Application Note, V1.0, Aug. 2008

AP08078

XC866

Using CCU6E for BLDC control with synchronous rectification (active freewheeling

Microcontrollers

Never stop thinking

Edition 2008-08-27

Published by
Infineon Technologies AG
81726 München, Germany

AP08078		
Revision History:	2008-08	V1.0
Previous Version:	none	

Page	Subjects (major changes since last revision)

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1 Introduction

For BLDC motor control applications that require synchronous rectification (sometimes called active freewhelling), the full Hall Sensor Mode of the CCU6E can not be used. These applications require complementary PWM generation with deadtime. This means that the dead-time counter DTC0 can not be used as a Hall effect sensor noise filter and Timer 12 cannot be used to time commutations. A new way to use the CCU6E for BLDC motor control with synchronous rectification will be introduced in this application note.

2 BLDC control with synchronous rectification

In the normal six step (sometimes called block or trapezoidal commutation) BLDC control, the PWM is gated to the appropriate inverter transistors according to the Hall effect sensor input pattern, with 6 input states and six output states (Figure 1) per electrical revolution. During each state, one inverter transistor is modulated with PWM, another transitor is on, and the rest of the inverter transistors are are off.

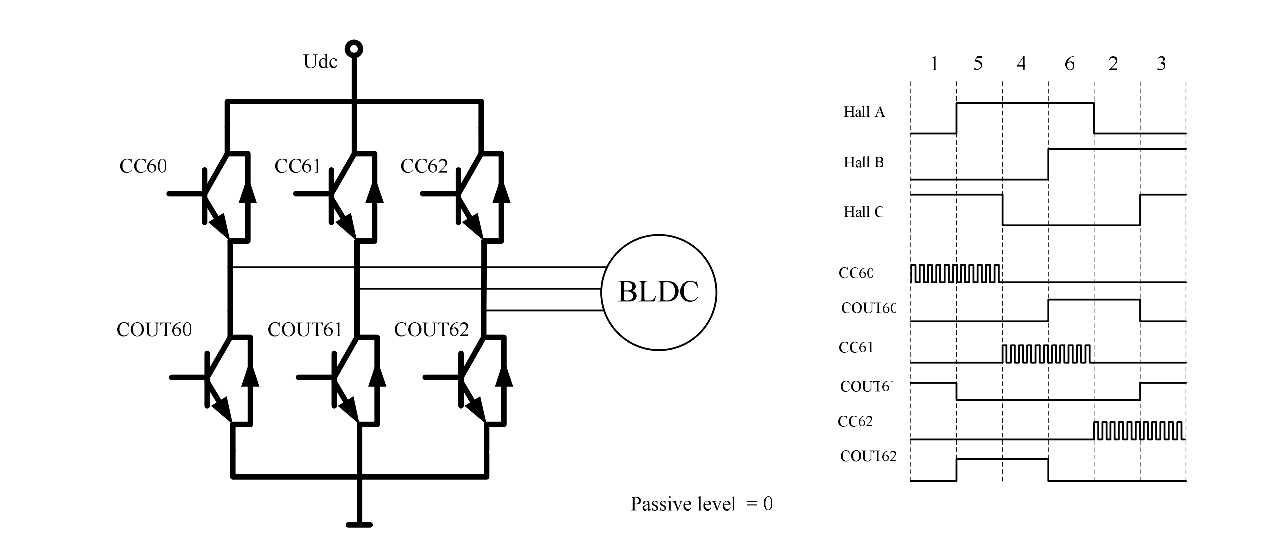

Figure 1 BLDC control topology, Hall input and PWM pattern

Figure 2 shows how the current flows through the inveter transistors and freewheeling diodes during the PWM on and off times. Using CC60 and COUT62 as an example, the current flows through Q1 and Q6 when the PWM is on, however during the PWM off time, the freewheeling current flows through diode D2 and Q6 (due to the inductance of the motor coils). Because the forward voltage of the diode is around 0.6 – 1V, during PWM off period there can be high power losses on the diode D2, especially for the high current applications.

