AN696

PIC18CXXX/PIC16CXXX DC Servomotor Application

Author: *Stephen Bowling*
Microchip Technology Inc.
Chandler, AZ

INTRODUCTION

The PICmicro® microcontroller makes an ideal choice for an embedded DC Servomotor application. The PICmicro family has many devices and options for the embedded designer to choose from. Furthermore, pin compatible devices are offered in the PIC16CXXX and PIC18CXXX device families, which makes it possible to use either device in the same hardware design. This gives the designer an easy migration path, depending on the features and performance required in the application. In particular, this servomotor has been implemented on both the PIC18C452 and PIC16F877 devices, and we'll look at the MCU resources required to support the servomotor application. With an understanding of the servomotor functions, you can start with the design shown here and implement your own custom DC servomotor application based on the PICmicro device that suits your needs.

The PICmicro MCU handles many functions in the servomotor application, such as:

- User control interface
- Measurement of motor position
- Computation of motion profile
- Computation of error signal and PID compensation algorithm
- Generation of motor drive signal
- Communication with non-volatile EEPROM memory

HARDWARE

A Pittman Inc. 9200 Series DC motor was used to develop the application source code. The motor was designed for a 24 V_{DC} bus voltage and has a no-load speed of 6000 RPM. The torque constant (K_T) for the motor is 5.17 oz-in/A and the back-EMF constant (K_E) is 3.82 V/kRPM. This motor has an internal incremental encoder providing a resolution of 500 counts-per-revolution (CPR). In practice, the design should be compatible with almost any brush-DC motor fitted with an incremental encoder.

A schematic diagram for the application is shown in Figure 1. The DC motor is driven by a SGS-Thomson L6203 H-bridge driver IC that uses DMOS output devices and can deliver up to 3 A output current at supply voltages up to 52 V. The device has an internal charge pump for driving the high-side transistors and dead-time circuitry, to prevent cross-conduction of the output devices. Each side of the bridge may be driven independently and the inputs are TTL compatible. An enable input and automatic thermal shutdown are also provided. A transient voltage suppressor is connected across the motor terminals to prevent damage to the L6203.

The PWM1 output from the MCU is connected to both sides of the H-bridge driver IC with one side of the bridge driven with an inverted PWM signal. You get more switching losses when the bridge is driven in this manner, because all four devices in the bridge are switched for each transition in the PWM signal. However, this arrangement provides an easy method of bi-directional control with a single input signal. For example, a 50% PWM duty cycle delivered to the H-bridge produces zero motor torque. A 100% duty cycle will produce maximum motor torque in the forward direction, while a 0% duty cycle will produce maximum motor torque in the opposite direction. The only other control signal is an enable input that turns the output of the H-bridge driver IC on or off.

The quadrature pulse outputs from the encoder are connected through external pull-up resistors. The outputs are then filtered and decoded into up and down pulse trains with a 74HC74 dual D flip-flop. Figure 2 shows a timing diagram, indicating the output of the decoder circuit for each direction of the motor. It's possible to decode the encoder outputs so that an output pulse is generated for every transition of the encoder output signals, which yields a 4x increase in the specified encoder resolution. However, the 1x decoding circuit is implemented here for simplicity (see Figure 1). The up and down pulse outputs from the D flip-flops are connected to the Timer0 and Timer1 clock inputs, respectively. This method of decoding the motor position is beneficial, because it requires low software overhead. The cumulative forward and reverse travel distances are maintained by the timers, while the MCU is performing other tasks.

FIGURE 1: DC SERVOMOTOR SCHEMATIC DIAGRAM

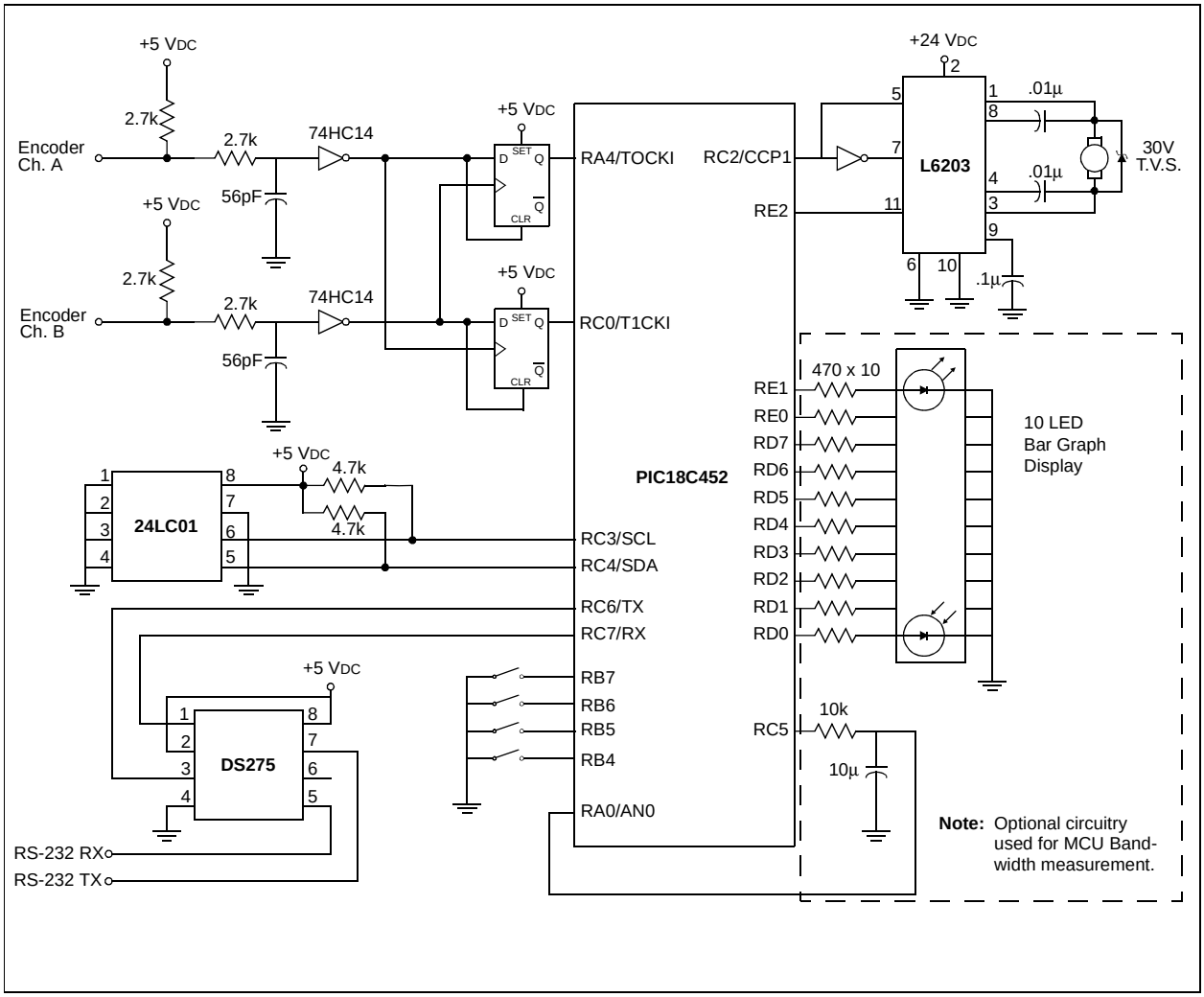
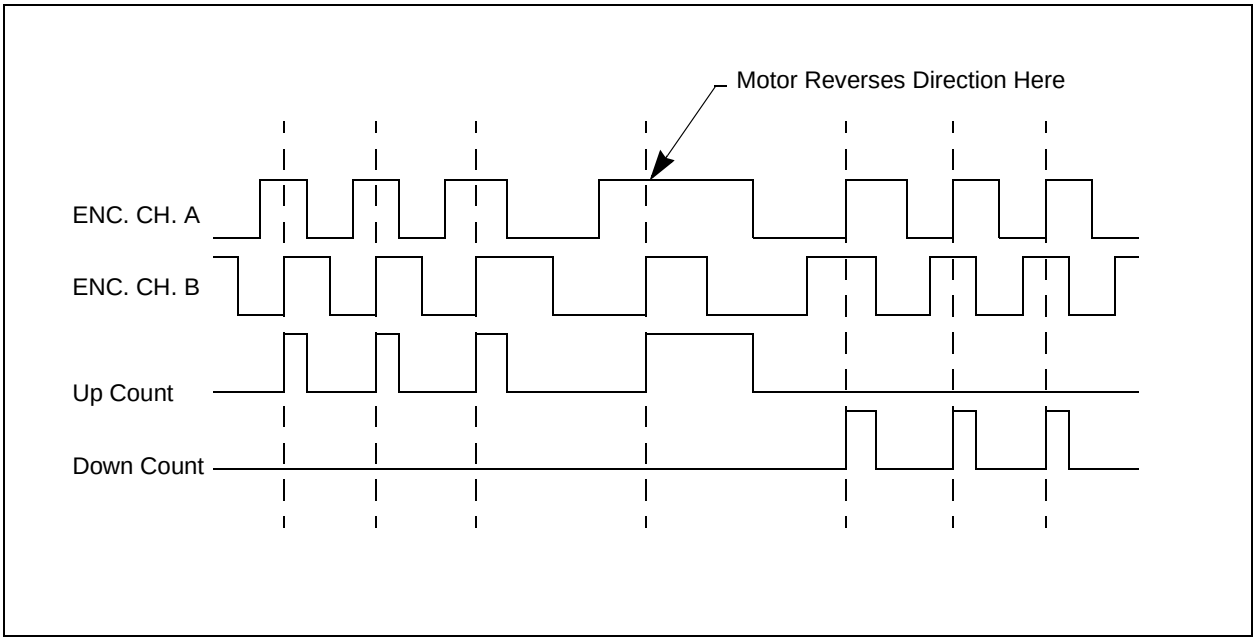


FIGURE 2: DECODER CIRCUIT TIMING DIAGRAM



The primary user interface is a RS-232 connection to a host PC. A Dallas Semiconductor DS275 transceiver is used in the design. This IC supports half-duplex communication and steals power from the host device for generating the transmit voltages required for the RS-232 standard. Four DIP switches are also included in the circuit and are connected to PORTB<7:4>. These switches are optional for the design and are used by the software to activate motion profiles when no host PC is available.

The LEDs shown in the schematic diagram are used to implement a bar graph display used by the firmware to indicate the percentage of the MCU bandwidth used by the servo calculations. To measure the bandwidth, I/O pin RC5 is toggled high when the servo calculations begin, and toggled low when they are completed. The resulting output is filtered to create a DC voltage proportional to the bandwidth used and is connected to Channel 0 of the A/D converter. The LEDs and filter circuit are not essential, and can be removed from the application if desired.

SOFTWARE

The servomotor software performs the servo position calculations and provides a command interpreter to create and control motion profiles.

Servo Calculations

The entire servomotor function is implemented in the Interrupt Service Routine (ISR), which must perform the following tasks:

- Get current motor position
- Get desired motor position
- Find the position error
- Determine new PWM duty cycle

Timer2, the timebase for the CCP1 module, is used to generate interrupts that time the servo calculations. This ensures that the PWM duty cycle changes are synchronous with the PWM period.

The frequency of the PWM signal that drives the motor should be high enough so that a minimal amount of current ripple is induced in the windings of the DC motor. The amount of current ripple can be derived from the PWM frequency, motor winding resistance, and motor inductance. More importantly, the PWM frequency is chosen to be just outside the audible frequency range. Depending on how much hearing loss you've suffered, a PWM frequency in the 15 kHz - 20 kHz range will be fine. There's no need to set the PWM frequency any higher; this will only increase the switching losses in the motor driver IC. For this application, the MCU is operated at 20 MHz and the PWM frequency is 19.53 kHz. At this PWM frequency, a Timer2 interrupt would occur every 51 µsec. The servo calculations do not need to be performed this often, so the Timer2 postscaler is used to set the Timer2 interrupt rate. Using the postscaler, interrupts may be generated at any frequency from 1/2 to 1/16th the PWM frequency.

Position Updates

The first task to be done in the servo calculations is to determine exactly where the motor is at the present moment. The function `UpdPos()` is called to get the new motor position. As mentioned earlier, Timer0 and Timer1 are used to accumulate the up and down pulses that are derived from the encoder output signals. The counters are never cleared to avoid the possibility of losing count information. Instead, the values of the Timer0 and Timer1 registers saved during the previous sample period are subtracted from the present timer values, using two's-complement signed arithmetic. This calculation provides us with the total number of up and down pulses accumulated during the servo update period. The use of two's-complement arithmetic, also accounts for a timer overflow that may have occurred since the last read. The down pulse count, `DnCount`, is then subtracted from `UpCount`, the up pulse count, which provides a signed result indicating the total distance (and direction) traveled during the sample period. This value also represents the measured velocity of the motor in encoder counts per servo update period and is stored in the variable `mvelocity`.

The measured position of the motor is stored in the variable `mposition`. The upper 24 bits of `mposition` holds the position of the motor in encoder counts. The lower 8 bits of `mposition` represent fractional encoder counts. The value of `mvelocity` is added to `mposition` to find the new position of the motor. With 24 bits, the absolute position of the motor may be tracked through 33,554 shaft revolutions using a 500 CPR encoder. If you need to cover greater distances with the motor, the size of `mposition` can be increased as needed.

