

RX62T

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Three Shunt Sensorless Vector Control of PMSM Motors

Introduction

This document presents the RX62T three shunt sensorless vector control solution, which has been implemented on RX62T evaluation kit with three shunt current measurement.

It describes the evaluation kit hardware platform, three shunt current measurement, three shunt sensorless vector control strategy, and software implementation. The sensorless vector control algorithm is based on the method introduced in Renesas Application Note REU05B0103-0100/Rev.1.00.

Specifically, the document explains how to modify the solution for different motors and applications. An example of parameter tuning is given.

Target Device

RX62T

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1. Overview

Recent years have seen rapid development and wide applications of microcontrollers in embedded control system such as motor control. 32-bit floating point units have also been adopted in the high-end motor control applications. The floating point architecture improves performance, simplifies programming, and enables more sophisticated motor control algorithms for advanced capabilities.

The Renesas RX MCU is a high performance and low cost 32-bit 100MHz/165DMIPS microcontroller. It supports the IEEE-754 standard format for single-precision 32-bit floating point data. The hardware FPU integrated in the RX core offloads the RX CPU and simplifies decimal-point calculations, boosting overall processing performance and simplifying firmware development.

For the developers of RX62T based motor control applications, the RX62T evaluation kit provides complete development platform with all of hardware and software required to get applications started on the right foot, and shorten time to production by allowing developers to apply what they learn in the evaluation phase to the real-applications.

The kit comes ready to run a brushless DC (BLDC) motor included. Simply power up the board to explore 5 different types of motor control solutions: 1) three shunt sensorless vector control; 2) single shunt sensorless vector control; 3) three shunt sensorless vector control with the internal PGA; 4) single shunt sensorless vector control with the internal PGA; 5) encoder based position control. Then, modify the demonstration application to develop the specific motor control applications. Through the GUI, the motor and control parameters can be modified to drive your own motor.

This document presents the RX62T three shunt sensorless vector control solution, which has been implemented on the RX62T evaluation kit with three shunt current measurement. It describes evaluation kit hardware platform, three shunt current measurement, three shunt sensorless vector control strategy, and software implementation. The sensorless vector control algorithm is based on the method introduced in Renesas Application Note REU05B0103-0100/Rev.1.00. Specifically, the document explains how to modify the solution for different motors and applications. An example of parameter tuning is given.

Software described in the application note is applicable to following devices and platforms.

- ❖ MCU:RX62T and RX62N
- ❖ Motor: three-phase BLDC and PMSM motors
- ❖ Platform: Renesas Evaluation Kit
- ❖ Control algorithm: Three Shunt Sensorless Vector Control

2. Hardware Platform

The RX62T evaluation board is a single board integrated power inverter with the controller. The hardware includes a low-voltage MOSFETs power stage, a communication stage, and a RX62T microcontroller based controller as shown in Figure 1.

The board has following features:

- ❖ A complete 3-phase inverter on-board with a low voltage motor
- ❖ 24V external power supply to provide DC bus voltage, 15V and 5V power supply
- ❖ Power devices use Renesas' low voltage MOSFETs
- ❖ Power rate up to 120watts
- ❖ Support 3 shunt and single shunt current measurement
- ❖ Easily jumper change from the external amplifiers to the internal PGA
- ❖ USB communication with the PC via a H8S2212 MCU
- ❖ User GUI to modify motor and control parameters, tune both speed and position control
- ❖ Connectors for hall sensors and encoder connections
- ❖ LCD display to monitor the operation status
- ❖ Support the standalone mode set by potentiometer and push buttons
- ❖ Support the second motor drive, signals and connector for another motor control power stage are available

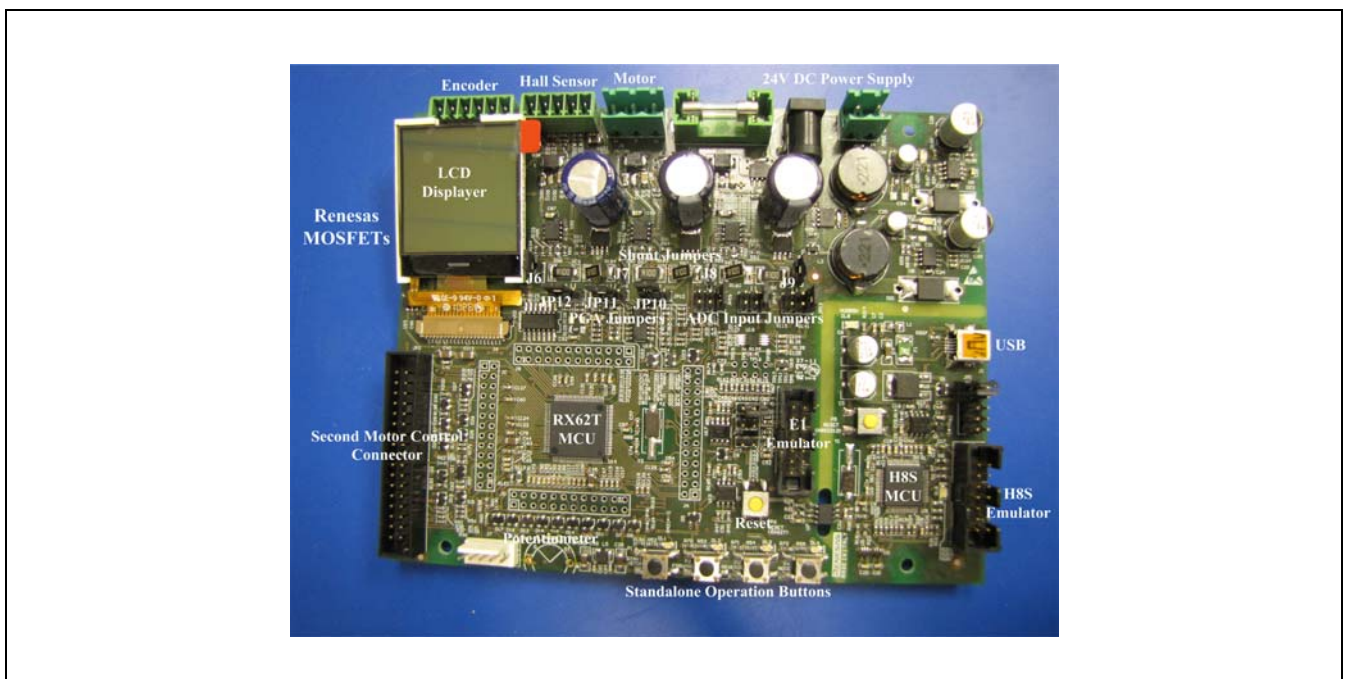


Figure 1 Evaluation board

3. Specification and Performance Data

The implementation of single shunt sensorless vector control is based on Renesas evaluation kit and RX62T MCU, the main specification data are described as following:

- ❖ Input voltage: 24VDC
- ❖ Rated bus voltage: 24V
- ❖ Output voltage: 24VAC
- ❖ Rated output power: 120W
- ❖ PWM Switch frequency: 20KHz
- ❖ Control loop frequency: 10KHz
- ❖ Current measurement: 3 shunt resistors
- ❖ Implementation: FPU
- ❖ CPU bandwidth: 19.7%
- ❖ Used flash memory: 33.816Kbytes
- ❖ Used RAM: 4.387Kbytes
- ❖ Used Stack : 336bytes

4. System Control Block Diagram

The RX62T is a 32-bit high-performance microcontroller with a maximum operating frequency of 100MHz and 165 DMIPS and single precision floating-point unit (FPU), which is equipped with multifunction timers (MTU, GPT), high-speed 12-bit A/D converter, and 10-bit A/D converter for facilitating motor control. Figure 2 depicts block diagram of a sensorless vector control of PMSM motors based on the Renesas RX62T Microcontroller.

The evaluation kit is capable to control two motors. The RX62T timer MTU3 channel 3 and 4 can be used to drive the second motor, which is not covered in this application. The MTU3 channel 6 and 7 are used to generate 6 PWM signals to drive the on-board motor in the complementary mode. The PWM modulation uses the space vector PWM or the sinusoidal PWM with the third harmonic. The three-phase inverter uses the Renesas low voltage MOSFETs, which generates three phase voltages with variable frequency and amplitude to drive the motor to the desired voltage.

