

# RX62T

R01AN1090ET0100

Rev.1.00

## 120-degree Trapezoidal-wave with Hall Sensor

July 01, 2012

### Abstract

This application note describes a method of driving a sensored Brushless DC Motor (BLDCM) with six step trapezoidal-wave controlled by RX62T. The motor control algorithm and experimental result are shown in following chapters.

### Target Device

RX62T

### Contents

1. Introduction.....	2
2. Programming.....	5
3. Implementation and Testing.....	8

### Figure

Figure 1-1 System Configuration.....	2
Figure 1-2 System Block Diagram.....	3
Figure 1-3 Upper Modulation (Active-low Drive) .....	3
Figure 1-4 Hall Mounting and Typical HALL Signature .....	4
Figure 1-5 Typical Commutation Sequence .....	4
Figure 2-1 Main Control Procedure .....	5
Figure 2-2 MTU3 Ch3 and Ch4 PWM Duty Calculation Procedure .....	6
Figure 2-3 Procedure of Saving A/D Conversion Result.....	7
Figure 2-4 Hall Signal of 2 Pole-pairs' Motor for One Revolution .....	7
Figure 2-5 Motor Speed Calculation Procedure .....	7
Figure 3-1 U, V, and W Description of BLWR110S.....	8
Figure 3-2 BLWR110S Specification .....	8
Figure 3-3 BEMF and Hall Signal.....	9
Figure 3-4 Pin Drive Look-up Tables.....	9
Figure 3-5 6-step PWM Signals (Active-low).....	10

## 1. Introduction

The 6-step method is one of the simplest methods for driving 3-phase BLDC motors. It is also known as 120-Degree trapezoidal, since it drives each winding for 120-degrees of the electrical rotation and leaves the winding un-driven for 60 degrees.

### 1.1 System Configuration

Target board is RX62T Evaluation Board designed by Renesas Electronics Taiwan. We use E1 to debug program, hall sensor input circuit to capture hall signal; inverter circuit to drive BLDC motor; variable resistor (VR) to control the motor rotational speed; UART port to output MCU information to terminal; switch button to control the motor spinning direction. In this application note, 120-degree trapezoidal control with hall sensor is applied. Table 1-1 lists the jumper setting for the hall signals input. Table 1-2 lists the jumper setting for the CPU mode selection.



Figure 1-1 System Configuration

Jumper	J9	J10	J11
Pins	2-3	2-3	2-3

Table 1-1 Jumper setting for hall sensor control

Jumper	J1	J2	J3	J4
Single chip mode	-	1-2	1-2	2-3
Boot mode	-	1-2	2-3	2-3

Table 1-2 CPU mode setting

### 1.2 Block Diagram

MTU3 module is mainly used in this example. Ch3 and ch4 are used for PWM output, which mode setting are reset-synchronized mode. Ch6 is used for calculating rotational speed. Ch1 is an auxiliary counter for 1ms and 2ms timing. Three GPIO connect with three hall sensor input signal. ADC receives VR value as a speed command to control rotational speed.