Trajectory Updates

Now that we know where the motor is, we need to determine where the motor is supposed to be. The commanded motor position is stored in the variable `position`. The size of `position` is 32 bits with the lower 8 bits representing fractional encoder counts. When the value of `position` is constant, the motor shaft will be held in a fixed position. We can also have the servomotor operate at a given velocity by adding a constant value to `position` at each servo update. The fractional bits in `position` allow the motor to be operated at very low velocities. In order for the servomotor to produce smooth motion, we need a motion profile algorithm that controls the speed and acceleration of the motor. In the context of this application, we must control the rate at which `position` is changed. The `UpdTraj()` function does this job and its purpose is to determine the next required value for `position`, based on the current motion profile parameters. For this application, a movement distance, velocity limit, and acceleration value are required to execute the profile. From this data, the servomotor will produce trapezoidal shaped velocity curves.

Figure 3 shows a flowchart of the `UpdTraj()` function. If the motion profile is running and the PWM output is not saturated, indicated by the `stat.run` and `stat.saturated` flags, the motion profile algorithm will find the next value for `position`. Figure 4 shows a flowchart of the motion profile operation.

FIGURE 3: `UpdTraj()` **FLOWCHART**

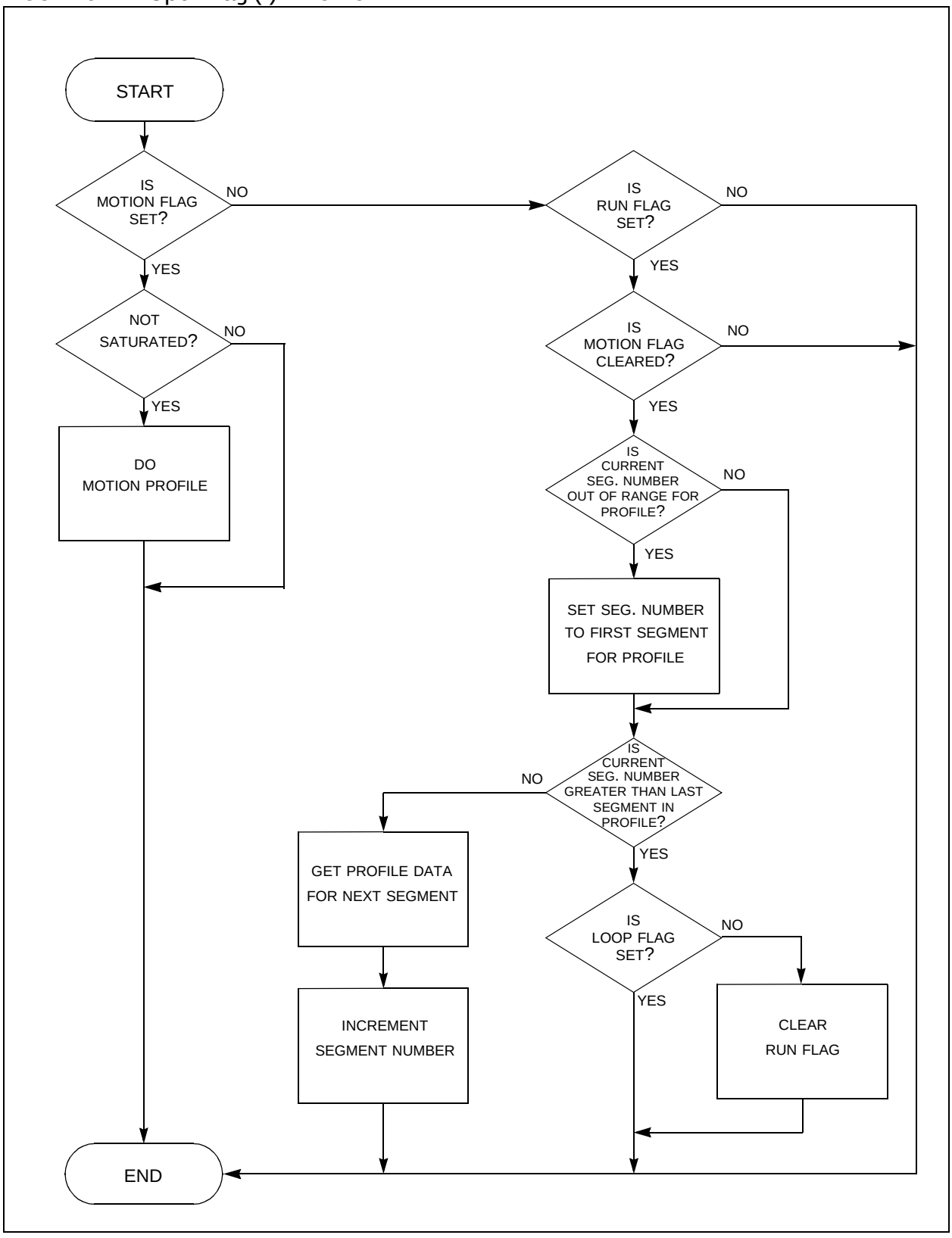
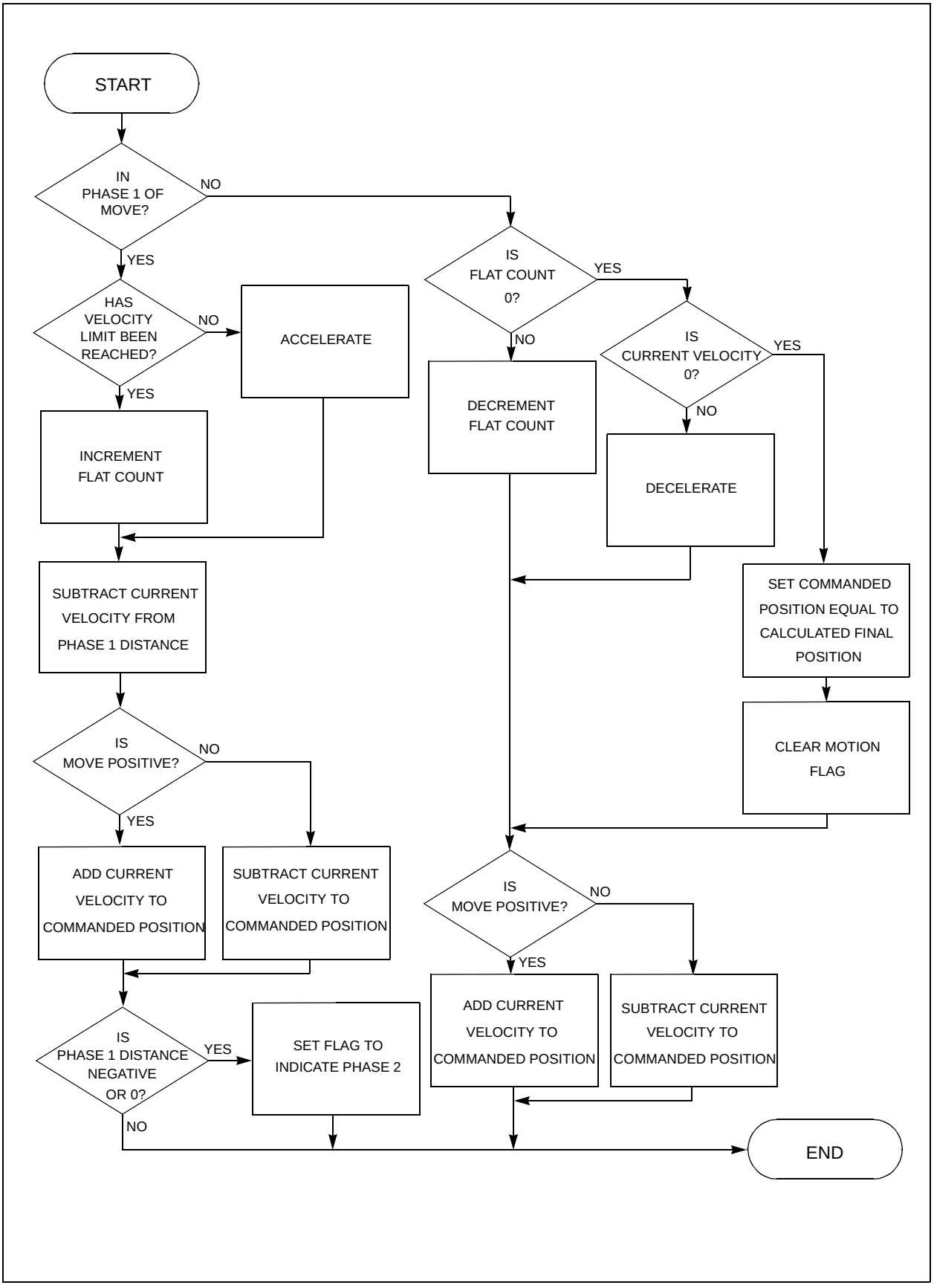


FIGURE 4: MOTION PROFILE FLOWCHART



The motion profile is executed in two phases. The first half of the movement distance is traveled in the first phase and the remaining distance in the second phase. The stat.phase flag indicates the current phase of the motion segment. Half of the total distance to be traveled is stored in the variable phase1dist. The final destination position for the motor is stored in fposition.

The velocity limit for the motion profile is stored in the variable vlim. The present commanded velocity of the motor is stored in velact. The acceleration value for the profile is stored in accel. A delay time for the motion profile is stored in the variable dtime. This variable tells the motion profile how many servo update periods to wait before executing the next motion segment. Finally, the direction of motion is set by the stat.neg_move flag.

Once the variables used for the motion profile have been loaded, the stat.motion flag is set and motion begins on the next servo update. This flag is cleared when the motion profile has completed.

The motor can be run at any desired speed by adding a constant value to position at each servo update, forcing the servomotor to track the new commanded position. The value added to position at each servo update is stored in the variable velact. Furthermore, the motor will accelerate (or decelerate) at a constant rate, if we add or subtract a value to velact at each servo update. The acceleration value for the profile is stored in the variable accel. The value of accel is added to velact at each servo update. The value of velact is then added or subtracted from the commanded motor position, position, depending on the state of the stat.neg_move flag. The value of velact is also subtracted from phase1dist to keep track of the distance traveled in the first half of the move. The motor stops accelerating when velact is greater than vlim. After the velocity limit has been reached, flatcount is incremented at each servo update period to maintain the number of servo updates for which no acceleration occurred.

The first half of the move is completed when phase1dist becomes zero or negative. At this time, the stat.phase flag is set to '1'. The variable flatcount is then decremented at each servo period. When flatcount = 0, the motor begins to decelerate. The move is complete when velact = 0. The motion profile then waits the number of sample periods stored in dtime. When dtime is 0, the previously calculated destination in fposition is written to the commanded motor position and the stat.motion flag is cleared to indicate the motion profile has completed.

When the motion profile is completed, the UpdTraj() function checks the present motion segment value in segnum to see if another motion segment should be executed. The first and last motion segments to be executed are stored in firstseg and lastseg, respectively. If segnum is not equal to lastseg, then segnum is incremented and the SetupMove() function is called to load the new segment parameters into the motion profile variables.

Error Calculation

The CalcError() function subtracts the measured motor position, mposition, from the commanded motor position in the variable position, to find the amount of position error. The position error result is shifted to the right and the lower 8 bits that hold fractional data are discarded. This leaves the 24-bit position error result in u0, which is then truncated to a 16-bit signed value for subsequent calculations.

Duty Cycle Calculations

The CalcPID() function implements a proportional-integral-derivative (PID) compensator algorithm and uses the 16-bit error result in u0 to determine the next required PWM duty cycle value. The PID gain constants, kp, ki, and kd, are stored as 16-bit values.

The proportional term of the PID algorithm provides a system response that is a function of the immediate position error, u0. The integral term of the PID algorithm accumulates successive position errors, calculated during each servo loop iteration and improves the low frequency open-loop gain of the servo system. The effect of the integral term is to reduce small steady-state position errors.

The differential term of the PID algorithm is a function of the measured motor velocity, mvelocity, and improves the high frequency closed-loop response of the servo system.

After the three terms of the PID algorithm are summed, the 32-bit result stored in ypid is saturated to 24 bits. The upper 16 bits of ypid are used to set the duty cycle, which effectively divides the output of the PID algorithm by 256. Since the PWM module has a 10-bit resolution, the value in the upper 16 bits of ypid is checked to see if it exceeds +511 or -512. When this condition occurs, the PWM duty cycle is set to the maximum positive or negative limit and the stat.saturated flag is set.

The commanded position will not be updated by UpdTraj() when the PWM output becomes saturated. In addition, the integral accumulation in the PID algorithm is bypassed. This allows the servomotor to smoothly resume motion when the saturation condition ends. If the integral error and the motion profile continued to update, the servomotor would produce sudden and erratic motions when recovering from a mechanical overload.