The motor currents of i_u, i_v, i_w are measured by three shunt resistors. The currents of i_u, i_v, i_w are measured by 12-bit ADC unit 0 of channel AN002, AN001 and AN000, respectively. In the meantime, the bus voltage is measured by 12-bit ADC unit 0 of channel AN003.

The second motor currents of i_u, i_v, i_w are measured by 12-bit ADC unit 1 of channel AN102, AN101 and AN100, respectively. The bus voltage is sampled by 12-bit ADC unit 1 of channel AN103.

The speed is given by an external potentiometer, which is input to 10-bit ADC channel AN1. The MOSFET temperature is measured by 10-bit ADC channel AN2.

The encoder pulse A and B are input to the TCLKA and TCLKB. The Z pulse is to IRQ0. For the second motor, The encoder pulse A and B are input to the TCLKC and TCLKD. The Z pulse is to IRQ3. MTU3 timer has phase counting mode to capture two-phase encoder pulse inputs.

When the motor and the power board have over current, the current ADC sample circuits generate a POE signal to immediately shut down the PWM outputs from the MCU hardware. In addition, the RX62T control system has various system level safety features to comply with the IEC60730 safety standard, such as: low voltage detection (LVD), independent watchdog timer (IWDT), clock stop detection, ADC converter self-diagnosis; and output port monitor, etc.

The graphic user interface (GUI) communicates with the RX62T MCU by the USB communication. It can display the motor operation status in the real time and tune the motor and control parameters. The board also can run in the stand alone mode. The LCD displays the motor status.

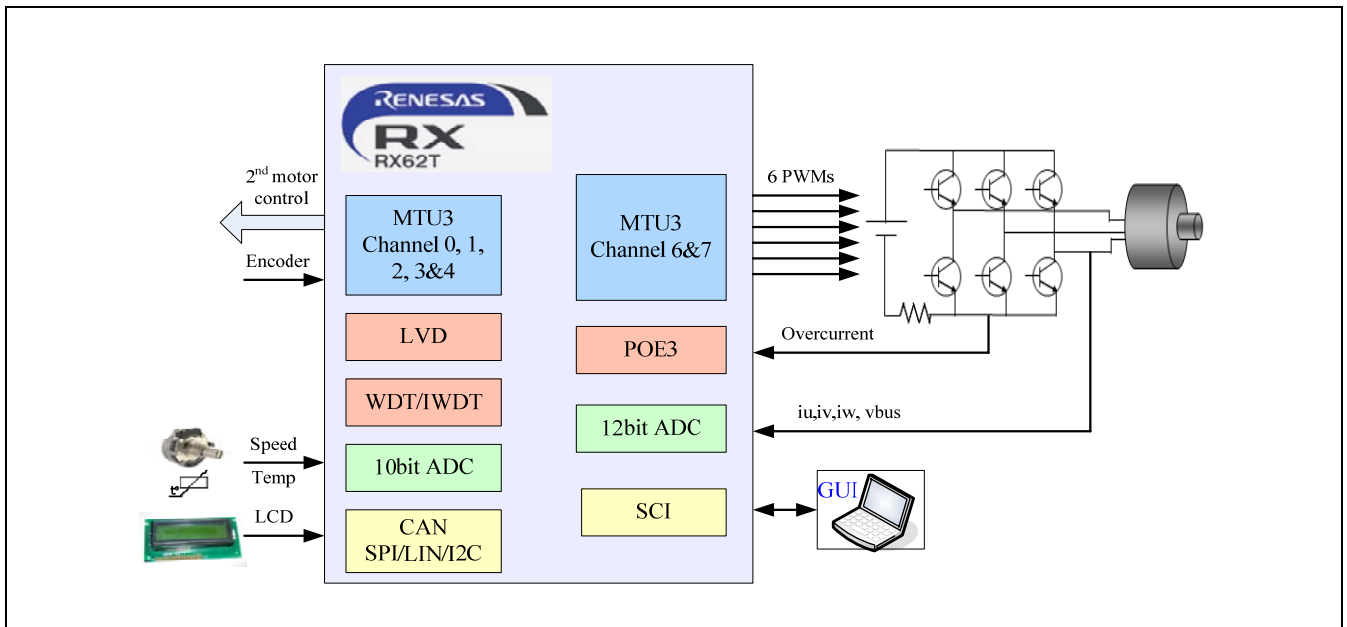


Figure 2 System control block diagram

5. Three Shunt Motor Phase Current Measurement

5.1 Three Shunt Current Measurement Method

The three phase motor currents are usually sampled by

- ❖ Shunt resistors
- ❖ LEM Hall Effect sensors

Shunt resistors are popular current sensors because they provide an accurate measurement at a low cost. LEM Hall Effect current sensors are widely used because they provide a non-intrusive measurement and are available in a small IC package such as: allegro current IC that combines the sensor and signal-conditioning circuit. Table 1 summarizes the advantages and disadvantages between the two current sensors.

Table 1 Current sensing comparison between Hall Effect sensor and shunt resistor

Current Sensing method	LEM Hall Effect Sensor	Shunt Resistors
Accuracy	good	good
Cost	high	low
Isolation	yes	no
AC/DC current	both	both
High current	good	poor
DC offset	no	yes
Intrusive	no	yes
Power consumption	low	high

Shunt resistors are a popular current-sensing sensor because of the low cost and good accuracy. The voltage drop across a known low value resistor is measured in order to determine the current flowing through the load. If the resistor is small in magnitude, the voltage drop is small and the measurement doesn't have a major effect on the motor circuit.

The selection criteria of a shunt current resistor requires the evaluation of several trade-offs, including:

- ❖ Increasing the resistance to increase the sensing voltage, which makes the voltage offset and input bias current offset amplifier errors less significant.
- ❖ A large resistance value causes a voltage loss and a reduction in the power efficiency, and also causes a voltage offset to the load in a low-side measurement that may impact the EMI characteristics and noise sensitivity of the system.
- ❖ Special-purpose, low inductance resistors are required if the current has a high-frequency content.
- ❖ The power rating of resistor must be evaluated because the $I^2 \times R$ power dissipation can produce self heating and a change in the nominal resistance of the shunt.

Low-side current measurements offer the advantages that the circuitry can be implemented with a low voltage op amp because the measurement is referenced to ground. The low-side measurement circuit can use a non-inverting amplifier and the input impedance of the circuit is equal to the large input impedance of the amplifier.

On the other hand, there are some disadvantages that the low-side resistor disrupts the ground path and the added resistance to the grounding system produces an offset voltage which can cause EMI noise problems. And also it can't detect a fault where the load is accidentally connected to ground via an alternative ground path.

5.2 Three Shunt Current Measurement Circuit

Figure 3 shows the evaluation kit hardware circuit for three shunt current measurement. Jumpers J6 and J9 are shorted, while J7 and J8 are open. The composite current of all three MOSFET inverter low side legs can be measured with a single shunt resistor of 0.1Ω, or that the current in each individual leg can be determined with three shunt resistors. Table 2 lists the jumper setting for the three shunt current measurement.

