AN205561

F²MC-8FX Family MB95200 Series 8-Bit Microcontroller BLDC Motor Back EMF 120° Driver Method

Associated Part Family: MB95200 Series

This document describes the BLDC (Brushless DC) motor back EMF 120° driver method used by MB95330H Series.

Contents

1 Introduction

This document describes the BLDC (Brushless DC) motor back EMF 120° driver method used by MB95330H series 8-bit microcontroller.

2 Background Description

This section describes the multi-pulse generator (MPG) and back EMF 120° driver BLDC motor.

2.1 Description of Multi-pulse Generator

The multi-pulse generator consists of a 16-bit PPG timer, a 16-bit reload timer and a waveform sequencer. By using the waveform sequencer, 16-bit PPG timer output signal can be directed to multi-pulse generator output (OPT5 to OPT0) according to the input signal of multi-pulse generator (SNI2 to SNI0). Meanwhile, the OPT5 to OPT0 output signal can be terminated by DTTI input in case of emergency. The OPT5 to OPT0 output signals are synchronized with the PPG signal in order to eliminate the unwanted glitch.

2.1.1 Block Diagram of Multi-pulse Generator

Figure 1. Block Diagram of Multi-pulse Generator

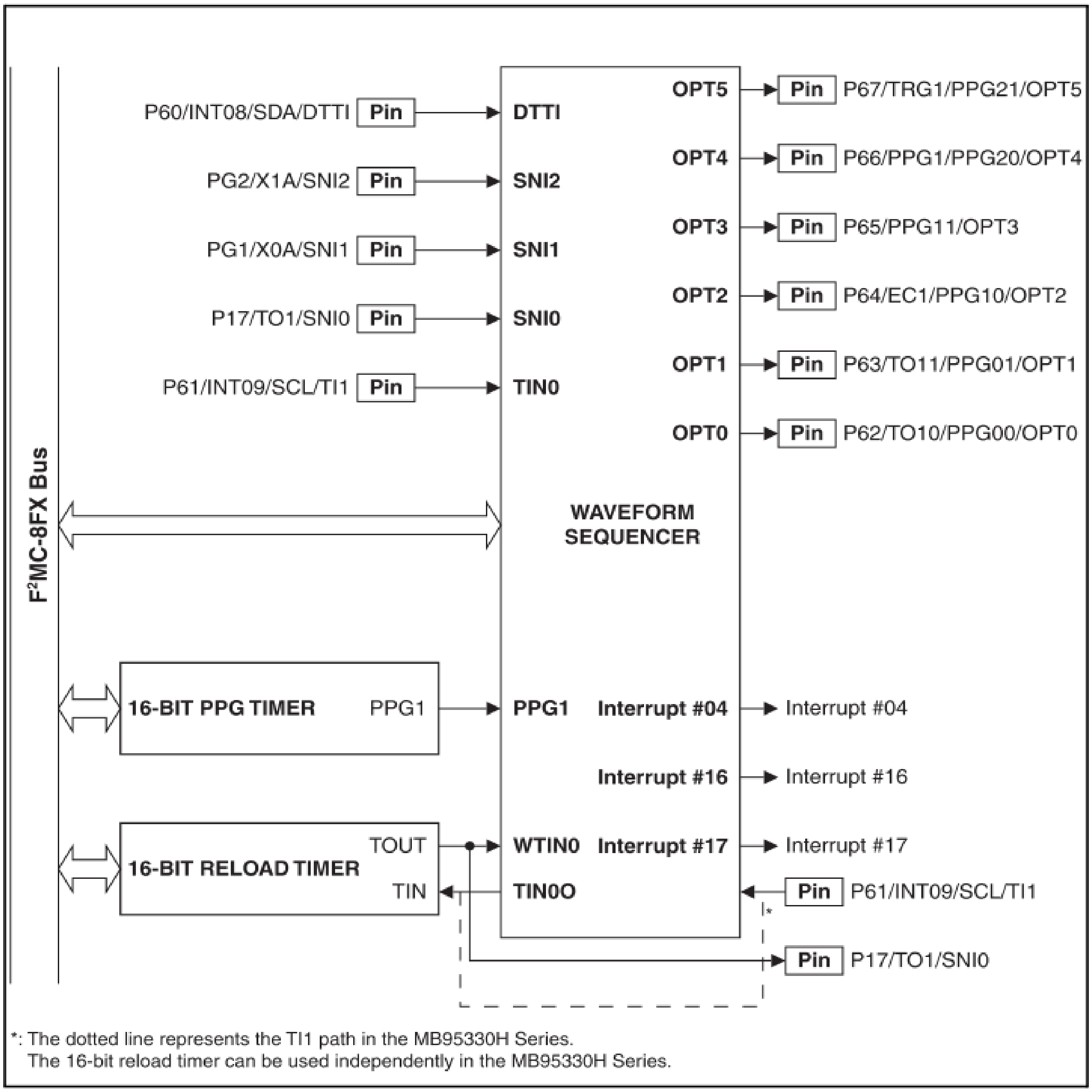


Figure 1 shows the block diagram of multi-pulse generator.

- 16-bit PPG Timer

  The 16-bit PPG timer is used to provide the PPG signal for waveform sequencer. Details of 16-bit PPG timer are described in Hardware Manual of MB95330H Series.

- 16-bit Reload Timer

  The 16-bit reload timer is used to act as interval timer for waveform sequencer. Details of 16-bit reload timer are described in Hardware Manual of MB95330H Series.

- Waveform Sequencer

  The waveform sequencer is the core of multi-pulse generator, which can generate various waveforms.

2.1.2 Registers of Multi-pulse Generator

Figure 2. Registers of Multi-pulse Generator

Output control register (upper)

Register	Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Initial value
OPCUR	0066_H	DTIE	DTIF	NRSL	OPS2	OPS1	OPS0	WTIF	WTIE	00000000_B
		R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	

Output control register (lower)

Register	Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Initial value
OPCLR	0067_H	PDIF	PDIE	OPE5	OPE4	OPE3	OPE2	OPE1	OPE0	00000000_B
		R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	

Output data register (upper)

Register	Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Initial value
OPDUR	$0FDC_H$	BNKF	RDA2	RDA1	RDA0	OP51	OP50	OP41	OP40	$0000XXXX_B$
		R	R	R	R	R	R	R	R	

Output data register (lower)

Register	Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Initial value
OPDLR	$0FDD_H$	OP31	OP30	OP21	OP20	OP11	OP10	OP01	OP00	$XXXXXXXX_B$
		R	R	R	R	R	R	R	R	

Output data buffer registers (upper)

Register	Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Initial value
OPDBURB - OPDBUR0	$0FC4_H$ - $0FDA_H$	BNKF	RDA2	RDA1	RDA0	OP51	OP50	OP41	OP40	00000000_B
(Even addresses)		R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	

Output data buffer registers (lower)

Register	Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Initial value
OPDBLRB - OPDBLR0	$0FC5_H$ - $0FDB_H$	OP31	OP30	OP21	OP20	OP11	OP10	OP01	OP00	00000000_B
(Odd addresses)		R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	

R/W : Readable/writable (The read value is the same as the write value.)
R : Read only (The read value is indeterminate.)
x : Indeterminate

(Continued)

(Continued)

Input control register (upper)

	Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Initial value
IPCUR	0068_H	WTS1	WTS0	CPIF	CPIE	CPD2	CPD1	CPD0	CMPE	00000000_B
		R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	

Input control register (lower)

	Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Initial value
IPCLR	0069_H	CPE1	CPE0	SNC2	SNC1	SNC0	SEE2	SEE1	SEE0	00000000_B
		R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	

Compare clear register (upper)

	Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Initial value
CPCUR	$0FDE_H$	CL15	CL14	CL13	CL12	CL11	CL10	CL09	CL08	$XXXXXXXX_B$
		R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	

Compare clear register (lower)

	Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Initial value
CPCLR	$0FDF_H$	CL07	CL06	CL05	CL04	CL03	CL02	CL01	CL00	$XXXXXXXX_B$
		R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	

Timer buffer register (upper)

	Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Initial value
TMBUR	$0FE2_H$	T15	T14	T13	T12	T11	T10	T09	T08	$XXXXXXXX_B$
		R	R	R	R	R	R	R	R	

Timer buffer register (lower)

	Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Initial value
TMBLR	$0FE3_H$	T07	T06	T05	T04	T03	T02	T01	T00	$XXXXXXXX_B$
		R	R	R	R	R	R	R	R	

Timer control status register

	Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Initial value
TCSR	$006B_H$	TCLR	MODE	ICLR	ICRE	TMEN	CLK2	CLK1	CLK0	00000000_B
		R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	

Noise cancellation control register

	Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Initial value
NCCR	$006A_H$	S21	S20	S11	S10	S01	S00	D1	D0	00000000_B
		R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	

R/W : Readable/writable (The read value is the same as the write value.)
R : Read only (The read value is indeterminate.)
x : Indeterminate

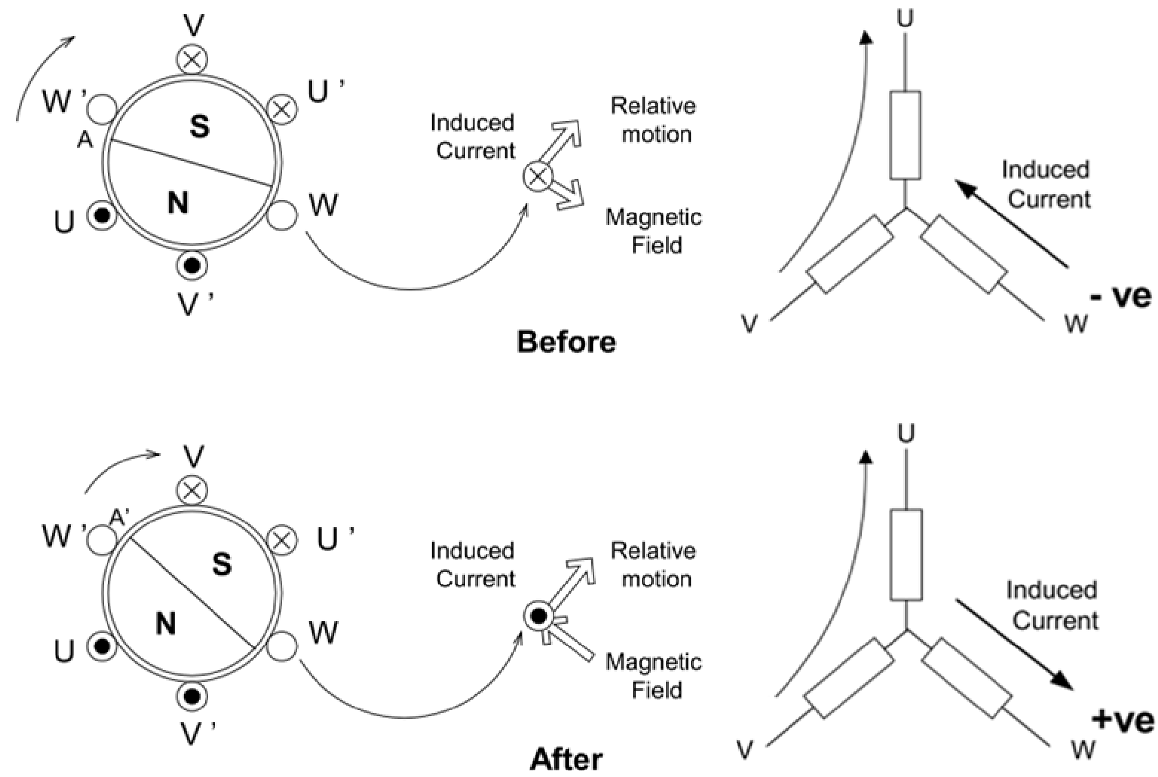
Figure 2 shows registers of multi-pulse generator. For more detailed information, please refer to Chapter 24 in Hardware Manual of MB95330H Series.

2.2 Back EMF Description

2.2.1 Back EMF Generation

Based on simple physical theory, when there is a relative motion between a conductor and a magnetic field, the current will flow through the conductor and a potential difference is generated.

Figure 3. Motor Relative Motion by Potential Difference



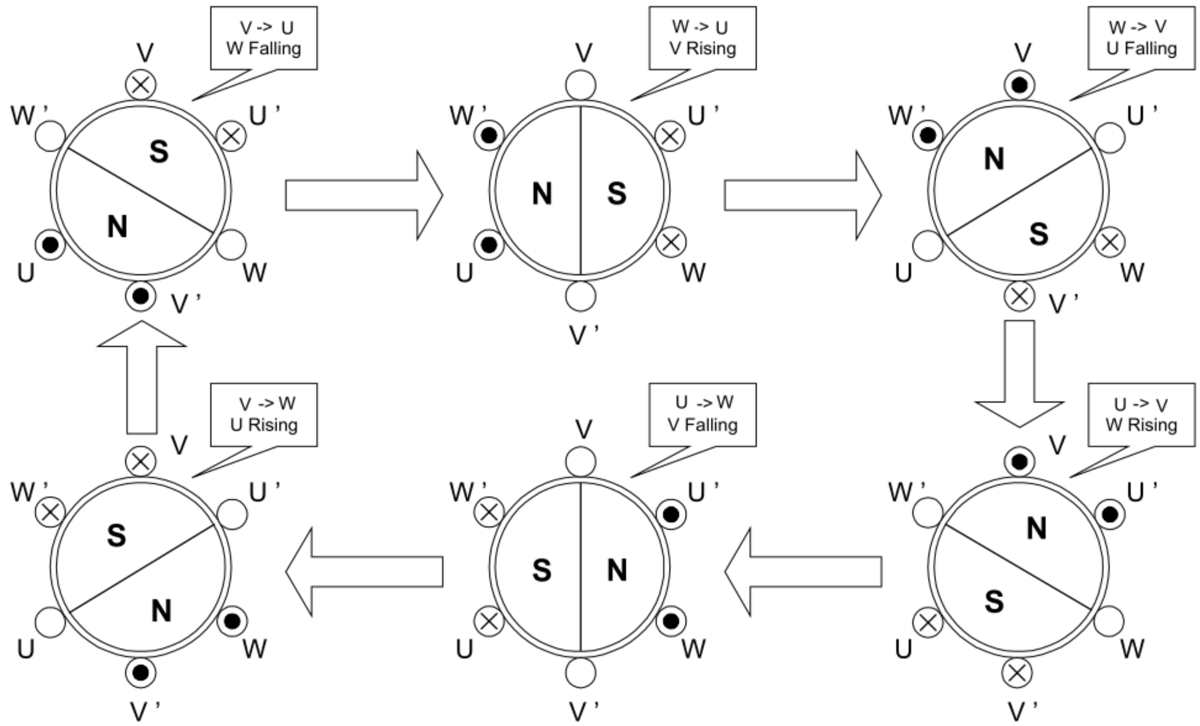
Apply the same principle to a brushless DC motor and user can find the induced current on the phase coil which is open.

Study the above situations and monitor the marker A and A' in the "Before" and "After" respectively, user can recognise the induced current and its direction.

2.2.2 Motor Complete Revolution

By applying the same analysis, below shows a motor rotating mechanism on the complete revolution.

