AN906

Stepper Motor Control Using the PIC16F684

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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.

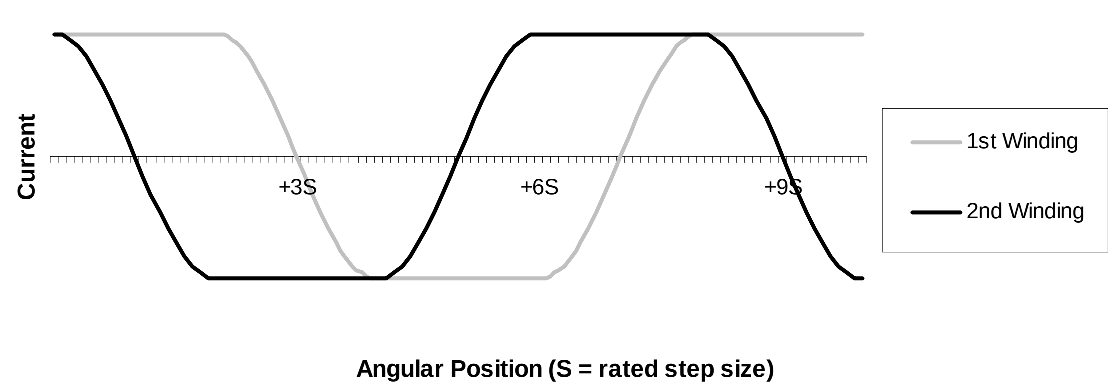
> **Note:** Please refer to AN907: *Stepping Motor Fundamentals* for information on the types of stepper motors, microstepping and current limiting techniques.

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.

FIGURE 1: HIGH TORQUE MICROSTEPPING



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:

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

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

Step Number	D	Step Number	D
1	251	9	24
2	238	10	70
3	217	11	114
4	188	12	154
5	154	13	188
6	114	14	217
7	70	15	238
8	24	16	251