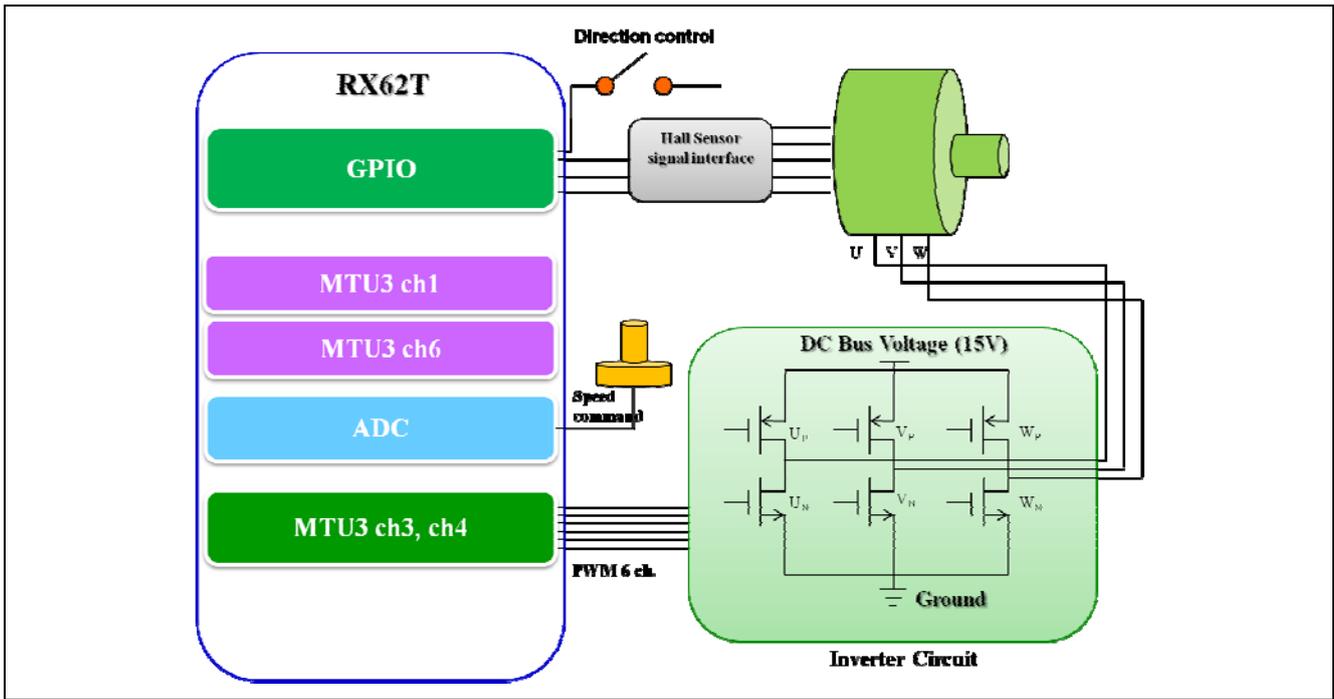


Figure 1-2 System Block Diagram

### 1.3 Controlling Phase Voltage

The basic voltage control for the three windings of the motor is performed using Phase-Width Modulation (PWM). In chapter 1.2, we showed how we will connect the microcontroller to the power inverter stage to control the gates of the MOSFETs. In effect, the PWM duty cycle controls the voltage at the motors terminal. There are various modulation methods used in today’s inverter drives. Typically modulation techniques are Upper modulation, Lower Modulation, rotating Modulation, or Balanced Modulation. For this application note we will be showing Upper modulation only. Figure 1-3 shows the basic upper modulation waveforms. Note that in this method, only the “P” or upper MOSFETs are modulated.

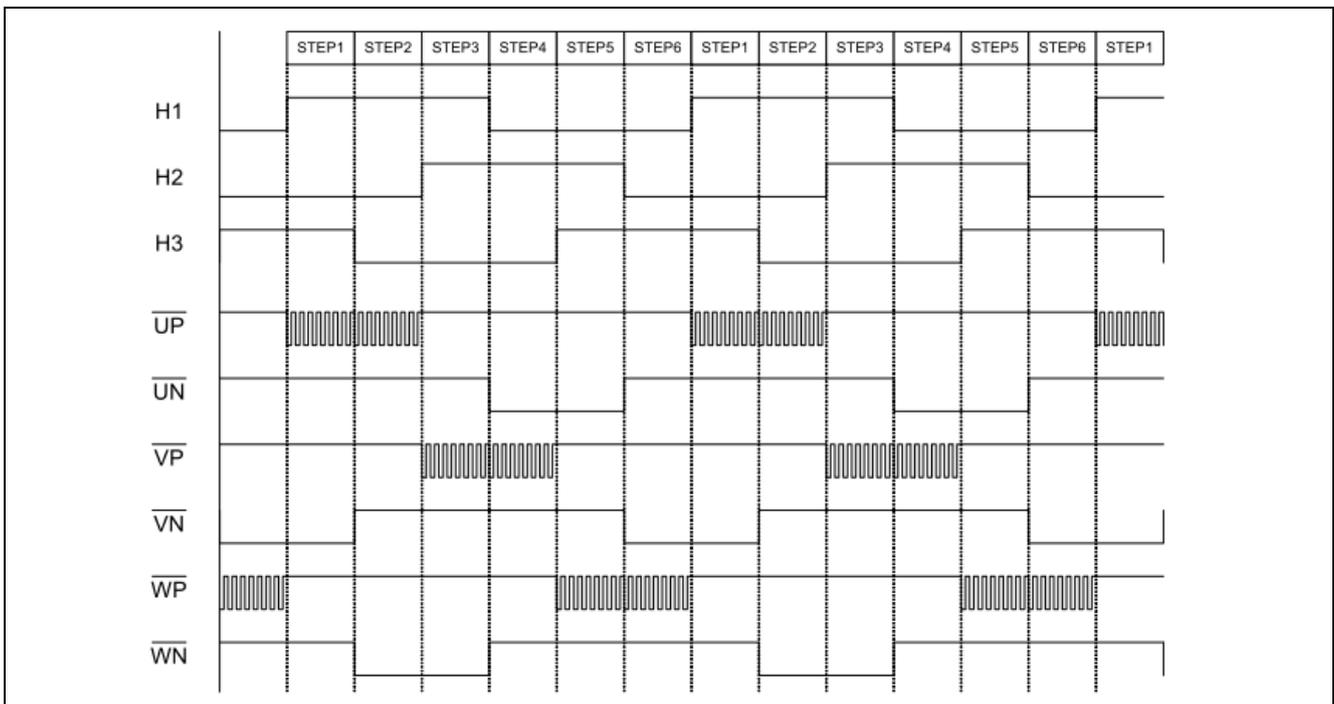


Figure 1-3 Upper Modulation (Active-low Drive)

Now we have control over the voltage on the windings (and indirectly the current) through the use of a PWM timer, but we must present these signals in the appropriate sequence to properly commutate the motor. In order to do this, we must know the rotor position. We will do this with the Hall sensors which sense the position of the rotor. They can do this because they are positioned relative to each motor phase winding in the stator coils (see Figure 1.4). Figure 1.5 shows a typical HALL cell signature. Note that the state changes every 60° for one electrical cycle. We can then read these on GPIO pins of the RX62T and decode them into a 60° rotor position. The number of electrical cycles in one mechanical rotation is based on the number of “pole-pairs” (magnetic poles) in the motor. For the figure given this is 1 pole pair, in this application note, 2 pole-pairs motor is used.