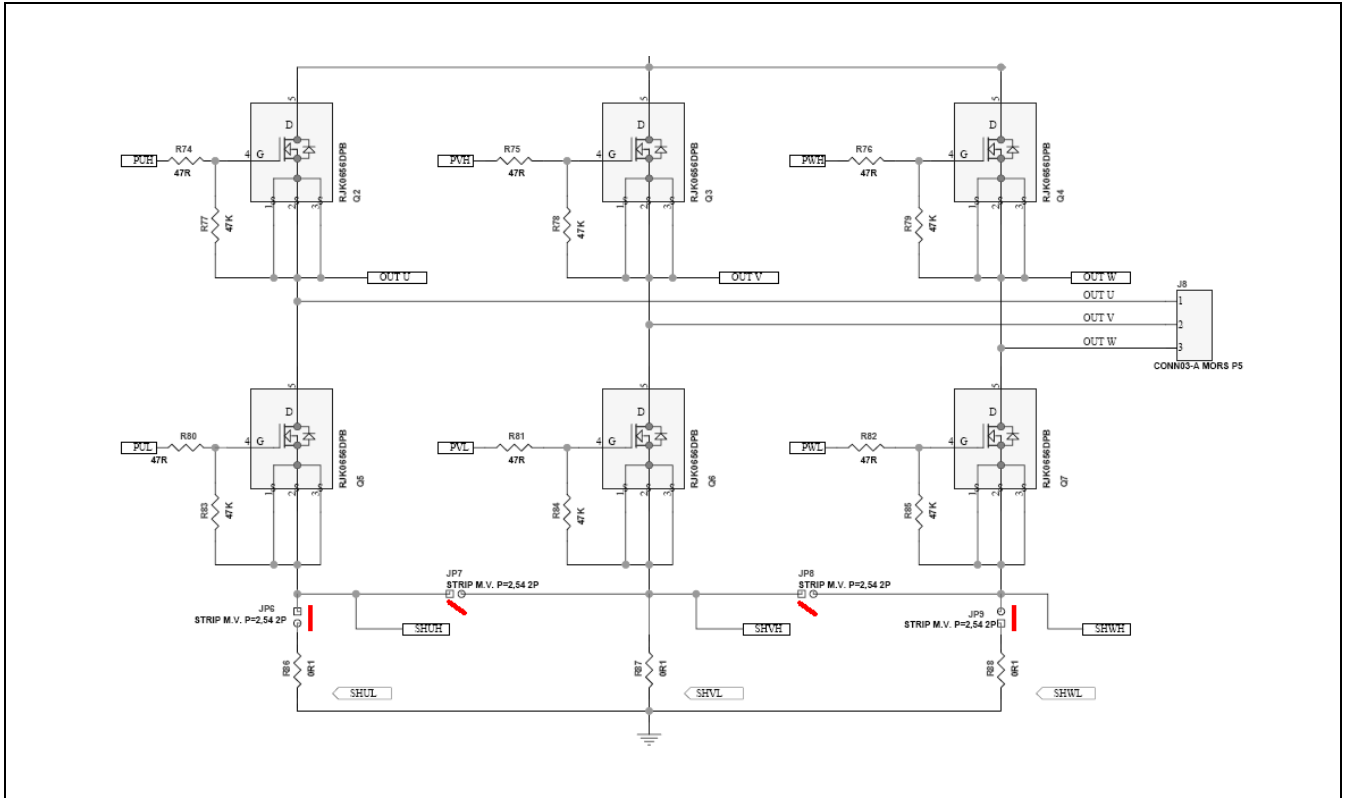


Figure 3 Three shunt current measurement in the low side inverter legs

Table 2 Jumper setting for three shunt current measurement

Jumper	J6	J7	J8	J9
State	ON	OFF	OFF	ON

5.3 Motor Current Reading from Three Shunts

Figure 4 depicts one leg of the inverter and voltage waveforms. If the low switch is ON and the gate command u^- is high, then:

- ❖ The gate command u^+ is low
- ❖ No current can flow through the high switch because it is OFF.
- ❖ No current flows through the high diode because it is inversely polarized. So, the high diode is OFF too.

If the low side switch is ON, the phase current flows through the shunt. Therefore, in order to read the motor phase current, the corresponding shunt current should be read when the related low side switch is ON.

On the other hand, observing the voltage waveforms obtained with three-phase modulation in Figure 4, it can be seen that in every moment two of the three phases are lower than the 90% of the maximum voltage value. It means, in every moment two of the three phases has a low switch ON period greater than 10% of the total period.

In a word, it is always possible to read two currents with a three shunt measurement system.

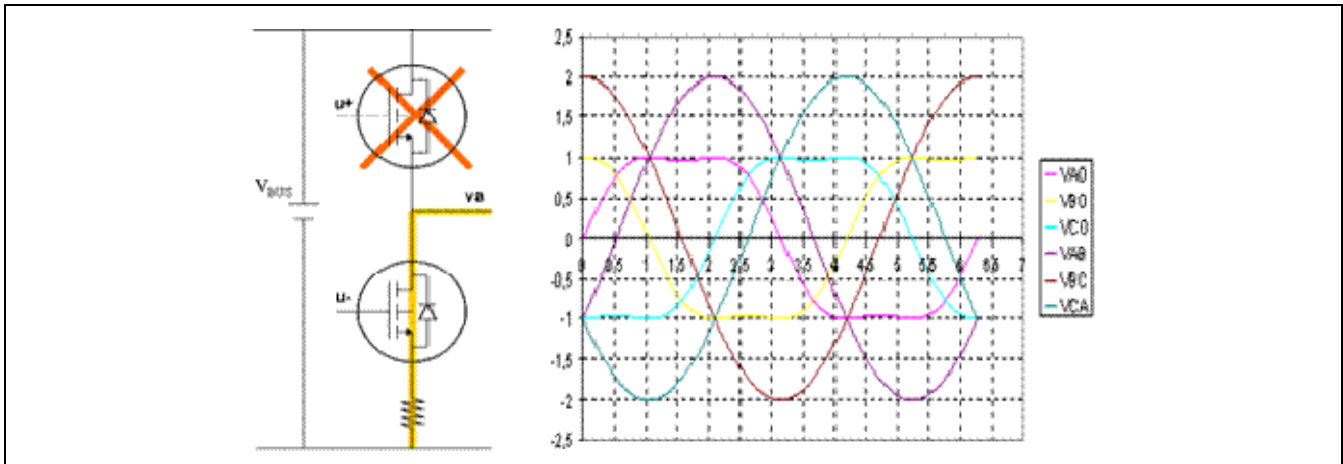


Figure 4 One leg of inverter (left) and motor voltage waveforms (right)

Figure 5 is the PWM waveform. The three shunt current reading depends on the PWM duties. The lesser is the duty, the higher voltage is output, so the lesser time the lower switch is on; those trees are chosen for which the lower arm on time is higher. The conversion in ampere should be made.

