open-Loop to Pl control.           General   Speed observer         Select enable/disable of speed observer process           General   Speed observer         Select the position control method.           Open-Loop   Step of d-axis current climbing         The d-axis current reference ramping dwn rate [A/msec].           Open-Loop   Step of d-axis current         The d-axis current reference ramping down rate [A/msec].           Open-Loop   Step of q-axis current         The q-axis current reference ramping down proportion to reference before open-loop [A/msec].           Open-Loop   Threshold of speed control         The speed threshold [rad/s] to ramp down the d-axis current [rpm].           Open-Loop   Threshold of speed control         Time to switch open-loop to sensor-less [sec].           Open-Loop   Preiod between open-loop to game are provide		
sensorless transition         from Open-Loop to PI control.           General   Speed observer         Select enable/disable of speed observer process           General   Control method         Select the position control method.           Open-Loop   Step of d-axis current climbing         The d-axis current reference ramping up rate [A/msec].           Open-Loop   Step of d-axis current         The d-axis current reference ramping down proportion to reference before open-loop [A/msec].           Open-Loop   Step of q-axis current         The d-axis current reference in open-loop drive [A].           Open-Loop   Step of d-axis current         The d-axis current reference in open-loop drive [A].           Open-Loop   Reference of d-axis current         The d-axis current reference in open-loop drive [A].           Open-Loop   Threshold of speed control         The speed threshold [rad/s] to ramp down the d-axis current [rpm].           Open-Loop   Threshold of speed control         Time to switch open-loop to sensor-less [sec].           BEMF (sec)         Time to switch open-loop to sensor-less [sec].           Open-Loop   Phase error(degree) to decide sensor-less switch timing         Speed PI Control parameter omega.           Design parameter   Speed PI loop omega         Speed PI Control parameter zeta.           Design parameter   Cutoff frequency of phase error LPF         The cut-off frequency [Hz] of phase error LPF gain design.           Design parameter   Speed observer zeta         Speed		Select enable/disable of flux weakening control at high
General   Speed observer         Select enable/disable of speed observer process           General   Selection of speed observer         Select the method of speed observer           General   Control method         Select the position control method.           Open-Loop   Step of d-axis current climbing         The d-axis current reference ramping down proportion to reference before open-loop [A/msec].           Open-Loop   Step of d-axis current         The q-axis current reference ramping down proportion to reference before open-loop [A/msec].           Open-Loop   Threshold of speed control descending         The d-axis current reference in open-loop drive [A].           Open-Loop   Threshold of speed control climbing         The speed threshold [rad/s] to ramp up the d-axis current [rpm].           Open-Loop   Period between open-loop to BEMF (sec)         Time to switch open-loop to sensor-less [sec].           Open-Loop   Phase error(degree) to decide sensor-less switch timing (electrical angle) [degree].         Time to switch open-loop to sensor-less [sec].           Design parameter   Speed PI loop omega         Speed PI Control parameter omega.         Design parameter   Speed PI loop zeta           Design parameter   Cutoff frequency of phase error LPF         The cut-off frequency [Hz] for HPF in open-loop damping gain design.           Design parameter   Speed observer zeta         Speed observer omega.         Design parameter   Speed observer zeta.           Design parameter   Speed observer zeta         Speed observer omega.	General   Torque compensation for	Select enable/disable of soft switching at the transition
General   Selection of speed observerSelect the method of speed observerGeneral   Control methodSelect the position control method.Open-Loop   Step of d-axis current climbingThe d-axis current reference ramping up rate [A/msec].Open-Loop   Step of d-axis currentThe d-axis current reference ramping down proportion to reference before open-loop [A/msec].Open-Loop   Reference of d-axis currentThe d-axis current reference ramping down proportion to reference before open-loop [A/msec].Open-Loop   Threshold of speed control descendingThe speed threshold [rad/s] to ramp down the d-axis current [rpm].Open-Loop   Threshold of speed control climbingThe speed threshold [rad/s] to ramp up the d-axis current [rpm].Open-Loop   Period between open-loop to BEMF (sec)The speed threshold [rad/s] to ramp up the d-axis current [rpm].Open-Loop   Phese error(degree) to decide sensor-less witch timingSpeed PI control parameter omega.Design parameter   Speed PI loop omegaSpeed PI Control parameter omega.Design parameter   Open-loop damping getaDamping ratio for open-loop damping gain design.Design parameter   Cutoff frequency of phase error LPFThe cut-off frequency [Hz] of phase error LPF gain design.Design parameter   Speed observer zetaSpeed observer zeta.Motor Parameter   Pole pairsPole pairs of target motor.Motor Parameter   Pole pairsPole pairs of target motor.Motor Parameter   Permanent magnetic fluxQu-axis inductance [H].Motor Parameter   Permanent magnetic fluxMagnetic flux [Wb].		
General         Control method         Select the position control method.           Open-Loop   Step of d-axis current climbing         The d-axis current reference ramping up rate [A/msec].           Open-Loop   Step of d-axis current         The d-axis current reference ramping down rate [A/msec].           Open-Loop   Step of q-axis current         The d-axis current reference ramping down proportion to reference before open-loop [A/msec].           Open-Loop   Threshold of speed control descending         The d-axis current reference in open-loop drive [A].           Open-Loop   Threshold of speed control climbing         The speed threshold [rad/s] to ramp up the d-axis current [rpm].           Open-Loop   Period between open-loop to BEMF (sec)         Time to switch open-loop to sensor-less [sec].           Open-Loop   Period between open-loop to sensor-less switch timing (electrical angle) [degree].         Speed PI Control parameter omega.           Design parameter   Speed PI loop zeta         Speed PI Control parameter zeta.         Natural frequency [Hz] of phase error LPF gain design.           Design parameter   Open-loop damping zeta         Damping ratio for open-loop damping gain design.         Damping ratio for open-loop damping gain design.           Design parameter   Speed observer zeta         Speed observer omega.         Damping ratio for open-loop damping gain design.           Design parameter   Speed observer zeta         Speed observer zeta.         Motor Parameter [ Speed observer zeta           Motor P	General   Speed observer	