Figure 4. Motor Rotating Mechanism on the Complete Revolution

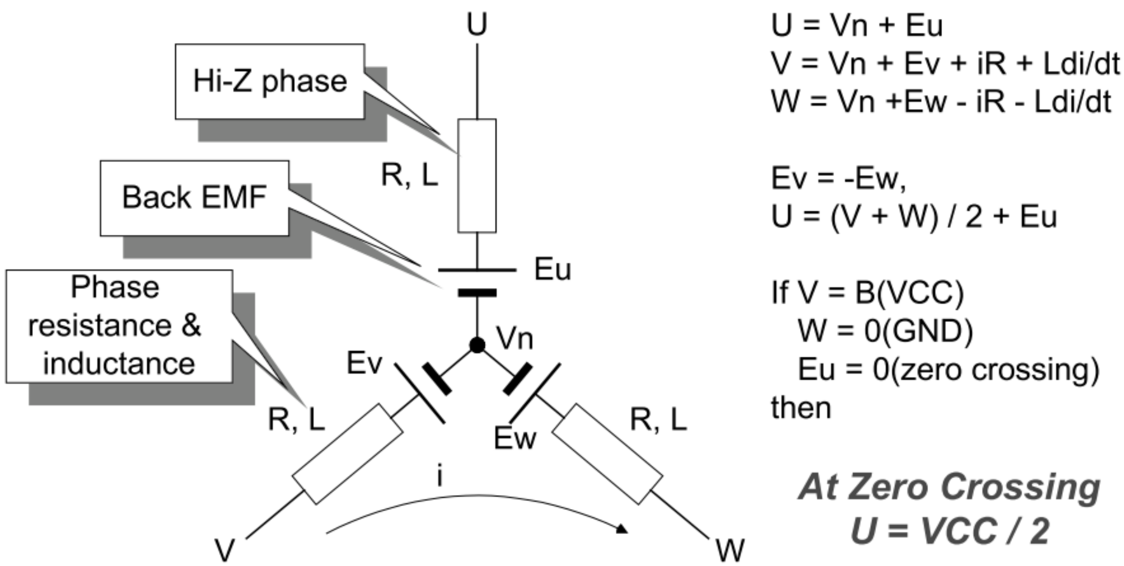


By detecting the rising and falling edge of induced voltage on the opened phase coil terminal, communication can be done electronically, it is the basic principle how sensorless control of brushless DC motor can work.

2.2.3 Back EMF Modeling

In order to understand how the back EMF is useful in the implementation, it is important to study the 3 phase back EMF modelling.

Figure 5. 3 Phase Back EMF Modelling



From the above explanation, we can see an important fact that the voltage on the opened terminal is equal to half of the power supply VCC at zero crossing.

Therefore, in order to recognise the time of zero crossing, the voltage on the terminal of phase coil is compared with the VCC/2. However, since the VCC is very high, VCC/2 level and the voltage from the terminal are scaled down to a suitable level so that it can be fed to the comparator.

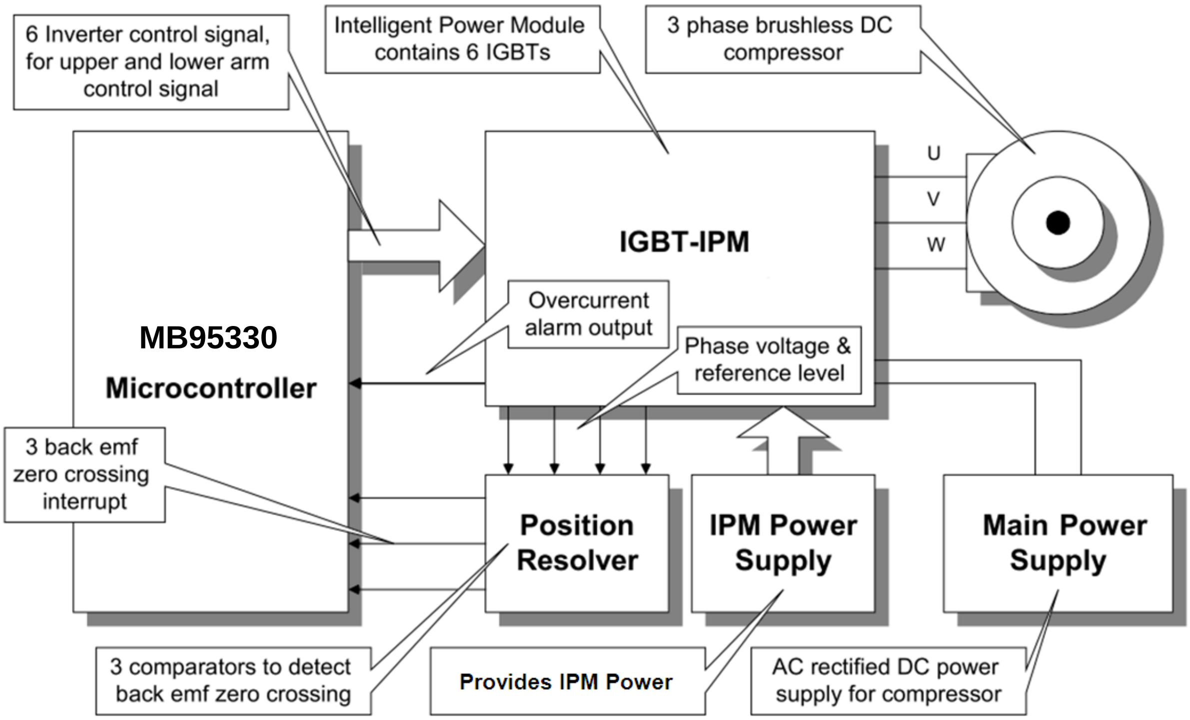
3 Hardware Design Description

This section describes system hardware design.

3.1 System Block Diagram Description

The basic configuration of a sensorless controlled brushless DC motor system is shown below.

Figure 6. System Block Diagram



The basic components are:

- IGBT-IPM

  IGBT-IPM (intelligent power module) consists of an IGBT model and a signal driver circuit. It is connected to the MCU output port and 3 phase brushless DC motor.

- Position resolver

  This circuit consists of a simple potential divider and isolators. It captures the potential from phase coils and is compared with a fixed voltage. Through the isolators are connected to the input port of MCU.

- MB95330

  Core of the sensorless control, which accepts output from position resolver and drives the IPM through the isolators.

- IPM power supply

  IPM can supply current to its upper arms switches and lower arm switches.

- Main power supply

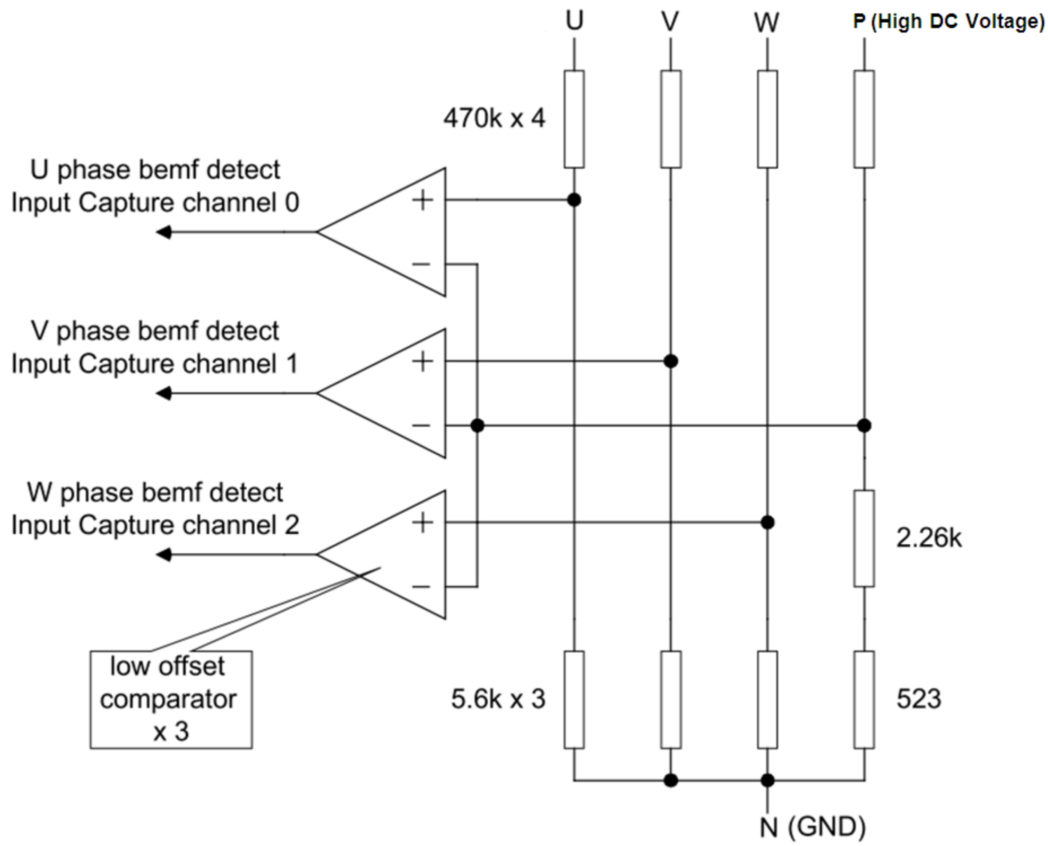
  Provides a stable high DC voltage to drive the motor or compressor.