Command Interpreter

The servomotor software has a command interpreter that allows you to enter motion profile segment data, run motion profiles, and change the PID gain constants. After all peripherals and data memory have been initialized, the main program loop polls the USART interrupt flag to detect incoming ASCII data. Each incoming byte of data is stored in `inpbuf[]` as it is received. A comma or a <CR> is used to delimit each command sequence and the `DoCommand()` function is called each time either of these characters are received to determine the correct response. The `DoCommand()` function can tell which portion of the command is in `inpbuf[]` by `comcount`, which holds the number of commas received since the last <CR>. A flowchart of the command interpreter operation is given in Figure 5 and Figure 6.

FIGURE 5: COMMAND INTERPRETER FLOWCHART

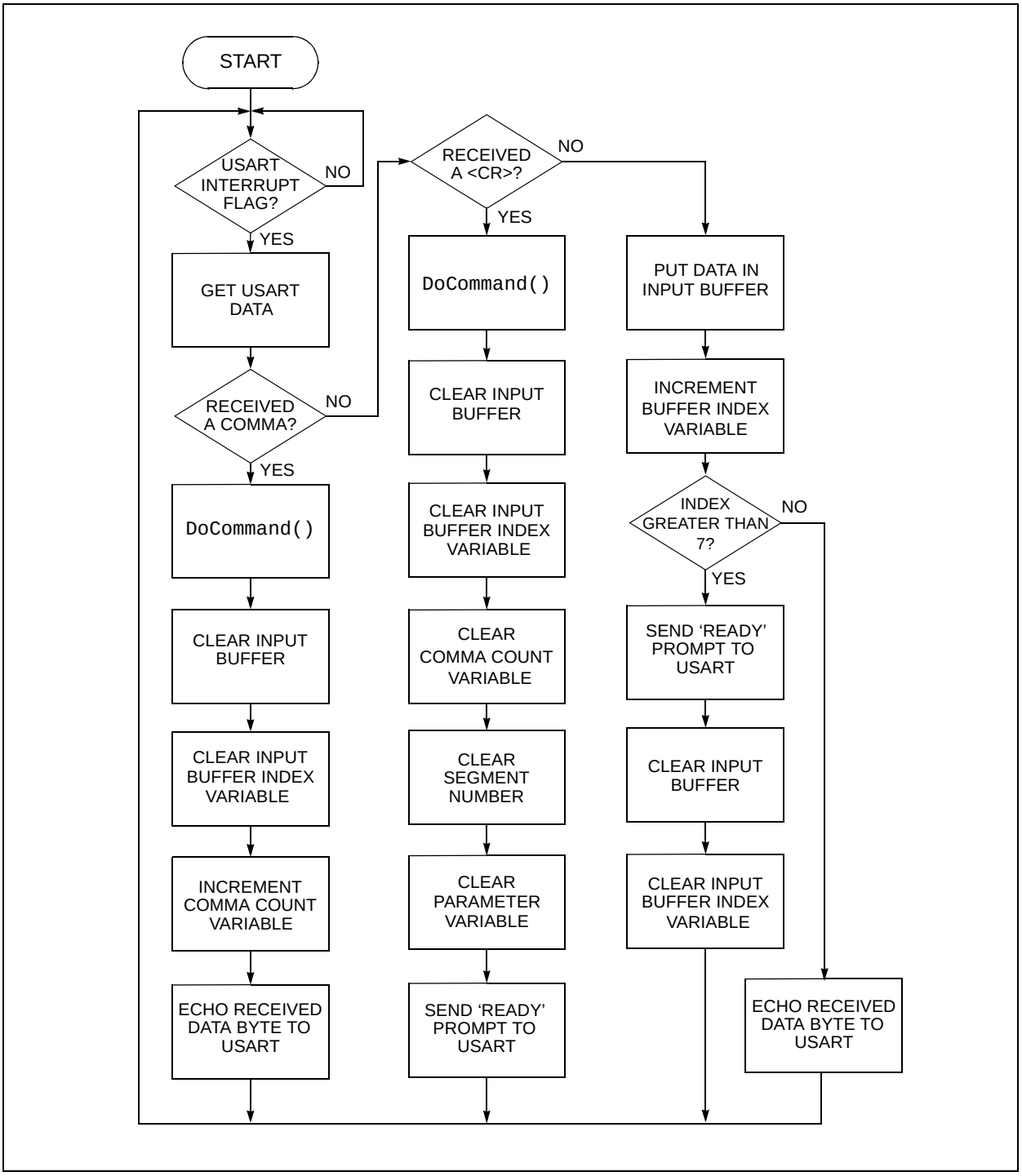
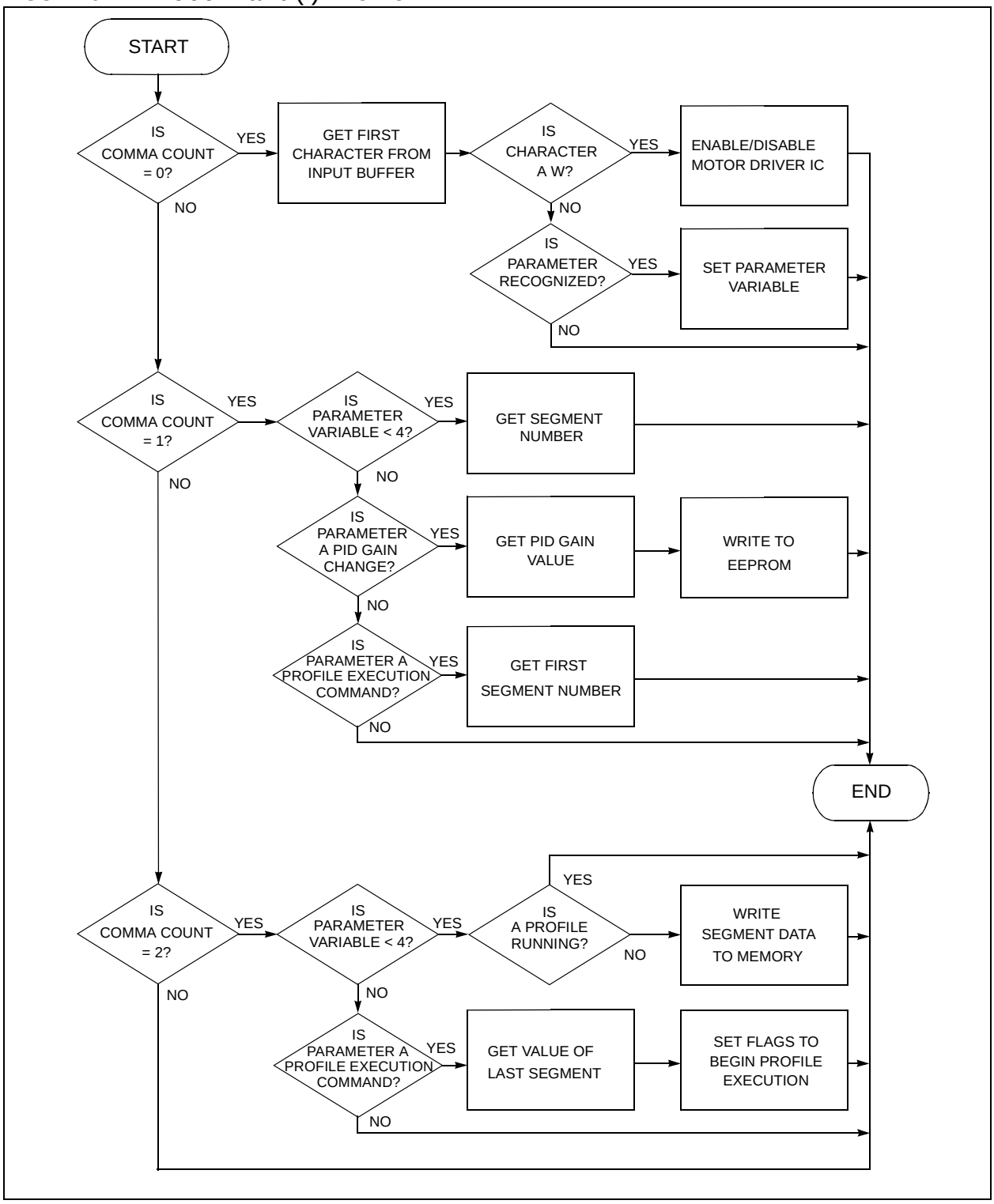


FIGURE 6: `DoCommand()` **FLOWCHART**



Motion profile segment data is stored as a 2 dimensional array of integer values in data memory. The data for each motion profile segment consists of a movement distance, acceleration value, velocity limit, and delay time. The software, as written, permits data for up to 24 motion profile segments to be entered and stored. However, the number of segments may be increased or decreased depending on the available memory resources in your application.

The ASCII string required to change motion profile segment parameter, consists of the parameter, the segment number, and the data. For example, let's assume

that you wish to change the acceleration value for segment 2 to 1000. To do this, you would send the following ASCII string to the servomotor:

```
A,2,1000 <CR>
```

This syntax can be used to change all motion profile segment parameters.

After all motion profile data has been entered, a single motion profile segment, or range of segments, may be executed using the 'G' or 'L' command. To execute segments 1 through 4, for example, you would send the following ASCII string to the servomotor:

```
G,1,4 <CR>
```

If you only want to run one motion segment, the desired segment number is entered twice as shown:

```
G,1,1 <CR>
```

The 'L' command is used the same way as the 'G' command, except that the range of motion segments is executed repeatedly. This command is useful for creating repetitive motions with the servomotor. The 'S' command stops the motion profile after the presently executing motion segment has completed.

Three commands are available to change the PID gain constants. With these commands, you can manually tune the PID algorithm to obtain the best performance from the motor in your application.

The 'W' command turns the motor driver IC on or off.

Note:	You may find the 'W' command to be extremely useful if the PID gain constants you've chosen cause the servomotor to become unstable.

A summary of all servomotor commands and their syntax is given in Table 1.

Two status flags, `stat.run` and `stat.loop`, are used to control execution of the motion profile. If a 'G' command is entered to run a series of motion segments, the `stat.run` flag is set. If a 'L' command is entered, the `stat.run` and the `stat.loop` flags are set. When the `SetupMove()` function determines that the last segment in the motion profile has executed, the `stat.loop` flag is checked. If `stat.loop` is set, the motion profile segment data for the first segment in the sequence is loaded and execution continues. If `stat.loop` is clear, then the `stat.run` flag is cleared and motion stops.

Operation With ASCII Terminal

You can use a PC terminal program, such as PROCOMM® or HyperTerminal®, to control the servomotor. The terminal program should be configured for 19.2 kBaud, no parity, 8 data bits, and 1 stop bit. When the servomotor is reset, you will see an introduction message and a 'READY>' prompt. You should now be able to enter any of the commands shown in Table 1.

TABLE 1: SERVOMOTOR COMMAND SUMMARY

Command: `X,seg#,data <CR>`
Sets the distance to be travelled for the specified motion profile segment. Data is provided in encoder counts relative to the present position. $0 \le seg\# \le 23$ $-32768 \le data \le 32767$
Command: `A,seg#,data <CR>`
Sets the acceleration for the specified motion profile segment. Data is provided in encoder counts/T_{SERVO}^2/65536. $0 \le seg\# \le 23$ $1 \le data \le 32767$
Command: `V,seg#,data <CR>`
Sets the velocity limit for the specified motion profile segment. Data is provided in encoder counts/T_{SERVO}/256. $0 \le seg\# \le 23$ $1 \le data \le 32767$
Command: `T,seg#,data <CR>`
Specifies the amount of time to wait before executing the next motion profile segment. Data is provided in T_{SERVO} multiples. $0 \le seg\# \le 23$ $0 \le data \le 32767$
Command: `G,startseg,stopseg <CR>`
Executes a range of motion profile segments. $0 \le startseg \le 23$ $0 \le stopseg \le 23$
Command: `S <CR>`
Stops execution of a motion profile.
Command: `P,data <CR>`
Changes the proportional gain for the PID algorithm. $-32768 \le data \le 32767$
Command: `I,data <CR>`
Changes the integral gain for the PID algorithm. $-32768 \le data \le 32767$
Command: `D,data <CR>`
Changes the differential gain for the PID algorithm. $-32768 \le data \le 32767$
Command: `W <CR>`
Enables or disables the PWM driver stage.

Stand-alone Operation

The provided application firmware allows the servomotor to perform a few basic motions without a PC connected. Specifically, data for three different motion profiles are stored in the MCU program memory and are loaded into data memory at start-up. Each profile is selected by turning on DIP switch #2, #3, or #4, connected to PORTB and pressing the $\overline{\text{MCLR}}$ button.

The software polls the DIP switches once, at start-up, to see if a profile should be executed. The selected profile will begin to execute immediately. If DIP switch #1 is turned on in combination with one of the other switches, the selected profile will execute repeatedly.

PICmicro MCU RESOURCES

There is a broad range of PICmicro devices that can be used to implement the servomotor application, depending on the level of performance that you need. To begin with, let's consider the processing time needed by the servo calculations.