Open-Loop         Step of d-axis current climbing         The d-axis current reference ramping up rate [A/msec].           Open-Loop         Step of d-axis current         The d-axis current reference ramping down rate [A/msec].           Open-Loop         Step of q-axis current         The d-axis current reference ramping down proportion to reference before open-loop [A/msec].           Open-Loop         Reference of d-axis current         The d-axis current reference in open-loop drive [A].           Open-Loop         Threshold of speed control descending         The speed threshold [rad/s] to ramp down the d-axis current [rpm].           Open-Loop         Theshold of speed control climbing         The speed threshold [rad/s] to ramp up the d-axis current [rpm].           Open-Loop   Previde between open-loop to BEMF (sec)         Time to switch open-loop to sensor-less [sec].           Open-Loop   Phase error(degree) to decide sensor-less switch timing (electrical angle) [degree].         Pase error to decide sensor-less switch timing (electrical angle) [degree].           Design parameter   Speed PI loop omega         Speed PI Control parameter zeta.         Natural frequency [H2] for HPF in open-loop damping gain design.           Design parameter   Open-loop damping zeta         Damping ratio for open-loop damping gain design.         Damping ratio for open-loop damping gain design.           Design parameter   Speed observer omega         Damping ratio for open-loop damping gain design.         Design parameter   Speed observer zeta	General   Selection of speed observer	Select the method of speed observer
Open-Loop         Step of d-axis current climbing         The d-axis current reference ramping up rate [A/msec].           Open-Loop         Step of d-axis current         The d-axis current reference ramping down rate [A/msec].           Open-Loop         Step of q-axis current         The d-axis current reference ramping down proportion to reference before open-loop [A/msec].           Open-Loop         Reference of d-axis current         The d-axis current reference in open-loop drive [A].           Open-Loop         Threshold of speed control descending         The speed threshold [rad/s] to ramp down the d-axis current [rpm].           Open-Loop         Theshold of speed control climbing         The speed threshold [rad/s] to ramp up the d-axis current [rpm].           Open-Loop   Previde between open-loop to BEMF (sec)         Time to switch open-loop to sensor-less [sec].           Open-Loop   Phase error(degree) to decide sensor-less switch timing (electrical angle) [degree].         Pase error to decide sensor-less switch timing (electrical angle) [degree].           Design parameter   Speed PI loop omega         Speed PI Control parameter zeta.         Natural frequency [H2] for HPF in open-loop damping gain design.           Design parameter   Open-loop damping zeta         Damping ratio for open-loop damping gain design.         Damping ratio for open-loop damping gain design.           Design parameter   Speed observer omega         Damping ratio for open-loop damping gain design.         Design parameter   Speed observer zeta	General   Control method	Select the position control method.
Open-Loop         Step of d-axis current descending         The d-axis current reference ramping down rate [A/msec].           Open-Loop         Step of q-axis current descending ratio         The d-axis current reference ramping down proportion to reference before open-loop [A/msec].           Open-Loop         Reference of d-axis current         The d-axis current reference in open-loop drive [A].           Open-Loop         Threshold of speed control descending         The speed threshold [rad/s] to ramp up the d-axis current [rpm].           Open-Loop         Phreshold of speed control climbing         The speed threshold [rad/s] to ramp up the d-axis current [rpm].           Open-Loop         Phase error (degree) to decide sensor-less switch timing         Phase error to decide sensor-less switch timing (electrical angle) [degree].           Design parameter         Speed PI loop omega         Speed PI Control parameter omega.           Design parameter         Open-loop damping zeta         Damping ratio for open-loop damping gain design.           Design parameter   Cutoff frequency of phase error LPF         The cut-off frequency [Hz] of phase error LPF gain design.           Design parameter   Speed observer omega         Speed observer omega.         Speed observer zeta.           Motor Parameter   Resistance (ohm)         Resistance of motor (ohm].         Resistance of motor [MI].           Motor Parameter   Inductance of d-axis (H)         D-axis inductance [H].         Magnetic flux [Wb]. <td>Open-Loop   Step of d-axis current climbing</td> <td>The d-axis current reference ramping up rate [A/msec].</td>	Open-Loop   Step of d-axis current climbing	The d-axis current reference ramping up rate [A/msec].
descending       Image: Control descending ratio         Open-Loop   Step of q-axis current descending ratio       The q-axis current reference ramping down proportion to reference before open-loop [A/msec].         Open-Loop   Reference of d-axis current       The d-axis current reference in open-loop drive [A].         Open-Loop   Threshold of speed control climbing       The speed threshold [rad/s] to ramp down the d-axis current [rpm].         Open-Loop   Threshold of speed control climbing       The speed threshold [rad/s] to ramp up the d-axis current [rpm].         Open-Loop   Period between open-loop to BEMF (sec)       Time to switch open-loop to sensor-less [sec].         Open-Loop   Phase error(degree) to decide sensor-less switch timing (electrical angle) [degree].       Phase error to decide sensor-less switch timing (electrical angle) [degree].         Design parameter   Speed PI loop omega       Speed PI Control parameter zeta.         Design parameter   Open-loop damping zeta       Damping ratio for open-loop damping gain design.         Zeta       Damping ratio for open-loop damping gain design.         Design parameter   Open-loop damping zeta       Speed observer omega.         Design parameter   Speed observer omega       Speed observer zeta.		