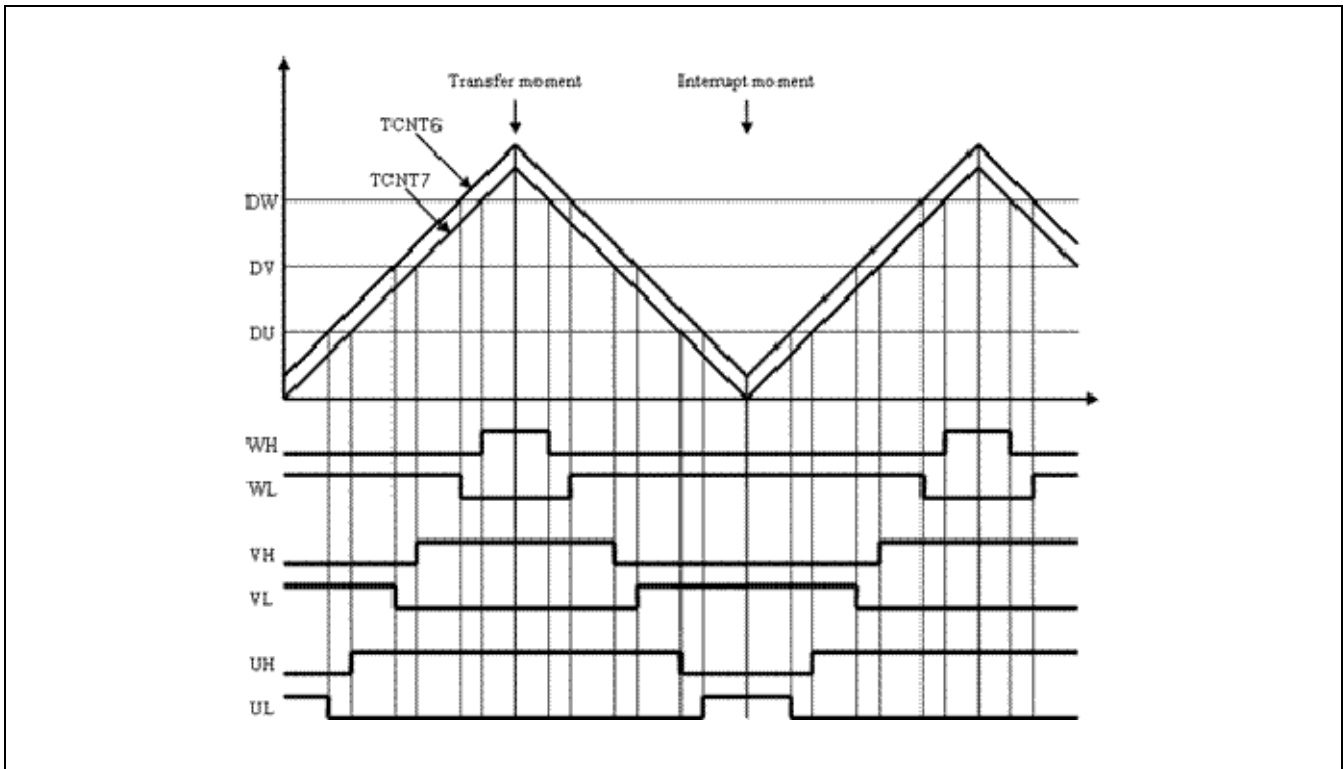


Figure 5 Three phase PWM duties and PWM waveform

5.4 Three Shunt Current ADC Sampling and Scaling

Figure 6 shows the three shunt current sample and amplifier circuit. Because of the current polarity, the offset should be added to shift the maximum negative current to the 0 volt. After the offset and amplifier, the three shunt currents input to the RX62T MCU ADC channel AN000, AN001 and AN002, respectively, are listed in Table 3.

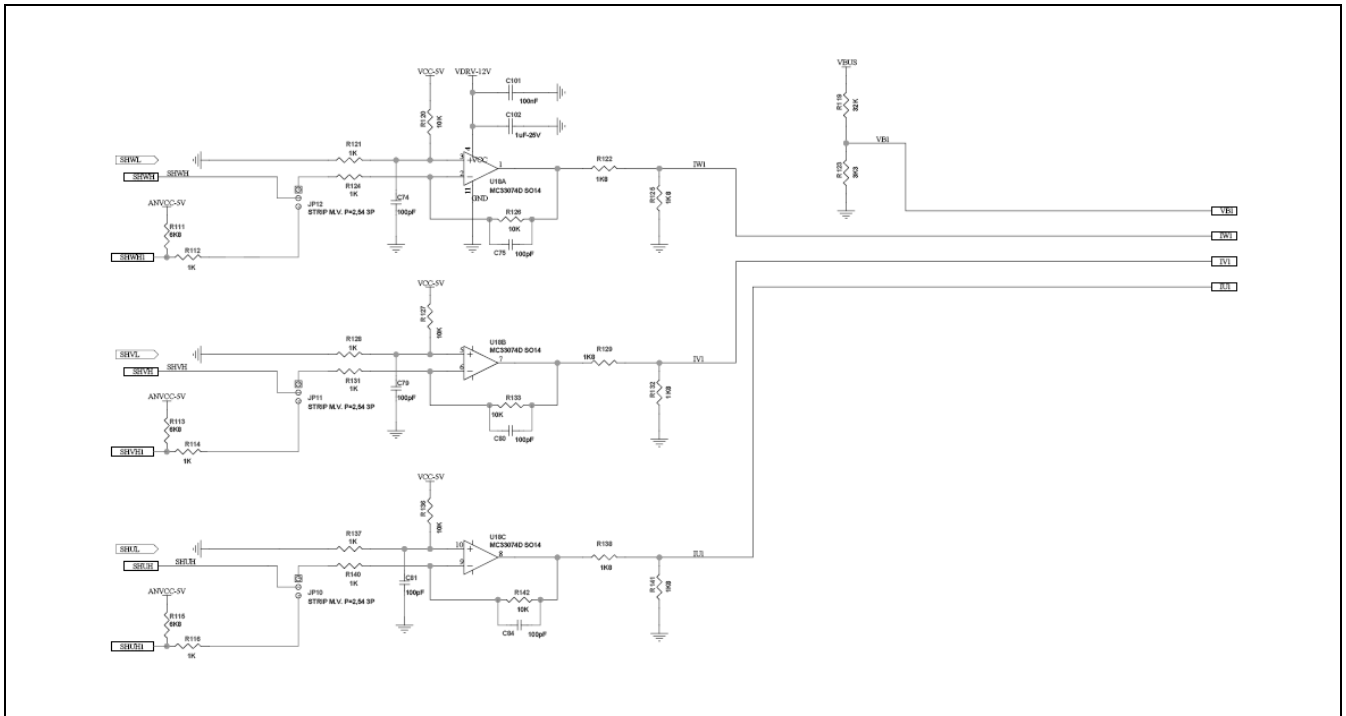


Figure 6 Motor Current measurement circuit

Table 3 ADC conversions

Item	ADC Channel	Conversion ratio (actual value/ADC input value)
Phase u current - i_u	AN002	-5A-5A/ 0-5V
Phase v current - i_v	AN001	-5A-5A/ 0-5V
Phase w current - i_w	AN000	-5A-5A/ 0-5V
DC bus voltage - v_{bus}	AN003	0-50V/0-5V

Basically, the signals can be categorized into two main types: bipolar and unipolar. The motor phase currents are examples of bipolar signal while the DC bus voltage is an example of unipolar signal.

The shunt resistor used in this application is 0.1Ω. The measured current range is from -5A to 5A. The gain of amplifier is set to 5. Figure 7 depicts the current sensing scale translation.

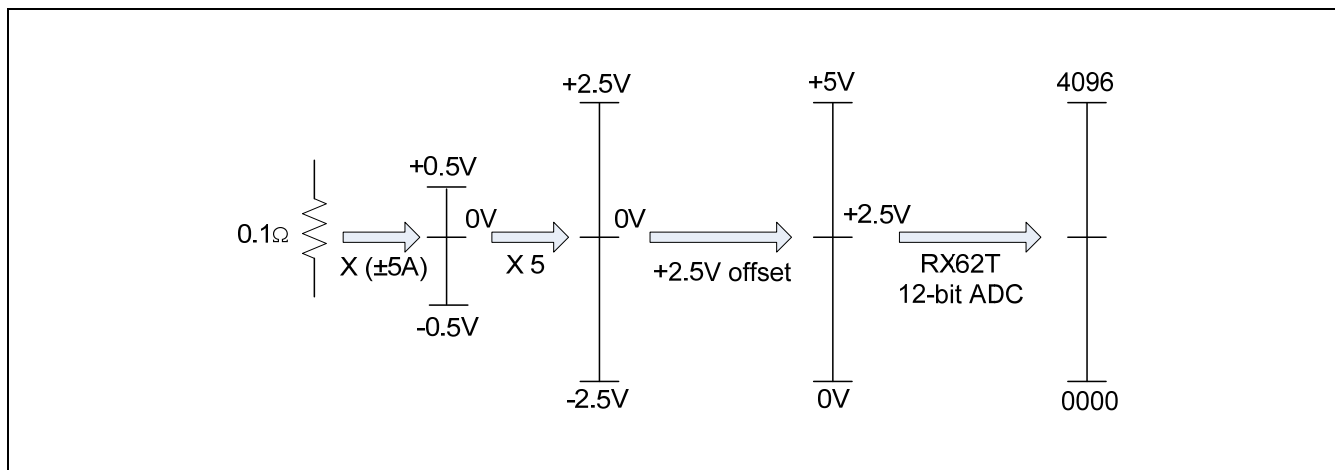


Figure 7 Motor current sensing scale translation

The shunt resistor 0.1Ω senses the maximum ± 5 Amps current to translate the current to the ± 0.5 volts voltage. The amplifier enlarges this voltage 5 times. The A/D inputs accept the analog input signals (i_u, i_v, i_w) in the range of 0-5 volts for RX62T with the ground referenced to 0 volt. The output voltage of the amplifier is added 2.5V offset. The A/D input value of 2.5 V is taken as the current of zero, and A/D input values from 2.5V to 5V correspond to positive current values and from 0 to 2.5V negative current values. The 12-bit ADC read the voltage into the digital value from 0 to 4096.

$$i_u = KADI * (AN002 - i_{u_offset})$$

$$i_v = KADI * (AN001 - i_{v_offset})$$

$$i_w = KADI * (AN000 - i_{w_offset})$$

$$KADI = 5 / (4096 * Rshunt * Kamp)$$

Where,

i_u, i_v and i_w are three phase motor currents;

$i_{u_offset}, i_{v_offset}$ and i_{w_offset} are u, v and w phase current offsets, respectively;

$AN002, AN001$ and $AN000$ are the 12-bit ADC reading values of u, v and w phase shunt currents, respectively;

$KADI$ is the motor phase current scaling;

$Rshunt$ is the value of the shunt resistor;

$Kamp$ is the gain of the current amplifier.