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

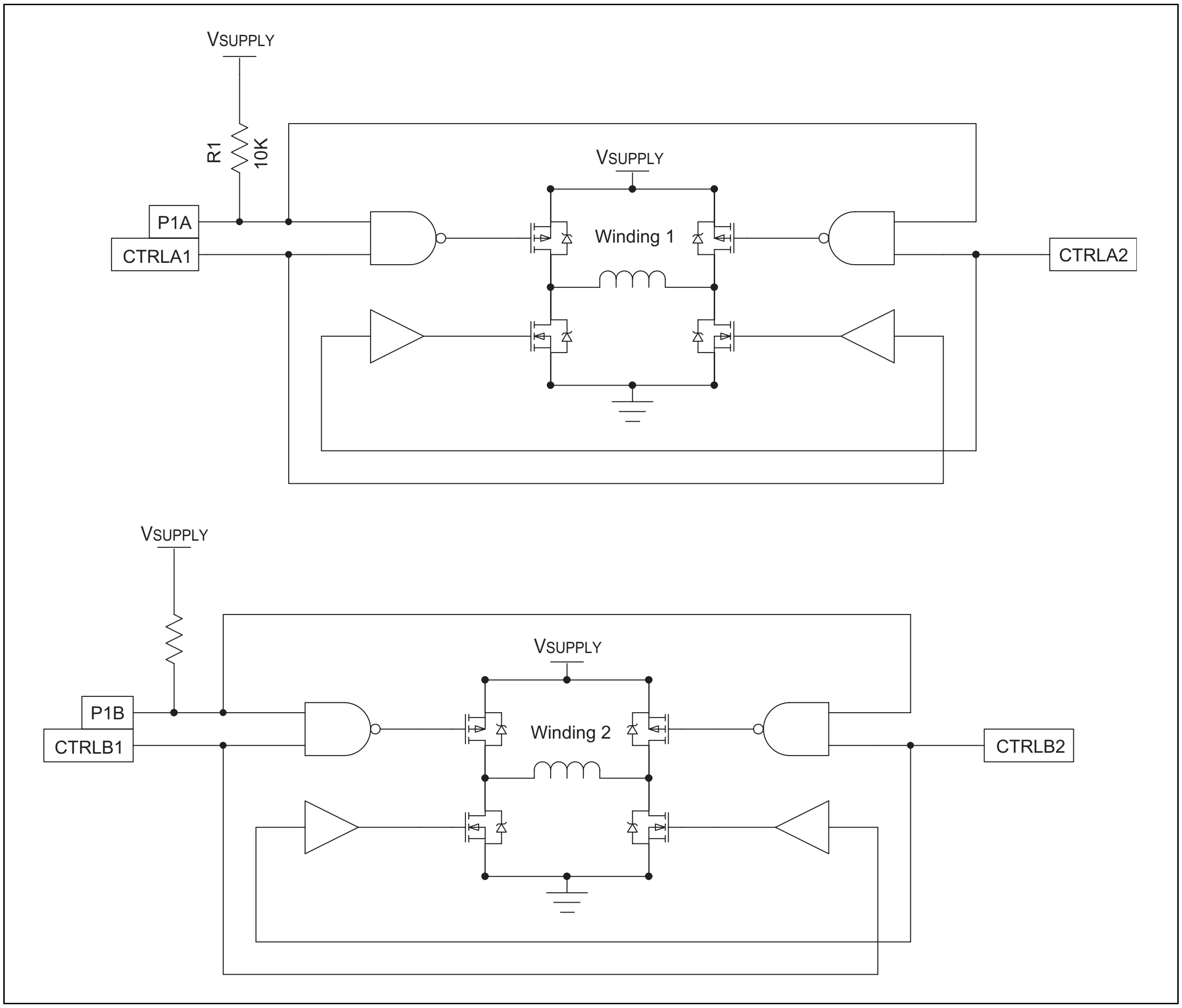
2) Half-bridge Output

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



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 it's transition sequence. The following table shows all eight winding states.

TABLE 2: WINDING STATES

STATE	0	1	2	3	4	5	6	7
Winding 1 Polarity	+ to 0	0 to -	-	-	- to 0	0 to +	+	+
Winding 2 Polarity	+	+	+ to 0	0 to -	-	-	- to 0	0 to +
P1A Duty Cycle	100% to 0	0 to 100%	100%*	100%*	100% to 0	0 to 100%	100%*	100%*
P1B Duty Cycle	100%*	100%*	100% to 0	0 to 100%	100%*	100%*	100% to 0	0 to 100%
TRISC, P1A	0	0	1	1	0	0	1	1
TRISC, P1B	1	1	0	0	1	1	0	0
CTRLA1	1	0	0	0	0	1	1	1
CTRLA2	0	1	1	1	1	0	0	0
CTRLB1	1	1	1	0	0	0	0	1
CTRLB2	0	0	0	1	1	1	1	0

* 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.