Open-Loop  Step of q-axis currentThe q-axis current reference ramping down proportion to reference before open-loop [A/msec].Open-Loop   Reference of d-axis currentThe d-axis current reference in open-loop drive [A].Open-Loop   Threshold of speed control descendingThe speed threshold [rad/s] to ramp down the d-axis current [rpm].Open-Loop   Threshold of speed control climbingThe speed threshold [rad/s] to ramp up the d-axis current [rpm].Open-Loop   Period between open-loop to BEMF (sec)Time to switch open-loop to sensor-less [sec].Open-Loop   Phase error(degree) to decide sensor-less switch timingPhase error to decide sensor-less switch timing (electrical angle) [degree].Design parameter   Speed PI loop zeta omegaSpeed PI Control parameter zeta.Design parameter   Open-loop damping zetaDamping ratio for open-loop damping gain design.Design parameter   Open-loop damping zetaDamping ratio for open-loop damping gain design.Design parameter   Open-loop damping zetaSpeed observer omegaDesign parameter   Speed observer omegaSpeed observer omega.Design parameter   Speed observer omegaSpeed observer omega.Design parameter   Pepe apirsPole pairs of target motor.Motor Parameter   Resistance (ohm)Resistance of motor [ohm].Motor Parameter   Inductance of q-axis (H)Q-axis inductance [H].Motor Parameter   Permanent magnetic flux (Wb)Magnetic flux [Wb].		
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Open-Loop   Threshold of speed control descendingThe speed threshold [rad/s] to ramp down the d-axis current [rpm].Open-Loop   Threshold of speed control climbingThe speed threshold [rad/s] to ramp up the d-axis current [rpm].Open-Loop   Period between open-loop to BEMF (sec)Time to switch open-loop to sensor-less [sec].Open-Loop   Phase error(degree) to decide sensor-less switch timingPhase error to decide sensor-less switch timing (electrical angle) [degree].Design parameter   Speed PI loop omegaSpeed PI Control parameter omega.Design parameter   Speed PI loop zetaSpeed PI Control parameter zeta.Design parameter   Open-loop damping zetaDamping ratio for open-loop damping gain design.Design parameter   Open-loop damping zetaDamping ratio for open-loop damping gain design.Design parameter   Speed observer omegaSpeed observer omega.Design parameter   Speed observer zetaSpeed observer omega.Design parameter   Pole pairsPole pairs of target motor.Motor Parameter   Resistance (ohm)Resistance of motor [ohm].Motor Parameter   Inductance of q-axis (H)Q-axis inductance [H].Motor Parameter   Permanent magnetic flux (Wb)Magnetic flux [Wb].		
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Design parameter   Speed PI loop zetaSpeed PI Control parameter zeta.Design parameter   Estimated d-axis HPF omegaNatural frequency [Hz] for HPF in open-loop damping gain design.Design parameter   Open-loop damping zetaDamping ratio for open-loop damping gain design.Design parameter   Cutoff frequency of phase error LPFThe cut-off frequency [Hz] of phase error LPF gain design.Design parameter   Speed observer omegaSpeed observer omega.Design parameter   Speed observer zetaSpeed observer zeta.Motor Parameter   Pole pairsPole pairs of target motor.Motor Parameter   Inductance of d-axis (H)D-axis inductance [H].Motor Parameter   Permanent magnetic flux (Wb)Magnetic flux [Wb].		•
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Design parameter   Estimated d-axis HPF omegaNatural frequency [Hz] for HPF in open-loop damping gain design.Design parameter   Open-loop damping zetaDamping ratio for open-loop damping gain design.Design parameter   Cutoff frequency of phase error LPFThe cut-off frequency [Hz] of phase error LPF gain design.Design parameter   Speed observer omegaSpeed observer omega.Design parameter   Speed observer zetaSpeed observer zeta.Motor Parameter   Pole pairsPole pairs of target motor.Motor Parameter   Resistance (ohm)Resistance of motor [ohm].Motor Parameter   Inductance of q-axis (H)D-axis inductance [H].Motor Parameter   Permanent magnetic flux (Wb)Magnetic flux [Wb].	Design parameter   Speed PI loop zeta	Speed PI Control parameter zeta.
zetaThe cut-off frequency of phase error LPFDesign parameter   Cutoff frequency of phase error LPFThe cut-off frequency [Hz] of phase error LPF gain design.Design parameter   Speed observer omegaSpeed observer omega.Design parameter   Speed observer zetaSpeed observer zeta.Motor Parameter   Pole pairsPole pairs of target motor.Motor Parameter   Resistance (ohm)Resistance of motor [ohm].Motor Parameter   Inductance of d-axis (H)D-axis inductance [H].Motor Parameter   Inductance of q-axis (H)Q-axis inductance [H].Motor Parameter   Permanent magnetic flux (Wb)Magnetic flux [Wb].		Natural frequency [Hz] for HPF in open-loop damping gain design.
phase error LPFSpeed observer omegaDesign parameter   Speed observer omegaSpeed observer omega.Design parameter   Speed observer zetaSpeed observer zeta.Motor Parameter   Pole pairsPole pairs of target motor.Motor Parameter   Resistance (ohm)Resistance of motor [ohm].Motor Parameter   Inductance of d-axis (H)D-axis inductance [H].Motor Parameter   Inductance of q-axis (H)Q-axis inductance [H].Motor Parameter   Permanent magnetic flux (Wb)Magnetic flux [Wb].		Damping ratio for open-loop damping gain design.
Design parameter   Speed observer zetaSpeed observer zeta.Motor Parameter   Pole pairsPole pairs of target motor.Motor Parameter   Resistance (ohm)Resistance of motor [ohm].Motor Parameter   Inductance of d-axis (H)D-axis inductance [H].Motor Parameter   Inductance of q-axis (H)Q-axis inductance [H].Motor Parameter   Permanent magnetic fluxMagnetic flux [Wb].		The cut-off frequency [Hz] of phase error LPF gain design.
Design parameter   Speed observer zetaSpeed observer zeta.Motor Parameter   Pole pairsPole pairs of target motor.Motor Parameter   Resistance (ohm)Resistance of motor [ohm].Motor Parameter   Inductance of d-axis (H)D-axis inductance [H].Motor Parameter   Inductance of q-axis (H)Q-axis inductance [H].Motor Parameter   Permanent magnetic fluxMagnetic flux [Wb].	Design parameter   Speed observer omega	Speed observer omega.
Motor ParameterPole pairsPole pairs of target motor.Motor ParameterResistance (ohm)Resistance of motor [ohm].Motor ParameterInductance of d-axis (H)D-axis inductance [H].Motor ParameterInductance of q-axis (H)Q-axis inductance [H].Motor ParameterPermanent magnetic fluxMagnetic flux [Wb].		· · · · · · · · · · · · · · · · · · ·
Motor Parameter   Resistance (ohm)Resistance of motor [ohm].Motor Parameter   Inductance of d-axis (H)D-axis inductance [H].Motor Parameter   Inductance of q-axis (H)Q-axis inductance [H].Motor Parameter   Permanent magnetic flux (Wb)Magnetic flux [Wb].		
Motor Parameter   Inductance of d-axis (H)       D-axis inductance [H].         Motor Parameter   Inductance of q-axis (H)       Q-axis inductance [H].         Motor Parameter   Permanent magnetic flux (Wb)       Magnetic flux [Wb].		
Motor Parameter   Inductance of q-axis (H)       Q-axis inductance [H].         Motor Parameter   Permanent magnetic flux (Wb)       Magnetic flux [Wb].		
Motor Parameter   Permanent magnetic flux [Wb]. (Wb)		
(Wb)		
Motor Parameter   Rotor inertia (kgm <sup>2</sup> ) Rotor inertia [kgm <sup>2</sup> ].	(Wb)	
	Motor Parameter   Rotor inertia (kgm^2)	Rotor inertia [kgm^2].