A large amount of time is spent in the servo calculations executing the compensator, which requires one or more multiplications depending on the type of algorithm used. Three 16 x 16 signed multiplications are required by the PID compensator algorithm used here. Since the servo update calculations must be performed frequently, a hardware multiplier can provide a significant reduction in the MCU bandwidth. With a 8 x 8 hardware multiplier, each 16 x 16 multiplication can be performed in approximately 32 instruction cycles. Without the hardware multiplier, each multiplication can take 500 instruction cycles or more, depending on the algorithm that is used.

The servo calculation times were compared for the PIC16CXXX and PIC18CXXX architectures, using the same source code. Table 2 shows the performance results. You can easily see the increase in available bandwidth gained by the hardware multiplier. For a given servo update period, the hardware multiplier in the PIC18CXXX architecture frees a large amount of MCU bandwidth for performing other tasks. In addition, extra MCU bandwidth may be obtained from the PIC18CXXX architecture, since the devices may be operated up to 40 MHz.

Table 3 and Table 4 show a comparison of memory usage by the servomotor application, for both the 16F877 and the 18C452. Depending on the memory requirements for motion profile segment data and other application functions, the design may be adapted for other MCUs. As an example of a minimal implementation, this application could be modified to operate on a PIC16C73B. The PIC16C73B has 22 I/O pins, 4K x 14 words of program memory, and 192 bytes of data memory.

The resolution of the available timer resources must be considered when using the position sensing method described here. The maximum RPM of the servomotor is a function of the timer resolution, servo update frequency, and the resolution of the incremental encoder. Because two's complement arithmetic is used to find the motor position, the timers used to accumulate the encoder pulses should not increment more than 2^{N-1} counts during each servo update interval, or position information will be lost.

When a PIC16CXXX device is used for the servomotor application, Timer0 and Timer1 are the only timers with an external clock input and Timer0 has only 8 bits of resolution. For some cases, this may limit the maximum motor RPM. A formula that can be used to calculate the maximum RPM is given in Equation 1 below:

EQUATION 1: MAXIMUM RPM

$$RPM_{MAX} = \frac{2^{N-1} \bullet f_s \bullet 60}{CPR}$$

In this equation, N represents the resolution of the timer in bits, f_S, is the servo update frequency, and CPR is the resolution of the encoder. The incremental encoder used in this application provides 500 CPR. For the moment, let's assume that our servo update frequency is 1000 Hz. Using 1x decoding, the maximum RPM that we can permit without a timer overflow, is over 15,000 RPM. This maximum limit is of no concern for us, since the motor we are using provides a no-load speed of 6000 RPM. Now, let's assume that a 4x decoding method was used, so that our encoder now provides 2000 CPR. Now, the maximum motor speed is 3840 RPM, which is definitely a problem! In this case, the servo update frequency would have to be increased, if possible, or the encoder resolution decreased.

TABLE 2: SERVO CALCULATION BANDWIDTH COMPARISON

Device	Operating Frequency	Hardware Multiplier	Servo Update Period	Maximum Servo Calculation Time	MCU Bandwidth Used
PIC16CXXX	20 MHz	No	563 µsec	540 µsec	96%
PIC18CXXX	20 MHz	Yes	563 µsec	97 µsec	17%

TABLE 3: PROGRAM MEMORY RESOURCES FOR SERVOMOTOR APPLICATION

Device	Available Program Memory	Program Memory Used by Application	Percentage Used
PIC16F877	8192 x 14	3002 x 14	37%
PIC18C452	32768 x 8	8265 x 8	25%

TABLE 4: DATA MEMORY RESOURCES FOR SERVOMOTOR APPLICATION

Device	Total Data Memory Available	Data Memory Used by Application	Data Memory Used by Compiler(1)	Available Data Memory
PIC16F877	368 bytes	78 bytes	44 bytes	246 bytes
PIC18C452	1536 bytes	78 bytes	386 bytes	1072 bytes

Note 1: The amount of data memory will depend on the compiler used. This memory is used for a software stack, temporary variable storage, etc.

SERVOMOTOR SOURCE CODE

Two source code listings are provided with this application note. The source code given in Appendix A was written for the MPLAB®-C18 compiler and will operate on a PIC18C452 or PIC18C442. If the LEDs are omitted from the design, the code may also be compiled to operate on the PIC18C242 or the PIC18C252, which are 28-pin devices with fewer I/O pins. The PIC18C452 application utilizes the MSSP peripheral to read and write data to a 24C01 serial EEPROM.

The source code given in Appendix B was written for the HiTech PICC compiler and will operate on the PIC16F877. In particular, the 16F877 source code was written to utilize the on-chip data EEPROM to store profile data and PID gain values. These routines may be omitted, if you wish to compile the source code for other devices in the PIC16CXXX family. Like the PIC18C452 source code, the LEDs may be removed for operation on a lower pin-count device.

GOING FURTHER…

A sufficient amount of MCU bandwidth is available when the servomotor application is implemented using the PIC18C452. This additional bandwidth could be used for a variety of purposes, depending on the requirements of the application. One use of the available MCU bandwidth takes advantage of the PIC18CXXX family architecture, reduces external hardware, and permits two servomotors to be controlled by the same device.

Although the hardware-based solution for decoding the quadrature encoder signals requires minimal software overhead, it does require that two timers be used for each encoder. There are not enough timer resources available on the PIC18C452 device to permit two encoders to be decoded. However, it is possible to decode the encoder outputs directly in software. Furthermore, the two priority level interrupt structure of the PIC18CXXX architecture, provides an elegant way to handle the software decoding algorithm. Using priority interrupts, the servo calculations are performed in the low priority ISR and the decoding algorithm is performed in the high priority ISR. The high priority ISR is able to override a low priority interrupt that is in progress. This is important in this case, because the encoder pulses can have short durations and must be processed quickly.

Figure 7 shows a flowchart of a software algorithm that performs a 1x decode of the quadrature encoder pulses. In addition, a possible connection diagram for a two-servomotor solution is shown in Figure 8. One of the encoder output signals is connected to an external interrupt pin on the MCU and the other is connected to an unused I/O pin. The external interrupt source is configured to provide an interrupt on each rising edge of the incoming signal. Each time an interrupt occurs, the state of the other encoder output is checked. An encoder count value is maintained in software and is incremented or decremented depending on the state of the encoder signal. The resulting count value is proportional to the motor velocity and direction, and is added to the measured position of the motor each time `UpdPos()` is executed.

The software decoding algorithm could be extended to provide a 2x or 4x decoding, if desired. For 2x decoding, the interrupt edge bit should be toggled each time an interrupt occurs, so interrupts occur on both the rising and falling edges of the encoder signal. For 4x decoding, the second encoder signal is connected to a second external interrupt pin. In this case, interrupts are generated on every transition of the encoder signals. You must be careful though, since the amount of MCU bandwidth needed for higher decode resolutions can become very high. For example, a 6000 RPM motor and 500 CPR encoder will produce interrupts every 5 µsec, when a 4x decoding algorithm is implemented at full speed. Considering that the maximum device frequency is 40 MHz, the MCU will be able to perform 50 instruction cycles between each encoder interrupt. In this case, the number of instruction cycles required to implement the software decoding algorithm will become very critical.

CONCLUSION

We have seen that the PIC18CXXX and PIC16CXXX architecture families can be used to implement an effective DC servomotor application. The source code and hardware solutions presented here can be applied to a range of devices in both families, depending on the hardware resources and MCU bandwidth that your application requires.

FIGURE 7: QUADRATURE DECODE FLOWCHART

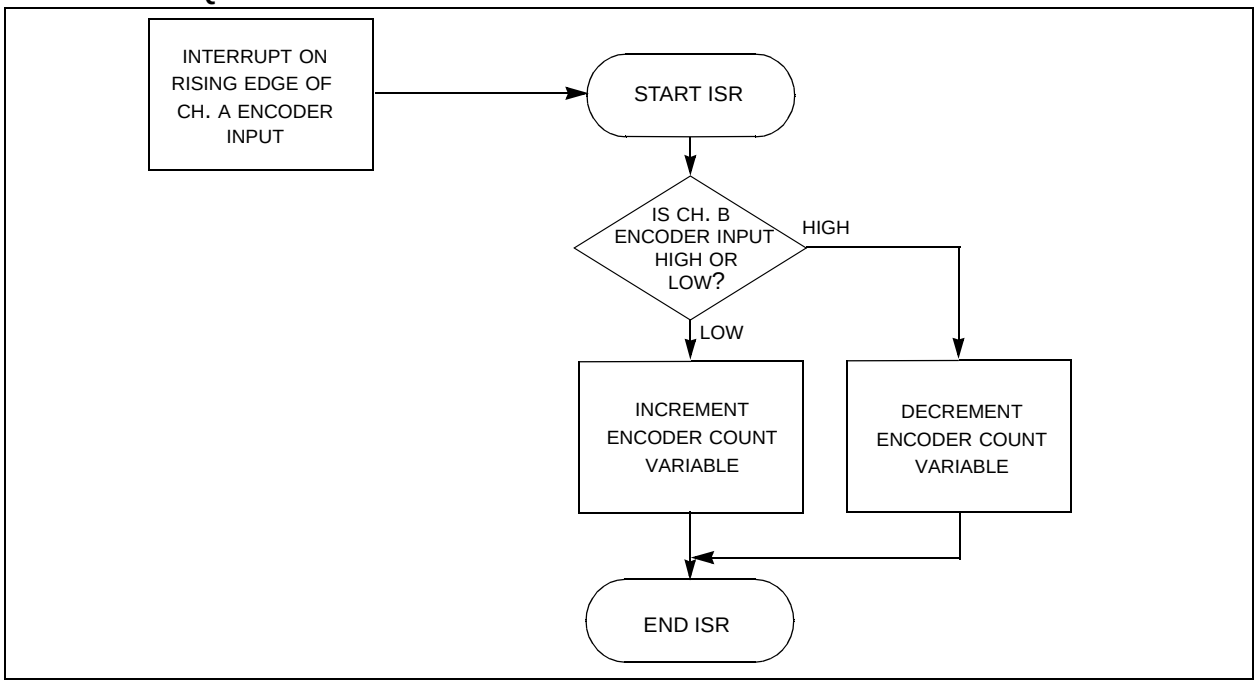
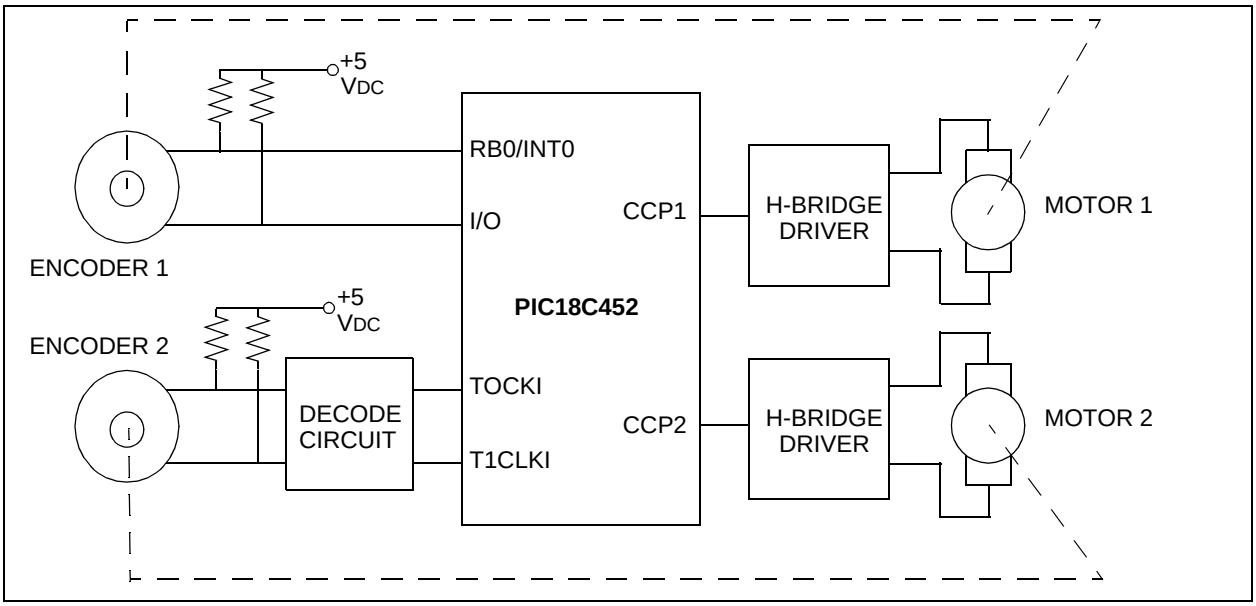