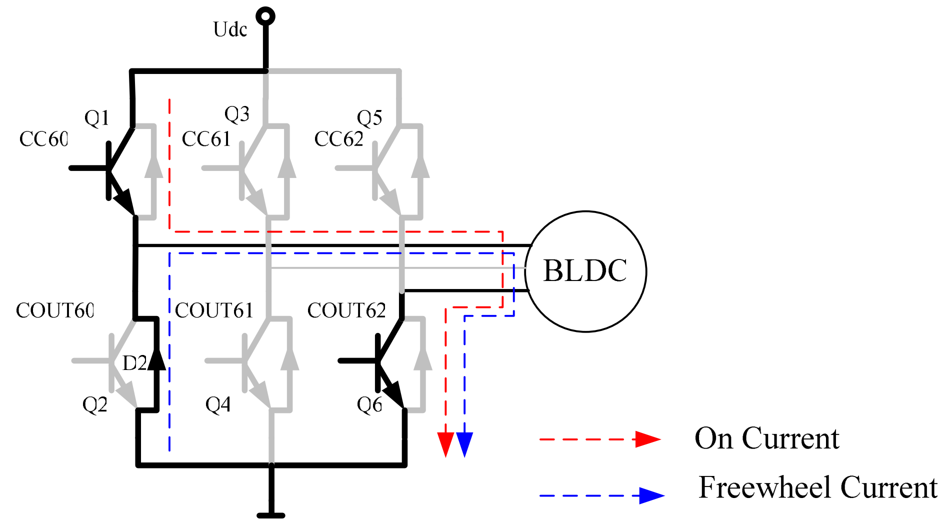

Figure 2 Current flow of normal BLDC control

The power loss can be minimized and the efficiency can be increased when the inverter is made of MOSFETs with small on resistance (R_{dson}) because current can flow in both directions through a MOSFET. For synchronous rectification MOSFET M2 is switched on during PWM off time so the freewheeling current flows through M2 instead of the diode D2.

For example, assume you have a 10 amp load and a 10 mOhm MOSFET with a 0.7V forward voltage drop across the body diode. The losses on the body diode would be 7W while the losses through the body of the MOSFET would be only 1W. Figure 3 shows how the current would flow for this type of PWM. This freewheeling current control method is called synchronous rectification.

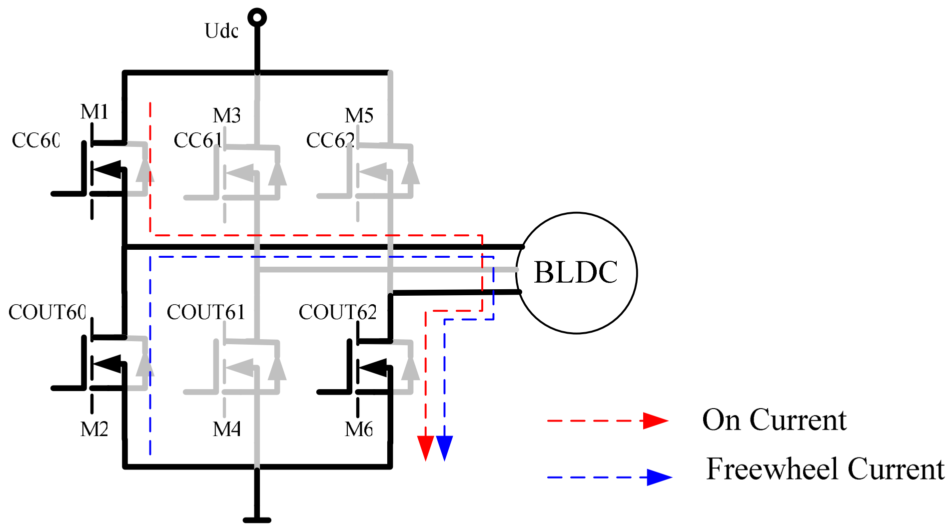

Figure 3 Current flow of synchronous rectification

To realize the synchronous rectification, the PWM on high and low side MOSFET must be complementary with dead-time inserted (to prevent shoot-through current), and the MCU PWM output will be like what is shown in the Figure 4.

