RX62T

120-degree Trapezoidal-wave with Hall Sensor

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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

Figure

1. Introduction

The 6-step method is one of the simplest methods for driving 3-phase BLDC motors. It is also know 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.

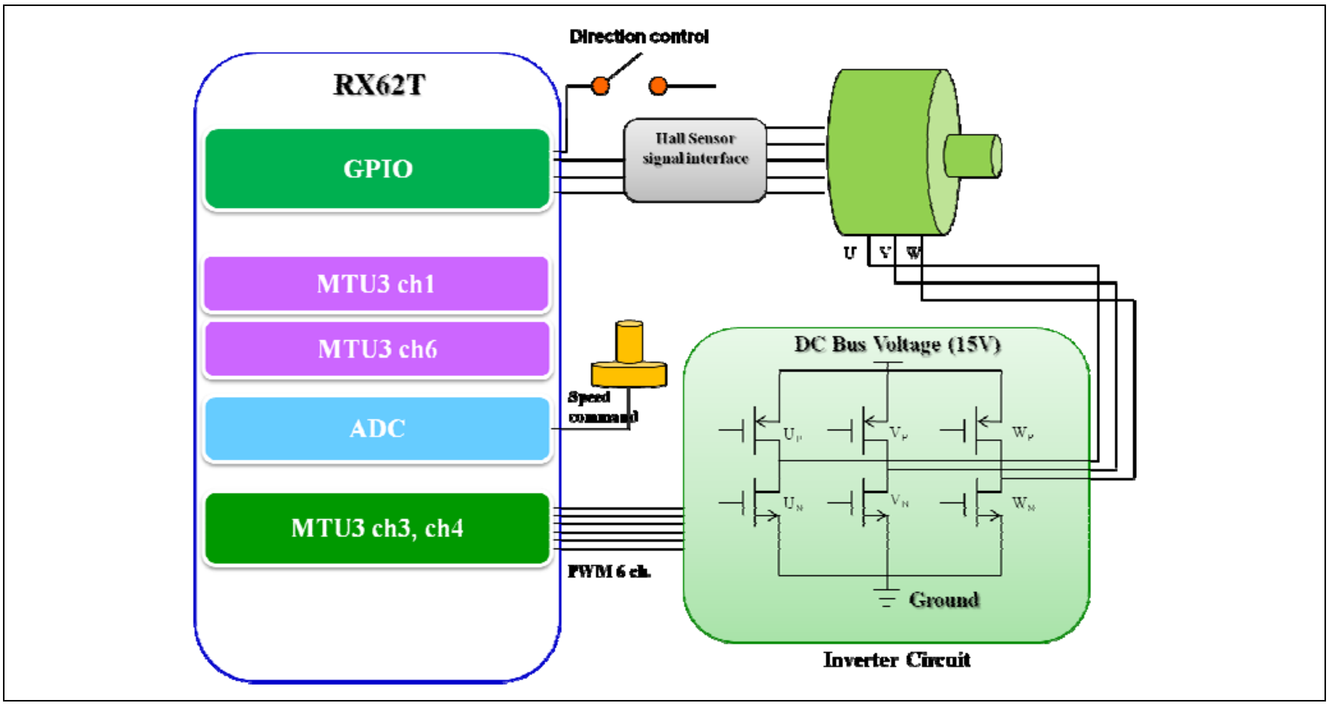


Figure 1-2 System Block Diagram

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.