FIGURE 8: TWO SERVOMOTOR SOLUTION



APPENDIX A: PIC18C452 SERVOMOTOR SOURCE CODE

```
//-----------------------------------------------------------------------
// File:18motor.c
//
// Written By:Stephen Bowling, Microchip Technology
//
// This code implements a brush-DC servomotor using the PIC18C452 MCU.
// The code was compiled using the MPLAB-C18 compliler ver. 1.00.
// The device frequency should be 20 MHz.
//
// The following files should be included in the MPLAB project:
//
//      18motor.c       -- Main source code file
//      p18c452.lkr     -- Linker script file
//
// The following project files are included by the linker script:
//
//      c018i.o         -- C startup code
//      clib.lib        -- Math and function libraries
//      p18c452.lib     -- Processor library
//
//-----------------------------------------------------------------------

#include <p18c452.h>            // Register definitions
#include <stdlib.h>
#include <string.h>
#include <i2c.h>                // I2C library functions
#include <pwm.h>                // PWM library functions
#include <adc.h>                // ADC library functions
#include <portb.h>              // PORTB library function
#include <timers.h>             // Timer library functions

//-----------------------------------------------------------------------
// Constant Definitions
//-----------------------------------------------------------------------

#define DIST    0               // Array index for segment distance
#define VEL     1               // Array index for segment vel. limit
#define ACCEL   2               // Array index for segment accel.
#define TIME    3               // Array index for segment delay time
#define INDEX   PORTBbits.RB0   // Input for encoder index pulse
#define NLIM    PORTBbits.RB1   // Input for negative limit switch
#define PLIM    PORTBbits.RB2   // Input for positive limit switch
#define GPI     PORTBbits.RB3   // General purpose input
#define MODE1   !PORTBbits.RB4  // DIP switch #1
#define MODE2   !PORTBbits.RB5  // DIP switch #2
#define MODE3   !PORTBbits.RB6  // DIP switch #3
#define MODE4   !PORTBbits.RB7  // DIP switch #4
#define SPULSE  PORTCbits.RC5   // Software timing pulse output
#define ADRES   ADRESH          // Redefine for 10-bit A/D converter
```

```
//-----------------------------------------------------------------------
// Variable declarations
//-----------------------------------------------------------------------

const rom char ready[] = "\n\rREADY>";
const rom char error[] = "\n\rERROR!";

char inpbuf[8];                     // Input command buffer

unsigned char
eeadr,                              // Pointer to EEPROM address
firstseg,                           // First segment of motion profile
lastseg,                            // Last segment of motion profile
segnum,                             // Current executing segment
parameter,                          // Index to profile data
i,                                  // index to ASCII buffer
comcount,                           // index to input string
udata                               // Received character from USART
;

struct {// Holds status bits for servo
    unsigned        phase:1;        // Current phase of motion profile
    unsigned     neg_move:1;        // Backwards relative move
    unsigned       motion:1;        // Segment execution in progress
    unsigned    saturated:1;        // PWM output is saturated
    unsigned         bit4:1;
    unsigned         bit5:1;
    unsigned          run:1;        // Enables execution of profile
    unsigned         loop:1;        // Executes profile repeatedly
} stat ;

int
dtime,                              // Motion segment delay time
integral,                           // Integral value for PID alg.
kp,ki,kd,                           // PID gain constants
vlim,                               // Velocity limit for segment
mvelocity,                          // Measured motor velocity
DnCount,                            // Holds accumulated 'up' pulses
UpCount                             // Holds accumulated 'down' pulses
;

union LNG
{
long l;
unsigned long ul;
int i[2];
unsigned int ui[2];
char b[4];
unsigned char ub[4];
};

union LNG
temp,                               // Temporary storage
accel,                              // Segment acceleration value
u0,                                 // PID error value
ypid,                               // Holds output of PID calculation
velact,                             // Current commanded velocity
phase1dist                          // Half of segment distance
;

long
position,                           // Commanded position.
mposition,                          // Actual measured position.
fposition,                          // Originally commanded position.
flatcount;                          // Holds the number of sample periods for which the
                                    // velocity limit was reached in the first half of the move.
```

```
#pragma udata segdata1 = 0x0100

int segment1[12][4];                // Holds motion segment values in data memory.
int segment2[12][4];                //                          "


#pragma udata

//----------------------------------------------------------------------
// Function Prototypes
//----------------------------------------------------------------------

void servo_isr(void);               // Does servo calculations
void isrhandler(void);              // Located at high interrupt vector

void DoCommand(void);               // Processes command input strings
void Setup(void);                   // Configures peripherals and variables
void UpdPos(void);                  // Gets new measured position for motor
void CalcError(void);               // Calculates position error
void CalcPID(void);                 // Calculates new PWM duty cycle
void UpdTraj(void);                 // Calculates new commanded position
void SetupMove(void);               // Gets new parameters for motion profile

// Writes a string from ROM to the USART
void putrsUSART(const rom char *data);

// ExtEEWrite and ExtEERead are used to read or write an integer value to the
// 24C01 EEPROM

void ExtEEWrite(unsigned char address, int data);
int ExtEERead(unsigned char address);


//----------------------------------------------------------------------
// Interrupt Code
//----------------------------------------------------------------------

// Designate servo_isr as an interrupt function and save key registers

#pragma interrupt servo_isr save = PRODL,PRODH,FSR0L,FSR0H

// Locate ISR handler code at interrupt vector

#pragma code isrcode=0x0008

void isrhandler(void)               // This function directs execution to the
{                                   // actual interrupt code
_asm
goto servo_isr
_endasm
}


#pragma code

//----------------------------------------------------------------------
// servo_isr()
// Performs the servo calculations
//----------------------------------------------------------------------

void servo_isr(void)
{
SPULSE = 1;                         // Toggle output pin for ISR code timing
```



```
UpdTraj();                          // Get new commanded position
UpdPos();                           // Get new measured position
CalcError();                        // Calculate new position error
CalcPID();

PIR1bits.TMR2IF = 0;                // Clear Timer2 Interrupt Flag.

SPULSE = 0;                         // Toggle output pin for ISR code timing
}

//-----------------------------------------------------------------------
// UpdTraj()
// Computes the next required value for the next commanded motor
// position based on the current motion profile variables. Trapezoidal
// motion profiles are produced.
//-----------------------------------------------------------------------

void UpdTraj(void)
{

if(stat.motion && !stat.saturated)
    {
    if(!stat.phase)                 // If in the first half of the move.
        {
        if(velact.ui[1] < vlim)     // If still below the velocity limit
            velact.ul += accel.ul;  // Accelerate


        else                        // If velocity limit has been reached,
            flatcount++;            // increment flatcount.

        temp.ul = velact.ul;        // Put velocity value into temp
                                    // and round to 16 bits
        if(velact.ui[0] == 0x8000)
            {
            if(!(velact.ub[2] & 0x01))
                temp.ui[1]++;
            else;
            }
        else

        if(velact.ui[0] > 0x8000) temp.ui[1]++;
        else;

        phase1dist.ul -= (unsigned long)temp.ui[1];

        if(stat.neg_move)
            position -= (unsigned long)temp.ui[1];
        else
            position += (unsigned long)temp.ui[1];

        if(phase1dist.l <= 0)       // If phase1dist is negative
                                    // first half of the move has
            stat.phase = 1;         // completed.
        }

    else                            // If in the second half of the move,
        {                           // Decrement flatcount if not 0.
        if(flatcount) flatcount--;

        else
        if(velact.ul)               // If commanded velocity not 0,
            {
            velact.ul -= accel.ul;  // Decelerate

            if(velact.i[1] < 0)
```

```
                velact.l = 0;
            }

        else                            // else
            {
            if(dtime) dtime--;          // Decrement delay time if not 0.
            else
                {
                stat.motion = 0;        // Move is done, clear motion flag
                position = fposition;
                }
            }

        temp.ul = velact.ul;            // Put velocity value into temp
                                        // and round to 16 bits
        if(velact.ui[0] == 0x8000)
            {
            if(!(velact.ub[2] & 0x01))
                temp.ui[1]++;
        else;
        }

        else

        if(velact.ui[0] > 0x8000) temp.ui[1]++;
        else;

        if(stat.neg_move)               // Update commanded position
            position -= (unsigned long)temp.ui[1];
        else
            position += (unsigned long)temp.ui[1];
        }
    }                                   // END if (stat.motion)

else
    {
    if(stat.run && !stat.motion)        // If motion stopped and profile
        {                               // running, get next segment number
        if(segnum < firstseg) segnum = firstseg;
        if(segnum > lastseg)
            {
            segnum = firstseg;          // Clear run flag if loop flag not set.
            if(!stat.loop) stat.run = 0;
            }
        else
            {
            SetupMove();                // Get data for next motion segment.
            segnum++;                   // Increment segment number.
            }
        }
    else;
    }
}

//---------------------------------------------------------------------
// SetupMove()
// Gets data for next motion segment to be executed
//---------------------------------------------------------------------

void SetupMove(void)
{
if(segnum < 12)                         // Get profile segment data from
    {                                   // data memory.
    phase1dist.i[0] = segment1[segnum][DIST];
    vlim = segment1[segnum][VEL];
    accel.i[0] = segment1[segnum][ACCEL];
```



```
    dtime = segment1[segnum][TIME];
    }
else if(segnum < 24)
    {
    phase1dist.i[0] = segment2[segnum - 12][DIST];
    vlim = segment2[segnum - 12][VEL];
    accel.i[0] = segment2[segnum - 12][ACCEL];
    dtime = segment2[segnum - 12][TIME];
    }


phase1dist.b[2] = phase1dist.b[1];    // Rotate phase1dist one byte
phase1dist.b[1] = phase1dist.b[0];    // to the left.
phase1dist.b[0] = 0;
if(phase1dist.b[2] & 0x80)            // Sign-extend value
   phase1dist.b[3] = 0xff;
else
   phase1dist.b[3] = 0;

accel.b[3] = 0;                       // Rotate accel one byte to
accel.b[2] = accel.b[1];              // the left
accel.b[1] = accel.b[0];
accel.b[0] = 0;

temp.l = position;

if(temp.ub[0] > 0x7f)                 // A fractional value is left
    temp.l += 0x100;                  // over in the 8 LSbits of
temp.ub[0] = 0;                       // position, so round position
                                      // variable to an integer value
position = temp.l;                    // before computing final move
                                      // position.
fposition = position + phase1dist.l;  // Compute final position for
                                      // the move
if(phase1dist.b[3] & 0x80)            // If the move is negative,
   {
   stat.neg_move = 1;                 // Set flag to indicate negative
   phase1dist.l = -phase1dist.l;      // move.
   }
else stat.neg_move = 0;               // Clear flag for positive move

phase1dist.l >>= 1;                   // phase1dist holds total
                                      // move distance, so divide by 2
velact.l = 0;                         // Clear commanded velocity
flatcount = 0;                        // Clear flatcount
stat.phase = 0;                       // Clear flag:first half of move
if(accel.l && vlim)
stat.motion = 1;                      // Enable motion
}

//-----------------------------------------------------------------------
// UpdPos()
// Gets the new measured position of the motor based on values
// accumulated in Timer0 and Timer1
//-----------------------------------------------------------------------


void UpdPos(void)
{
// Old timer values are presently stored in UpCount and DnCount, so
// add them into result now.

mvelocity = DnCount;
mvelocity -= UpCount;

//  Write new timer values into UpCount and DnCount variables.
```

```
UpCount = ReadTimer0();
DnCount = ReadTimer1();

// Add new count values into result.

mvelocity += UpCount;
mvelocity -= DnCount;

// Add measured velocity to measured position to get new motor
// measured position.

mposition += (long)mvelocity << 8;
}

//-----------------------------------------------------------------------
// CalcError()
// Calculates position error and limits to 16 bit result
//-----------------------------------------------------------------------

void CalcError(void)
{
temp.l = position;                    // Put commanded pos. in temp
temp.b[0] = 0;                        // Mask out fractional bits
u0.l = mposition - temp.l;            // Get error
u0.b[0] = u0.b[1];                    // from desired position and
u0.b[1] = u0.b[2];                    // shift to the right to discard
u0.b[2] = u0.b[3];                    // lower 8 bits.

if (u0.b[2] & 0x80)                   // If error is negative.
    {
    u0.b[3] = 0xff;                   // Sign-extend to 32 bits.

    if((u0.ui[1] != 0xffff) || !(u0.ub[1] & 0x80))
        {
        u0.ui[1] = 0xffff;            // Limit error to 16-bits.
        u0.ui[0] = 0x8000;
        }
    else;
    }

else                                  // If error is positive.
    {
    u0.b[3] = 0x00;

    if((u0.ui[1] != 0x0000) || (u0.ub[1] & 0x80))
        {
        u0.ui[1] = 0x0000;            // Limit error to 16-bits.
        u0.ui[0] = 0x7fff;
        }
    else;
    }
}

//-----------------------------------------------------------------------
// CalcPID()
// Calculates PID compensator algorithm and determines new value for
// PWM duty cycle
//-----------------------------------------------------------------------

void CalcPID(void)
{
ypid.i[0] = u0.i[0]*kp;               // Calculate proportional term.
ypid.ub[2] = AARGB1;                  // Get upper two bytes of 16 x 16
ypid.ub[3]= AARGB0;                   // multiply routine.
```



```
if(!stat.saturated)                 // If output is not saturated,
    integral += u0.i[0];            // add present error to integral
                                    // value.
if(ki)                              // If integral value is not 0,
    {
    temp.i[0] = integral*ki;// calculate integral term.
    temp.ub[2] = AARGB1;            // Get upper two bytes of 16 x 16
    temp.ub[3]= AARGB0;             // multiply routine.
    ypid.l += temp.l;               // Add multiply result to ypid.
    }

if(kd)                              // If differential term is not 0,
{
    temp.i[0] = mvelocity*kd;// calculate differential term.
    temp.ub[2] = AARGB1;            // Get upper two bytes of 16 x 16
    temp.ub[3]= AARGB0;             // multiply routine.
    ypid.l += temp.l;               // Add multiply result to ypid.