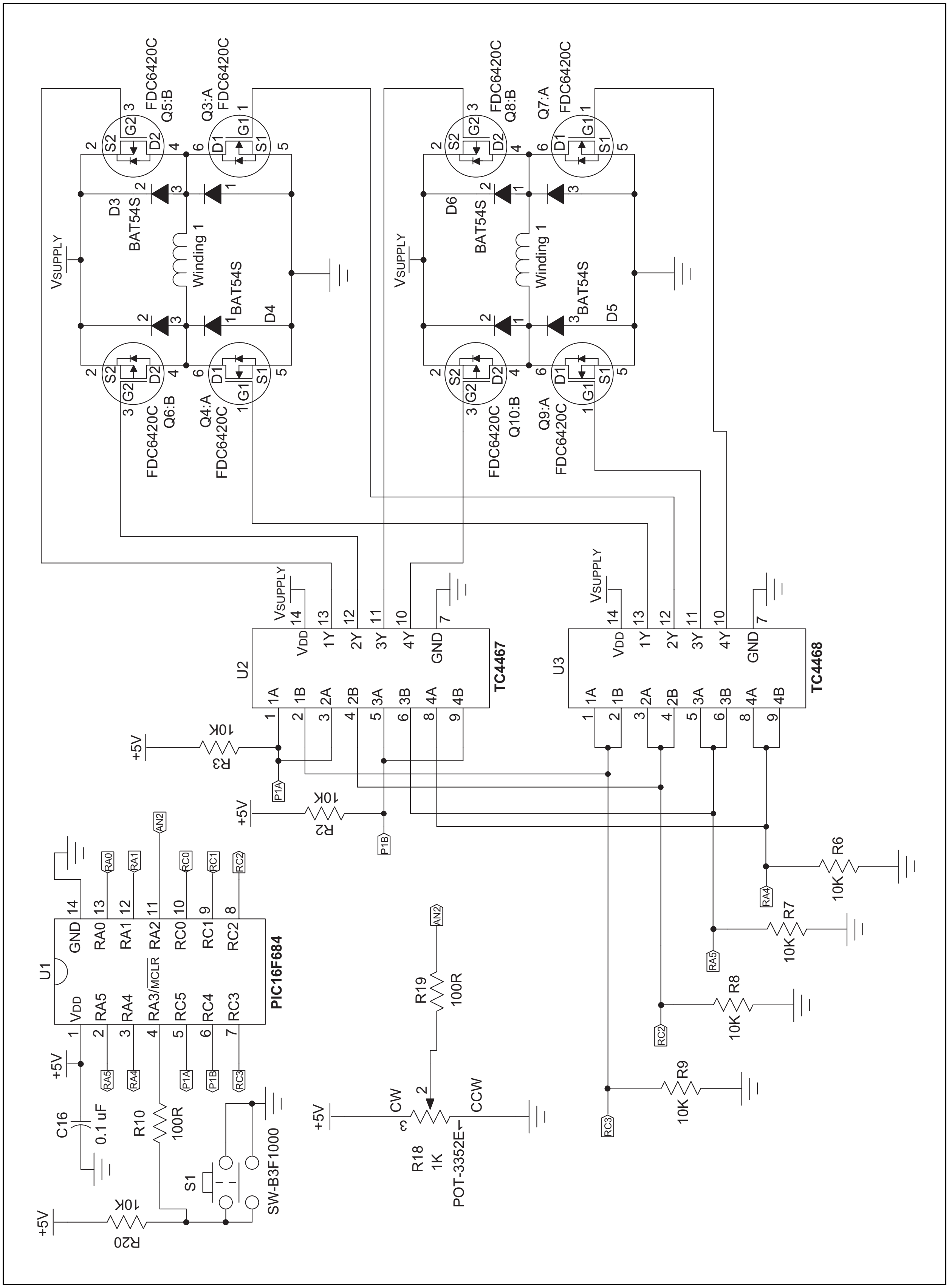
CONCLUSION

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.