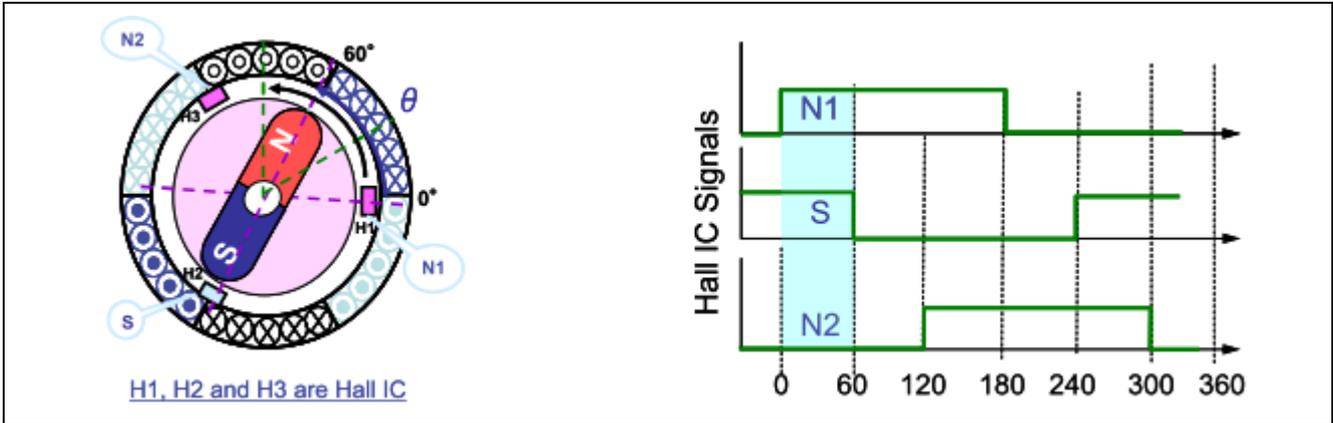


Figure 1-4 Hall Mounting and Typical HALL Signature

### 1.4 Commutating

So now we can control the voltage, we know where the rotor is so let's put them together. A motor manufacturer's data sheet will typically tell you "...when you see this HALL signature, drive these phase windings". Figure 1-5 shows a typical commutation sequence. For this motor, when we see the HALL signature for STEP1, we drive UP and VN. The rotor will move because the torque being caused by the magnetic fields in the stator coils are being applied at the correct angle to the magnets on the rotor and they will attempt to align. When we see the Hall signature change state to indicate Step 2 we switch the drive from UP and VN to UP and WN, and the rotor will continue to move. This will continue for the entire cycle until we are back at Step one and the process repeats. This is how we commutate the motor;

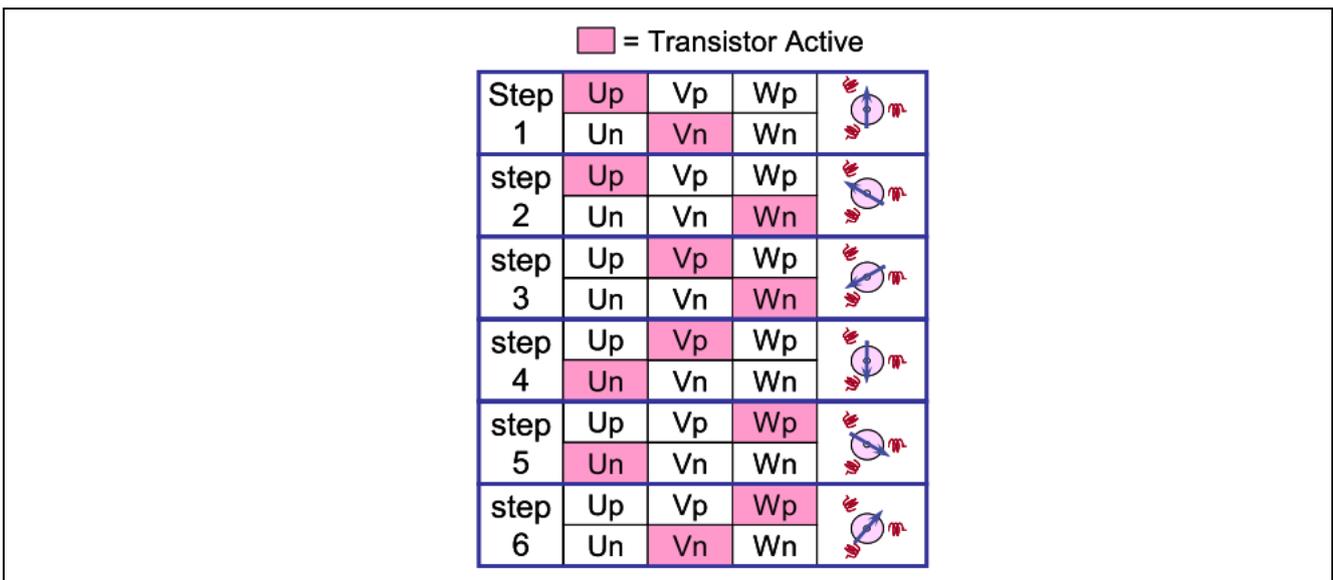


Figure 1-5 Typical Commutation Sequence

## 2. Programming

Chapter 2 is going to show how program is designed in this application note. Figure 2-1 shows the main routine that describes how program is executed. The carrier frequency of this sample code is 15 KHz, which stands for one PWM duty cycle will be calculated 15K times in one second, each interrupt procedure is shown in Figure 2-2. The maximum duty and minimum duty of the PWM in this example are limited at 80% and 10% respectively. The limitation of PWM duty depends on each motor's specification. Figure 2-4 and 2-5 show how mechanical speed in a rotating motor is measured.