# Table 3-18 Configuration Options initial value(rm\_motor\_speed.h)

Options	RA6T2	RA4T1	RA6T3	RA8T1
Common   Position support	-	-	-	-
General   Speed control period (sec)	0.001	0.002	0.001	0.001
General   Step of speed climbing (rpm)	0.5	2.0	0.5	0.5
General   Maximum rotational speed (rpm)	2400	2400.0	2400.0	2400.0
General   Speed LPF omega	10.0	10.0	10.0	10.0
General   Limit of q-axis current (A)	1.67	1.67	1.67	1.67
General   Step of speed feedback at open- loop	0.2	0.2	0.2	0.2
General   Natural frequency	100.0	100.0	100.0	100.0
General   Open-loop damping	Enable	Enable	Enable	Enable
General   Flux weakening	Disable	Disable	Disable	Disable
General   Torque compensation for sensorless transition	Enable	Enable	Enable	Enable
General   Speed observer	Disable	Disable	Disable	Disable
General   Selection of speed observer	Normal	Normal	Normal	Normal
General   Control method	-	-	-	-
Open-Loop   Step of d-axis current climbing	0.6	1.2	0.6	0.6
Open-Loop   Step of d-axis current descending	0.6	1.2	0.6	0.6
Open-Loop   Step of q-axis current descending ratio	1.0	1.0	1.0	1.0
Open-Loop   Reference of d-axis current	0.3	0.3	0.3	0.3
Open-Loop   Threshold of speed control descending	700	700	700	700
Open-Loop   Threshold of speed control climbing	500	500	500	500
Open-Loop   Period between open-loop to BEMF (sec)	0.025	0.025	0.025	0.025
Open-Loop   Phase error(degree) to decide sensor-less switch timing	10	10	10	10
Design parameter   Speed PI loop omega	3.0	3.0	3.0	3.0
Design parameter   Speed PI loop zeta	1.0	1.0	1.0	1.0
Design parameter   Estimated d-axis HPF omega	2.5	2.5	2.5	2.5
Design parameter   Open-loop damping zeta	1.0	1.0	1.0	1.0
Design parameter   Cutoff frequency of phase error LPF	10.0	10.0	10.0	10.0
Design parameter   Speed observer omega	-	-	-	-
Design parameter   Speed observer zeta	-	-	-	-
Motor Parameter   Pole pairs	4	4	4	4
Motor Parameter   Resistance (ohm)	1.3	1.3	1.3	1.3
Motor Parameter   Inductance of d-axis (H)	0.0013	0.0013	0.0013	0.0013
Motor Parameter   Inductance of q-axis (H)	0.0013	0.0013	0.0013	0.0013
Motor Parameter   Permanent magnetic flux (Wb)	0.01119	0.01119	0.01119	0.01119
Motor Parameter   Rotor inertia (kgm^2)	0.000003666	0.000003666	0.000003666	0.000003666



# Table 3-19 Configuration Options for Angle and Speed Estimation

Configuration Options (rm_motor_estimate.h)	
Options	Description
Motor Parameter   Pole pairs	Pole pairs of target motor.
Motor Parameter   Resistance (ohm)	Resistance of motor [ohm].
Motor Parameter   Inductance of d-axis (H)	D-axis inductance [H].
Motor Parameter   Inductance of q-axis (H)	Q-axis inductance [H].
Motor Parameter   Permanent magnetic flux (Wb)	Magnetic flux [Wb].
Motor Parameter   Rotor inertia (kgm^2)	Rotor inertia [kgm^2].
Motor Parameter   Nominal current (Arms)	Nominal current [Arms]
Openloop damping	Select enable/disable of Open-Loop Damping Control
Natural frequency of BEMF observer	Natural frequency for BEMF observer [Hz].
Damping ratio of BEMF observer	Damping ratio for BEMF observer.
Natural frequency of PLL Speed estimate loop	Natural frequency for rotor position Phase-Locked
Natural frequency of PLL Speed estimate loop	Loop [Hz].
Damping ratio of PLL Speed estimate loop	Damping ratio for rotor position Phase-Locked Loop.
Control period	Period of Speed Control [sec]

# Table 3-20 Configuration Options initial value(rm\_motor\_estimate.h)

Options	RA6T2	RA4T1	RA6T3	RA8T1
Motor Parameter   Pole pairs	4	4	4	4
Motor Parameter   Resistance (ohm)	1.3	1.3	1.3	1.3
Motor Parameter   Inductance of d-axis (H)	0.0013	0.0013	0.0013	0.0013
Motor Parameter   Inductance of q-axis (H)	0.0013	0.0013	0.0013	0.0013
Motor Parameter   Permanent magnetic flux (Wb)	0.01119	0.01119	0.01119	0.01119
Motor Parameter   Rotor inertia (kgm^2)	0.000003666	0.000003666	0.000003666	0.000003666
Motor Parameter   Nominal current (Arms)	1.67	1.67	1.67	1.67
Openloop damping	Enable	Enable	Enable	Enable
Natural frequency of BEMF observer	1000.0	500.0	1000.0	1000.0
Damping ratio of BEMF observer	1.0	1.0	1.0	1.0
Natural frequency of PLL Speed estimate loop	20.0	20.0	20.0	20.0
Damping ratio of PLL Speed estimate loop	1.0	1.0	1.0	1.0
Control period	0.0001	0.0002	0.0001	0.0001



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# Table 3-21 Configuration Options for Driver Access

