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April 1\textsuperscript{st}, 2010
Renesas Electronics Corporation

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R32C/118
Six Step Method for Brushless DC Motor based on R32C/118

Introduction
This application note is shown how to use R32C/118 to drive brushless DC motor (BLDCM) using the three phase timer module. The characteristic of the driver is using six step method and balanced PWM outputs to make the same switching loss on high side and low side IGBTs. The LED will be flashing to show that the system is working.

Target Device
The target device is the R32C/100 Series.

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1. **The Configuration of the system**

The configuration of the system is shown in Figure 1. R32C/118 EVB generates the different PWM output according to the hall sensor signals. The three phase signals are generated after the PWM signals drive the Inverter board.

![Figure 1 the configuration of the system](image-url)
2. Hardware Specification

2.1 Brushless DC Motor Specification

The specification of the motor used in this document is shown in Table 1 and Figure 1. The shape of N2341S014 is shown in Figure 2. The number of the pole in this motor is 2. It is a kind motor of distributed wiring so that the back-EMF waveform of the motor is sinusoidal wave. However, the trapezoidal waveform still can be used to drive this motor and the method is shown in the following.

Table 1 Motor specification

<table>
<thead>
<tr>
<th>Model</th>
<th>N2341S014 (PITTMAN® ELCOM ST™)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Pole</td>
<td>2 (1 pair)</td>
</tr>
<tr>
<td>Sensor:</td>
<td>Hall sensor: U V W</td>
</tr>
<tr>
<td></td>
<td>Encoder: 500 CPR, A, B, Z</td>
</tr>
<tr>
<td>Voltage</td>
<td>24 Volt</td>
</tr>
</tbody>
</table>

Figure 2 N2341S014

Figure 3 The structure of N2341S014
2.2 The relationship of the hall sensor signals and the Back-EMF

We need to know the relationship between hall sensor signals and the Back-EMF at each phase. A simple method to get this relationship is shown in this paper.

The direction of torque will be decided by the phase delay between Back-EMF and the current into motor. The phase delay should be zero if the rotor rotates in clockwise. However the phase delay should be 180 degree if the rotor will rotate in counter clockwise. Figure 4 shows the phase between inputs current I and Back-EMF.

![Figure 4 Current phase between Back-EMF and input current](image)

Figure 5 shows the example how to measure the Back-EMF from motor. The voltage of the Back-EMF will be scaled by the rotating speed of the rotor. It will be larger in high speed than in the low speed. We can get the relationship between Back-EMF and sensor signals if we measure those signals simultaneously. Then we can make the switching table to drive the motor according to the measurement result.

![Figure 5 Measurement for the Back-EMF of the motor](image)
Figure 6 can be got by rotating the rotor smoothly. It will be unstable waveform if the rotating speed is not constant. Figure 7 can be got according to Figure6. The unit of X axis is electrical phase. The switching table can be made by the result of Figure 7.
2.3 Construct the switching table

How to use trapezoidal waveform to drive the motor which is the type of the distributed winding is shown in Figure 8. The blue line is the Back-EMF of the motor and the red line is the driving voltage. The simple model of the system is shown in Figure 9. In the Eq1 it explains how to get the value of the input current $i$. However it is just a brief expansion because of ignoring the real complex model. The trapezoidal can not fully match to sinusoidal waveform so that the torque will not be a constant. The noise and torque ripper will be larger in using trapezoidal waveform than sinusoidal waveform for distributed winding.

\[
i = \frac{V_{out} - E}{r} \tag{Eq.1}
\]

Figure 8 Use trapezoidal waveform to replace sinusoidal waveform

Figure 9 The driving voltage and Back-EMF

By turning on the switch during 120 degrees of a half electrical cycle, the trapezoidal waveform can be constructed. A total electrical phase can be divided into six zones. Each zone is 60 degrees. There are always two switches turned on at each zone. This method is called “six step method”, “120 degrees driving method” or “trapezoidal waveform driving” etc.

Figure 10 shows the switching table according to Figure 7. Each PWM signal is output during 120 degrees at a electrical period. The signal is chopping at the first 60 degrees and then full opening at the last 60 degrees. This method is called balanced PWM output which means the both positive and negative signal are chopping. The IGBTs which are for the one phase will consume the same switching loss. The life cycle of the IGBT can be extended.
Figure 10 six-step switching table
3. Software Specification

The software specification of the sample code is shown on the Table 2.

**Table 2 Software specification**

<table>
<thead>
<tr>
<th>Control method</th>
<th>Six-Step method (120-degree commutation using trapezoidal waves)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor position detection</td>
<td>Detecting by hall sensors</td>
</tr>
<tr>
<td>Carrier frequency</td>
<td>20KHz</td>
</tr>
<tr>
<td>PWM method</td>
<td>Balanced PWM method (chopping at high side and low side)</td>
</tr>
</tbody>
</table>

The positive phase and negative phase will be chopping at each turned-on period. We called this balanced PWM method in Figure 11. There is the same switching loss for the IGBTs or MOSFETs of the inverter at high side and low side. The method is also useful to reduce the ripple of the torque.

**Figure 11 Balanced PWM method**
4. Program follow chart

**Figure 12 Program follow chart of main()**

**Figure 13 Program follow chart of hw_setup()**
Figure 14 Program follow chart of three phase timer setup

1. setup icb2 = 2, tb2 interrupt frequency = carrier frequency

2. protect off

3. inv0 = 0x14 triangular wave modulation mode

4. inv1 = 0x12 Three phase timer mode 1, Active high

5. protect on

6. setup the three phase output buffer register

7. setup timer A1, A2, A3 in one-shot mode, timer B2 in timer mode

8. setup the compare match point

9. setup the interrupt control register

10. timer startup

11. enable three phase timer output

12. port function selection for three phase timer
1. Hall sensor input service routine
2. Routine for check the rotor is running or locking
3. Routine for check the startup state
4. Routine for led flash control
5. Add Led1_cnt, Lock_cnt, Start_cnt by one

Ta1 = ta2 = ta4 = 100
Ta11 = ta21 = ta41 = 500
Led_cnt = 10000

ADD Led1_cnt Lock_cnt Start_cnt

Speed down after exit startup status

Figure 15 Program follow chart of tb2_int()
Figure 16 Program flow chart of hall_isr( )

1. i < 3
   Check the hall sensor input status

2. Get the hall sensor input

3. Justify the input is equal to last hall input

4. If equal, add 1
   Else Hall_isr = current input, I clear

5. J add by one

6. If j is equal to 10,
   exit the routine

7. Change PWM output buffer register according to Hall sensor input

Figure 17 Program flow chart of get_hallsensor( )

1. or the value of p1_7 and then shift left 1 bit

2. or the value of p1_5 and then shift left 1 bit

3. or the value of p1_6

4. Return the input value
5. Reference Hardware

The reference circuit of the inverter will be shown in this chapter. The connections are shown in Figure 18.

The six PWM outputs are connected to IPM and the hall sensor signals are feedback though the pulling-high circuit.

Figure 18 The hardware connection

5.1 Reference circuit of the pulling-high circuit for hall sensor input

The output stage of the hall sensors is open-drain and there are pulling-high circuit to supply the voltage to signals.

Figure 19 the pulling high circuit
5.2 Reference circuit of inverter circuit

The reference inverter circuit is shown in Figure 20. The IPM module is PS21964.

Figure 20 The reference inverter circuit
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