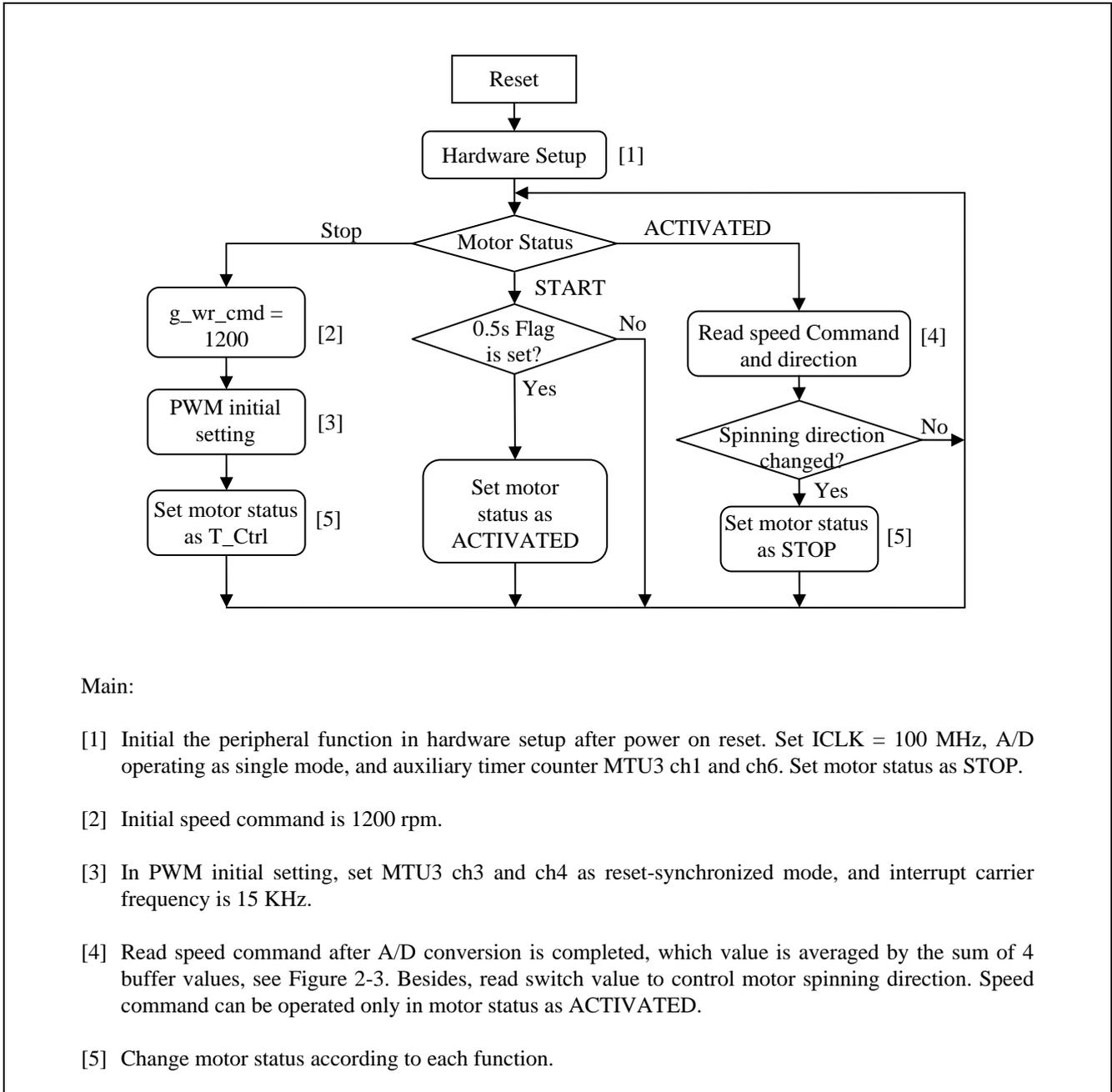
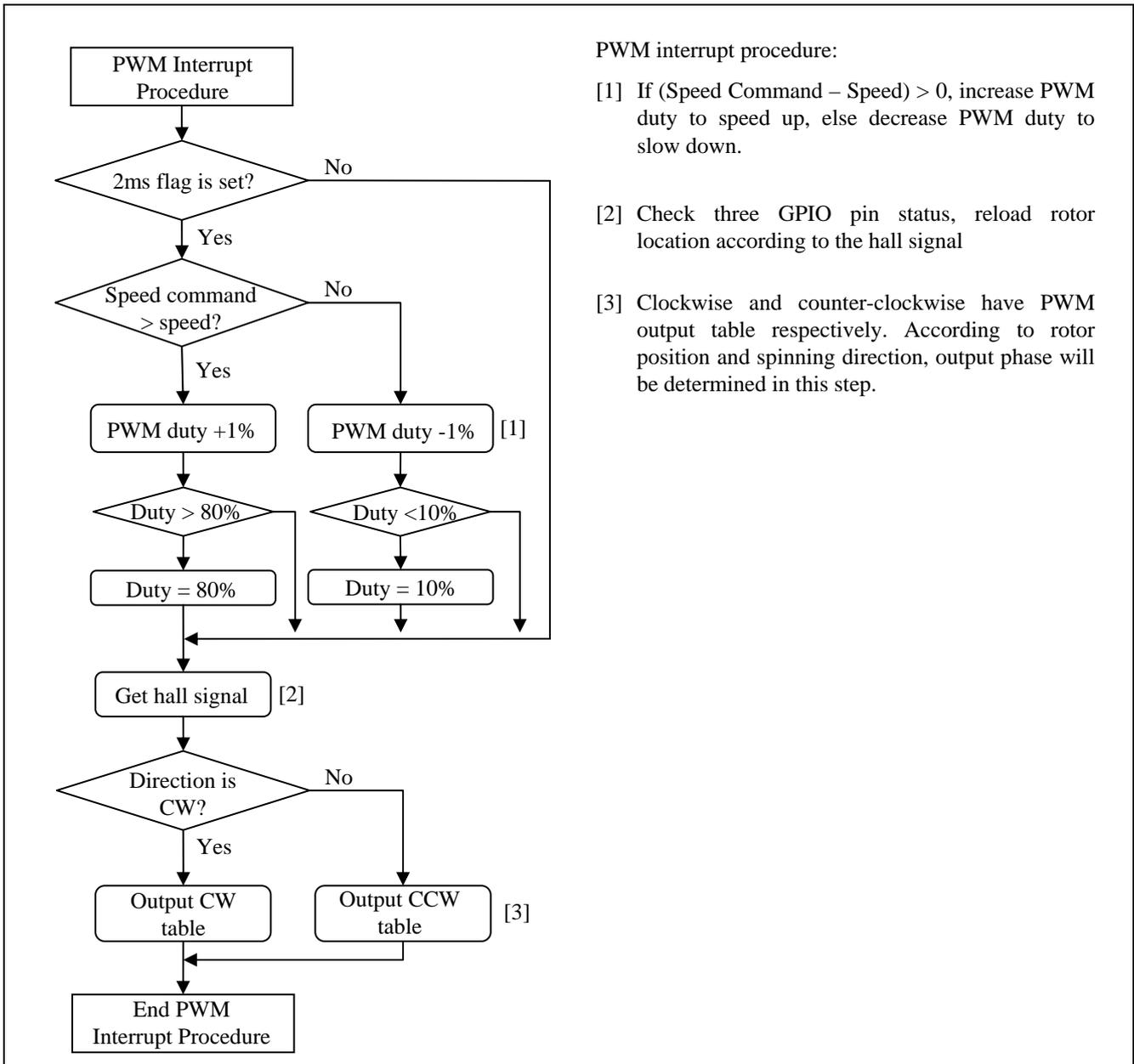