5.5 Three Shunt Current Reading Software implementation

The software implementation includes the shunt current offset calculation `MC_SetOff()` and the shunt current reading `MC_Read_TS()`.

- ❖ `MC_SetOff()` reads the offset of the ADC channels when the currents are 0; it is executed once at the beginning.
- ❖ `MC_Read_TS()` is called every interrupt at the trough. It reads ADC conversion results. Given the duty-cycle values, it calculates which two channels are to be read. Those are corresponding to the longer ON period of the lower switches. It has to subtract the channel offsets and converts into the motor actual currents; The 3rd current is calculated as minus the sum of the other two.

Figure 8 shows the flowchart of the three shunt current measurements.

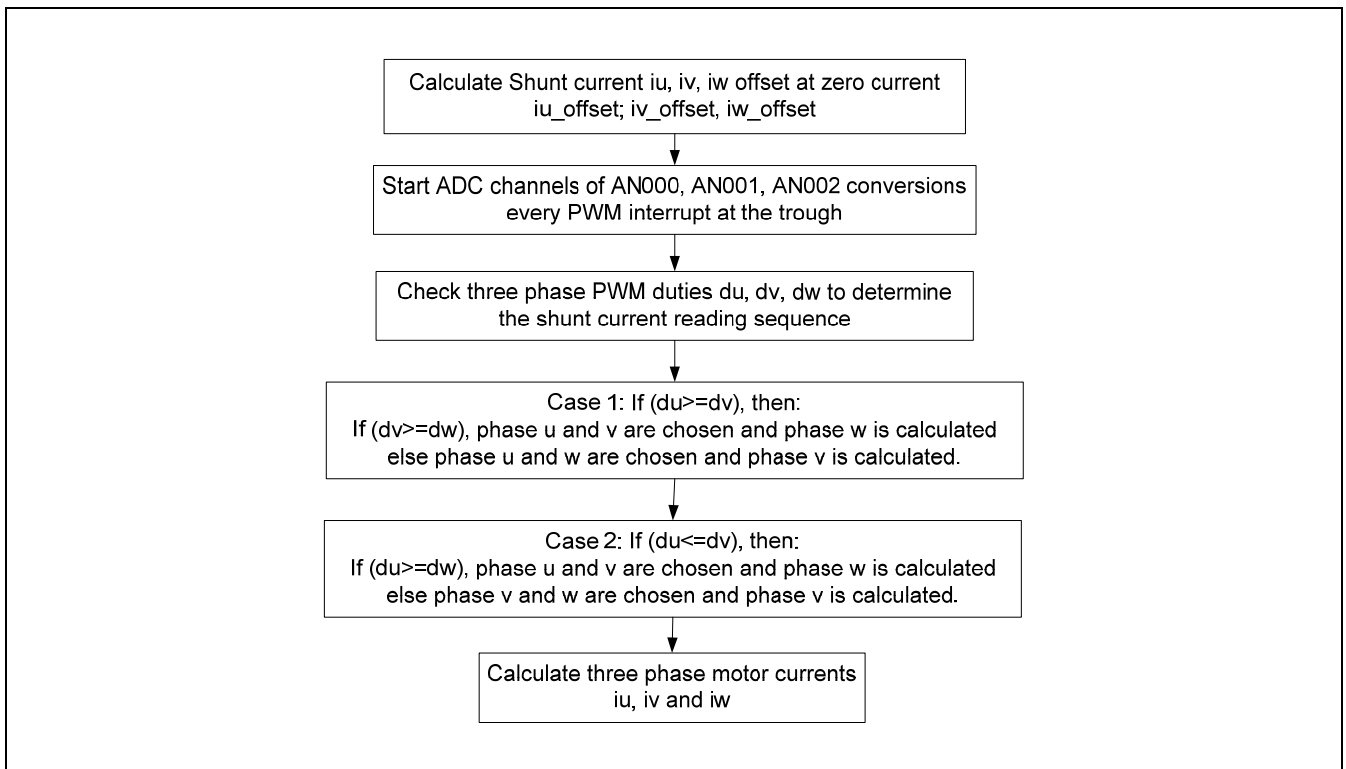


Figure 8 Flowchart of three shunt current measurements

6. Three Shunt Sensorless Vector Control Strategy

Vector control formulation depicted in Figure 9 provides a straightforward way to control the flux and the torque in much the same way as the control of DC motors – the flux is controlled by the I_d current, while the torque is controlled by the I_q current. Due to its nature, the 3-phase motor has three windings and three currents which are 120 degrees apart. Vector formulation uses Clarke and Park transforms to convert the measured phase currents from the (u, v, w) frame to first transform them in the static orthogonal (α, β) frame (which is 90 degrees apart), and then, to the rotor frame which is also an orthogonal frame aligned along the magnetic field axes known as the (d,q) frame. These transformations use the transcendental functions sine and cosine of the rotor angle, thus, it is a requirement that the rotor angle is known at the time the calculation is made. Once the currents are transformed in the (d,q) frame, the control algorithm simply runs the PID or PI loop to calculate the required voltages for the torque and flux. These required voltages (V_{dc} , V_{qc}) are then transformed back in the (u, v, w) frame using the inverse Clarke and inverse Park transforms to further calculate the PWM duty cycle.

All these blocks form the inner current loop shown in Figure 9 with two computing blocks known as flux observer and speed estimation, which are a special part of the sensorless vector control formulation. When a sensor is used to measure the rotor angle and speed measurements, these two blocks change significantly.

In sensorless implementation, because there is NO sensor to measure the angle and speed, a motor model is used to calculate the flux and estimate the speed based on the measured phase currents and motor parameters, thus making computations more involved. These computations further involve the use of transcendental functions and filters.

Phase currents measured with ADC are first converted into proper current values. Third-order filters are employed to reduce the noise and other undesired effects and integrate the flux continuously as required. Finally, the inverse tangent ARCTAN function is used to derive the rotor angle. The speed is estimated based on two consecutive rotor angle computations again with some filtering employed. All these calculations take a significant amount of time and consume the CPU bandwidth. This is where the FPU helps to reduce the CPU bandwidth, and it also reduces the code size.