3.2 Position Detection Resolver

3.2.1 Position Detection Circuit Design

One of the critical circuitry is the position resolver; it must be very precise to differentiate a few micro-volt signals.

Figure 7. Position Detection Resolver Circuit Design



- Comparators

  Low offset type can give more precise position detection timing.

  Practically, protection diode circuit for each input is used to avoid exceeding signal swinging.

- Resistors

  The resistors should be kept stable when temperature changes.

  Low tolerance type should be used and the precision is at least 1%.

  The precision of these resistors is critical to sensorless control.

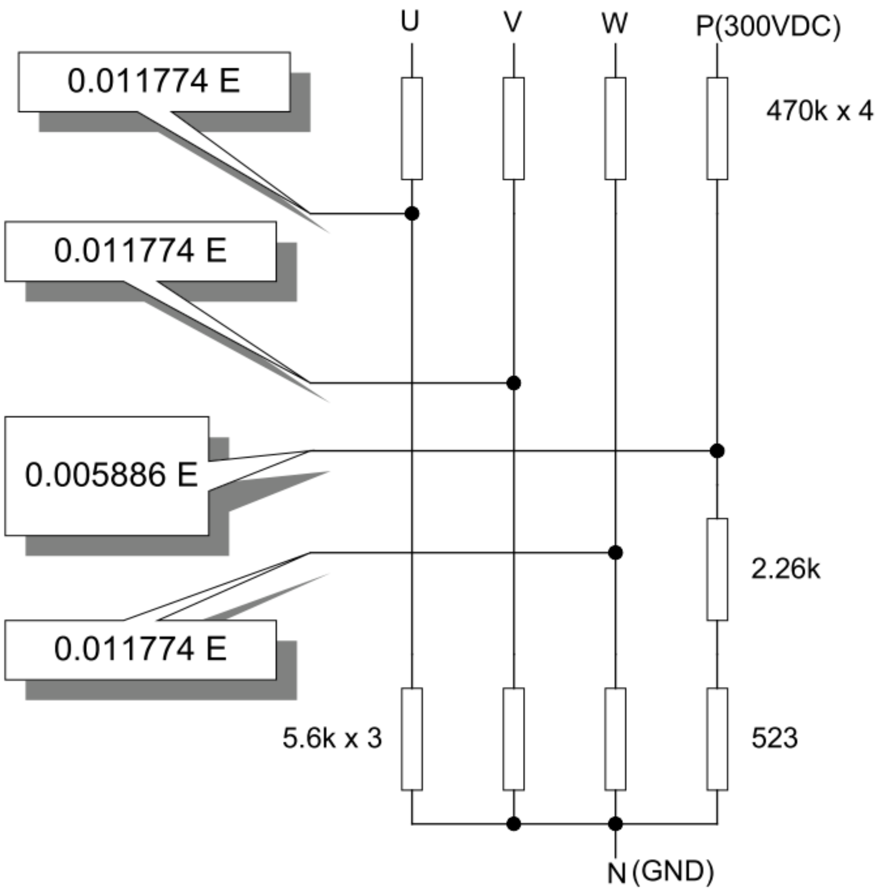
- Decoupling capacitors

  PWM noise from the phase voltage should be decoupled before being fed to the MCU. Therefore, each comparator input should build in a decoupling capacitor.

3.2.2 Potential Divider

The high voltage on the terminal should be scaled down by a carefully designed potential divider circuitry.

Figure 8. 3 Phase Back EMF Potential Divider Circuitry



Above is the potential divider used in the implementation. Resistors with low tolerance and special values such as 523 Ω and 2.26 kΩ are used to realize a precise potential divider. Precision is very critical to the sensorless control, an insufficient precision design generally leads to unstable startup.

U, V and W are connected to the 3 phase terminal. P is connected to the positive terminal of power supply, the 470 kΩ, 2.26 kΩ and 523 Ω resistors create a scaled down value of VCC/2.

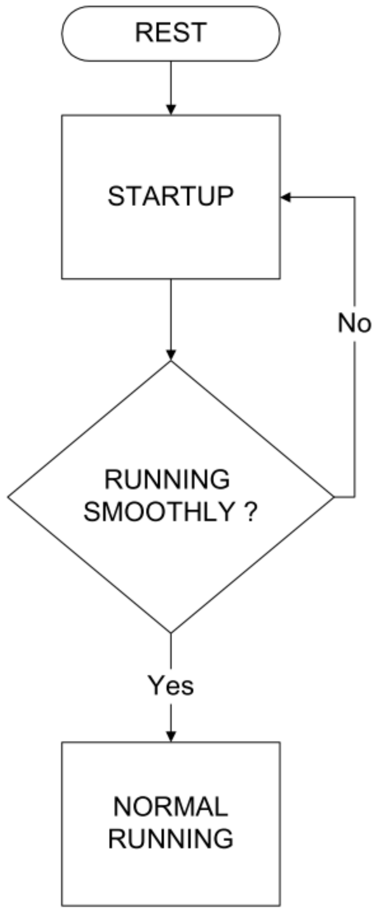
4 Firmware Principles and Theory

The section describes firmware operation principles and theory.

4.1 Firmware Main Flowchart

When the rotor stops, the rotor position is unknown because of the missing of position sensor, so the back EMF measurement does not work.

Figure 9. Flow Chart of Startup Motor Rotor



There are 2 stages before entering normal running status.

- Sensorless startup

  The rotor may rotate opposite to the desired direction for a short moment, or even very seldom fail to startup, in this case, user can perform forced startup. Forced startup can be implemented easily by small code size and is very suitable to control brushless DC compressor. User can try startup again by retry function when the compressor starts abnormally.