Figure 2-1 Main Control Procedure



PWM interrupt procedure:

- [1] If  $(\text{Speed Command} - \text{Speed}) > 0$ , increase PWM duty to speed up, else decrease PWM duty to slow down.
- [2] Check three GPIO pin status, reload rotor location according to the hall signal
- [3] Clockwise and counter-clockwise have PWM output table respectively. According to rotor position and spinning direction, output phase will be determined in this step.

Figure 2-2 MTU3 Ch3 and Ch4 PWM Duty Calculation Procedure

To get more precisely speed command value, we set four variables for saving A/D conversion results. In Fig 3-2, the interrupt procedure is triggered while A/D conversion is completed, then the result will be stored in buf1, and others saved value will be shifted in sequence. Four variables will be summed up and divided by 4, which used as speed command.

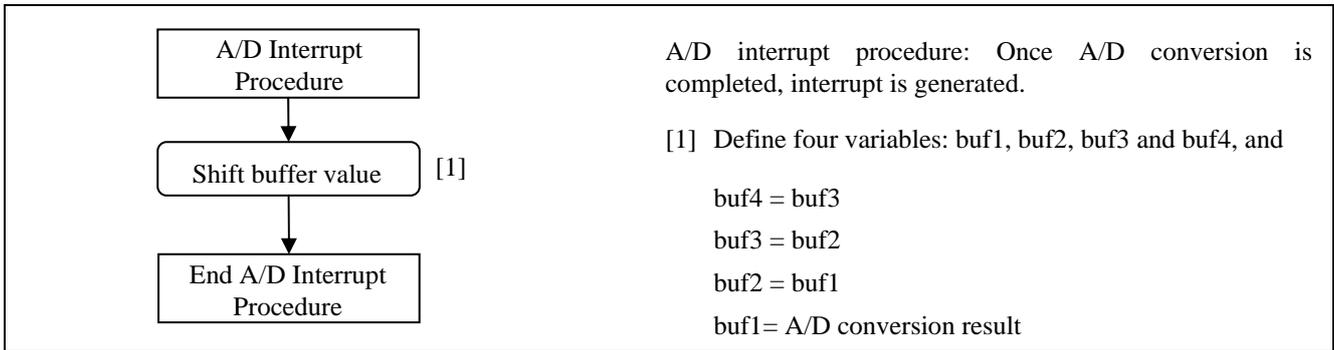


Figure 2-3 Procedure of Saving A/D Conversion Result

Speed calculation is one of the most important issues in motor control process. In this example, a two-pole-pairs motor is used, which generates 2 pulses in one revolution. One timer is selected to calculate motor rotation speed. As shown in Figure 2-4, timer operating frequency is 390625Hz, counter value will be saved in TGRA at rising and falling edge.

In this case, motor rotation speed is 60 rpm (i.e. 1 rps, Revolutions Per Second). While rising and falling edge is to trigger timer for capturing counter value, the TGRA value should be 97656. Depending on this condition, we calculate the ratio between 97656 and TGRA, and this is how we estimate motor rotation speed in this program. Speed calculation procedure is shown in Figure 2-5.