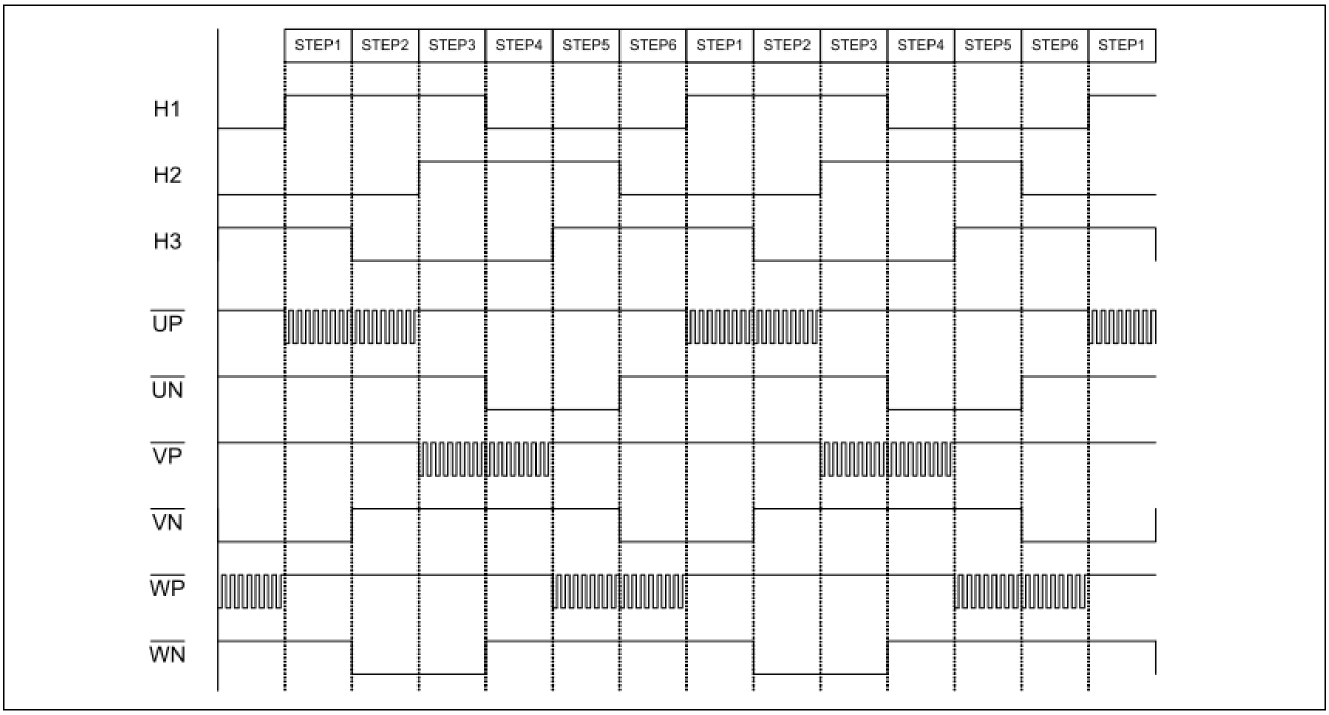


Figure 1-3 Upper Modulation (Active-low Drive)

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.

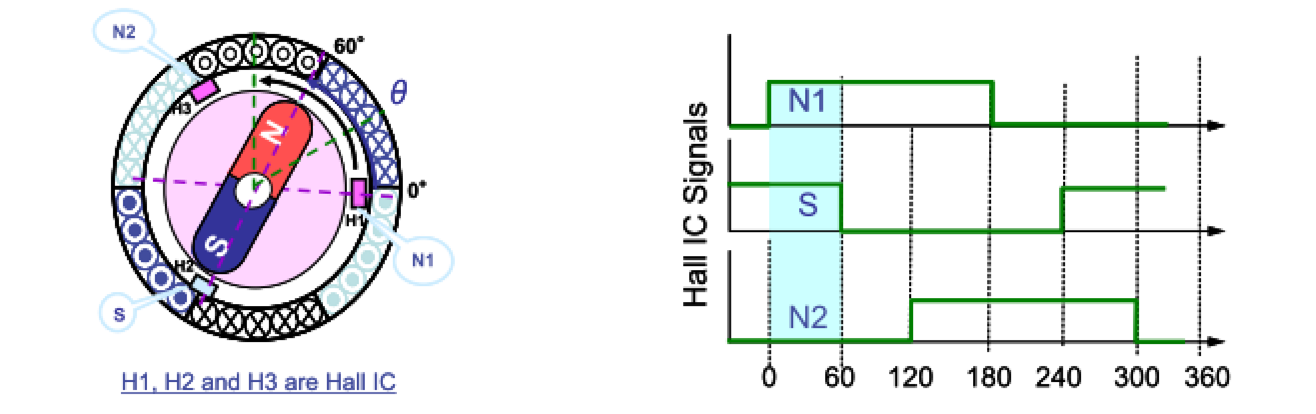


Figure 1-4 Hall Mounting and Typical HALL Signature

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;