Configuration Options (rm_motor_driver.h)	
Options	Description
Common   ADC_B Support	ADC_B module support
Common   Shared ADC support	Selection of using shared ADC module
Common   Supported Motor Number	Number of driven motors
General   Shunt type	Current detection method selection
General   Modulation method	Selection of the method of modulation
General   PWM output port UP	Port setting of U phase upper arm
General   PWM output port UN	Port setting of U phase lower arm
General   PWM output port VP	Port setting of V phase upper arm
General   PWM output port VN	Port setting of V phase lower arm
General   PWM output port WP	Port setting of W phase upper arm
General   PWM output port WN	Port setting of W phase lower arm
General   PWM Timer Frequency (MHz)	PWM Timer Clock Frequency [MHz]
General   PWM Carrier Period (Microseconds)	PWM Carrier Period [Micro seconds]
General   Dead Time (Raw Counts)	PWM Dead time [raw counts]
General   Current Range (A)	Measurement Range of Electric current [A]
General   Voltage Range (V)	Measurement Range of Inverter Voltage [V]
General   Counts for current offset measurement	Counts of measurement the offset of A/D Conversion at
	electric current input.
General   A/D conversion channel for U Phase current	A/D channel for U-phase current
General   A/D conversion channel for W Phase current	A/D channel for W-phase current
General   A/D conversion channel for Main Line	A/D channel for main line voltage
Voltage	
General   A/D conversion channel for V Phase current	A/D channel for V-phase current
General   A/D conversion channel for sin signal	A/D channel for sin signal
General   A/D conversion channel for cos signal	A/D channel for cos signal
General   Using ADC scan group	Set ADC scan group according to ADC module setting.
General   A/D conversion unit for U Phase current	Select the A/D conversion module for U phase current
General   A/D conversion unit for W Phase current	Select the A/D conversion module for W phase current
General   A/D conversion unit for main line voltage	Select the A/D conversion module for main line voltage
General   A/D conversion unit for V Phase current	Select the A/D conversion module for V phase current
General   A/D conversion unit for sin signal	Select the A/D conversion module for sin signal
General   A/D conversion unit for cos signal	Select the A/D conversion module for cos signal
General   ADC interrupt module	Select from which module ADC interrupt happens
General   Adjustment value to current A/D	Current A/D timing adjustment (for 1shunt)
General   Minimum difference of PWM duty	Minimum difference of PWM duty setting (for 1shunt)
General   Adjustment delay of A/D conversion	A/D conversion delay timing adjustment (for 1shunt)
General   1shunt interrupt phase	Which phase is used to detect 1shunt current
	(for 1shunt)
General   Input Voltage (V)	Range of input for main line voltage
General   Resolution of A/D conversion	Resolution of A/D conversion
	Please set same value with ADC module setting.
General   Offset of A/D conversion for current	Offset level of A/D conversion input for current
	Please set according to the circuit.
General   Conversion level of A/D conversion for	Conversion level of A/D conversion for voltage
voltage	Please set when the CPU main voltage is different.
General   GTIOCA stop level	-
	Output level of upper arm at stop status
General   GTIOCB stop level	Output level of lower arm at stop status
Modulation   Maximum duty	Maximum duty of PWM
	Maximum duty except dead time.



# Table 3-22 Configuration Options initial value(rm\_motor\_driver.h)[1/2]

Options	RA6T2	RA4T1	RA6T3	RA8T1
Common   ADC_B Support	Enabled	-	-	-
Common   Shared ADC support	Disabled	Disabled	Disabled	Enabled
Common   Supported Motor Number	1	1	1	1
General   Shunt type	1shunt	1shunt	1shunt	1shunt
General   Modulation method	SVPWM	SVPWM	SVPWM	SVPWM
General   PWM output port UP	BSP_IO_PORT _11_PIN_04	BSP_IO_PORT _04_PIN_09	BSP_IO_PORT _04_PIN_09	BSP_IO_PORT _01_PIN_15
General   PWM output port UN	BSP_IO_PORT _11_PIN_05	BSP_IO_PORT _04_PIN_08	BSP_IO_PORT _04_PIN_08	BSP_IO_PORT _06_PIN_09
General   PWM output port VP	BSP_IO_PORT _11_PIN_06	BSP_IO_PORT _01_PIN_03	BSP_IO_PORT _01_PIN_03	BSP_IO_PORT _01_PIN_13
General   PWM output port VN	BSP_IO_PORT _11_PIN_07	BSP_IO_PORT _01_PIN_02	BSP_IO_PORT _01_PIN_02	BSP_IO_PORT _01_PIN_14
General   PWM output port WP	BSP_IO_PORT _11_PIN_08	BSP_IO_PORT _01_PIN_11	BSP_IO_PORT _01_PIN_11	BSP_IO_PORT _03_PIN_00
General   PWM output port WN	BSP_IO_PORT _11_PIN_09	BSP_IO_PORT _01_PIN_12	BSP_IO_PORT _01_PIN_12	BSP_IO_PORT _01_PIN_12
General   PWM Timer Frequency (MHz)	120.0	100.0	100.0	120.0
General   PWM Carrier Period (Microseconds)	100.0	100.0	100.0	100.0
General   Dead Time (Raw Counts)	240	200	200	240
General   Current Range (A)	16.5	16.5	16.5	16.5
General   Voltage Range (V)	73.26	73.26	73.26	73.26
General   Counts for current offset measurement	500	500	500	500
General   A/D conversion channel for U Phase current	4	0	0	-
General   A/D conversion channel for W Phase current	-	-	-	-
General   A/D conversion channel for Main Line Voltage	6	4	4	8
General   A/D conversion channel for V Phase current	-	-	-	1
General   A/D conversion channel for signal	-	-	-	-
General   A/D conversion channel for cos signal	-	-	-	-
General   Using ADC scan group	0	-	-	-



### Table 3-23 Configuration Options initial value(rm\_motor\_driver.h)[2/2]

Options	RA6T2	RA4T1	RA6T3	RA8T1
General   A/D conversion unit for U Phase current	-	0	0	-
General   A/D conversion unit for W Phase current	-	-	-	-
General   A/D conversion unit for main line voltage	-	0	0	0
General   A/D conversion unit for V Phase current	-	-	-	0
General   A/D conversion unit for sin signal	-	-	-	-
General   A/D conversion unit for cos signal	-	-	-	-
General   ADC interrupt module	-	1st	1st	1st
General   Adjustment value to current A/D	0.0	20.0	20.0	20.0
General   Minimum difference of PWM duty	900	500	500	500
General   Adjustment delay of A/D conversion	600	250	250	250
General   1shunt interrupt phase	PHASE_U	PHASE_U	PHASE_U	PHASE_V
General   Input Voltage (V)	24.0	24.0	24.0	24.0
General   Resolution of A/D conversion	0xFFF	0xFFF	0xFFF	0xFFF
General   Offset of A/D conversion for current	0x7FF	0x7FF	0x7FF	0x7FF
General   Conversion level of A/D conversion for voltage	1.0	1.0	1.0	1.0
General   GTIOCA stop level	Pin Level Low	Pin Level Low	Pin Level Low	Pin Level Low
General   GTIOCB stop level	Pin Level High	Pin Level High	Pin Level High	Pin Level High
Modulation   Maximum duty	0.9375	0.9375	0.9375	0.9375