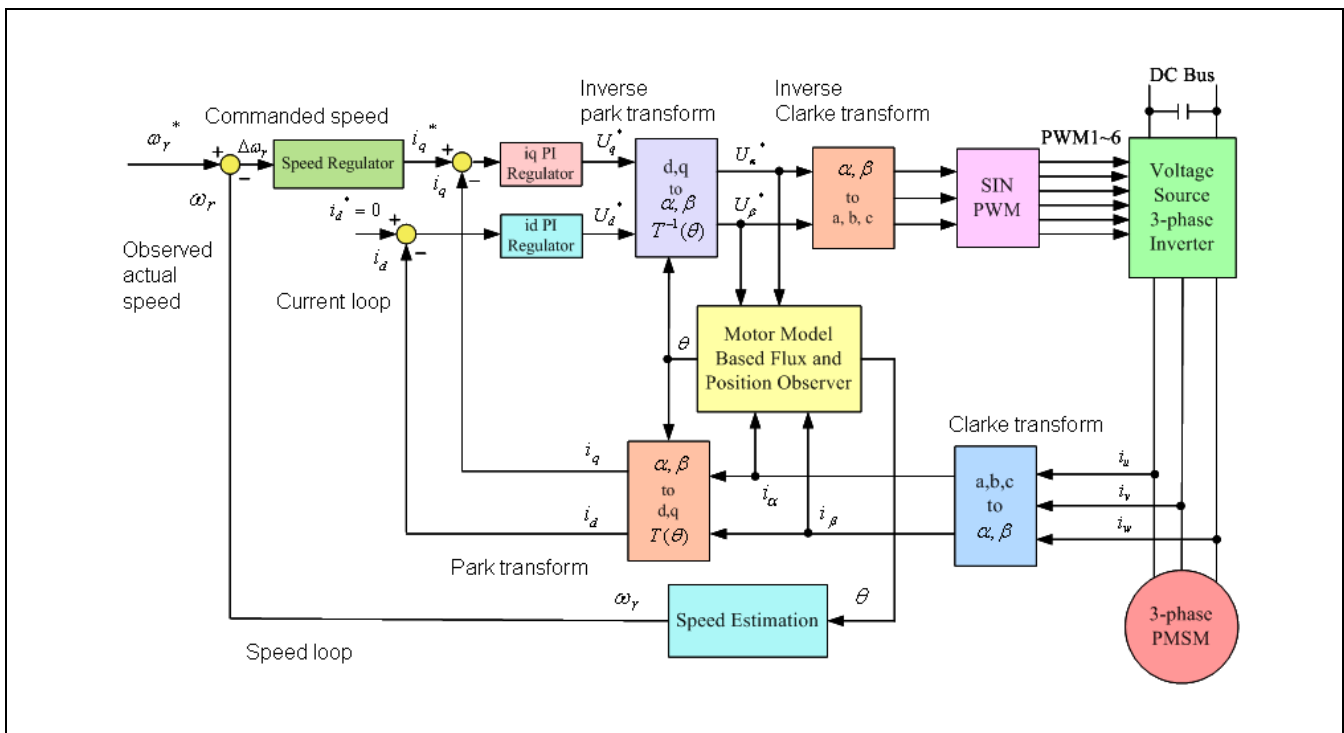


Figure 9 Block diagram of sensorless vector control

As shown, the SVC uses the complex coordinate transformations and motor mathematical model, which requires large amount of calculations. Thus SVC necessitates a fast MCU with high computing capability. Currently, most of the SVC implementations are based on the fixed-point MCUs or DSPs. While a few of them adopt the floating point processors the cores of those processors are actually fixed-point and they are thus not true FPU implementation.

7. Software Descriptions

The three shunt sensorless vector control software has the following features:

- ❖ All codes are written in C language;
- ❖ The software is modularized according to the SVC block diagram (as shown in Figure 9);
- ❖ Core SVC modules can be generally used without any changes;
- ❖ I/O definitions and basic MCU drivers are automatically generated by HEW;
- ❖ Motor and control parameters are easily tuned through a header file of “customize.h” and GUI user interface

7.1 Three Shunt Sensorless Vector Control Software Implementation

Three shunt sensorless vector control software architecture is similar to the one in Renesas' Application Note REU05B0103-0100/Rev.1.00. Shown in Figure 10 is the workspace for three shunt sensorless vector control using Renesas' HEW. The codes include `dbstc.c`; `hwsetup.c`, `intprg.c`; `main.c`; `motorcontrol.c`; `resetprg.c`, `userif.c` and `vectbl.c`. Core sensorless vector control modules for vector control transformation and speed and position observer are put in the library of `3Shnt_SVC_Lib.lib`.

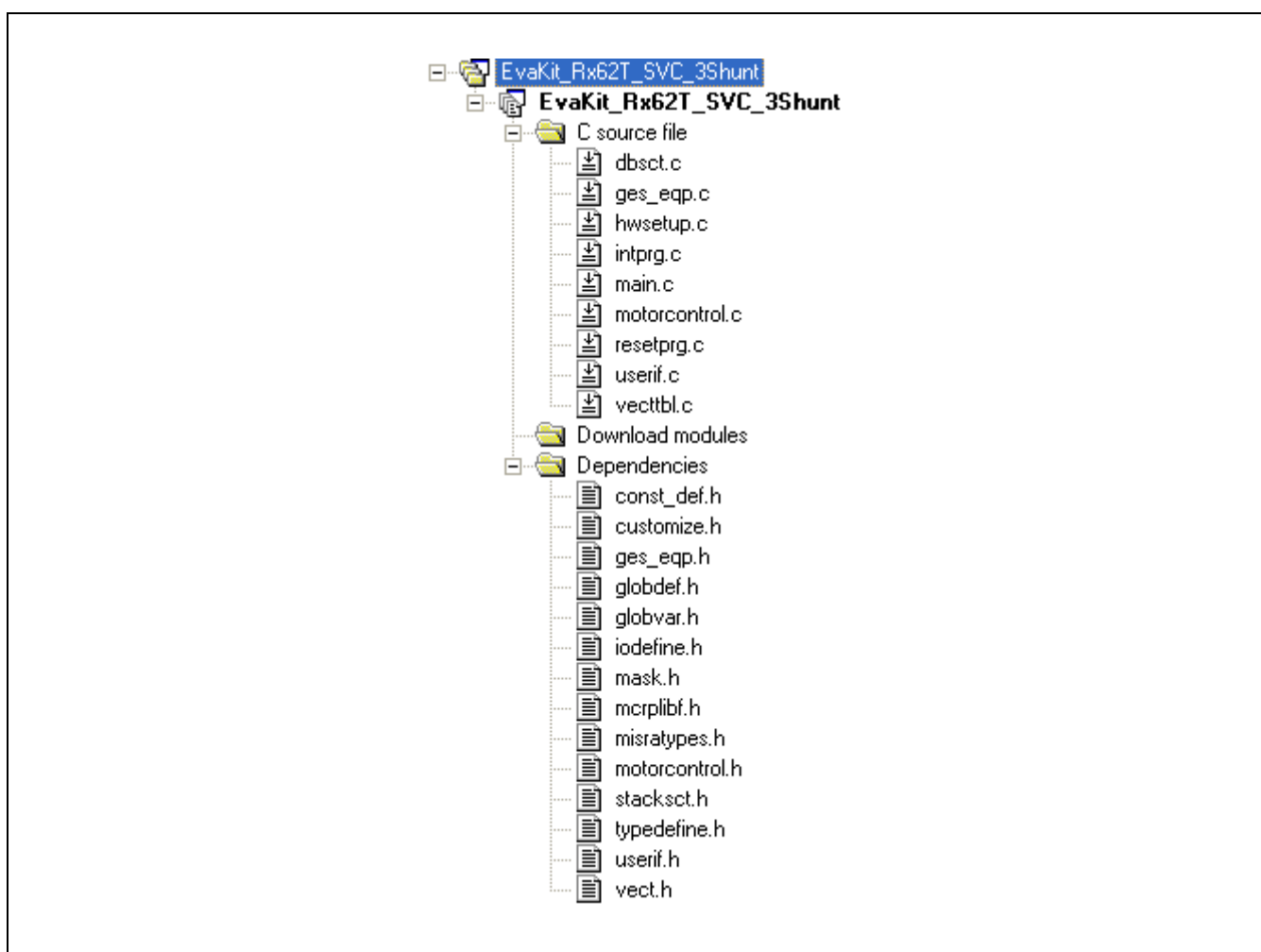


Figure 10 Three shunt SVC software workspace

7.2 Flowchart of Three Shunt Sensorless Vector Control

MTU3 timer interrupt is to implement three shunt sensorless vector control. Figure 11 is a flowchart of the PWM interrupt. It starts with the open loop, and then switches to the closed speed loop.

The procedures in the PWM interrupt of MC_ConInt() are:

- ❖ Motor phase motor currents and DC bus voltage are first sampled;
- ❖ When the motor powers on, the startup procedure handles open loop starting;
- ❖ After the motor starts up at the given time, the system switches into the closed speed loop;
- ❖ The rotor position and the speed are estimated in sync with the carrier frequency in order to update the position and the speed timely;
- ❖ The current PI controller outputs of v_d and v_q are transformed back to three-phase voltages of v_u , v_v and v_w , which are used to calculate PWM duty ratios to drive motor to the desired voltages.