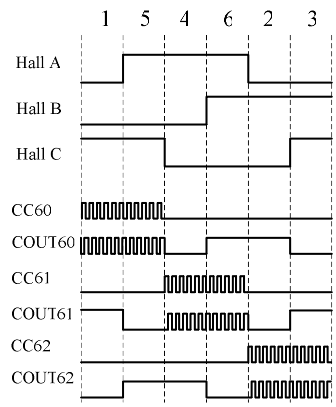

Figure 4 Hall input and PWM output at synchronous rectification

3 Implementation with CCU6E

The Capture/Compare unit 6 (CCU6E) peripheral is embedded in most of Infineon's 8/16-bit MCUs, and it has a special Hall Sensor Mode for BLDC control. The structure of Hall Sensor Mode is shown in figure 5. The Hall signals are sampled through the dedicated input pins (CCPOS0,1,2). A change in the Hall state will trigger a filter operation which uses the dead-time counter DTC0 as a delay timer. After the delay, the Hall signals from CCPOS0,1,2 are sampled again and compared with the expected Hall pattern (EXPH). If the sampled pattern is equal to the expected pattern, this Hall change will be a correct Hall event (CHE) and generate an interrupt to the CPU (if the corresponding interrupt is enabled). The CHE can trigger the commutation which will change the output pattern on the 6 PWM pins. In Hall Sensor Mode timer 13 (T13) is used to generate PWM and the compare output is then gated with the MCMP bits to modulate the six PWMs.

The embedded Hall Sensor Mode has a lot of advantages. It does the Hall sampling, filtering, compare and commutation automatically, and frees the CPU from such operations. This reduces the code size and response time. The commutation error (delay between Hall change and commutation) is also minimized. It is especially useful for high speed BLDC control.

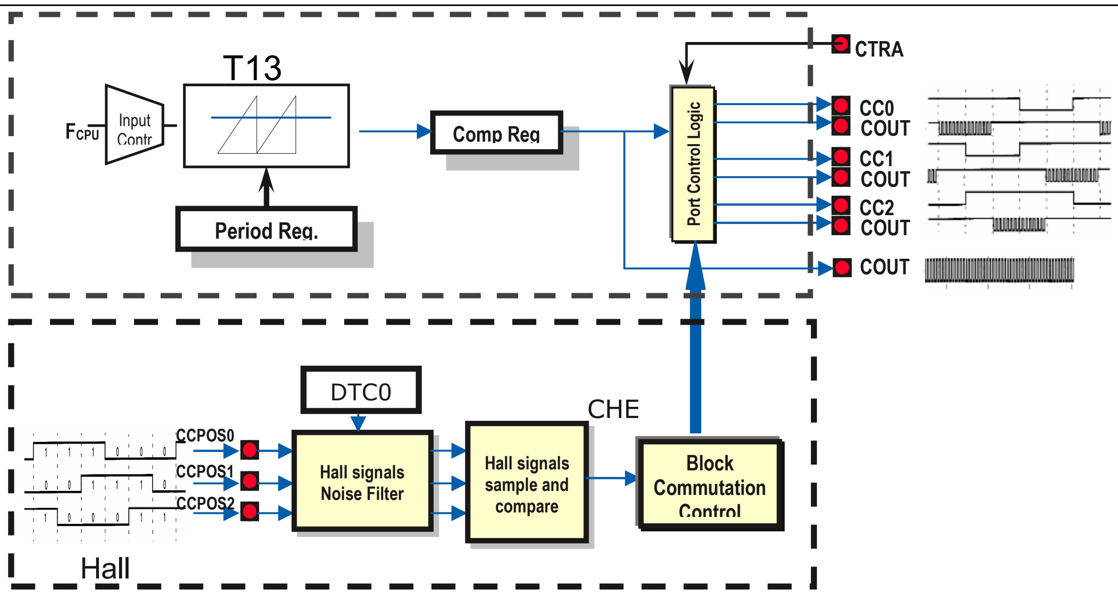

Figure 5 Block diagram of Hall sensor mode

To implement synchronous rectification, complementary PWM outputs are needed, and T12 and compare channels 0,1,2 are used to generate the PWM. This means that the Hall Sensor Mode cannot be used and the DTC0 must be used for deadtime generation. In this case T13 can be used for a Hall effect sensor noise filter Instead of DTC0, This is possible because T13 can be started by any Hall state change on the pin CCPOSx (x = 0,1,2) (T13TEC = 0x07), and a T13 period match can trigger the Hall signal sample and compare operation (HSYNC = 0x02). The DBYP needs to set to 1 to bypass the DTC0 from Hall filtering. The system diagram is shown in figure 6.

