INTRODUCTION

This application note describes how to drive a bipolar stepping motor with the PIC16F684. The Enhanced Capture Compare PWM (ECCP) module is used to implement a microstepping technique known as high-torque microstepping. The microcontroller’s 8 MHz internal oscillator allows the signals generated by the ECCP module to achieve frequencies above the audible range.

MICROSTEPPING

Single stepping, or turning a stepping motor at its rated step size, results in less than smooth movement. Microstepping is a technique used to smooth the motor’s movement between full steps and to improve the step resolution of the motor. Microstepping also improves the efficiency of the system, because the current in the windings of the motor is manipulated in a controlled manner rather than being turned on and off abruptly.

A microstepping technique known as high torque microstepping alternately varies the current in the two windings of a stepping motor. Figure 1 shows a graph of the current in the windings vs. angular position using this technique.

![High Torque Microstepping Graph](image)

Angular Position (S = rated step size)

A brief description of what is happening is that one winding is powered while the current in the other winding is gradually dropped to zero, reversed, and then ramped up again. This sequence is then repeated for the other winding. Note that the transition between a winding being energized in one direction and then energized in the other direction has a sinusoidal shape (refer to Figure 1). This shape gives the smoothest transition between the motor’s rated step increments (i.e., 7.5 degrees). The way this shape is achieved using a microcontroller is through the use of pulse-width modulation. Modulating the input to the drive circuitry for a particular winding will result in a current that is proportional to the duty cycle of the modulated waveform.

For instance, if a 5V stepping motor is rated at 1 amp, then modulating a 5V supply across the winding at 50% will result in a current of 1/2 amp (assuming a low inductance motor). Equation 1 shows this relationship:

**EQUATION 1:**

\[ I = D \times I_{MAX} \]

where \( I_{MAX} \) is the rated current of the motor and \( D \) is the duty cycle.
In order to achieve the sinusoidal transition from a positive to negative charge in a winding, numerous microsteps are needed. The number of microsteps typically ranges from 4 to 32 microsteps per rated step size. Rather than calculating the duty cycle for a particular microstep on the fly, a duty cycle look-up table is implemented in firmware. The number of table values is equal to the number of steps desired for a particular microstepping sequence. Equation 2 is used to obtain the duty cycle values for the top half of the table. The second half of the table is simply the top half in reverse order.

**EQUATION 2:**

\[
D(\text{step number}) = \cos((\text{step number} \times \pi)/(\text{(number of steps})+1)) \times ((2^{\text{bits resolution}})-1)
\]

Using Equation 2, the following duty cycle values were calculated for a 16 microsteps per full step sequence using an 8-bit resolution PWM waveform:

**TABLE 1: DUTY CYCLE VALUES FOR MICROSTEPPING**

<table>
<thead>
<tr>
<th>Step Number</th>
<th>D</th>
<th>Step Number</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>251</td>
<td>9</td>
<td>24</td>
</tr>
<tr>
<td>2</td>
<td>238</td>
<td>10</td>
<td>70</td>
</tr>
<tr>
<td>3</td>
<td>217</td>
<td>11</td>
<td>114</td>
</tr>
<tr>
<td>4</td>
<td>188</td>
<td>12</td>
<td>154</td>
</tr>
<tr>
<td>5</td>
<td>154</td>
<td>13</td>
<td>188</td>
</tr>
<tr>
<td>6</td>
<td>114</td>
<td>14</td>
<td>217</td>
</tr>
<tr>
<td>7</td>
<td>70</td>
<td>15</td>
<td>238</td>
</tr>
<tr>
<td>8</td>
<td>24</td>
<td>16</td>
<td>251</td>
</tr>
</tbody>
</table>

**PWM Generation Using the ECCP Module**

The ECCP module on the PIC16F684 is well suited for generating the PWM signal required for microstepping. The module is capable of generating a 10-bit resolution PWM waveform at frequencies ranging up to 7.81 kHz using the microcontroller’s 8 MHz internal oscillator. Higher frequencies are more practical in motor control applications because a motor will typically produce undesirable audible noise at frequencies less than 16 kHz. Only 8-bit resolution is needed for this application, which means frequencies up to 31.2 kHz can be achieved with the ECCP module.