# 3.4 Control flowcharts

# 3.4.1 Main process

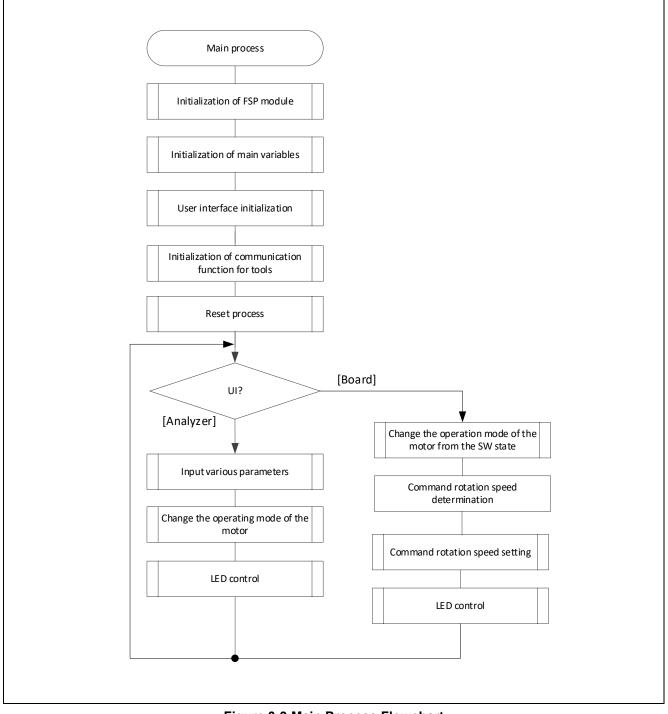


Figure 3-9 Main Process Flowchart



#### 3.4.2 Current Control Period Interrupt (Carrier synchronized Interrupt) Process

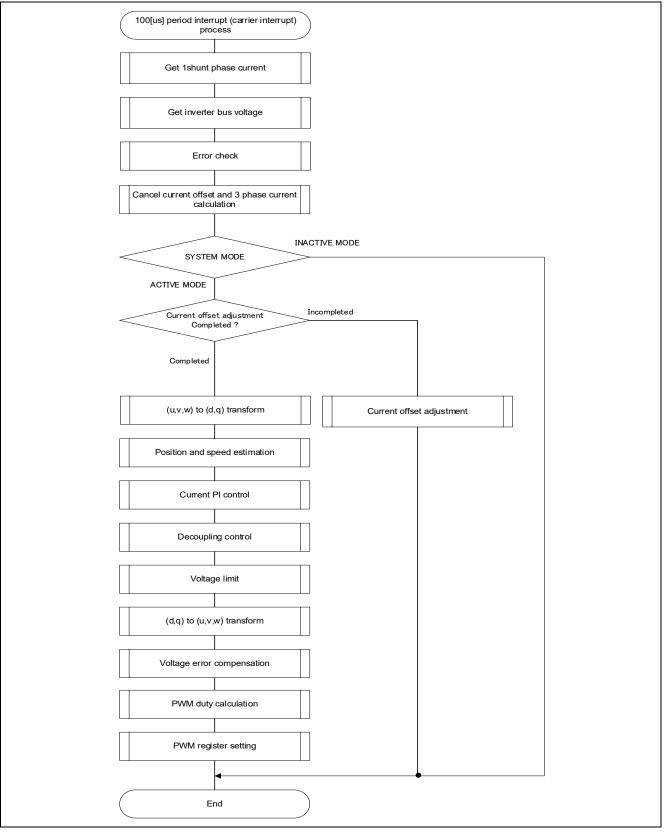


Figure 3-10 Current Control Period Interrupt (Carrier Interrupt) Process Flowchart

#### 3.4.3 Speed Control Period Interrupt Process

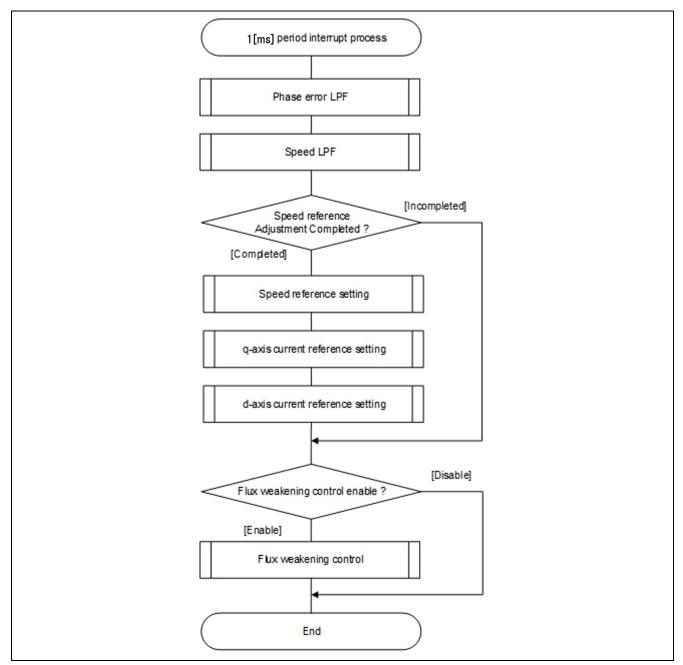


Figure 3-11 Speed Control Period Interrupt Process Flowchart



# 3.4.4 Over Current Detection Interrupt Process

The overcurrent detection interrupt is an interrupt that occurs when an external overcurrent detection signal is input. The PWM output terminal are put in the high impedance state. Therefore, at the start of execution of this interrupt processing, the PWM output terminal is already in the high impedance state and the output to the motor had been stopped.

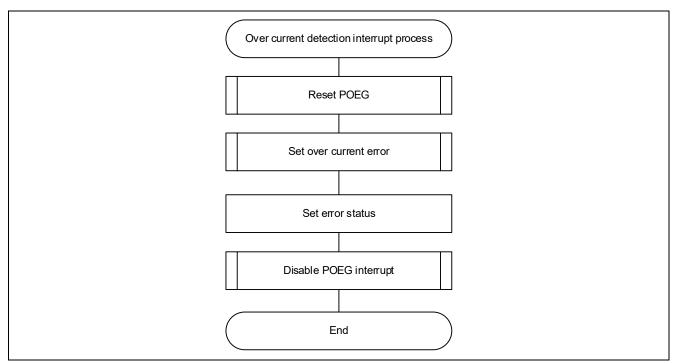


Figure 3-12 Over Current Detection Interrupt Process Flowchart



# 4. Evaluation environment explanation

# 4.1 Importing the Demo Project

The sample application provided with this document may be imported into e<sup>2</sup>studio using the steps in this section.