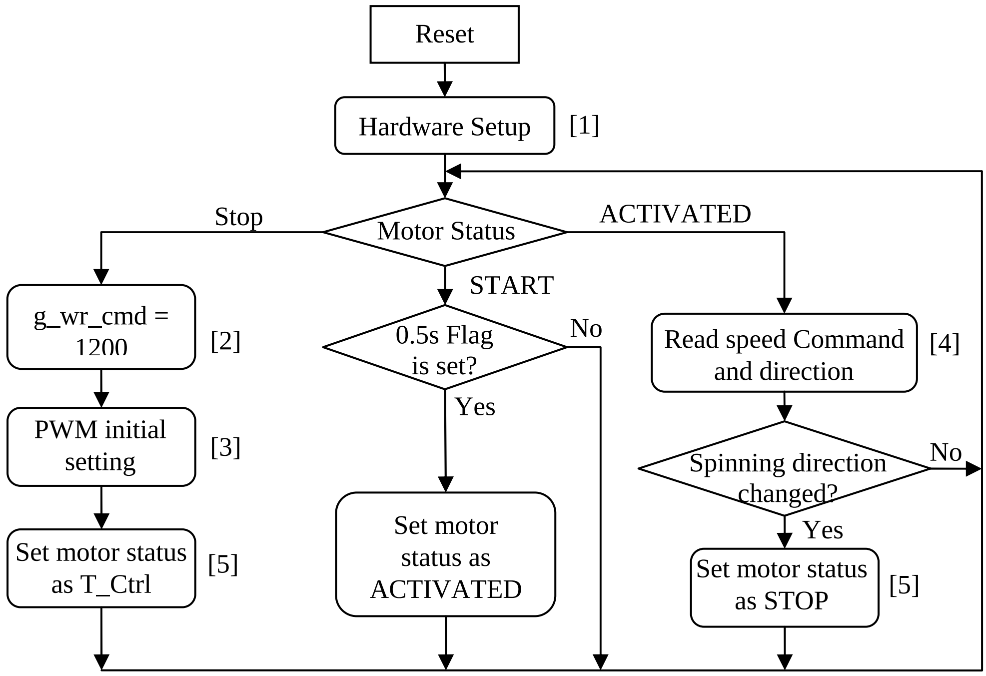
= Transistor Active (active transistors marked in pink; shown here in bold)

Step 1	**Up**	Vp	Wp
	Un	**Vn**	Wn
step 2	**Up**	Vp	Wp
	Un	Vn	**Wn**
step 3	Up	**Vp**	Wp
	Un	Vn	**Wn**
step 4	Up	**Vp**	Wp
	Un	Vn	Wn
step 5	Up	Vp	**Wp**
	Un	Vn	Wn
step 6	Up	Vp	**Wp**
	Un	**Vn**	Wn

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.



Main:

[1] Initial the peripheral function in hardware setup after power on reset. Set ICLK = 100 MHz, A/D operating as single mode, and auxiliary timer counter MTU3 ch1 and ch6. Set motor status as STOP.