- Judgement of normal running state

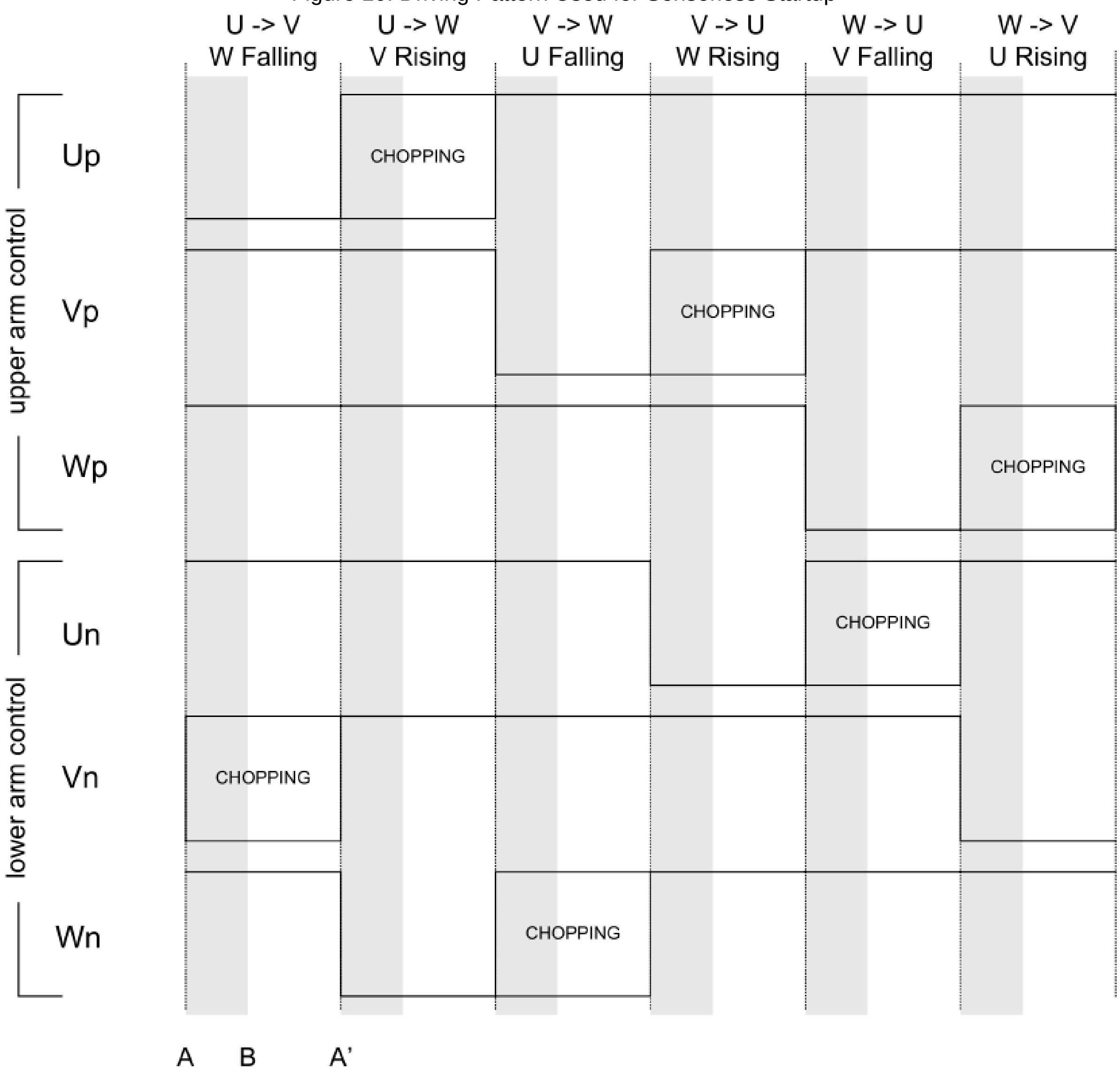
  This judgment algorithm ensures the compressor is running perfectly and is suitable to enter normal running.

4.2 Sensorless Startup

4.2.1 Startup Driving Pattern

Here is the driving pattern used for sensorless startup.

Figure 10. Driving Pattern Used for Sensorless Startup



Although the pattern is simple to be implemented, the sensorless startup is very reliable. The compressor always starts up successfully without any retry.

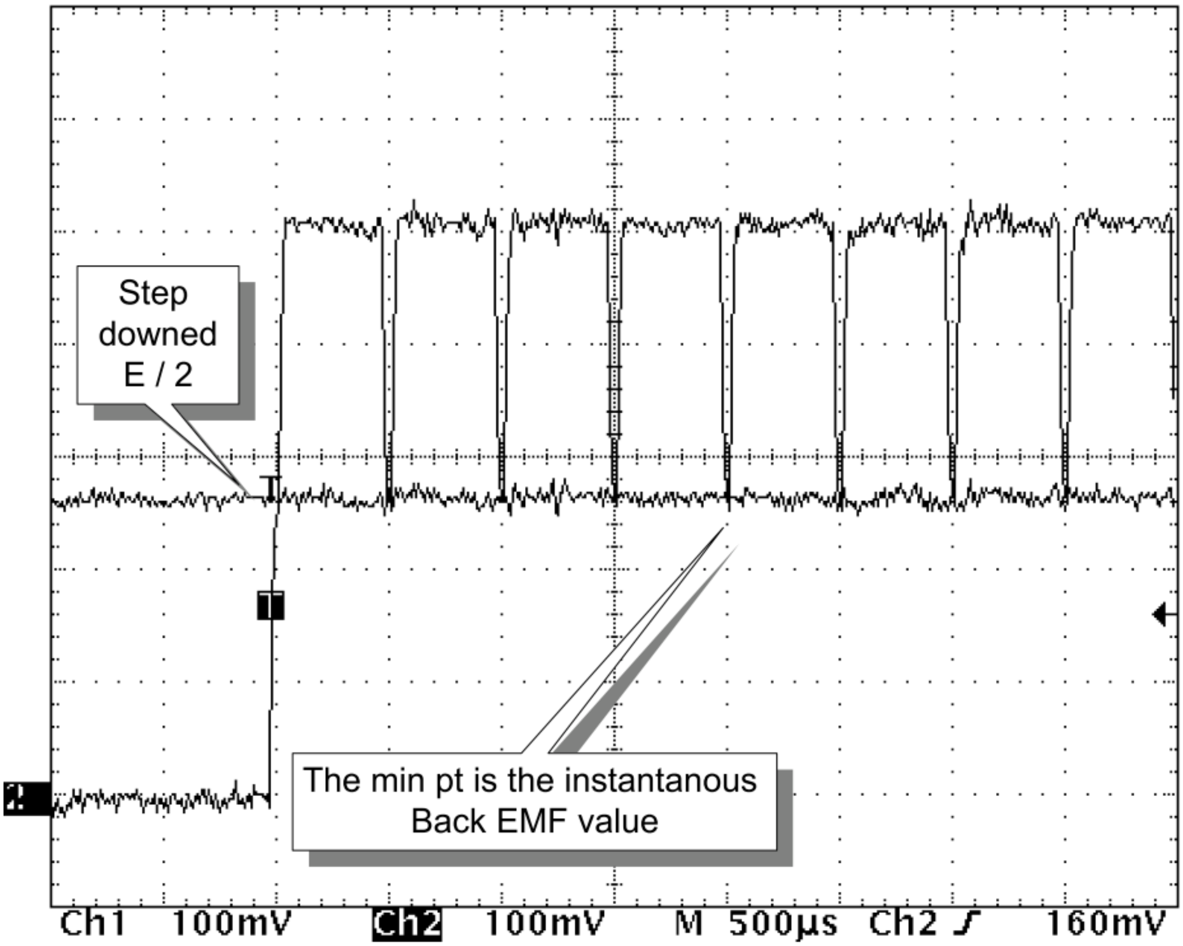
A – B is the mask-off time which MCU external interrupts are disabled.

B – A' is the time which MCU external interrupts are enabled.

4.2.2 Back EMF Zero Crossing Detection

In sensorless startup, the back EMF generated at the very first moment is extremely small. Below is a captured waveform showing the back EMF in the terminal and the scaled down VCC/2 level.