1. Select File  $\rightarrow$  Import.

File	Edit	Source	Refacto	r Navig	gate	Search	Projec
<u></u>	Open	File Projects nt Files	from File S	System		Alt+Sh	ift+N > >
		Editor All Edito	rs			Ct Ctrl+Shi	trl+W ft+W
	Save Save	As				(	Ctrl+S
r)	Save Rever					Ctrl+Sh	nift+S
	Move						
5	Renai						F2
68	Refree Conv		)elimiters T	Го			F5 >
₽	Print.					C	îtrl+P
è	Impo	rt					
4	Ехро	rt					
	Prope	erties				Alt+	Enter
	Switc Resta Exit	h Worksp rt	bace				>

Figure 4-1 File Menu



2. Select "Existing Projects into Workspace".

C Import	$\Box$ $\times$
Select Create new projects from an archive file or directory.	Ľ
Select an import wizard:	
type filter text	
🗸 🦢 General	^
🕼 Archive File	
CMSIS Pack	
😭 Existing Projects into Workspace	
🔁 File System	
Preferences	
Projects from Folder or Archive	
😭 Rename & Import Existing C/C++ Project 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 "e<sup>2</sup>studio Getting Started Guide (R20UT4204)".



# 4.3 Motor Demonstration Project Overview

# 4.3.1 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 on the inverter board 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 (VR1) on the inverter board.
  - Turn the variable resistor (VR1) right: Rotate clockwise
  - Turn the variable resistor (VR1) left: Rotate 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, the push 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.

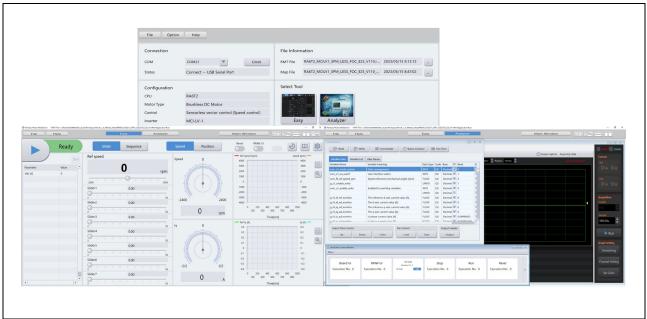


Figure 4-4 Renesas Motor Workbench – Appearance

Set up for "Renesas Motor Workbench"



- (1) Start 'Renesas Motor Workbench' by clicking this icon.
- (2) Drop down menu [File]  $\rightarrow$  [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 '4.5.2 Easy function operation example' or '4.5.4 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".

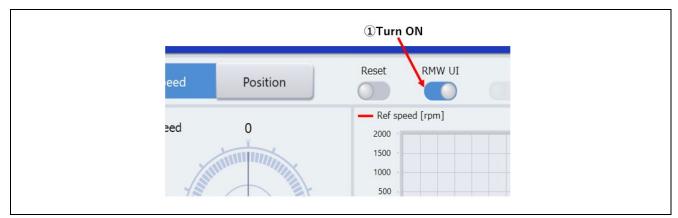


Figure 4-5 Procedure for changing to use Renesas Motor Workbench

- Change the user interface to use Renesas Motor Workbench
  - (1) Press the "Run" button

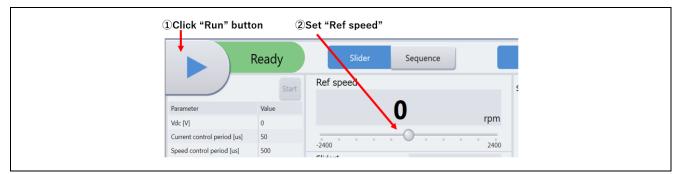


Figure 4-6 Motor rotation procedure

- 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

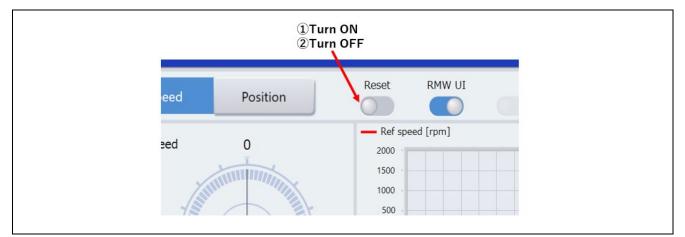


Figure 4-8 Error clearing procedure



## 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	Туре	Content
		User interface switch
com_u1_sw_userif (*)	uint8_t	0: Analyzer use
		1: Board user interface use (default)
com u1 mode system(*)	uint8 t	State management
	unito_t	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_e_obs_omega	float	Natural frequency of BEMF estimation system [Hz]
com_f4_e_obs_zeta	float	Damping ratio of BEMF estimation system
com_f4_pll_est_omega	float	Natural frequency of position estimation system [Hz]
com_f4_pll_est_zeta	float	Damping ratio of position estimation 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
som få id down anord rom	float	Speed when start to subtract d-axis current reference (mechanical
_com_f4_id_down_speed_rpm	lioat	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 ut anable write	uint9 t	Enabled to rewriting variables
com_u1_enable_write	uint8_t	(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 4-4. Regarding specification of "Control Window", refer to 'Renesas Motor Workbench User's Manual'.

- Change the user interface to Analyzer

- (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.

#### - Driving 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.

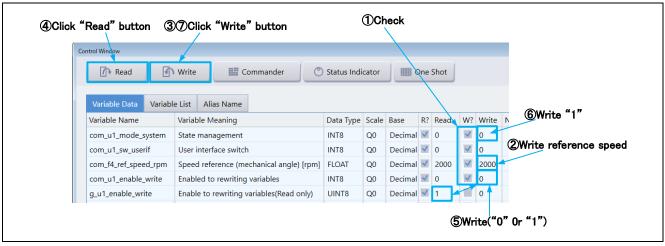


Figure 4-9 Procedure - Driving the motor

## - Stop the motor

- (1) Enter "0" in the [Write] box of "com\_u1\_mode\_system".
- (2) Click the "Write" button.