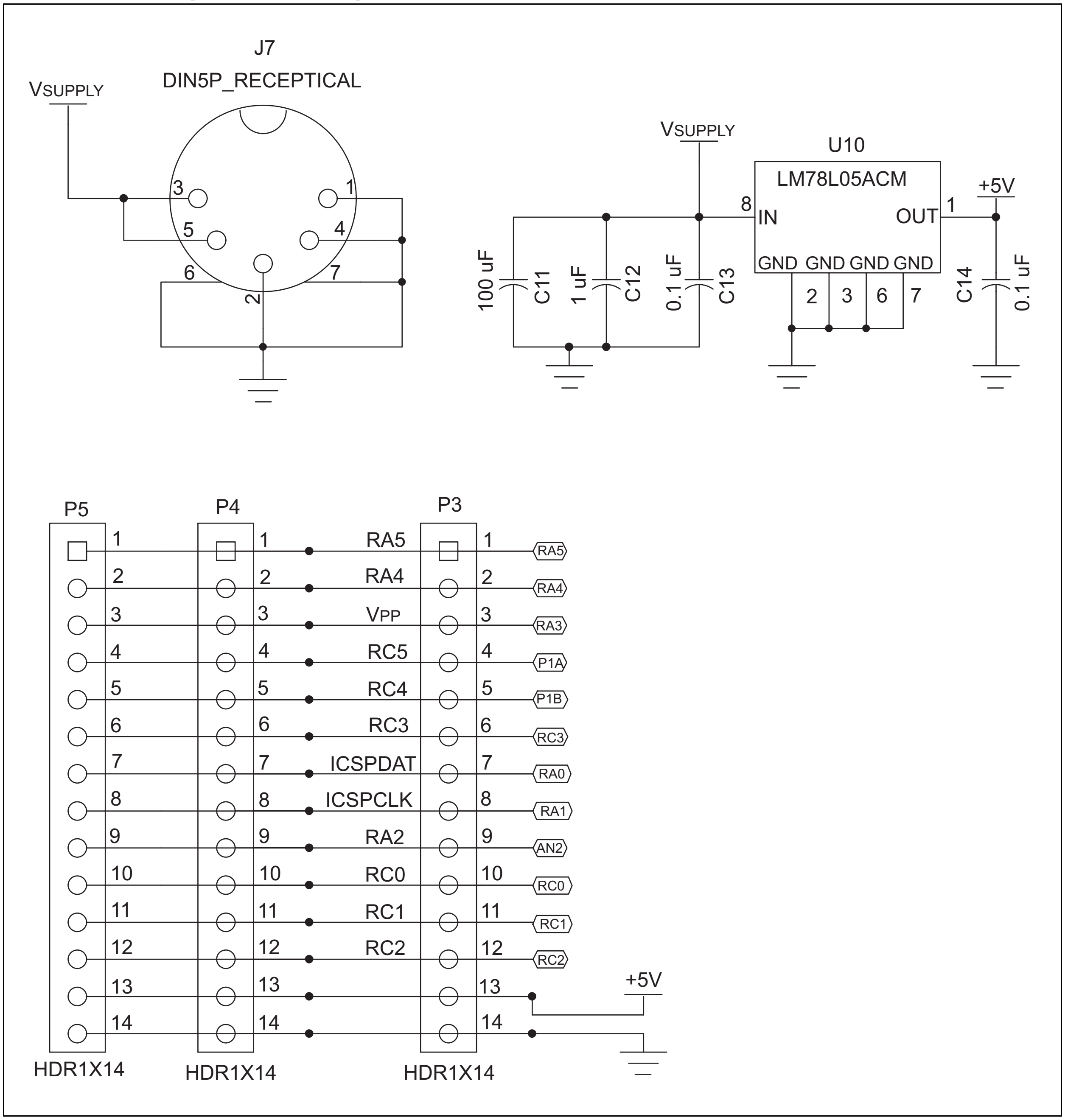
REFERENCES

AN907: "*Stepper Motor Fundamentals*"

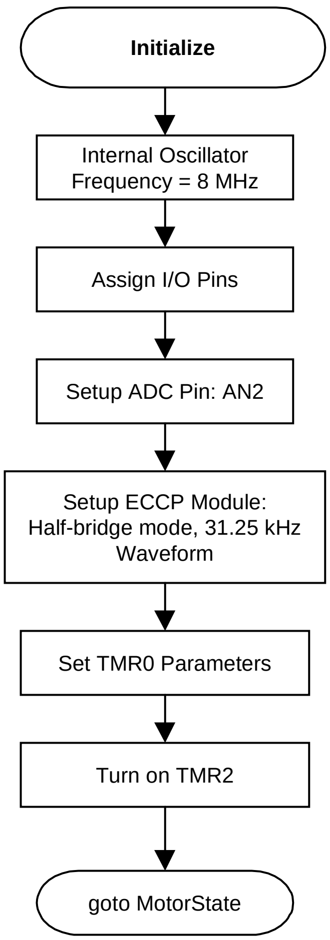
APPENDIX A:


FDC6420C
Q5:B
Q3:A
Q6:B
Q4:A
Q8:B
Q7:A
Q10:B
Q9:A
D3
D4
D5
D6
BAT54S
Winding 1
VSUPPLY
U2
TC4467
U3
TC4468
VDD
1Y
2Y
3Y
4Y
GND
1A
1B
2A
2B
3A
3B
4A
4B
+5V
R3
10K
R2
P1A
P1B
R6
R7
R8
R9
RA4
RA5
RC2
RC3
U1
PIC16F684
RA0
RA1
RA2
RC0
RC1
RC2
RA5
RA4
RA3/MCLR
RC5
RC4
RC3
AN2
C16
0.1 uF
R10
100R
S1
SW-B3F1000
R20
R19
R18
1K
POT-3352E
CW
CCW