The ECCP module has four modes of operation:
1) Single Output
2) Half-bridge Output
3) Full-bridge Forward Output
4) Full-bridge Reverse Output

In Half-bridge mode, the module modulates two pins simultaneously, pins P1A and P1B. For this application, these two outputs are used to drive the two windings of a stepping motor. Only one pin is set active at a time. Enabling and disabling one pin or the other is done by modifying the TRISC register. The following circuit diagram shows how these pins are connected to a bipolar drive circuit.
FIGURE 2: BIPOLAR DRIVE CIRCUIT

VSUPPLY

P1A
CTRLA1
Winding 1
CTRLA2

R1
10K

VSUPPLY

P1B
CTRLB1
Winding 2
CTRLB2

VSUPPLY
Note the pull-up resistor on pins P1A and P1B. These resistors clamp the respective line high when the pin is tristated. It is important that the non-modulated line be clamped high so that the NAND gates on either end of the winding can turn on the adjacent MOSFET when the respective control line is enabled.

The ECCP module is set up so that the waveforms on pins P1A and P1B are identical. This is done by configuring the CCP1CON register so that P1A is active high and P1B is active low. With no dead band delay, these pins will behave identically. Configuring the module in this way enables each winding control block to use the same duty cycle look-up table values for its transition sequence. The following table shows all eight winding states.

<table>
<thead>
<tr>
<th>STATE</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winding 1 Polarity</td>
<td>+ to 0</td>
<td>0 to -</td>
<td>-</td>
<td>-</td>
<td>- to 0</td>
<td>0 to +</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Winding 2 Polarity</td>
<td>+</td>
<td>+</td>
<td>+ to 0</td>
<td>0 to -</td>
<td>-</td>
<td>-</td>
<td>- to 0</td>
<td>0 to +</td>
</tr>
<tr>
<td>P1A Duty Cycle</td>
<td>100% to 0</td>
<td>0 to 100%</td>
<td>100%*</td>
<td>100%*</td>
<td>100% to 0</td>
<td>0 to 100%</td>
<td>100%*</td>
<td>100%*</td>
</tr>
<tr>
<td>P1B Duty Cycle</td>
<td>100%*</td>
<td>100%*</td>
<td>100% to 0</td>
<td>0 to 100%</td>
<td>100%*</td>
<td>100%*</td>
<td>100% to 0</td>
<td>0 to 100%</td>
</tr>
<tr>
<td>TRISC, P1A</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>TRISC, P1B</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CTRLA1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>CTRLA2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CTRLB1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>CTRLB2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

* Pin is tristated and the pull-up resistor is clamping the line high.

In states 0, 2, 4 and 6, the first half of the duty cycle sine look-up table (decreasing values) is referenced. In states 1, 3, 5 and 7, the second half of the duty cycle sine look-up table (increasing values) is referenced.
EXAMPLE APPLICATION

This example application demonstrates how to drive a 3.6 degree-per-step stepping motor. The motor used is a bipolar stepping motor rated to draw 1/2 amp at 12V.

Hardware

Appendix A shows a schematic for the example application included with this application note. The drive circuit is composed of four Fairchild® Semiconductor half-bridge MOSFET ICs (part number FDC6420C). Two Microchip logic-input CMOS quad drivers are used to drive the MOSFET ICs and to provide the logic necessary for the implementation described in this application note. The TC4467 has four on-chip NAND gates and the TC4468 has four on-chip AND gates. The inputs to each of the AND gates on the TC4468 are tied together because this IC is used as a non-inverting quad MOSFET driver for this implementation.

Firmware

A flowchart illustrating the microstepping firmware implementation of this example is in Appendix B. The source code for this application note is included with this application note on Microchip’s web site, www.microchip.com.

Operation

There are five modes of operation in the example that are sequenced through with single button presses. The modes of operation are:

1. Motor Off
2. Single-step mode
3. Half-step mode
4. Microstep mode
5. Position Control mode

In modes 2, 3 and 4, the speed of the stepping motor is controlled by turning the potentiometer. Mode 5 uses the potentiometer as a position dial. Turning the potentiometer will cause the motor to microstep in one direction or the other for a distance proportional to the distance the potentiometer was turned.

CONCLUSION

The PIC16F684 has an ideal set of features for low-cost stepper motor control. High torque microstepping can be implemented using its ECCP module and very few external logic components. The PIC16F684’s 8 MHz internal oscillator will allow the ECCP module to drive the transitioning phase of the bipolar stepping motor at a frequency of 31.2 kHz and still provide 8-bits of duty cycle resolution. This frequency effectively eliminates unwanted audible noise generated by the motor.