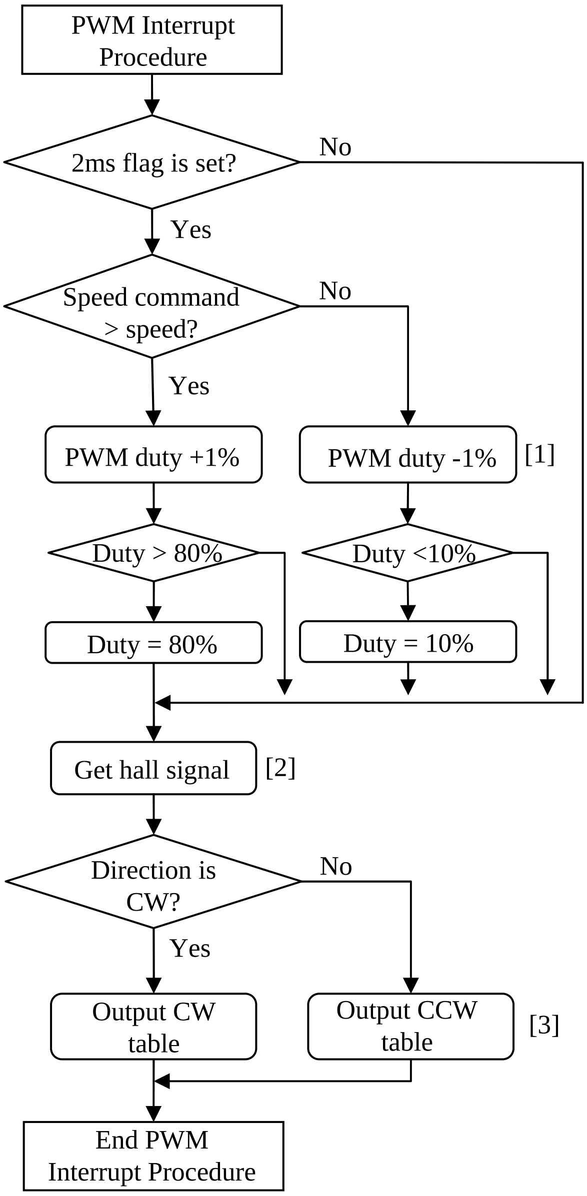
[2] Initial speed command is 1200 rpm.

[3] In PWM initial setting, set MTU3 ch3 and ch4 as reset-synchronized mode, and interrupt carrier frequency is 15 KHz.

[4] Read speed command after A/D conversion is completed, which value is averaged by the sum of 4 buffer values, see Figure 2-3. Besides, read switch value to control motor spinning direction. Speed command can be operated only in motor status as ACTIVATED.

[5] Change motor status according to each function.

Figure 2-1 Main Control Procedure



PWM interrupt procedure:

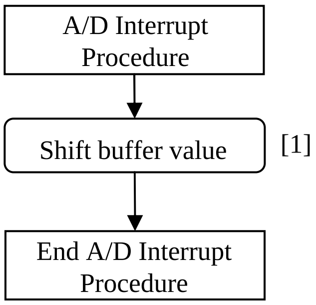
[1] If (Speed Command – Speed) > 0, increase PWM duty to speed up, else decrease PWM duty to slow down.

[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.



A/D interrupt procedure: Once A/D conversion is completed, interrupt is generated.

[1] Define four variables: buf1, buf2, buf3 and buf4, and

buf4 = buf3

buf3 = buf2

buf2 = buf1

buf1= A/D conversion result

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.

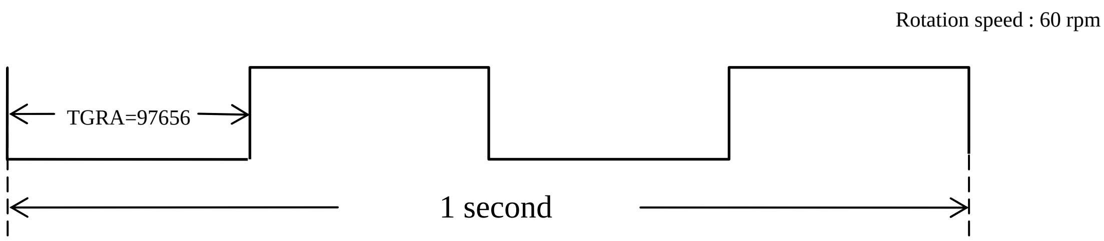
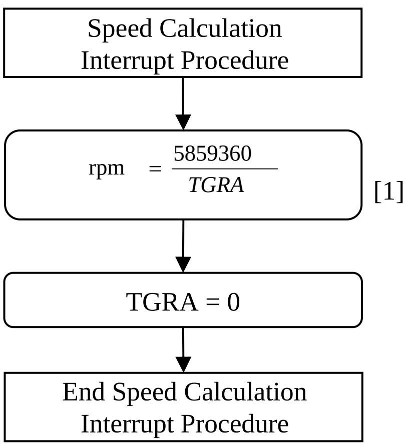