    }

if(ypid.ub[3] & 0x80)               // If PID result is negative
    {
    if((ypid.ub[3] < 0xff) || !(ypid.ub[2] & 0x80))
        {
        ypid.ui[1] = 0xff80;        // Limit result to 24-bit value
        ypid.ui[0] = 0x0000;
        }
    else;
    }

else                                // If PID result is positive
    {
    if(ypid.ub[3] || (ypid.ub[2] > 0x7f))
        {
        ypid.ui[1] = 0x007f;        // Limit result to 24-bit value
        ypid.ui[0] = 0xffff;
        }
    else;
    }
ypid.b[0] = ypid.b[1];              // Shift PID result right to
ypid.b[1] = ypid.b[2];              // get upper 16 bits.

stat.saturated = 0;                 // Clear saturation flag and see
if(ypid.i[0] > 500)                 // if present duty cycle output
    {                               // exceeds limits.
    ypid.i[0] = 500;
    stat.saturated = 1;
    }

if(ypid.i[0] < -500)
    {
    ypid.i[0] = -500;
    stat.saturated = 1;
    }

ypid.i[0] += 512;                   // Add offset to get positive
                                    // duty cycle value.

SetDCPWM1(ypid.i[0]);               // Write the new duty cycle.
}


//-----------------------------------------------------------------------
//  Setup() initializes program variables and peripheral registers
//-----------------------------------------------------------------------

void Setup(void)
```

```
{
firstseg = 0;                       // Initialize motion segment
lastseg = 0;                        // variables
segnum = 0;
parameter = 0;                      // Motion segment parameter#
i = 0;                              // Receive buffer index
comcount = 0;                       // Input command index
udata = 0;                          // Holds USART received data

stat.phase = 0;                     // Set flags to 0.
stat.saturated = 0;
stat.motion = 0;
stat.run = 0;
stat.loop = 0;
stat.neg_move = 0;
dtime = 0;
integral = 0;
vlim = 0;
mvelocity = 0;
DnCount = 0;
UpCount = 0;
temp.l = 0;
accel.l = 0;
u0.l = 0;
ypid.l = 0;
velact.l = 0;
phase1dist.l = 0;
position = 0;
mposition = 0;
fposition = 0;
flatcount = 0;
udata = 0;
memset(inpbuf,0,8);                 // clear the input buffer

// Setup A/D converter
OpenADC(ADC_FOSC_32 & ADC_LEFT_JUST & ADC_1ANA_0REF,
        ADC_CH0 & ADC_INT_OFF);

OpenPWM1(0xff);                     // Setup Timer2, CCP1 to provide
                                    // 19.53 Khz PWM @ 20MHz

OpenTimer2(T2_PS_1_1 & T2_POST_1_10 & TIMER_INT_ON);
SetDCPWM1(512);                     // 50% initial duty cycle

EnablePullups();                    // Enable PORTB pullups
PORTC = 0;                          // Clear PORTC
PORTD = 0;                          // Clear PORTD
PORTE = 0x00;                       // Clear PORTD
TRISC = 0xdb;                       //
TRISD = 0;                          // PORTD all outputs.
TRISE = 0;                          // PORTE all outputs.

// Setup the USART for 19200 baud @ 20MHz

SPBRG = 15;                         // 19200 baud @ 20MHz
TXSTA = 0x20;                       // setup USART transmit
RCSTA = 0x90;                       // setup USART receive

putrsUSART("\r\nPIC18C452 DC Servomotor");
putrsUSART(ready);

OpenI2C(MASTER,SLEW_OFF);           // Setup MSSP for master I2C
SSPADD = 49;                        // 100KHz @ 20MHz

kp = ExtEERead(122);                // Get PID gain constants
ki = 0;                             // from data EEPROM
```



```
kd = ExtEERead(126);

TMR0L = 0;                          // Clear timers.
TMR0H = 0;
TMR1L = 0;
TMR1H = 0;

OpenTimer0(TIMER_INT_OFF & T0_16BIT & TIMER_INT_OFF & T0_EDGE_RISE &
           T0_SOURCE_EXT & T0_PS_1_1);
OpenTimer1(TIMER_INT_OFF & T1_SOURCE_EXT & T1_16BIT_RW & TIMER_INT_OFF
           & T1_PS_1_1 & T1_SYNC_EXT_ON & T1_OSC1EN_OFF );

// Load motion profile data for segments 1 through 12 from
// data EEPROM

for(segnum=0;segnum < 12;segnum++)
    {
    for(parameter=0;parameter < 4;parameter++)
        {
        eeadr = (segnum << 3) + (parameter << 1);
        segment1[segnum][parameter] = ExtEERead(eeadr);
        }
    }

segment2[0][DIST] = 29500;          // Motion profile data for segments
segment2[0][VEL] = 4096;            // 13 through 24 are loaded into RAM
segment2[0][ACCEL] = 2048;          // from program memory
segment2[0][TIME] = 1200;

segment2[1][DIST] = -29500;
segment2[1][VEL] = 1024;
segment2[1][ACCEL] = 512;
segment2[1][TIME] = 1200;

segment2[2][DIST] = 737;
segment2[2][VEL] = 4096;
segment2[2][ACCEL] = 2048;
segment2[2][TIME] = 1200;

segment2[3][DIST] = 737;
segment2[3][VEL] = 4096;
segment2[3][ACCEL] = 2048;
segment2[3][TIME] = 1200;

segment2[4][DIST] = 738;
segment2[4][VEL] = 4096;
segment2[4][ACCEL] = 2048;
segment2[4][TIME] = 1200;

segment2[5][DIST] = 738;
segment2[5][VEL] = 4096;
segment2[5][ACCEL] = 2048;
segment2[5][TIME] = 1200;

segment2[6][DIST] = -2950;
segment2[6][VEL] = 1024;
segment2[6][ACCEL] = 128;
segment2[6][TIME] = 1200;

segment2[7][DIST] = 2950;
segment2[7][VEL] = 256;
segment2[7][ACCEL] = 64;
segment2[7][TIME] = 1200;

segment2[8][DIST] = -2950;
segment2[8][VEL] = 4096;
```

```
segment2[8][ACCEL] = 512;
segment2[8][TIME] = 1200;

segment2[9][DIST] = 29500;
segment2[9][VEL] = 1024;
segment2[9][ACCEL] = 512;
segment2[9][TIME] = 1200;

segment2[10][DIST] = 29500;
segment2[10][VEL] = 2048;
segment2[10][ACCEL] = 512;
segment2[10][TIME] = 1200;

segment2[11][DIST] = 29500;
segment2[11][VEL] = 4096;
segment2[11][ACCEL] = 1024;
segment2[11][TIME] = 1200;

if(MODE1)                           // Check DIP switches at powerup
   stat.loop = 1;                   // If SW1 is on, set for loop mode

if(MODE2)                           // If SW2 is on, execute
   {                                // segments 12 and 13
   firstseg = 12;
   lastseg = 13;
   segnum = 12;
    stat.run = 1;
   }
else if(MODE3)                      // If SW3 is on, execute
   {                                // segments 14 through 18
    firstseg = 14;
   lastseg = 18;
   segnum = 14;
    stat.run = 1;
   }
else if(MODE4)                      // If SW4 is on, execute
   {                                // segments 18 and 19
    firstseg = 18;
   lastseg = 19;
   segnum = 18;
   stat.run = 1;
    }
else;

INTCONbits.PEIE = 1;                // Enable peripheral interrupts
INTCONbits.GIE = 1;                 // Enable all interrupts
}

//---------------------------------------------------------------------
// main()
//---------------------------------------------------------------------

void main(void)
{
Setup();                            // Setup peripherals and software
                                    // variables.

while(1)                            // Loop forever
    {
   ClrWdt();                        // Clear the WDT

   ConvertADC();                    // Start an A/D conversion
   while(BusyADC());                // Wait for the conversion to complete
    PORTD = 0;                      // Clear the LED bargraph display.
    PORTE&= 0x04;                   //                    "
```



```
    if(ADRES > 225)
        {
        PORTE |= 0x03;               // Turn on 10 LEDS
        PORTD = 0xff;
        }
    if(ADRES > 200)
        {
        PORTE |= 0x01;               // Turn on 9 LEDS
        PORTD = 0xff;
        }
    else if(ADRES > 175) PORTD = 0xff;// Turn on 8 LEDS
    else if(ADRES > 150) PORTD = 0x7f;// 7 LEDS
    else if(ADRES > 125) PORTD = 0x3f;// 6 LEDS
    else if(ADRES > 100) PORTD = 0x1f;// 5 LEDS
    else if(ADRES > 75) PORTD = 0x0f; // 4 LEDS
    else if(ADRES > 50) PORTD = 0x07; // 3 LEDS
    else if(ADRES > 25) PORTD = 0x03; // 2 LEDS
    else if(ADRES > 0) PORTD = 0x01;  // 1 LED
    else;

    if(PIR1bits.RCIF)                           // Check for USART interrupt
        {
        switch(udata = RCREG)
            {
            case ',': DoCommand();              // process the string
                      memset(inpbuf,0,8);       // clear the input buffer
                      i = 0;                    // clear the buffer index
                      comcount++;               // increment comma count
                      TXREG = udata;            // echo the character
                      break;


            case 0x0d:DoCommand();              // process the string
                      memset(inpbuf,0,8);       // clear the input buffer
                      i = 0;                    // clear the buffer index
                      comcount = 0;             // clear comma count
                      segnum = 0;               // clear segment number
                      parameter = 0;            // clear paramater
                      putrsUSART(ready);        // put prompt to USART
                      break;

            default:  inpbuf[i] = udata;        // get received char
                      i++;                      // increment buffer index
                      if(i > 7)                 // If more than 8 chars
                           {                    // received before getting
                           putrsUSART(ready);   // a <CR>, clear input
                           memset(inpbuf,0,8);  // buffer
                           i = 0;               // the buffer index
                           }
                      else TXREG = udata;       // echo character
                      break;                    //

            }                                   //end switch(udata)

        }                                       //end if(RCIF)
    }                                           //end while(1)
}


//-------------------------------------------------------------------
// DoCommand()
// Processes incoming USART data.
//-------------------------------------------------------------------

void DoCommand(void)
{
```

```
if(comcount == 0)                   // If this is the first parameter of the input
    {                               // command...
    switch(inpbuf[0])
        {
        case 'X': parameter = DIST;    // Segment distance change
                  break;

        case 'V': parameter = VEL;     // Segment velocity change
                  break;

        case 'A': parameter = ACCEL;   // Segment acceleration change
                  break;

        case 'T': parameter = TIME;    // Segment delay time change
                  break;

        case 'P': parameter = 'P';     // Change proportional gain
                  break;

        case 'I': parameter = 'I';     // Change integral gain
                  break;

        case 'D': parameter = 'D';     // Change differential gain
                  break;

        case 'L': parameter = 'L';     // Loop a range of segments
                  break;

        case 'S': stat.run = 0;        // Stop execution of segments
                  break;

        case 'G': parameter = 'G';     // Execute a range of segments
                  break;

        case 'W': if(PORTEbits.RE2)    // Enable or disable motor
                      {                // driver IC
                      putrsUSART("\r\nPWM On");
                      PORTEbits.RE2 = 0;

                  else
                      {
                      putrsUSART("\r\nPWM Off");
                      PORTEbits.RE2 = 1;

                  break;

        default:  if(inpbuf[0] != '\0')
                      {
                      putrsUSART(error);
                      }
                  break;

        }
    }

else if(comcount == 1)              // If this is the second parameter of the
    {                               // input command.
    if(parameter < 4) segnum = atob(inpbuf);
    else
    switch(parameter)
        {
        case 'P': kp = atoi(inpbuf);   // proportional gain change
                  ExtEEWrite(122, kp); // Store value in EEPROM
                  break;

        case 'I': ki = atoi(inpbuf);   // integral gain change
```



```
                ExtEEWrite(124, ki); // Store value in EEPROM
                break;

        case 'D': kd = atoi(inpbuf);   // differential gain change
                ExtEEWrite(126, kd); // Store value in EEPROM
                break;

        case 'G': firstseg = atob(inpbuf);
                break;
                                     // Get the first segment in
                                     // the range to be executed.

        case 'L': firstseg = atob(inpbuf);
                break;

        default: break;
        }
    }

else if(comcount == 2)
    {
    if(!stat.run)                    // If no profile is executing
        {
        if(parameter < 4)            // If this was a segment parameter
            {                        // change.
            if(segnum < 12)
                {
                // Write the segment paramater into data memory
                segment1[segnum][parameter] = atoi(inpbuf);
                // Compute EEPROM address and write data to EEPROM
                eeadr = (segnum << 3) + (parameter << 1);
                ExtEEWrite(eeadr, segment1[segnum][parameter]);
                }

            else if(segnum < 24)
                // Write segment parameter data into data memory
                segment2[segnum - 12][parameter] = atoi(inpbuf);
            }
        else switch(parameter)
            {
              case 'G': lastseg = atob(inpbuf);   // Get value for
                        segnum = firstseg;        // last segment.
                        stat.loop = 0;
                        stat.run = 1;             // Start profile.
                        break;

              case 'L': lastseg = atob(inpbuf);   // Get value for
                        segnum = firstseg;        // last segment.
                        stat.loop = 1;            // Enable looping
                        stat.run = 1;             // Start profile
                        break;

              default: break;
              }
        }
    }

else;
}

//---------------------------------------------------------------------
// ExtEEWrite()
// Writes an integer value to an EEPROM connected to the I2C bus at
// the specified location.
//---------------------------------------------------------------------
```

```
void ExtEEWrite(unsigned char address, int data)
{
union
{
char b[2];
int i;
}
temp;

char error, retry;

temp.i = data;
error = 0;

retry = 10;                          // Poll the EEPROM up to 10 times
do
    {
    error = EEAckPolling(0xA0);
    retry--;
    } while(error && retry > 0);

retry = 10;                          // Attempt to write low byte of data
do                                   // up to 10 times
    {
    error = EEByteWrite(0xA0, address, temp.b[0]);
    retry--;
    } while(error && retry > 0);

retry = 10;                          // Poll the EEPROM up to 10 times
do
    {
    error = EEAckPolling(0xA0);
    retry--;
    } while(error && retry > 0);


retry = 10;                          // Attempt to write high byte of data
do                                   // up to 10 times
    {
    error = EEByteWrite(0xA0, address + 1, temp.b[1]);
    retry--;
    } while(error && retry > 0);

}

//-----------------------------------------------------------------------
// ExtEEWrite()
// Reads an integer value from an EEPROM connected to the I2C bus at
// the specified location.
//-----------------------------------------------------------------------

int ExtEERead(unsigned char address)
{
union
{
char b[2];
int i;
}
data;

union
{
char b[2];
int i;
}
temp;
```



```
char retry;

retry = 10;                          // Attempt to read low byte of data
do                                   // up to 10 times
    {
    temp.i = EERandomRead(0xA0, address);
    retry--;
    } while(temp.b[1] && retry > 0);

if(temp.b[1]) data.b[0] = 0;// Make read result 0 if error
else data.b[0] = temp.b[0];// Otherwise get the low byte of data

retry = 10;                          // Attempt to read high byte of data
do                                   // up to 10 times
    {
    temp.i = EERandomRead(0xA0, address + 1);
    retry--;
    } while(temp.b[1] && retry > 0);

if(temp.b[1]) data.b[1] = 0;         // Make read result 0 if error
else data.b[1] = temp.b[0];          // Otherwise get the high byte of data

return data.i;
}

//-----------------------------------------------------------------------
// putrsUSART()
// Writes a string of characters in program memory to the USART
//-----------------------------------------------------------------------

void putrsUSART(const rom char *data)
{
    do
    {
        while(!(TXSTA & 0x02));
        TXREG = *data;
    } while( *data++ );
}
```