Figure 11. Back EMF Zero Crossing Detection

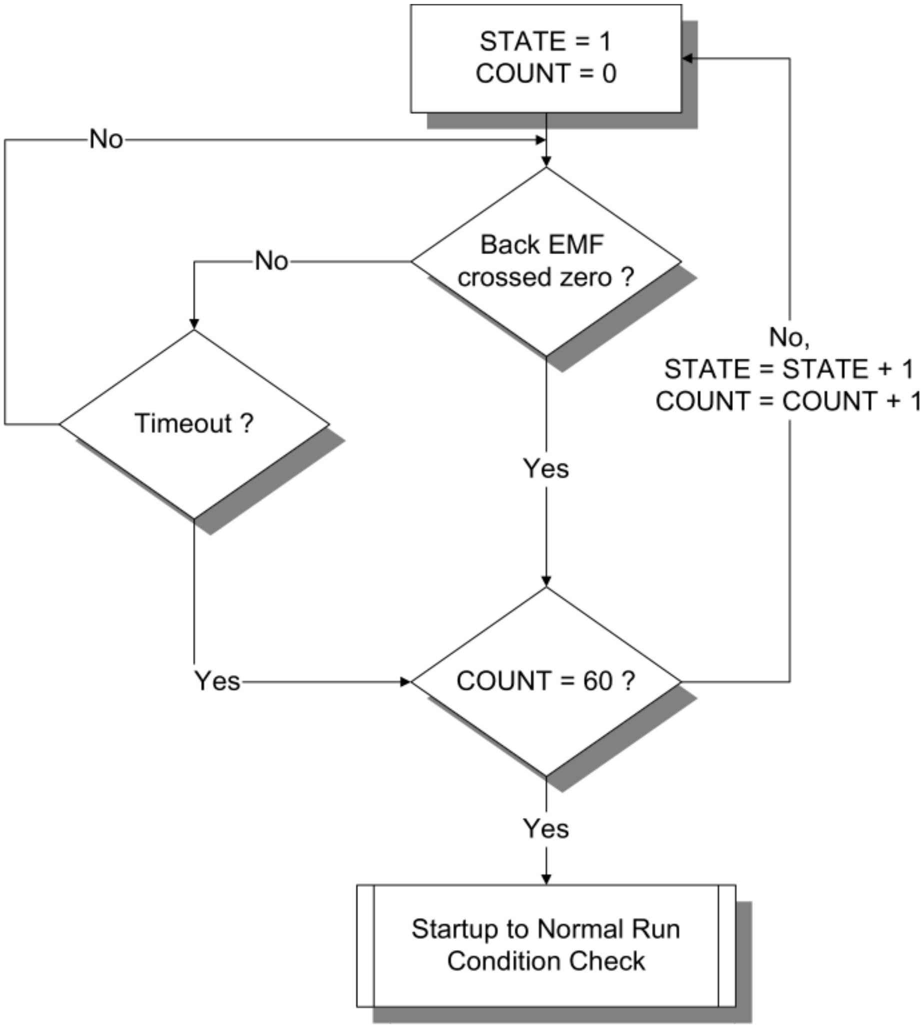


Back EMF zero crossing happens when the minimum point has a value lower than that of E/2.

4.2.3 Startup Algorithm

There is a simple algorithm used in startup stage.

Figure 12. Simple Algorithm Used in Startup Stage



- Change state

  Change state when there is a back EMF zero crossing interrupt or a preset timer timeout. Preset timer value ranges from 50 ms to 200 ms tested according to the compressor used.

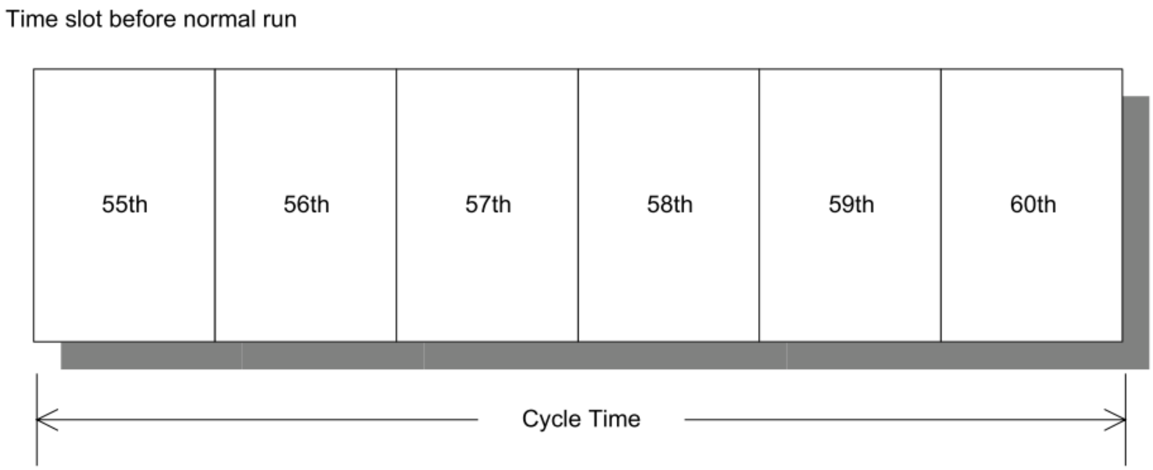
- Change to normal run

  The state change is monitored for about 10 - 30 electrical cycles, if the deviation of the duration is not too much, it is assumed the compressor is running smoothly.

4.3 Transition from Startup to Normal Run

In the implementation, only the state change duration of last electrical cycle is considered.

Figure 13. Ensure Electrical Cycle's Value of Startup to Normal Run



A simple formula below can be used to ensure the value of last 6 items does not exceed the smallest deviation value.

$$T_{max} < k * T_{min}$$

Where Tmin and Tmax are the minimum value and maximum value of the 6 items, k is a constant and the range of k is from 5 to 10.

4.4 Normal Run

4.4.1 Driving Pattern

The normal-run consists of 12 different driving patterns and 6 different states. Below shows the relationship between the driving patterns and the expected interrupts from the position detection circuit.

Marker explanation:

A : position detection interrupts

B : change state

C : change chopping-arm

D : position detection interrupt enable

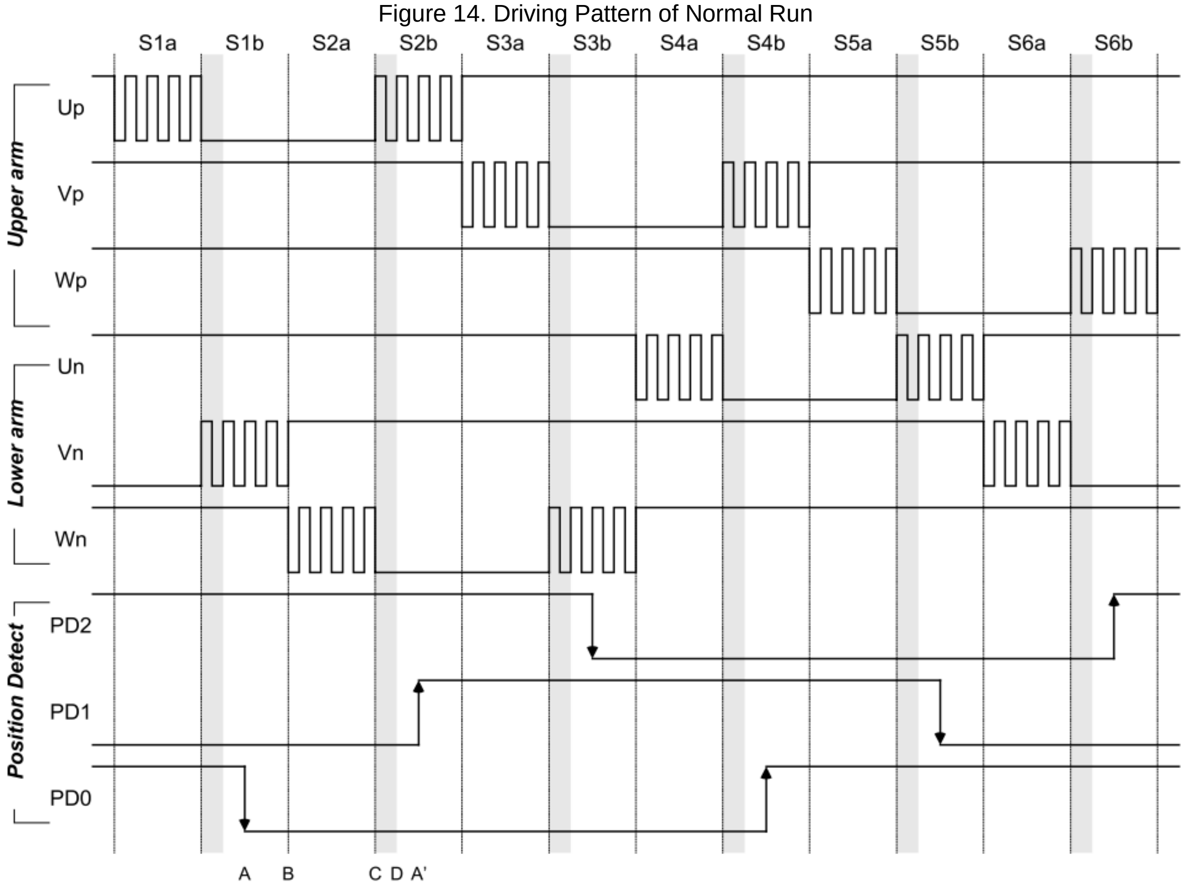
A' : next position detection interrupts

A – B: commutation delay

B – C: change arm delay

C – D: change arm mask-off period

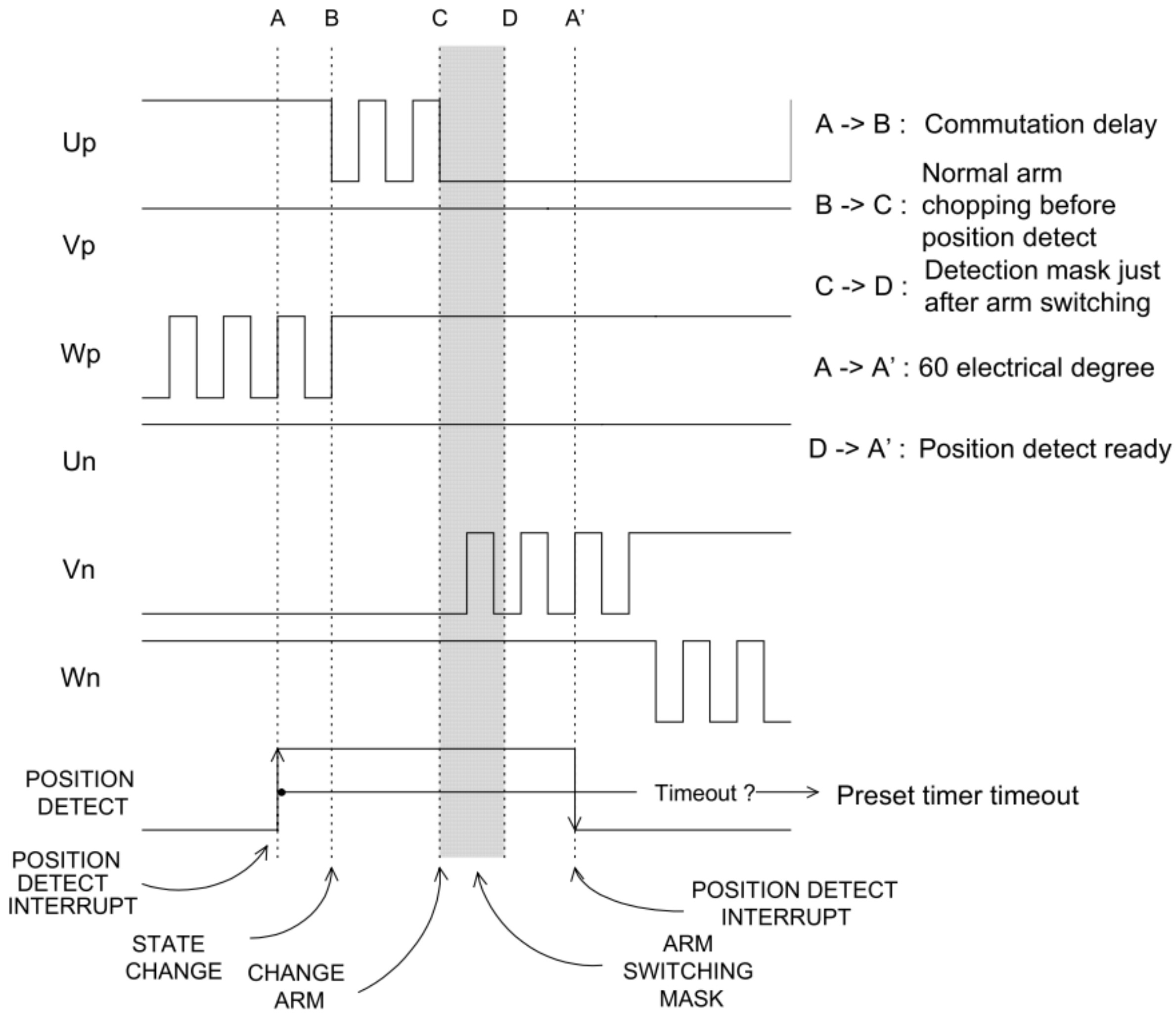
Figure 14. Driving Pattern of Normal Run



4.4.2 Real Time Parameters

Some real-time parameters are very important in normal running status and are critical to the motor operation.

Figure 15. In Fact Drive Pattern of the Motor Operation



- Commutation delay

  It is the state change delay after the position detection interrupts.

  This parameter depends on the characteristics of the target motor and current rotational speed.

  0 to 30 electrical degrees are typical practical value.

  This parameter usually used to fine the efficiency and torque at different speed.

- Position detection mask

  Position detect interrupt is masked off just after arm changes, an unwanted interrupt may happens at that time.

- Position detection ready

  Starting from that time, position detection interrupt is possible to interrupt the MCU.

4.4.3 Arm Chopping Technique

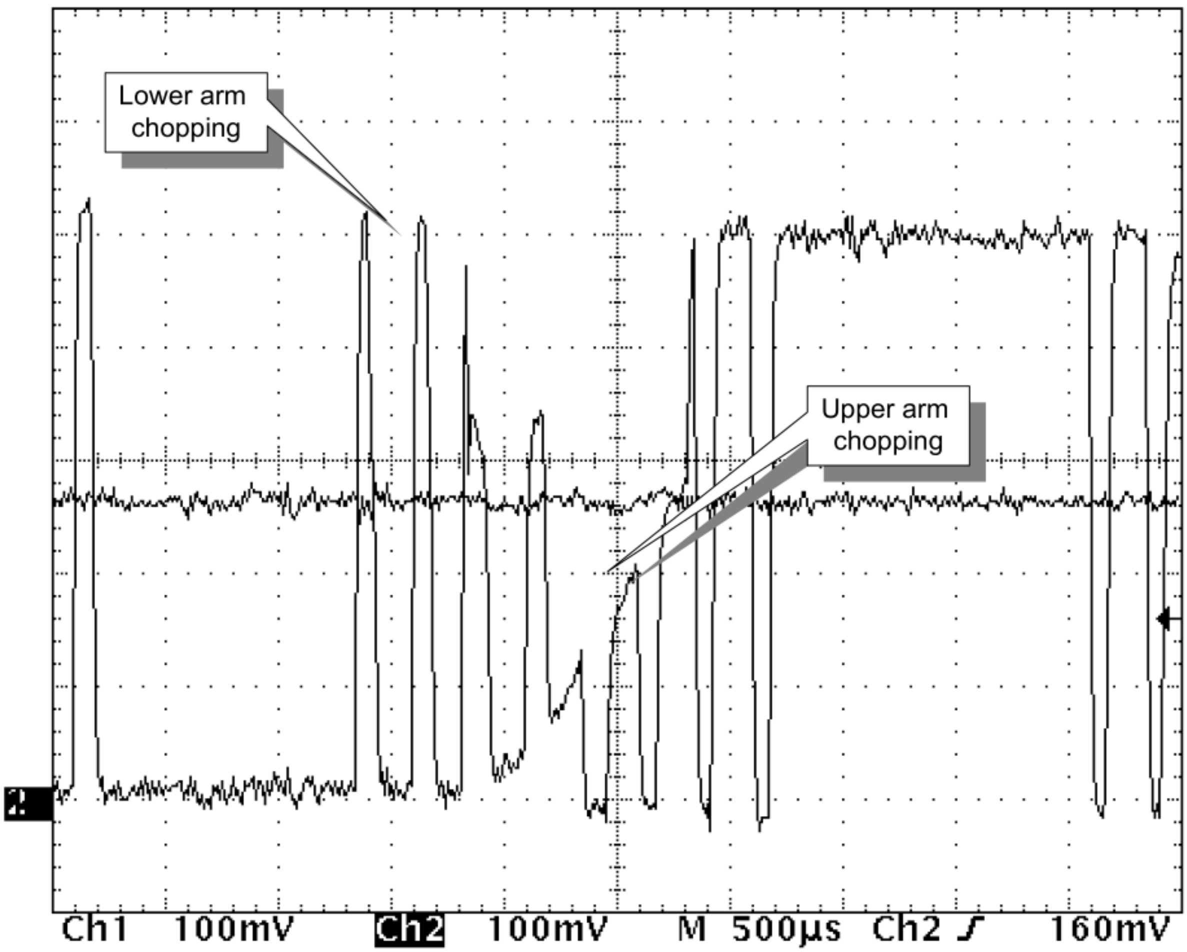
The use of arm chopping to capture rising or falling edge of back EMF is critical. Here describes how to capture rising and falling edge of back EMF using appropriate chopping arm.