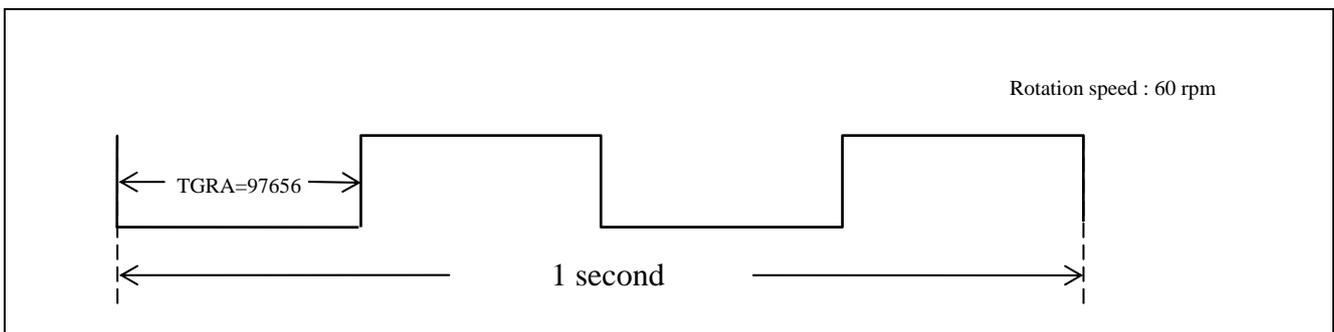


Figure 2-4 Hall Signal of 2 Pole-pairs' Motor for One Revolution

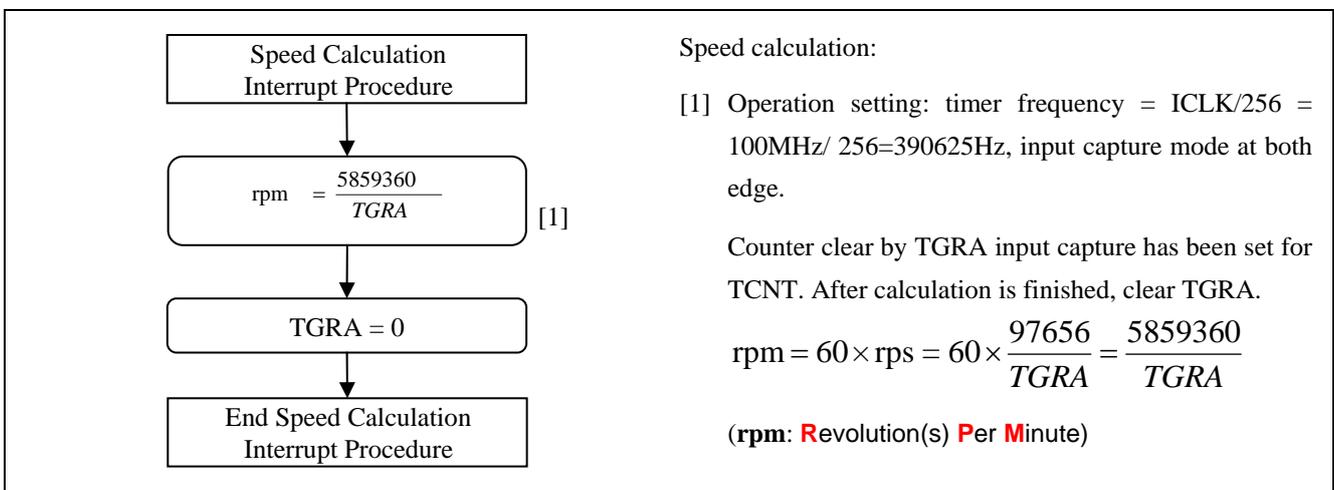


Figure 2-5 Motor Speed Calculation Procedure

### 3. Implementation and Testing

The specification of BLDC motor is shown in Figure 3-1 and Figure 3-2. The model number of target motor is BLWR110S-15V-8000, maximum speed can up to 8000 rpm, and in this experimental result, we can drive target motor up to 8000 rpm under PWM duty is 80%, the minimum speed of this motor without any loading is 300 rpm. PHASE A, PHASE B and PHASE C stand for U, V and W respectively.

Description	Motor Wire Color	Cable Adder Color
Hall Supply	Yellow	Red/White
Hall A	Blue	Orange/White
Hall B	Orange	Orange
Hall C	Brown	Yellow/White
Hall Ground	White	Black/White
Phase A	Green	Yellow
Phase B	Red	Red
Phase C	Black	Black

Figure 3-1 U, V, and W Description of BLWR110S

Winding Type:	Star, 4 Poles	Max. Radial Force:	15N @ 10mm from the flange
Hall Effect Angle:	120 degree electrical angle	Max. Axial Force:	10N
Shaft Run Out:	0.025mm	Insulation Class:	Class B
Radial Play:	0.02mm@450g	Dielectric Strength:	500VDC for one minute
End Play:	0.08mm@450g	Insulation Resistance:	100MOhm, 500VDC

Figure 3-2 BLWR110S Specification

The Capability of this target board is shown in Table 3-1.

Item	Value	Unit
CPU loading	1.42	%
Max. Speed	8000	rpm
Min. Speed	300	rpm
Timer Used	4	channel
Input BUS voltage	15	V

Table 3-1 Capability of RX62T Evaluation Board

Figure 3-3 shows the relationship between Hall A and U back Electromotive Force (EMF) signal. As you can see,  $U_p$  PWM chopping period is outputted for 120-degree.