APPENDIX B: PIC16F877 SERVOMOTOR SOURCE CODE

```
//-----------------------------------------------------------------------
//
// File:16mot877.c
//
// Written By:Stephen Bowling, Microchip Technology
//
// This code implements a brush-DC servomotor using the PIC18F877 MCU.
// The code was compiled using the HiTech PICC compliler ver. 7.85.
//
// The following files should be included in the MPLAB project:
//
//     16mot877.c-- Main source code file
//
//-----------------------------------------------------------------------

#include <pic.h>
#include <string.h>
#include <ctype.h>
#include <math.h>
#include <stdlib.h>
#include <stdio.h>

//-----------------------------------------------------------------------
//Constant Definitions
//-----------------------------------------------------------------------

#define  DIST   0                  // Array index for segment distance
#define  VEL    1                  // Array index for segment vel. limit
#define  ACCEL  2                  // Array index for segment accel.
#define  TIME   3                  // Array index for segment delay time
#define  INDEX  RB0                // Input for encoder index pulse
#define  NLIM   RB1                // Input for negative limit switch
#define  PLIM   RB2                // Input for positive limit switch
#define  GPI    RB3                // General purpose input
#define  MODE1  !RB4               // DIP switch #1
#define  MODE2  !RB5               // DIP switch #2
#define  MODE3  !RB6               // DIP switch #3
#define  MODE4  !RB7               // DIP switch #4
#define  SPULSE RC5                // Software timing pulse output
#define  ADRES  ADRESH             // Redefine for 10-bit A/D converter
#define  KP     250
#define  KI     252
#define  KD     254

//-----------------------------------------------------------------------
// Variable declarations
//-----------------------------------------------------------------------

const char ready[] = "\n\rREADY>";
const char error[] = "\n\rERROR!";

char inpbuf[8];

char tempch,UpCount;

unsigned char
eeadr,
firstseg,
lastseg,
segnum,
parameter,
i,                                 // index to ASCII buffer
comcount,                          // index to input string
udata                              // received character from USART
;
```



```
struct {                            // holds status bits for servo
    unsigned      phase:1;          // first half/ second half of profile
    unsigned   neg_move:1;          // backwards relative move
    unsigned     motion:1;          //
    unsigned  saturated:1;          // servo output is saturated
    unsigned       bit4:1;
    unsigned       bit5:1;
    unsigned        run:1;
    unsigned       loop:1;
} stat ;

union INTVAL
{
int i;
char b[2];
};

union LNG
{
long l;
unsigned long ul;
int i[2];
unsigned int ui[2];
char b[4];
unsigned char ub[4];
};

bank1 union LNG
accel,
temp,
u0,
ypid,
velact,
phase1dist
;


bank1 int
dtime,                              // Segment delay time
integral,
kp,ki,kd,                           // PID gain constants
vlim, velcom,
mvelocity,
DnCount
;

bank1 long
position,                           // Commanded position.
mposition,                          // Actual measured position.
fposition,                          // Originally commanded position.
flatcount;                          // Holds # of sample periods for which the
                                    // velocity limit was reached in first half of the move.

bank2 int segment1[12][4];          // array in bank2 for 12 motion segments
bank3int segment2[12][4];           // array in bank3 for 12 motion segments

// Function Prototypes-------------------------------------------------

interrupt void servo_isr( void);
void putrsUSART(const char *data);
void DoCommand(void);
void Setup(void);
void UpdPos(void);
void UpdTraj(void);
void CalcError(void);
```

```
void CalcPID(void);
void SetupMove(void);
void EEDatWrite(unsigned char address, int data);
int EEDatRead(unsigned char address);


//-----------------------------------------------------------------------
// servo_isr()
// Performs the servo calculations
//-----------------------------------------------------------------------

interrupt void servo_isr(void)
{
SPULSE = 1;                          // Toggle output pin for ISR code timing
UpdTraj();                           // Get new commanded position
UpdPos();                            // Get new measured position
CalcError();                         // Calculate new position error
CalcPID();

TMR2IF = 0;                          // Clear Timer2 Interrupt Flag.

SPULSE = 0;                          // Toggle output pin for ISR code timing
}

//-----------------------------------------------------------------------
// UpdTraj()
// Computes the next required value for the next commanded motor
// position based on the current motion profile variables. Trapezoidal
// motion profiles are produced.
//-----------------------------------------------------------------------

void UpdTraj(void)
{
if(stat.motion && !stat.saturated)
    {
    if(!stat.phase)                  // If in the first half of the move.
        {
        if(velact.ui[1] < vlim)      // If still below the velocity limit
            velact.ul += accel.ul;   // Accelerate

        else                         // If velocity limit has been reached,
            flatcount++;             // increment flatcount.

        temp.ul = velact.ul;         // Put velocity value into temp
                                     // and round to 16 bits
        if(velact.ui[0] == 0x8000)
            {
            if(!(velact.ub[2] & 0x01))
                temp.ui[1]++;
            else;
            }
        else

        if(velact.ui[0] > 0x8000) temp.ui[1]++;
        else;

        phase1dist.ul -= (unsigned long)temp.ui[1];

        if(stat.neg_move)
            position -= (unsigned long)temp.ui[1];
        else
            position += (unsigned long)temp.ui[1];

        if(phase1dist.l <= 0)        // If phase1dist is negative
                                     // first half of the move has
            stat.phase = 1;          // completed.
```



```
        }

    else                            // If in the second half of the move,
        {                           // Decrement flatcount if not 0.
        if(flatcount) flatcount--;

        else
        if(velact.ul)               // If commanded velocity not 0,
            {
            velact.ul -= accel.ul;  // Decelerate

            if(velact.i[1] < 0)
                velact.l = 0;
            }

        else                        // else
            {
            if(dtime) dtime--;      // Decrement delay time if not 0.
            else
                {
                stat.motion = 0;    // Move is done, clear motion flag
                position = fposition;
                }
            }

        temp.ul = velact.ul;        // Put velocity value into temp
                                    // and round to 16 bits
        if(velact.ui[0] == 0x8000)
            {
            if(!(velact.ub[2] & 0x01))
                temp.ui[1]++;
            else;
            }

        else

        if(velact.ui[0] > 0x8000) temp.ui[1]++;
        else;

        if(stat.neg_move)           // Update commanded position
            position -= (unsigned long)temp.ui[1];
        else
            position += (unsigned long)temp.ui[1];
        }

    }                               // END if (stat.motion)

else
    {
    if(stat.run && !stat.motion)    // If motion stopped and profile
        {                           // running, get next segment number
        if(segnum < firstseg) segnum = firstseg;
        if(segnum > lastseg)
            {
            segnum = firstseg;      // Clear run flag if loop flag not set.
            if(!stat.loop) stat.run = 0;
            }
        else
            {
            SetupMove();            // Get data for next motion segment.
            segnum++;               // Increment segment number.
            }
        }
    else;
    }
}
```

```
//-----------------------------------------------------------------------
// SetupMove()
// Gets data for next motion segment to be executed
//-----------------------------------------------------------------------

void SetupMove(void)
{
if(segnum < 12)                      // Get profile segment data from
    {                                // data memory.
    phase1dist.i[0] = segment1[segnum][DIST];
    vlim = segment1[segnum][VEL];
    accel.i[0] = segment1[segnum][ACCEL];
    dtime = segment1[segnum][TIME];
    }
else if(segnum < 24)
    {
    phase1dist.i[0] = segment2[segnum - 12][DIST];
    vlim = segment2[segnum - 12][VEL];
    accel.i[0] = segment2[segnum - 12][ACCEL];
    dtime = segment2[segnum - 12][TIME];
    }


phase1dist.b[2] = phase1dist.b[1];   // Rotate phase1dist one byte
phase1dist.b[1] = phase1dist.b[0];   // to the left.
phase1dist.b[0] = 0;
if(phase1dist.b[2] & 0x80)           // Sign-extend value
    phase1dist.b[3] = 0xff;
else
    phase1dist.b[3] = 0;

accel.b[3] = 0;                      // Rotate accel one byte to
accel.b[2] = accel.b[1];             // the left
accel.b[1] = accel.b[0];
accel.b[0] = 0;

temp.l = position;

if(temp.ub[0] > 0x7f)                // A fractional value is left
    temp.l += 0x100;                 // over in the 8 LSbits of
temp.ub[0] = 0;                      // position, so round position
                                     // variable to an integer value
position = temp.l;                   // before computing final move
                                     // position.
fposition = position + phase1dist.l; // Compute final position for
                                     // the move
if(phase1dist.b[3] & 0x80)           // If the move is negative,
    {
    stat.neg_move = 1;               // Set flag to indicate negative
    phase1dist.l = -phase1dist.l;    // move.
    }
else stat.neg_move = 0;              // Clear flag for positive move

phase1dist.l >>= 1;                  // phase1dist holds total
                                     // move distance, so divide by 2
velact.l = 0;                        // Clear commanded velocity
flatcount = 0;                       // Clear flatcount
stat.phase = 0;                      // Clear flag:first half of move
if(accel.l && vlim)
stat.motion = 1;                     // Enable motion
}

//-----------------------------------------------------------------------
// UpdPos()
//-----------------------------------------------------------------------
```



```
void UpdPos(void)
{
mvelocity = DnCount;                  // Get old DnCount value

temp.b[0] = TMR1L;                    // Read Timer1
temp.b[1] = TMR1H;

if(TMR1L < temp.b[0])                 // If a rollover occurred, read
    {                                 // Timer1 again.
        temp.b[0] = TMR1L;
        temp.b[1] = TMR1H;
    }

DnCount = temp.i[0];                  // Store timer value in DnCount

mvelocity -= DnCount;                 // Subtract new value from
                                      // measured velocity

tempch = -UpCount;                    // Put old UpCount value in
                                      // temporary variable.
UpCount = TMR0;                       // Read Timer0
tempch += UpCount;

if(tempch > 0)
    mvelocity += (int)tempch;
else
    mvelocity -= (int)(tempch);

mposition += (long)(mvelocity << 8);  // Update measured position
}

//-----------------------------------------------------------------------
// CalcError()
// Calculates position error and limits to 16 bit result
//-----------------------------------------------------------------------

void CalcError(void)
{
u0.l = mposition - position;          // Get error
u0.b[0] = u0.b[1];                    //
u0.b[1] = u0.b[2];                    // shift to the right to discard
u0.b[2] = u0.b[3];                    // lower 8 bits.

if (u0.b[2] & 0x80)                   // If error is negative.
    {
    u0.b[3] = 0xff;                   // Sign-extend to 32 bits.

    if((u0.i[1] != 0xffff) || !(u0.b[1] & 0x80))
        {
        u0.ui[1] = 0xffff;            // Limit error to 16-bits.
        u0.ui[0] = 0x8000;
        }
    else;
    }

else                                  // If error is positive.
    {
    u0.b[3] = 0x00;

    if((u0.i[1] != 0x0000) || (u0.b[1] & 0x80))
        {
        u0.ui[1] = 0x0000;            // Limit error to 16-bits.
        u0.ui[0] = 0x7fff;
        }
```

```
    else;
    }
}

//-----------------------------------------------------------------------
// CalcPID()