REFERENCES

AN907: “Stepper Motor Fundamentals”
APPENDIX A:

[Diagram of PIC16F684 and TC4467]
APPENDIX A: (CONTINUED)

![Diagram of J7 DIN5P_RECEPTICAL connection and U10 LM78L05ACM circuit diagram with components labeled.

- J7 DIN5P_RECEPTICAL pin connections:
  - Pin 3: Vsupply
  - Pin 4: 100 uF capacitor
  - Pin 6: C11 1 uF capacitor
  - Pin 7: C12 0.1 uF capacitor
  - Pin 8: C13 0.1 uF capacitor

- U10 LM78L05ACM connections:
  - IN: 1
  - OUT: 8
  - IN: 2
  - OUT: 3
  - IN: 4
  - OUT: 6
  - IN: 5
  - OUT: 7

- Component labels:
  - Pin 1: +5V
  - Pin 2: IN
  - Pin 3: OUT
  - Pin 4: GND
  - Pin 5: GND
  - Pin 6: GND
  - Pin 7: GND

- Connector pins labeled:
  - P5: RA5, RA4, VPP, RA3, RA2, RC4, RC3, RC2, RA1, RA0
  - P4: RA5, RA4, RA3, RA2, RC4, RC3, RC2, RA1, RA0
  - P3: RA5, RA4, RA3, RA2, RC4, RC3, RC2, RA1, RA0

- Component values:
  - 100 uF capacitor
  - 1 uF capacitor
  - 0.1 uF capacitor
APPENDIX B:

- **Initialize**
  - Internal Oscillator:
    - Frequency = 8 MHz
  - Assign I/O Pins
  - Setup ADC Pin: AN2
  - Setup ECCP Module:
    - Half-bridge mode, 31.25 kHz waveform
  - Set TMR0 Parameters
  - Turn on TMR2
  - goto MotorState
APPENDIX B: (CONTINUED)

MotorState

TMR0 Interrupt Flag Set?

Yes

Clear TMR0 Interrupt Flag

Delay = Delay - 1

No

Is Delay equal to zero?

Yes

Read Potentiometer

No

Move high 4-bits of ADC Value into Delay and Increment

Initiate next ADC read

Load CCP1CON an CCPR1L with Next Duty Cycle Value

State?

No

End/Middle of Look-up Table?

Yes

Increment State


goto State0
goto State2
goto State4
goto State6
goto State1
goto State3
goto State5
goto State7
APPENDIX B: (CONTINUED)

State0
- Enable P1A
- Disable P1B
- CTRLA1 = 0
- CTRLA2 = 0
- CTRLB1 = 1
- CTRLB2 = 1
- goto MotorState

State1
- Enable P1A
- Disable P1B
- CTRLA1 = 0
- CTRLA2 = 1
- CTRLB1 = 1
- CTRLB2 = 0
- goto MotorState

State2
- Disable P1A
- Enable P1B
- CTRLA1 = 0
- CTRLA2 = 0
- CTRLB1 = 1
- CTRLB2 = 1
- goto MotorState

State3
- Disable P1A
- Enable P1B
- CTRLA1 = 0
- CTRLA2 = 1
- CTRLB1 = 0
- CTRLB2 = 1
- goto MotorState

State4
- Enable P1A
- Disable P1B
- CTRLA1 = 0
- CTRLA2 = 1
- CTRLB1 = 0
- CTRLB2 = 1
- goto MotorState

State5
- Enable P1A
- Disable P1B
- CTRLA1 = 1
- CTRLA2 = 0
- CTRLB1 = 0
- CTRLB2 = 1
- goto MotorState

State6
- Disable P1A
- Enable P1B
- CTRLA1 = 1
- CTRLA2 = 0
- CTRLB1 = 0
- CTRLB2 = 1
- goto MotorState

State7
- Disable P1A
- Enable P1B
- CTRLA1 = 1
- CTRLA2 = 0
- CTRLB1 = 1
- CTRLB2 = 1
- goto MotorState
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AMERICAS
Corporate Office
2355 West Chandler Blvd.
Chandler, AZ  85224-6199
Tel: 480-792-7200
Fax: 480-792-7277
Web Address: http://www.microchip.com

Atlanta
3780 Mansell Road, Suite 130
Alpharetta, GA  30022
Tel: 770-640-0034
Fax: 770-640-0077

Boston
2 Lan Drive, Suite 120
Westford, MA  01886
Tel: 978-692-3848
Fax: 978-692-3821