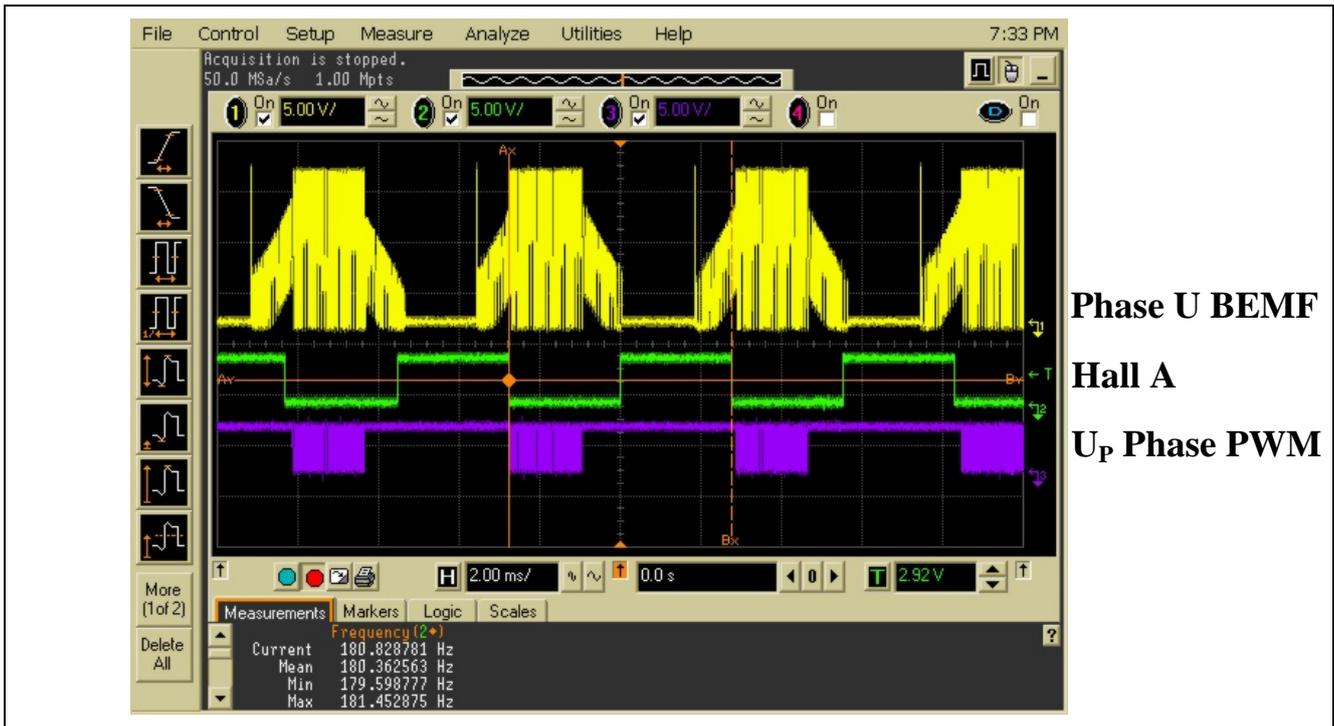


Figure 3-3 BEMF and Hall Signal

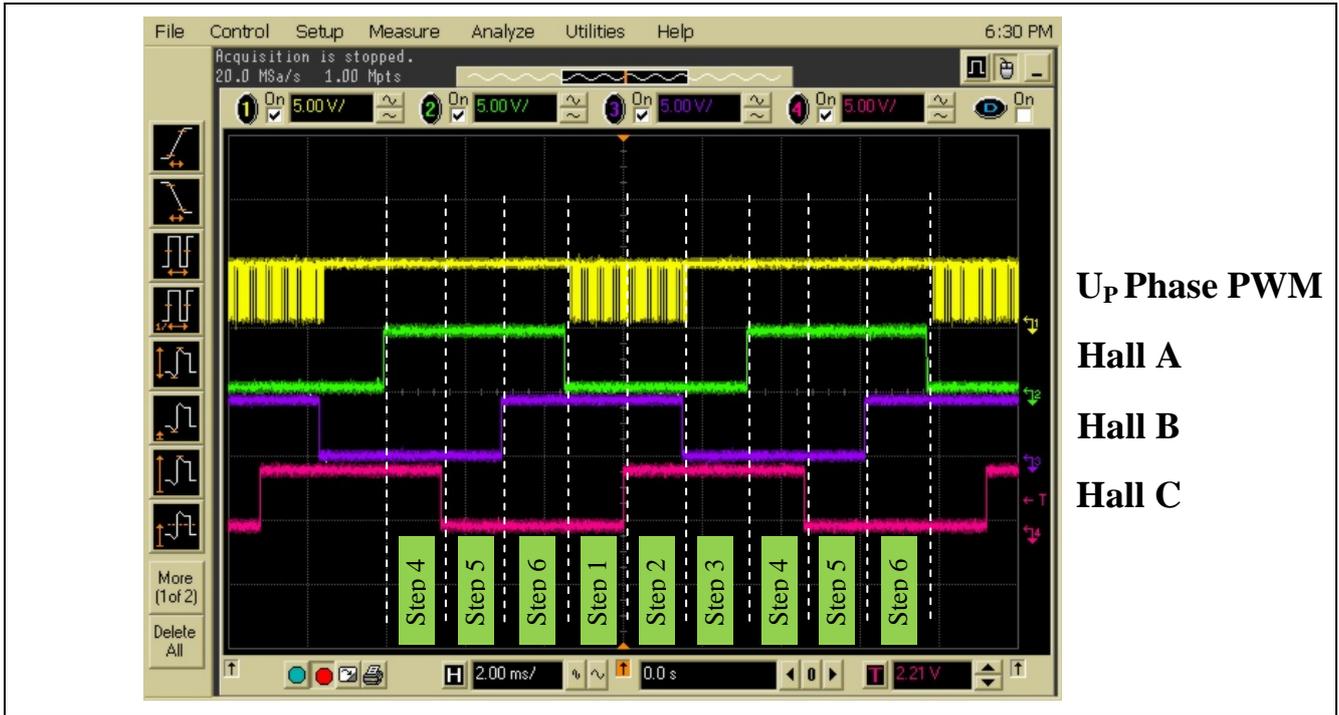
Figure 3-5 shows three hall sensor signals feedback to RX62T. While power is turning on, rotor's location is detected by three hall sensor. According to each phase, PWM is outputted that depends on look-up table which shows from the code piece in Figure 3-4. We have defined the steps in such a manner as to provide a direction look-up into the drive tables (i.e. STEP1 through STEP6 equal 1 through 6 respectively).

```

/* switch table for pwm output */
const unsigned char Output_CW[8] =
{
    /* WF VF UF */
    0xD8, /* output disable */
    0xDB, /* STEP 1 */
    0xDD, /* STEP 2 */
    0xD9, /* STEP 3 */
    0xDE, /* STEP 4 */
    0xDA, /* STEP 5 */
    0xDC, /* STEP 6 */
    0xD8, /* output disable */
};

```

Figure 3-4 Pin Drive Look-up Tables



**U<sub>P</sub> Phase PWM**  
**Hall A**  
**Hall B**  
**Hall C**

Figure 3-5 6-step PWM Signals (Active-low)

**Website and Support**

Renesas Electronics Website

<http://www.renesas.com/>

Inquiries

<http://www.renesas.com/inquiry>

All trademarks and registered trademarks are the property of their respective owners.