- Rising edge detection

  Lower arm chopping will cause the voltage on the opened terminal to exceed the middle reference level, and generates a lot of unwanted interrupts, MCU input interrupt is masked off at this moment.

  Upper arm chopping will cause the voltage on the opened terminal to exceed the middle reference level only when the back EMF is really zero-crossing, it is a valuable instance to MCU.

Figure 16. Rising Edge Detection Waveform of Back EMF

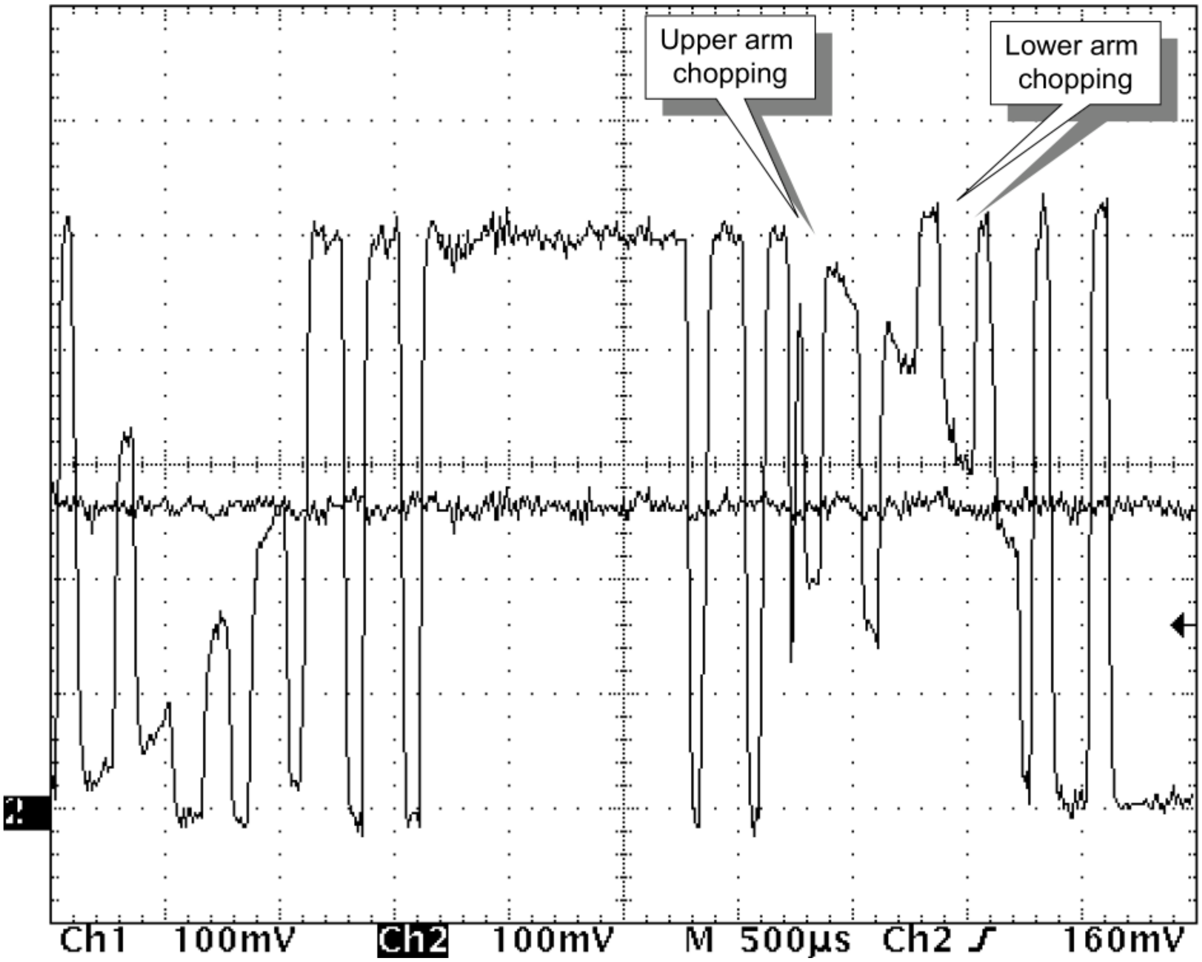


- Falling edge detection

  Upper arm chopping will cause the voltage on the opened terminal to exceed the middle reference level, and generates a lot of unwanted interrupts, MCU input interrupt is masked off at this moment.

  Lower arm chopping will cause the voltage on the opened terminal to exceed the middle reference level only when the back EMF is really zero-crossing, it is a valuable instance to MCU.

Figure 17. Falling Edge Detection Waveform of Back EMF



5 Notes on Using Back EMF Driver method

The section describes notes on using BLDC motor Back EMF 120° Driver method.

5.1 Relationship between Driving Patterns and Position Detection

The relationship between the driving patterns and the expected interrupts from the position detection circuit varies depending on BLDC motor, so user should first find the relationship of them, and then set registers in code.

5.2 Notes on Operation of DTTI Input Control

In system, the DTTI over current protection should be enabled. The OPT5 to OPT0 is fixed at the inactive level when the low input level is placed at the DTTI pin.

Even while the output is fixed at the inactive level by the input of the DTTI pin, the timer keeps running, the position detection function does not stop and the data transfer from the output data buffer register (OPDBR) to the output data register (OPDR) is continued for waveform generation, but no waveform is output to the OPT5 to OPT0 pins.

5.3 Advantage or Disadvantage of Sensorless Control

5.3.1 Advantage of Sensorless Control

BLDC motor back EMF 120° driver is sensorless control. The system has no position sensor of hardware design. It drives BLDC motor which has position sensor or position sensorless motor. As a result, the system debases difficulty of hardware design.

5.3.2 Disadvantage of Sensorless Control

The system has no position, so user should calculate the back EMF to find current position of motor by position detection triggered. As a result, the system increases operation of software design and increases difficulty of firmware design.

6 Additional Information

For more information on Cypress MB95200 products, please visit following website:

http://www.cypress.com/MB95200

Document History

Document Title: AN205561 – F²MC-8FX Family MB95200 Series 8-Bit Microcontroller BLDC Motor Back EMF 120° Driver Method

Document Number: 002-05561

Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	-	CBZH	04/30/2009	Initial release
			05/13/2009	Modify according Document Feedback
*A	5266026	CBZH	05/10/2016	Migrated Spansion Application Note MCU-AN-500042-E-11 to Cypress format.
*B	5841765	AESATMP9	08/02/2017	Updated logo and copyright.

Worldwide Sales and Design Support

Cypress maintains a worldwide network of offices, solution centers, manufacturer's representatives, and distributors. To find the office closest to you, visit us at Cypress Locations.

Products

ARM® Cortex® Microcontrollers	cypress.com/arm
Automotive	cypress.com/automotive
Clocks & Buffers	cypress.com/clocks
Interface	cypress.com/interface
Internet of Things	cypress.com/iot
Memory	cypress.com/memory
Microcontrollers	cypress.com/mcu
PSoC	cypress.com/psoc
Power Management ICs	cypress.com/pmic
Touch Sensing	cypress.com/touch
USB Controllers	cypress.com/usb
Wireless Connectivity	cypress.com/wireless

PSoC® Solutions

PSoC 1 | PSoC 3 | PSoC 4 | PSoC 5LP | PSoC 6

Cypress Developer Community

Forums | WICED IOT Forums | Projects | Videos | Blogs | Training | Components

Technical Support

cypress.com/support

Cypress Semiconductor
198 Champion Court
San Jose, CA 95134-1709