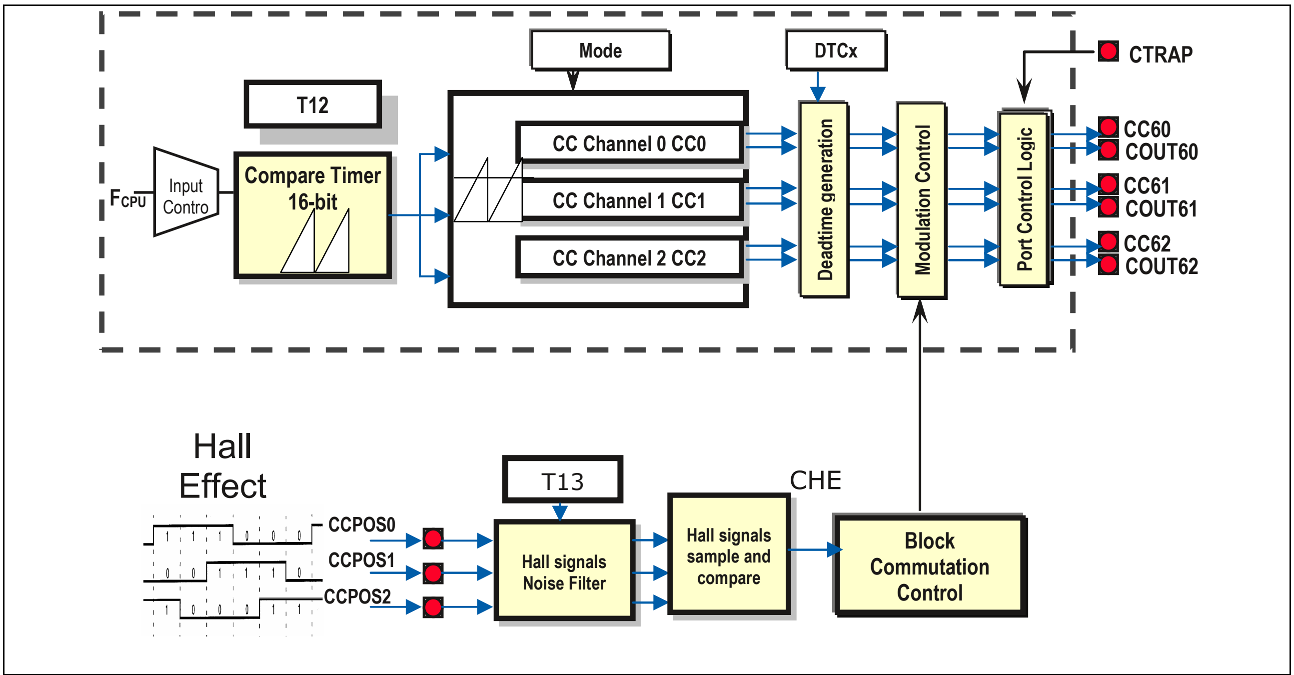

Figure 6 Block diagram of CCU6E for synchronous rectification

4 Configuration of CCU6E for synchronous rectification

To setup the CCU6E for BLDC control using synchronous rectification, the settings of CCU6E compared with normal Hall Sensor Mode are summarized as following:

1. Setup T13 in single shot mode
2. Setup T13 to be triggered by any Hall change event on CCPOSx (T13TEC = 0x07)
3. Setup the T13 period match event to trigger the Hall sample and compare operation (HSYNC = 0x02)
4. Setup the block commutation to be triggered by a correct Hall event (SWSEL = 0x01)
5. Set the DBYP = 1 to bypass the DTC0 as the Hall filter counter.
6. Setup all of the PWM outputs to be modulated by T12 (T12MODENx = 1)
7. Use the MCMP bits to modulate the outputs according to the method presented in Figure 4.

5 Result and conclusion

The source code related to this application note was tested on a low voltage motor drive board for 24V BLDC control. The Hall sensors are connected to CCPOS0,1,2. Hall input filter time is set to 10us (T13 period value) and motor is running well and the result are show below.