## 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 document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

### 1. Handling of Unused Pins

Handle unused pins in 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 a product with a different part number, confirm that the change will not lead to problems.

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

## Notice

1. All information included in this document is current as of the date this document is issued. Such information, however, is subject to change without any prior notice. Before purchasing or using any Renesas Electronics products listed herein, please confirm the latest product information with a Renesas Electronics sales office. Also, please pay regular and careful attention to additional and different information to be disclosed by Renesas Electronics such as that disclosed through our website.
  2. Renesas Electronics does not assume any liability for infringement of patents, copyrights, or other intellectual property rights of third parties by or arising from the use of Renesas Electronics products or technical information described in this document. No license, express, implied or otherwise, is granted hereby under any patents, copyrights or other intellectual property rights of Renesas Electronics or others.
  3. You should not alter, modify, copy, or otherwise misappropriate any Renesas Electronics product, whether in whole or in part.
  4. Descriptions of circuits, software and other related information in this document are provided only to illustrate the operation of semiconductor products and application examples. You are fully responsible for the incorporation of these circuits, software, and information in the design of your equipment. Renesas Electronics assumes no responsibility for any losses incurred by you or third parties arising from the use of these circuits, software, or information.
  5. When exporting the products or technology described in this document, you should comply with the applicable export control laws and regulations and follow the procedures required by such laws and regulations. You should not use Renesas Electronics products or the technology described in this document for any purpose relating to military applications or use by the military, including but not limited to the development of weapons of mass destruction. Renesas Electronics products and technology may not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable domestic or foreign laws or regulations.
  6. Renesas Electronics has used reasonable care in preparing the information included in this document, but Renesas Electronics does not warrant that such information is error free. Renesas Electronics assumes no liability whatsoever for any damages incurred by you resulting from errors in or omissions from the information included herein.
  7. Renesas Electronics products are classified according to the following three quality grades: "Standard", "High Quality", and "Specific". The recommended applications for each Renesas Electronics product depends on the product's quality grade, as indicated below. You must check the quality grade of each Renesas Electronics product before using it in a particular application. You may not use any Renesas Electronics product for any application categorized as "Specific" without the prior written consent of Renesas Electronics. Further, you may not use any Renesas Electronics product for any application for which it is not intended without the prior written consent of Renesas Electronics. Renesas Electronics shall not be in any way liable for any damages or losses incurred by you or third parties arising from the use of any Renesas Electronics product for an application categorized as "Specific" or for which the product is not intended where you have failed to obtain the prior written consent of Renesas Electronics. The quality grade of each Renesas Electronics product is "Standard" unless otherwise expressly specified in a Renesas Electronics data sheets or data books, etc.  
"Standard": Computers; office equipment; communications equipment; test and measurement equipment; audio and visual equipment; home electronic appliances; machine tools; personal electronic equipment; and industrial robots.  
"High Quality": Transportation equipment (automobiles, trains, ships, etc.); traffic control systems; anti-disaster systems; anti-crime systems; safety equipment; and medical equipment not specifically designed for life support.  
"Specific": Aircraft; aerospace equipment; submersible repeaters; nuclear reactor control systems; medical equipment or systems for life support (e.g. artificial life support devices or systems), surgical implantations, or healthcare intervention (e.g. excision, etc.), and any other applications or purposes that pose a direct threat to human life.
  8. You should use the Renesas Electronics products described in this document within the range specified by Renesas Electronics, especially with respect to the maximum rating, operating supply voltage range, movement power voltage range, heat radiation characteristics, installation and other product characteristics. Renesas Electronics shall have no liability for malfunctions or damages arising out of the use of Renesas Electronics products beyond such specified ranges.
  9. Although Renesas Electronics endeavors to improve the quality and reliability of its products, semiconductor products have specific characteristics such as the occurrence of failure at a certain rate and malfunctions under certain use conditions. Further, Renesas Electronics products are not subject to radiation resistance design. Please be sure to implement safety measures to guard them against the possibility of physical injury, and injury or damage caused by fire in the event of the failure of a Renesas Electronics product, such as safety design for hardware and software including but not limited to redundancy, fire control and malfunction prevention, appropriate treatment for aging degradation or any other appropriate measures. Because the evaluation of microcomputer software alone is very difficult, please evaluate the safety of the final products or system manufactured by you.
  10. Please contact a Renesas Electronics sales office for details as to environmental matters such as the environmental compatibility of each Renesas Electronics product. Please use Renesas Electronics products in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. Renesas Electronics assumes no liability for damages or losses occurring as a result of your noncompliance with applicable laws and regulations.
  11. This document may not be reproduced or duplicated, in any form, in whole or in part, without prior written consent of Renesas Electronics.
  12. Please contact a Renesas Electronics sales office if you have any questions regarding the information contained in this document or Renesas Electronics products, or if you have any other inquiries. (Note 1)
- "Renesas Electronics" as used in this document means Renesas Electronics Corporation and also includes its majority-owned subsidiaries.
- (Note 2) "Renesas Electronics product(s)" means any product developed or manufactured by or for Renesas Electronics.



SALES OFFICES

Renesas Electronic Corporation

<http://www.renesas.com>

Refer to "<http://www.renesas.com/>" for the latest and detailed information.

**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: +49-211-6503-0, 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.**

13<sup>th</sup> Fl., No. 363 Fu Shing N. Rd., Taipei, 10543 Taiwan R.O.C.  
Tel: +886-2-8175-9600, Fax: +886-2-8175-9672

**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 Laviel'or Bldg., 720-2 Yeoksam-Dong, Kangnam-Ku, Seoul 135-080, Korea

Tel: +82-2-558-3737, Fax: +82-2-558-5141