Figure 2-4 Hall Signal of 2 Pole-pairs' Motor for One Revolution



Speed calculation:

[1] Operation setting: timer frequency = ICLK/256 = 100MHz/ 256=390625Hz, input capture mode at both edge.

Counter clear by TGRA input capture has been set for TCNT. After calculation is finished, clear TGRA.

$$rpm = 60 \times rps = 60 \times \frac{97656}{TGRA} = \frac{5859360}{TGRA}$$

(**rpm**: Revolution(s) Per Minute)

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

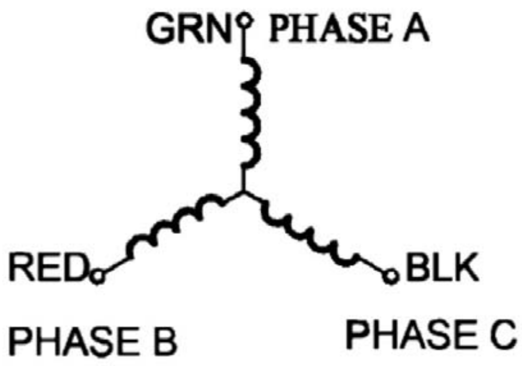


Figure 3-1 U, V, and W Description of BLWR110S

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.

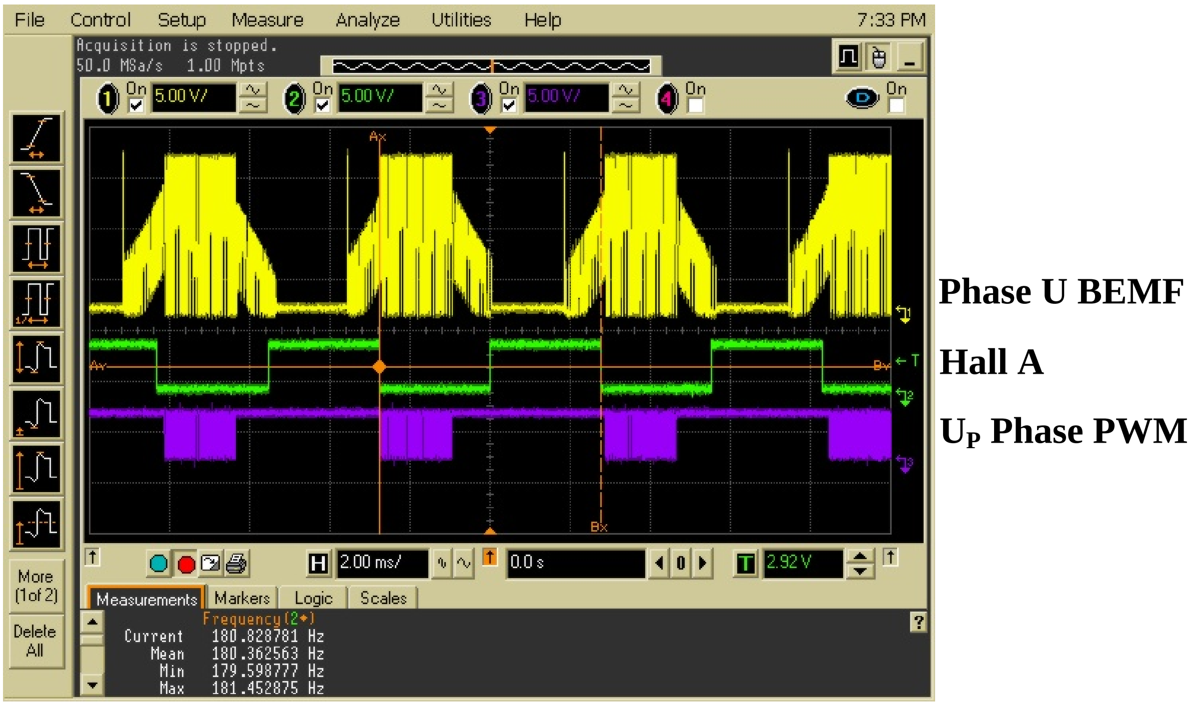


Figure 3-3 BEMF and Hall Signal

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

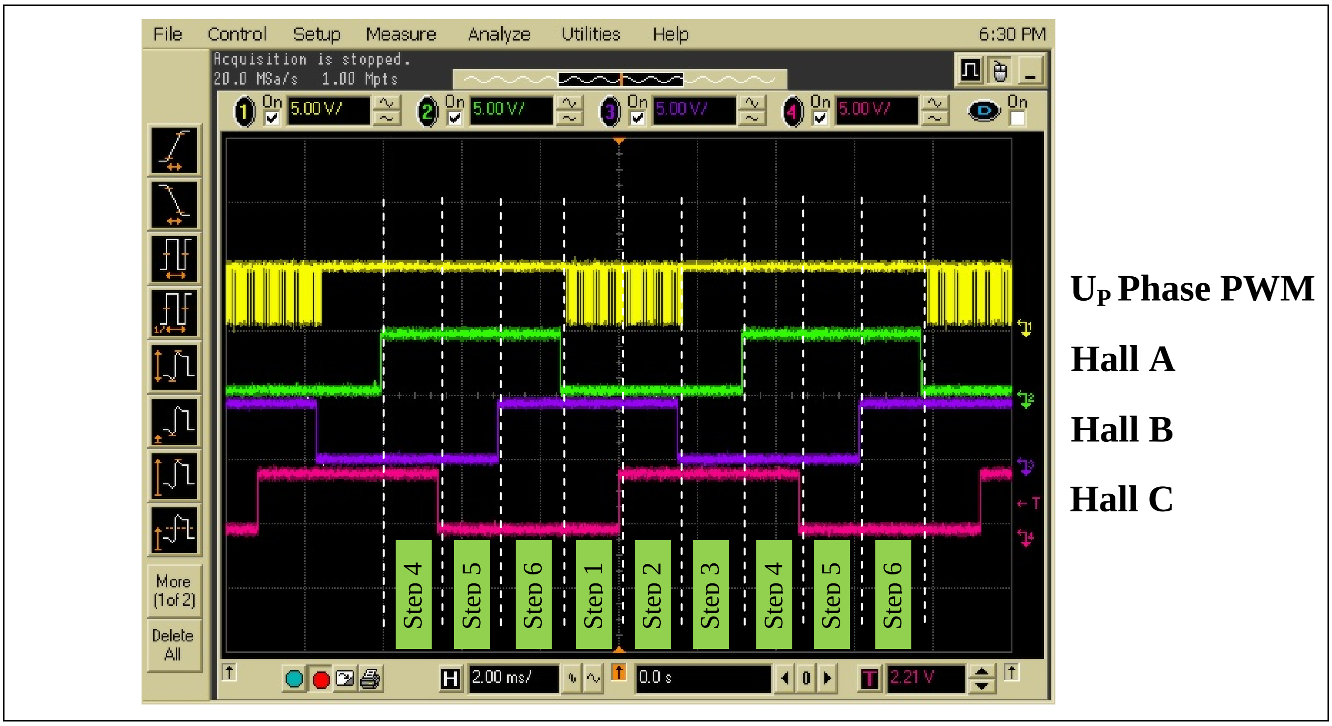


Figure 3-5 6-step PWM Signals (Active-low)

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Revision Record

Rev.	Date	Description	
		Page	Summary
1.00	July.01.12	—	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 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.

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