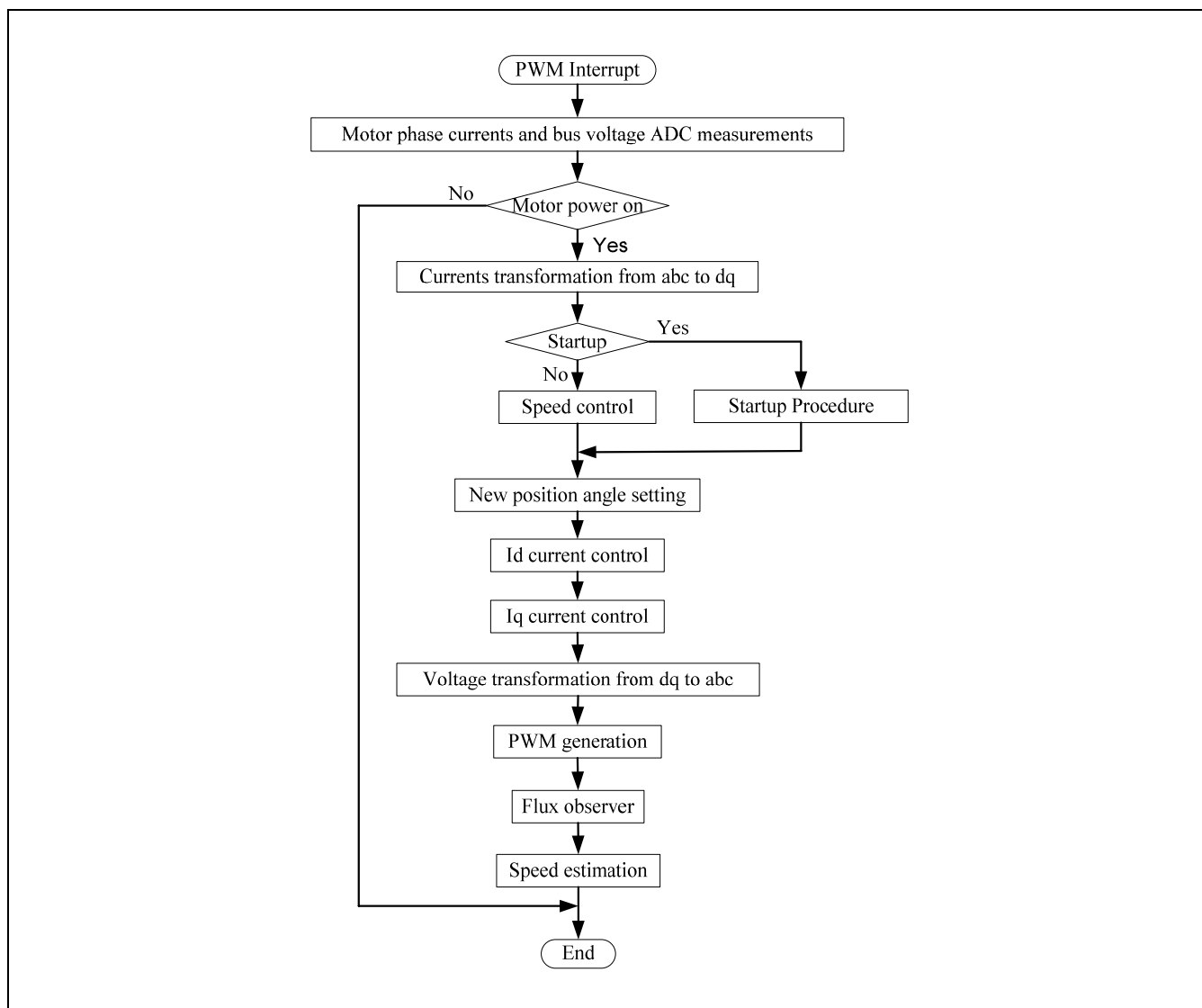


Figure 11 Flowchart of PWM interrupt

Figure 12 shows a flowchart of the three shunt sensorless vector control algorithm.

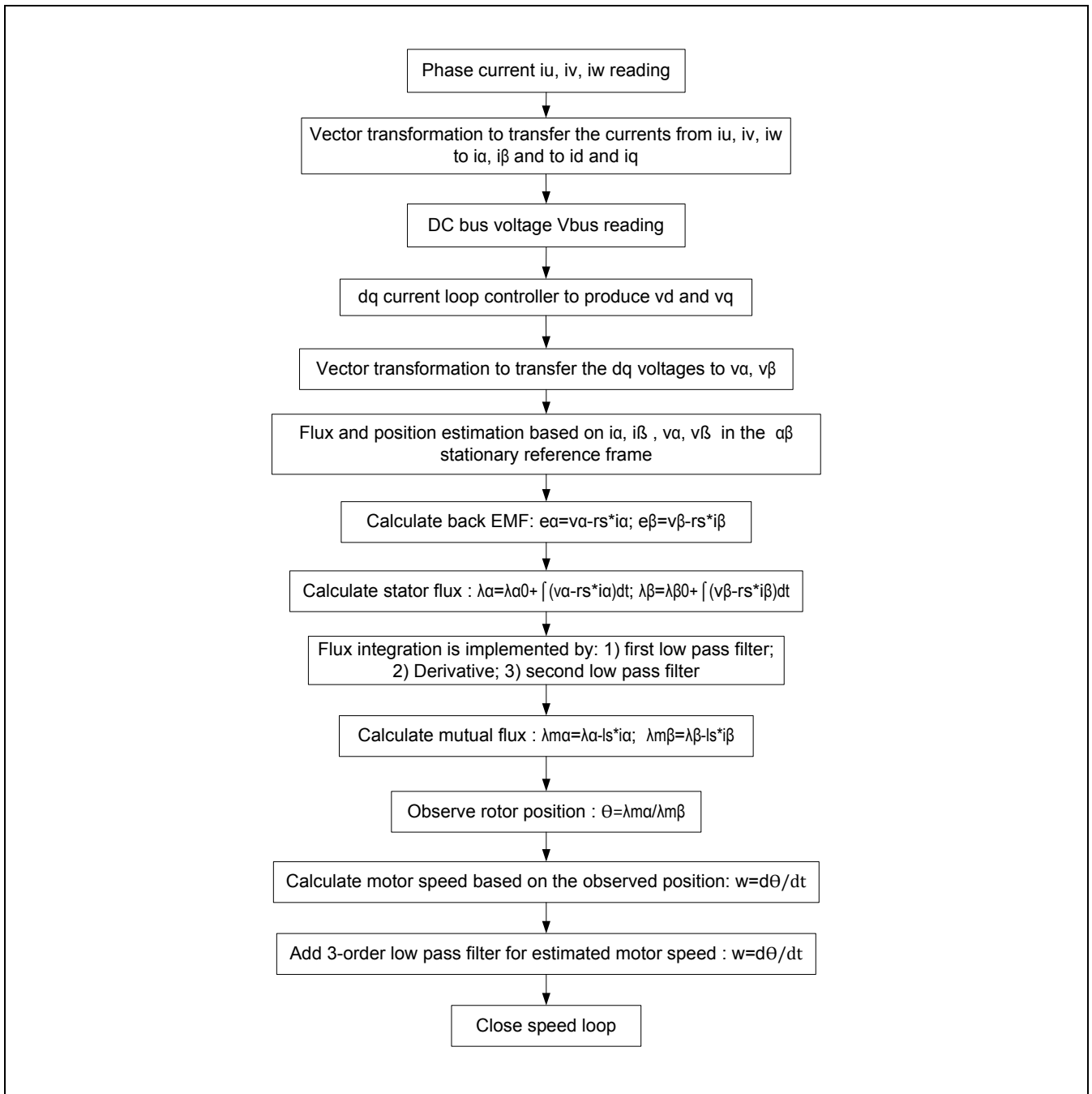


Figure 12 Flowchart of three shunt sensorless vector control algorithm

8. Motor and Control Parameter Tuning Example

8.1 Tuning through header file

Shown in Figure 13 and Table 4 are a BLDC motor and its data sheet. The motor is a 24V 4-pole 3-phase BLDC motor equipped with hall sensors and a 1000 line per revolution quadratic encoder with index. The rated power is 30watts, and the rated speed is 4,000 rpm. According to the data sheet, motor and control parameters have to be properly modified to run three shunt sensorless vector control.