Chicago
333 Pierce Road, Suite 180
Itasca, IL  60143
Tel: 630-285-0071
Fax: 630-285-0075

Dallas
4570 Westgrove Drive, Suite 160
Addison, TX 75001
Tel: 972-818-7423
Fax: 972-818-2924

Detroit
Tri-Atria Office Building
32255 Northwestern Highway, Suite 190
Farmington Hills, MI  48334
Tel: 248-538-2250
Fax: 248-538-2260

Kokomo
2767 S. Albright Road
Kokomo, IN  46902
Tel: 765-263-1888
Fax: 765-263-1338

Los Angeles
18201 Von Karman, Suite 1090
Irvine, CA  92612
Tel: 949-263-1888
Fax: 949-263-1338

San Jose
1300 Terra Bella Avenue
Mountain View, CA  94043
Tel: 650-215-1444
Fax: 650-961-0286

Toronto
6285 Northam Drive, Suite 108
Mississauga, Ontario L4V 1X5, Canada
Tel: 905-673-0699
Fax: 905-673-6509

ASIA/PACIFIC
Australia
Suite 22, 41 Rawson Street
Epping 2121, NSW
Australia
Tel: 61-2-9868-6733
Fax: 61-2-9868-6755

China - Beijing
Unit 706B
Wan Tai Bei Hai Bldg.
No. 6 Chaoyangmen Bei Str.
Beijing, 100027, China
Tel: 86-10-85282100
Fax: 86-10-85282104

China - Chengdu
Rm. 2401-2402, 24th Floor,
Ming Xing Financial Tower
No. 88 TIDU Street
Chengdu 610016, China
Tel: 86-28-86766200
Fax: 86-28-86766599

China - Fuzhou
Unit 28F, World Trade Plaza
No. 71 Wusi Road
Fuzhou 350001, China
Tel: 86-591-7505360
Fax: 86-591-75053521

China - Hong Kong SAR
Unit 901-6, Tower 2, Metropiazza
233 Hing Fong Road
Kwai Fong, N.T., Hong Kong
Tel: 852-2401-1200
Fax: 852-2401-3431

China - Shanghai
Room 701, Bldg. B
Far East International Plaza
No. 317 Xian Xai Road
Shanghai, 200051, China
Tel: 86-21-6275-5700
Fax: 86-21-6275-5060

China - Shenzhen
Rm. 1812, 18/F, Building A, United Plaza
No. 5022 Binhe Road, Futian District
Shenzhen 518033, China
Tel: 86-755-82901380
Fax: 86-755-8295-1393

Korea
188-1, Youngbo Bldg. 3 Floor
Samsung-Dong, Kangnam-Ku
Seoul, Korea 135-882
Tel: 82-2-554-7200 Fax: 82-2-558-5932 or
82-2-558-5934

Singapore
200 Middle Road
#07-02 Prime Centre
Singapore, 189980
Tel: 65-6334-8870 Fax: 65-6334-8850

Taiwan
Kaohsiung Branch
3F - 1 No. 8
Min Chuan 2nd Road
Kaohsiung 806, Taiwan
Tel: 886-7-536-4818
Fax: 886-7-536-4803

Taiwan
Taiwan Branch
11F-3, No. 207
Tung Hua North Road
Taipei, 105, Taiwan
Tel: 886-2-2717-7175 Fax: 886-2-2545-0139

EUROPE
Austria
Durisolstrasse 2
A-4600 Wels
Austria
Tel: 43-7242-2244-399
Fax: 43-7242-2244-393

Denmark
Regus Business Centre
Laurupshol 1-3
Ballersp DK-2750 Denmark
Tel: 45-4420-9895 Fax: 45-4420-9910

France
Parc d'Activite du Moulin de Massy
43 Rue du Saule Trapu
91300 Massy, France
Tel: 33-1-69-53-63-20
Fax: 33-1-69-30-90-79

Germany
Steinheilstrasse 10
D-65737 Idnaiming, Germany
Tel: 49-89-627-144-0
Fax: 49-89-627-144-44

Italy
Via Quasimodo, 12
20025 Legnano (MI)
Milan, Italy
Tel: 39-0331-742611
Fax: 39-0331-466781

Netherlands
P. A. De Biesbosch 14
NL-5152 SC Drunen, Netherlands
Tel: 31-69-53-63-20
Fax: 31-69-30-90-79

United Kingdom
Steinheilstrasse 10
D-65737 Idnaiming, Germany
Tel: 49-89-627-144-0
Fax: 49-89-627-144-44

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