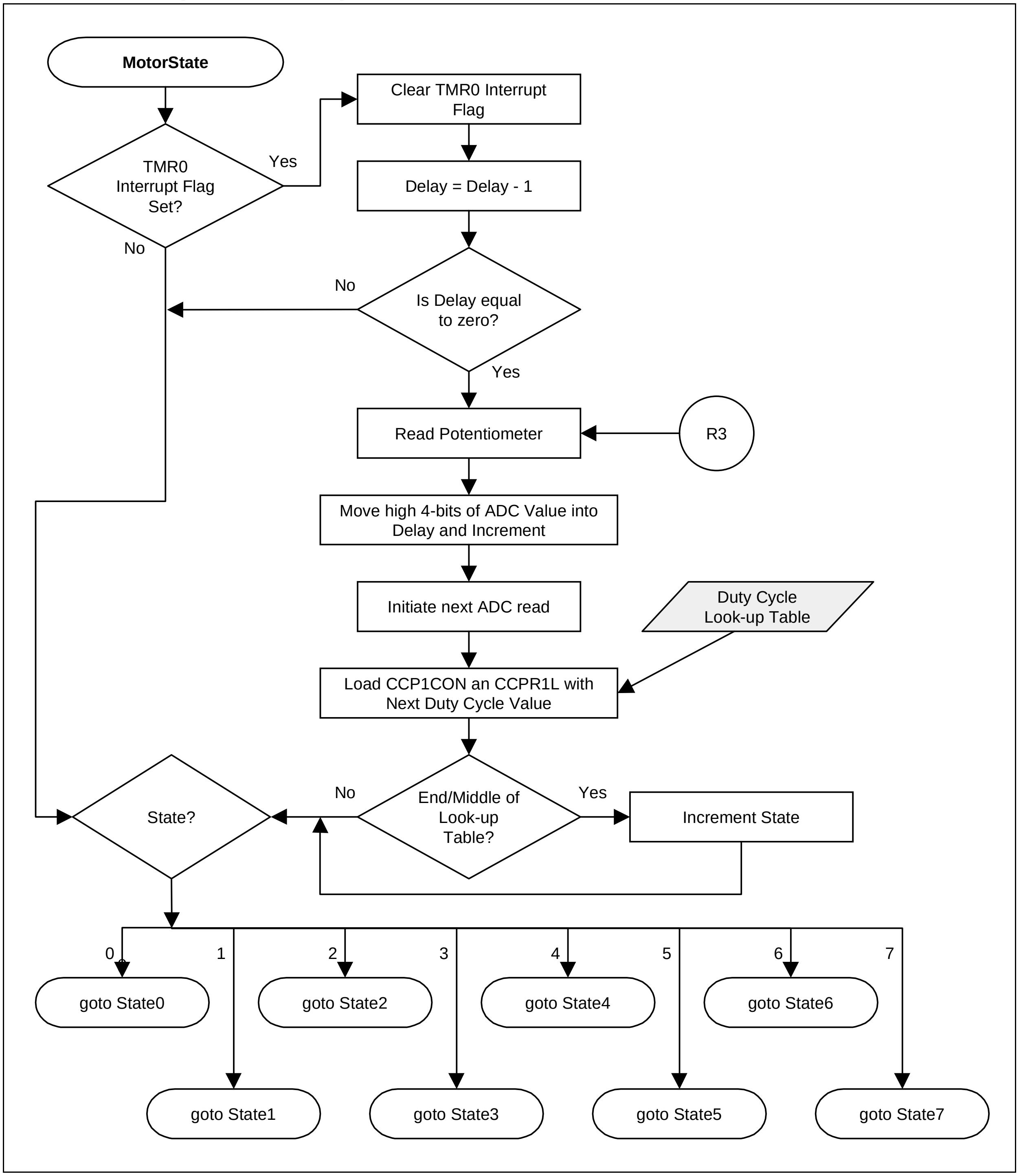
APPENDIX A: (CONTINUED)