Figure 13 A BLDC motor for evaluation kit

Table 4 Motor data sheet

Motor Poles	8
Phase	3
Voltage	24 V
Current	1.5 A
Power	30watts
Speed	4000 rpm
Inductance	2.3 mh
Stator Resistor	1.68Ω
Hall sensors	3
Encoder	1000pulses/rev

First, define motor parameters:

```
❖ #define R_STA_CUSTOM      8           // stator phase resistance 0.8 Ω *10
❖ #define L_SYN_CUSTOM     11          // inductance in Henry 2.3mh*10000
❖ #define POLES_CUSTOM     4           // 4 pair of poles
❖ #define I_START_CUSTOM   1.5         // startup current of 1.5A
❖ #define IQ_MAX_CUSTOM    5.0         // maximum iq current of 5.0A
❖ #define RPM_MIN_CUSTOM   500         // minimum motor speed of 500rpm
❖ #define RPM_MAX_CUSTOM   4000        // maximum motor speed of 4,000rpm
```

Second, tune control parameters:

```
❖ #define R_ACC_CUSTOM     1000        // acceleration ramp in 1000rpm/sec
❖ #define KP_CUR_CUSTOM    60          // proportional gain of current controller
❖ #define KI_CUR_CUSTOM    80          // integral gain of current controller
❖ #define KP_SPD_CUSTOM    40          // proportional gain of speed controller
❖ #define KI_SPD_CUSTOM    150         // integral gain of speed controller
```

8.2 Tuning by GUI

The motor and control parameters can be tuned through Renesas friendly graphic user interface as shown in Figure 14. Without modifying the code, the parameters can be set for the different motors and applications. There is a parameter window to set up 20 parameters. Scrolling up and down through these parameters, the user can make changes to the settings, and “Write” to EEPROM, but this doesn’t change the “customize.h” file. The original values will be restored upon RESET. From Figure 15, it can be seen that these parameters mirror the #defines in the “customize.h” file. The motor and control parameters can be easily changed by the GUI.



Figure 14 Evaluation GUI interface

INDEX	DESCRIPTION	UNIT	MIN	MAX	VALUE	VALID
1	00. Default Parameters Setting	-	0	32767	0	true
2	01. Minimum Speed	rpm	200	5000	500	true
3	02. Maximum Speed	rpm	1000	20000	2500	true
4	03. Acceleration	rpm/s	1	10000	1000	true
5	04. Deceleration	rpm/s	1	10000	1000	true
6	05. Polar couples	-	1	5	5	true
7	06. Startup Current	Apk/10	0	5000	10	true
8	07. Maximum "q" Current	Apk/10	0	5000	20	true
9	08. Stator Resistance	Ohm/10	0	5000	17	true
10	09. Synchronous Inductance	Henry/10000	0	5000	12	true
11	10. Startup Time	ms	300	10000	1000	true
12	11. Current Loop Kp	-	0	2047	60	true
13	12. Current Loop Ki	-	0	1023	80	true
14	13. Speed Loop Kp	-	0	4095	10	true
15	14. Speed Loop Ki	-	0	4095	100	true
16	15. Startup offset V	V/10	0	32767	0	true
17	16. Startup delta V	V/10	0	32767	0	true
18	17. PI Tuning trigger	-	0	32767	0	true
19	18. Free	-	0	32767	0	true
20	19. Free	-	0	32767	0	true

Figure 15 Parameter window

Appendix A - References

1. RX62T Group User's Manual: Hardware, R01UH0034EJ0110, April 20, 2011
2. DevCon 2010 Courses:
 - ID-620C, Complete Motor Control Integration with RX62T.
 - ID-623C, Understanding Sensor-less Vector Control with Floating Point Unit (FPU) Implementation.
3. Application Note of Sensorless Vector Control of three-phase PMSM motors, REU05B0103-0100/Rev.1.00, March, 2009
4. Application Note of Mcrp05: Brushless AC Motor Reference Platform, REU05B0051-0100, Feb, 2009
5. Huangsheng Xu, Rohan Hubin, and Dave Cocca, "Sensorless Vector Control of PMSM Motor using One Shunt Current Detection", IEEE-IAS 2008, Oct. 5-9, Edmonton, Alberta, Canada.
6. Huangsheng Xu, and Yashvant Jani, "Understanding Sensorless Vector Control for Brushless DC Motors", ESC-2008, Embedded System Silicon Valley conference, April 15-17, San Jose, California, USA.

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Revision Record

Rev.	Date	Description	
		Page	Summary
1.00	Nov. 18, 2011.	—	First edition issued

General Precautions in the Handling of MPU/MCU Products

The following usage notes are applicable to all MPU/MCU products from Renesas. For detailed usage notes on the products covered by this manual, refer to the relevant sections of the manual. If the descriptions under General Precautions in the Handling of MPU/MCU Products and in the body of the manual differ from each other, the description in the body of the manual takes precedence.

1. Handling of Unused Pins

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

- The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible. Unused pins should be handled as described under Handling of Unused Pins in the manual.

2. Processing at Power-on

The state of the product is undefined at the moment when power is supplied.

- The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the moment when power is supplied.

In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the moment when power is supplied until the reset process is completed.

In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the moment when power is supplied until the power reaches the level at which resetting has been specified.

3. Prohibition of Access to Reserved Addresses

Access to reserved addresses is prohibited.

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

4. Clock Signals

After applying a reset, only release the reset line after the operating clock signal has become stable.

When switching the clock signal during program execution, wait until the target clock signal has stabilized.

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

5. Differences between Products

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

- The characteristics of MPU/MCU in the same group but having different type numbers may differ because of the differences in internal memory capacity and layout pattern. When changing to products of different type numbers, implement a system-evaluation test for each of the products.

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Renesas Electronics America Inc.

2880 Scott Boulevard Santa Clara, CA 95050-2554, U.S.A.
Tel: +1-408-588-6000, Fax: +1-408-588-6130

Renesas Electronics Canada Limited

1101 Nicholson Road, Newmarket, Ontario L3Y 9C3, Canada
Tel: +1-905-898-5441, Fax: +1-905-898-3220

Renesas Electronics Europe Limited

Dukes Meadow, Millboard Road, Bourne End, Buckinghamshire, SL8 5FH, U.K
Tel: +44-1628-585-100, Fax: +44-1628-585-900

Renesas Electronics Europe GmbH

Arcadiastrasse 10, 40472 Düsseldorf, Germany
Tel: +49-211-65030, Fax: +49-211-6503-1327

Renesas Electronics (China) Co., Ltd.

7th Floor, Quantum Plaza, No.27 ZhiChunLu Haidian District, Beijing 100083, P.R.China
Tel: +86-10-8235-1155, Fax: +86-10-8235-7679

Renesas Electronics (Shanghai) Co., Ltd.

Unit 204, 205, AZIA Center, No.1233 Lujiazui Ring Rd., Pudong District, Shanghai 200120, China
Tel: +86-21-5877-1818, Fax: +86-21-6887-7858 / -7898

Renesas Electronics Hong Kong Limited

Unit 1601-1613, 16/F., Tower 2, Grand Century Place, 193 Prince Edward Road West, Mongkok, Kowloon, Hong Kong
Tel: +852-2886-9318, Fax: +852-2886-9022/9044

Renesas Electronics Taiwan Co., Ltd.

13F, No. 363, Fu Shing North Road, Taipei, Taiwan
Tel: +886-2-8175-9600, Fax: +886-2-8175-9670

Renesas Electronics Singapore Pte. Ltd.

1 HarbourFront Avenue, #06-10, Keppel Bay Tower, Singapore 098632
Tel: +65-6213-0200, Fax: +65-6278-8001

Renesas Electronics Malaysia Sdn.Bhd.

Unit 906, Block B, Menara Amcorp, Amcorp Trade Centre, No. 18, Jln Persiaran Barat, 46050 Petaling Jaya, Selangor Darul Ehsan, Malaysia
Tel: +60-3-7955-9390, Fax: +60-3-7955-9510

Renesas Electronics Korea Co., Ltd.

11F., Samik Lavied' or Bldg., 720-2 Yeoksam-Dong, Kangnam-Ku, Seoul 135-080, Korea
Tel: +82-2-558-3737, Fax: +82-2-558-5141