Control Window  Read Write Commander Status Indicator One Shot  Variable Data Variable List Alias Name Variable Name Variable Meaning Data Type Scale Base R? Read W? Write N Write N Write "0"	Image: Commander       Image: Commander <td< th=""><th>2</th><th>Click "Write" button</th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th></td<>	2	Click "Write" button								
Variable Data       Variable List       Alias Name         Variable Name       Variable Meaning       Data Type       Scale       Base       R?       Read       W?       Write       N       Write "0"	Variable Data       Variable List       Alias Name         Variable Name       Variable Meaning       Data Type       Scale       Base       R?       Read       W?       Write       N       Write "0"	Control Window									
Variable Name Variable Meaning Data Type Scale Base R? Read W? Write N Write "0"	Variable Name Variable Meaning Data Type Scale Base R? Read W? Write N Write "0"	🚺 Read	Write Commander	🕐 Status Indi	cator		Dne Sl	hot			
Variable Name Variable Meaning Data Type Scale Base R? Read W? Write N Write "0"	Variable Name Variable Meaning Data Type Scale Base R? Read W? Write N Write "0"										
							_				
	com_u1_mode_system State management INT8 Q0 Decimal 1 0 0			Data Tupo	Scolo	Pasa	D2 0	Pood	14/2 1	M/rito	Write "0"

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.

Q	Click "Write" button					
ntrol Window						
	Write Commander Commander	Status Indica	tor C	One Shot		
Variable Name	Variable Meaning	Data Type S	cale Base	R? Read	W? Write	1 Write "3"
com_u1_mode_system	State management	INT8 C	0 Decimal	✓ 1	3	
com ut au usorif	User interface switch		Docimal	<b>V</b> 0		

Figure 4-11 Procedure - Error cancel operation

# 4.4.5 Tuner function

For sensorless 1shunt vector control, regrettably there is no sample code to support "Tuner" function. Therefore, if you want to confirm the motor parameters with "Tuner" function, please use the executable file provided by Renesas Motor Workbench or

"RA6T2(RA8T1,RA6T3,RA4T1)\_MCILV1\_SPM\_LESS\_FOC\_TUNER\_E2S\_Vxxx" included in the sample software with 2shunts (or 3shunts). At that time, please take care to change current detection settings (refer to 2.2.2).

For details on how to use the Tuner function, refer to the Renesas Motor Workbench User's Manual.



# 4.4.6 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)
  - 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

#define MTR_ICS_DECIMATION	(1)
/* For TCS */	
#define ICS_BRR	(1)
#define ICS_INI_MODE	(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
    - (2) Change the value of MTR\_ICS\_DECIMATION in r\_mtr\_ics.h to 1.

File Option	Help
Connection	
СОМ	Clock
Status	Clock Setting
	00,000,000 Hz

Figure 4-13 Clock frequency setting

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

## 4.4.7 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

(1) Connect the CPU board and PC via a USB / serial conversion board, etc.



- Preparing a project for built-in communication (example of RA6T2 921600bps)
  - (1) Cancel the registration of ICS2\_RA6T2.o

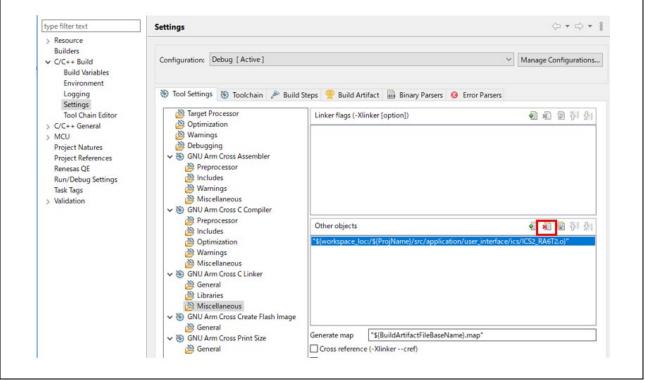


Figure 4-14 Unregister ICS2\_RA6T2.o

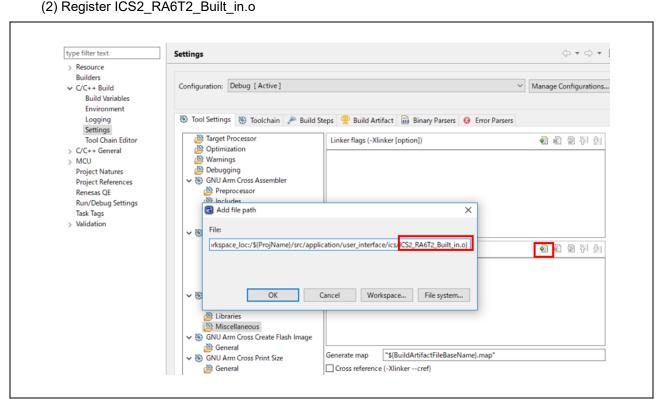


Figure 4-15 Register ICS2\_RA6T2.o

(3) Change the value of USE\_BUILT\_IN in r\_mtr\_ics.h to 1.

#define	USE_BUILT_IN	(1)
#if USE BUI	LT 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.

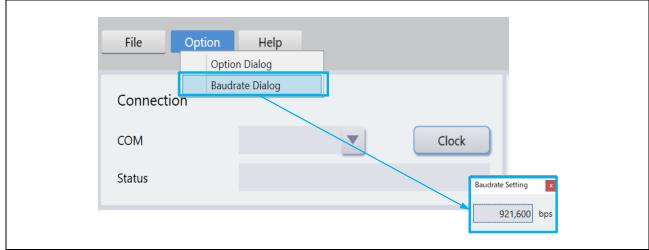


Figure 4-17 Baud rate setting



# 5. Reference Documents

RA6T2 Group User's Manual: Hardware (R01UH0951) RA4T1 Group User's Manual: Hardware (R01UH0998) RA6T3 Group User's Manual: Hardware (R01UH0999) RA8T1 Group User's Manual: Hardware (R01UH1016) RA Flexible Software Package Documentation Application note: 'Sensorless vector control for permanent magnet synchronous motor (Algorithm)' (R01AN3786) Renesas Motor Workbench User's Manual (R21UZ0004) Renesas Motor Workbench Quick start guide (R21QS0011) MCK-RA6T2 User's Manual (R12UZ0091) MCK-RA4T1 User's Manual (R12UZ0114) MCK-RA6T3 User's Manual (R12UZ0115) MCK-RA8T1 User's Manual (R12UZ0133)



# **Revision History**

		Description	
Rev.	Date	Page	Summary
1.00	May 23, 2023	-	First edition issued
1.10	Jan 23, 2024	-	Added description related to RA8T1
1.11	Dec 23, 2024	-	Update target software



# 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 is supplied until the power is supplied until the power reaches the level at which reseting 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 systemevaluation test for the given product.

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