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)



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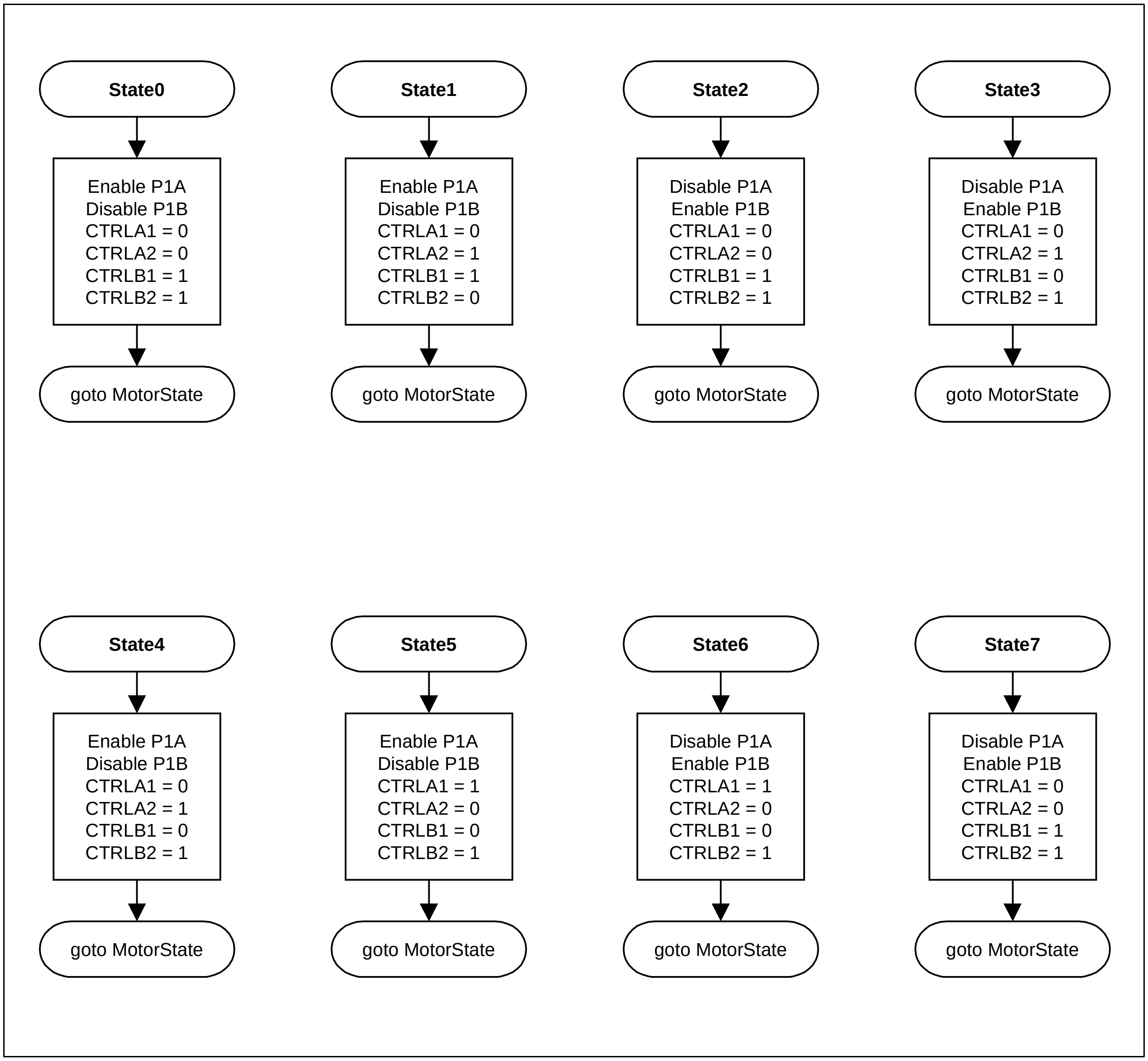

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