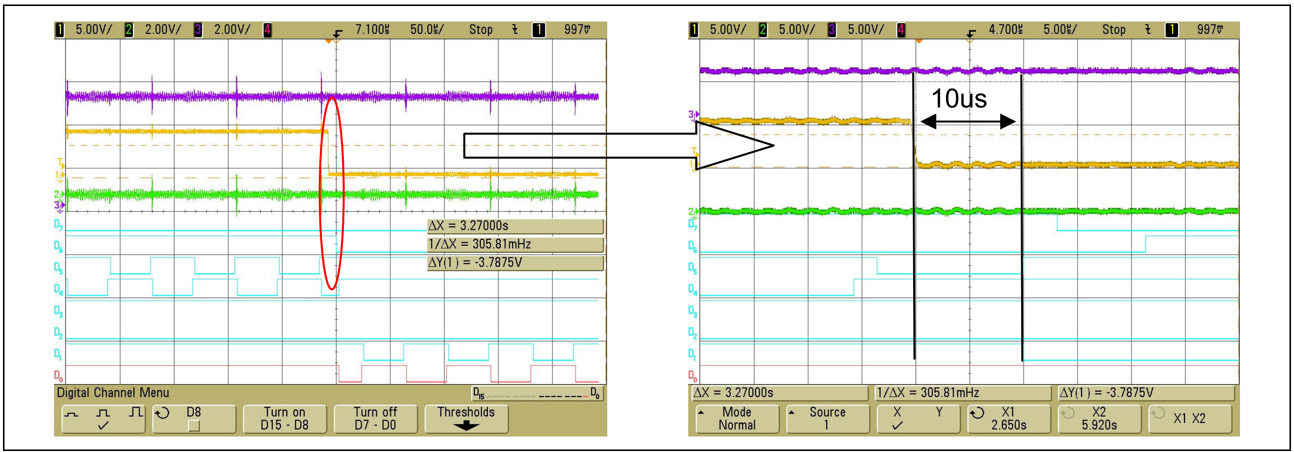

Figure 7 Hall filtering using T13 at commutation

Figure 7 shows the waveform of the Hall inputs together with the 6 PWM outputs. The figure on the right is a zoomed-in waveform of the point where a Hall sensor changes state. D0 – D5 are the PWM outputs (cc60 – cout62). The yellow, pink and purple lines are the Hall signals. D7 shows an I/O pin that is toggled in the T13 period match interrupt. D6 is connected to an I/O pin that is toggled after a correct Hall event interrupt.

From the waveform it can clearly be seen that the delay between the Hall signal changing and the PWM output being updated is 10us which is exactly the T13 period. The additional delay of the D6 and D7 is because of the interrupt respond time, but the D6 toggles earlier than D7 which means T13 interrupt comes first then the correct Hall event which is triggered by the T13.

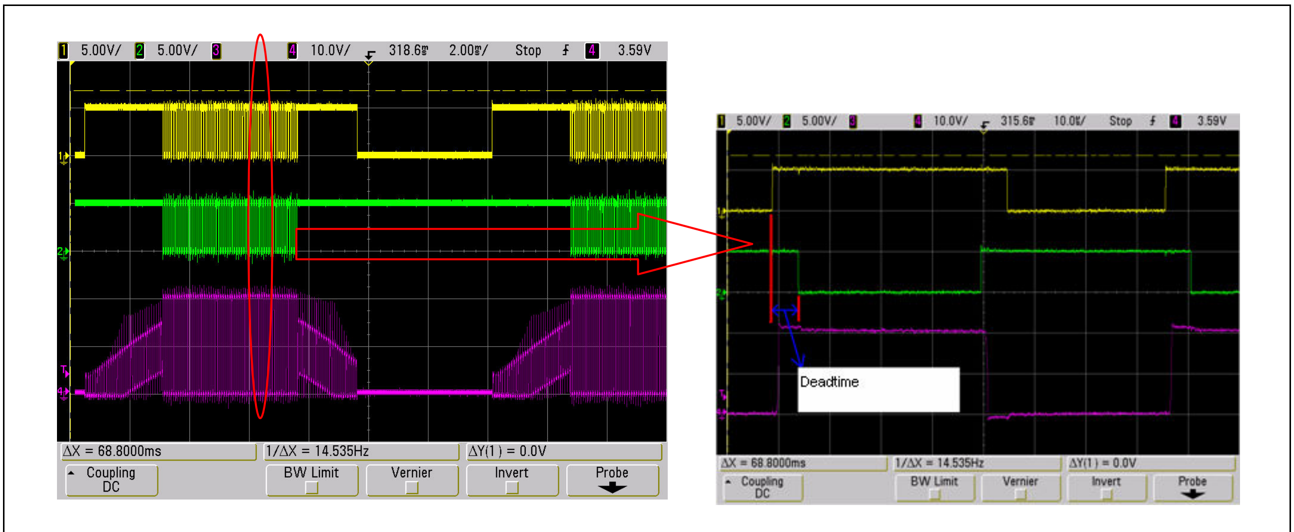

Figure 8 BLDC phase voltage with synchronous rectification

Figure 8 shows the motor terminal voltage with its driving PWM signals. The PWM of the half-bridges is complementary and deadtime is inserted.

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