// Calculates PID compensator algorithm and determines new value for
// PWM duty cycle
//-----------------------------------------------------------------------

void CalcPID(void)
{
ypid.l = (long)u0.i[0]*(long)kp;      // If proportional gain is not 0,
                                      // calculate proportional term.
if(!stat.saturated)                   // If output is not saturated,
    integral += u0.i[0];              // add present error to integral
                                      // value.
if(ki)                                // If integral value is not 0,
ypid.l += (long)integral*(long)ki;    // calculate integral term.

if(kd)                                // If differential term is not 0,
ypid.l += (long)mvelocity*(long)kd;   // calculate differential term.

if(ypid.b[3] & 0x80)                  // If PID result is negative
    {
    if((ypid.b[3] < 0xff) || !(ypid.b[2] & 0x80))
        {
        ypid.ui[1] = 0xff80;          // Limit result to 24-bit value
        ypid.ui[0] = 0x0000;
        }
    else;
    }

else                                  // If PID result is positive
    {
    if(ypid.b[3] || (ypid.b[2] > 0x7f))
        {
        ypid.ui[1] = 0x007f;          // Limit result to 24-bit value
        ypid.ui[0] = 0xffff;
        }
    else;
    }
ypid.b[0] = ypid.b[1];                // Shift PID result right to
ypid.b[1] = ypid.b[2];                // get upper 16 bits.

stat.saturated = 0;                   // Clear saturation flag and see
if(ypid.i[0] > 500)                   // if present duty cycle output
    {                                 // exceeds limits.
    ypid.i[0] = 500;
    stat.saturated = 1;
    }

if(ypid.i[0] < -500)
    {
    ypid.i[0] = -500;
    stat.saturated = 1;
    }

ypid.i[0] += 512;                     // Add offset to get positive
ypid.i[0] <<= 6;                      // duty cycle and shift left to
                                      // get 8 Msb's in upper byte.
CCPR1L = ypid.b[1];                   // Write upper byte to CCP register
                                      // to set duty cycle.

                                      // Set 2 LSb's of duty cycle in
                                      // CCP1CON register.
```



```
if(ypid.b[0] & 0x80) CCP1X = 1;
else CCP1X = 0;
if(ypid.b[0] & 0x40) CCP1Y = 1;
else CCP1Y = 0;

TMR2IF = 0;                          // Clear Timer2 Interrupt Flag.
SPULSE = 0;
}


//---------------------------------------------------------------------
//  Setup() initializes program variables and peripheral registers
//---------------------------------------------------------------------

void Setup(void)
{
firstseg = 0;                        // Initialize motion segment
lastseg = 0;                         // variables
segnum = 0;
parameter = 0;                       // Motion segment parameter#
i = 0;                               // Receive buffer index
comcount = 0;                        // Input command index
udata = 0;                           // Holds USART received data


stat.phase = 0;                      // Initialize flags and variables
stat.saturated = 0;                  // used for servo calculations.
stat.motion = 0;
stat.run = 0;
stat.loop = 0;
stat.neg_move = 0;
dtime = 0;
integral = 0;
vlim = 0;
velcom = 0;
mvelocity = 0;
DnCount = 0;
UpCount = 0;
temp.l = 0;
accel.l = 0;
u0.l = 0;
ypid.l = 0;
velact.l = 0;
phase1dist.l = 0;
position = 0;
mposition = position;
fposition = position;
flatcount = 0;

memset(inpbuf,0,8);                  // clear the input buffer
udata = RCREG;
udata = RCREG;
RCREG = 0;
udata = 0;

SPBRG = 15;                          // 19200 baud @ 20MHz
TXSTA = 0x20;                        // setup USART transmit
RCSTA = 0x90;                        // setup USART receive
SSPADD = 49;                         // Setup MSSP for master I2C
SSPSTAT = 0;                         // 100Khz @ 20MHz
SSPCON2 = 0;                         //
SSPCON = 0x28;                       //
PR2 = 0xff;                          // Setup Timer2 and CCP1 for
T2CON = 0x4c;                        // 19.53 Khz PWM @ 20MHz
CCPR1L = 0x7f;                       // 50% initial duty cycle
```

```
CCP1CON = 0x0f;//
TMR2IF = 0;                         //
TMR2IE = 1;                         // Enable Timer2 interrupts
TMR1H = 0;                          //
TMR1L = 0;                          //
T1CON = 0x07;                       // Enable Timer1, ext. sync. clock
TMR0 = 0;                           //
OPTION = 0x6f;                      // Enable Timer0
ADCON1 = 0x04;                      // Setup A/D converter
ADCON0 = 0x81;                      //
PORTC = 0;                          // Clear PORTC
PORTD = 0;                          // Clear PORTD
PORTE = 0x00;                       // Clear PORTE
TRISC = 0xdb;                       //
TRISD = 0;                          // PORTD all outputs
TRISE = 0;                          // PORTE all outputs


kp = EEDatRead(KP);// Get PID gain values from
ki = 0;                             // data EEPROM
kd = EEDatRead(KD);//

putrsUSART("\r\nPIC16F877 DC Servomotor");
putrsUSART(ready);

PEIE = 1;                           // Enable interrupts.
GIE = 1;                            //
}

//---------------------------------------------------------------------
// main()
//---------------------------------------------------------------------

main()
{
Setup();


for(segnum=0;segnum < 12;segnum++)    // Reads profile data into RAM for
    {                                 // from data EEPROM.
    for(parameter=0;parameter < 4;parameter++)
        {
        eeadr = (segnum << 3) + (parameter << 1);
        segment1[segnum][parameter] = EEDatRead(eeadr);
        }
    }

segment2[0][DIST] = 29500;            // Initialize last 12 motion segments in
segment2[0][VEL] = 4096;              // RAM to pre-determined values for test
segment2[0][ACCEL] = 2048;            // purposes.  This profile data is used
segment2[0][TIME] = 1200;             // when a profile is selected via the DIP
                                      // switches on the motor PCB.
segment2[1][DIST] = -29500;
segment2[1][VEL] = 1024;
segment2[1][ACCEL] = 512;
segment2[1][TIME] = 1200;

segment2[2][DIST] = 737;
segment2[2][VEL] = 4096;
segment2[2][ACCEL] = 2048;
segment2[2][TIME] = 1200;

segment2[3][DIST] = 737;
segment2[3][VEL] = 4096;
segment2[3][ACCEL] = 2048;
segment2[3][TIME] = 1200;
```



```
segment2[4][DIST] = 738;
segment2[4][VEL] = 4096;
segment2[4][ACCEL] = 2048;
segment2[4][TIME] = 1200;

segment2[5][DIST] = 738;
segment2[5][VEL] = 4096;
segment2[5][ACCEL] = 2048;
segment2[5][TIME] = 1200;

segment2[6][DIST] = -2950;
segment2[6][VEL] = 1024;
segment2[6][ACCEL] = 128;
segment2[6][TIME] = 1200;

segment2[7][DIST] = 2950;
segment2[7][VEL] = 256;
segment2[7][ACCEL] = 64;
segment2[7][TIME] = 1200;

segment2[8][DIST] = -2950;
segment2[8][VEL] = 4096;
segment2[8][ACCEL] = 512;
segment2[8][TIME] = 1200;

segment2[9][DIST] = 29500;
segment2[9][VEL] = 1024;
segment2[9][ACCEL] = 512;
segment2[9][TIME] = 1200;

segment2[10][DIST] = 29500;
segment2[10][VEL] = 2048;
segment2[10][ACCEL] = 512;
segment2[10][TIME] = 1200;

segment2[11][DIST] = 29500;
segment2[11][VEL] = 4096;
segment2[11][ACCEL] = 1024;
segment2[11][TIME] = 1200;


if(MODE1)                           // If DIP switch #1 is on, set for looping mode.
    stat.loop = 1;

if(MODE2)
    {                               // If DIP switches #2,#3, or #4 turned on,
    firstseg = 12;                  // execute predetermined profile from above.
    lastseg = 13;
    segnum = 12;
    stat.run = 1;
    }
else if(MODE3)
    {
    firstseg = 14;
    lastseg = 18;
    segnum = 14;
    stat.run = 1;
    }
else if(MODE4)
    {
    firstseg = 18;
    lastseg = 19;
    segnum = 18;
    stat.run = 1;
    }
```

```
else;


while(1)
    {
    CLRWDT();

    ADGO = 1;                       // Start an A/D conversion
    while(ADGO);                    // Wait for the conversion to complete
    PORTD = 0;                      // Clear the LED bargraph display.
    PORTE &= 0x04;                  //                "

    if(ADRES > 225)
        {
        PORTE |= 0x03;              // Turn on 10 LEDS
        PORTD = 0xff;
        }
    if(ADRES > 200)
        {
        PORTE |= 0x01;              // Turn on 9 LEDS
        PORTD = 0xff;
        }
    else if(ADRES > 175) PORTD = 0xff;// Turn on 8 LEDS
    else if(ADRES > 150) PORTD = 0x7f;// 7 LEDS
    else if(ADRES > 125) PORTD = 0x3f;// 6 LEDS
    else if(ADRES > 100) PORTD = 0x1f;// 5 LEDS
    else if(ADRES > 75) PORTD = 0x0f; // 4 LEDS
    else if(ADRES > 50) PORTD = 0x07; // 3 LEDS
    else if(ADRES > 25) PORTD = 0x03; // 2 LEDS
    else if(ADRES > 0) PORTD = 0x01;  // 1 LED
    else;

    if(RCIF)
        {
        switch(udata = RCREG)
            {
            case ',':  DoCommand();           // process the string
                       memset(inpbuf,0,8);    // clear the input buffer
                       i = 0;                 // clear the buffer index
                       comcount++;            // increment comma count
                       TXREG = udata;         // echo the character
                       break;


            case 0x0d: DoCommand();           // process the string
                       memset(inpbuf,0,8);    // clear the input buffer
                       i = 0;                 // clear the buffer index
                       comcount = 0;          // clear comma count
                       segnum = 0;            // clear segment number
                       parameter = 0;         // clear paramater
                       putrsUSART(ready);     // put prompt to USART
                       break;

            default:   inpbuf[i] = udata;     // get received char
                       i++;                   // increment buffer index
                       if(i > 7)              // If more than 8 chars
                           {                  // received before getting
                           putrsUSART(ready); // a <CR>, clear input
                           memset(inpbuf,0,8);// buffer
                           i = 0;             // the buffer index
                       }
                       else TXREG = udata;    // echo character
                       break;                 //

            }                                 //end switch(udata)
        }                                     //end if(RCIF)
```



```
    }                                       //end while(1)
}

//-------------------------------------------------------------------
// DoCommand()
// Processes incoming USART data.
//-------------------------------------------------------------------

void DoCommand(void)
{
if(comcount == 0)                   // If this is the first parameter of the input
    {                               // command...
    switch(inpbuf[0])
        {
        case 'X': parameter = DIST;    // Segment distance change
                  break;

        case 'V': parameter = VEL;     // Segment velocity change
                  break;

        case 'A': parameter = ACCEL;// Segment acceleration change
                  break;

        case 'T': parameter = TIME;    // Segment delay time change
                  break;

        case 'P': parameter = 'P';     // Change proportional gain
                  break;

        case 'I': parameter = 'I';     // Change integral gain
                  break;

        case 'D': parameter = 'D';     // Change differential gain
                  break;

        case 'L': parameter = 'L';     // Loop a range of segments
                  break;

        case 'S': stat.run = 0;        // Stop execution of segments
                  break;

        case 'G': parameter = 'G';     // Execute a range of segments
                  break;

        case 'W': if(RE2)              // Enable or disable motor
                      {                // driver IC
                      putrsUSART("\r\nPWM On");
                      RE2 = 0;
                      }
                  else
                      {
                      putrsUSART("\r\nPWM Off");
                      RE2 = 1;
                      }
                  break;

        default:  if(inpbuf[0] != '\0')
                      {
                      putrsUSART(error);
                      }
                  break;

        }
    }

else if(comcount == 1)              // If this is the second parameter of the
```

```
    {                               // input command.
    if(parameter < 4) segnum = (char)(atoi(inpbuf));
    else
    switch(parameter)
        {
        case 'P': kp = atoi(inpbuf);   // proportional gain change
                  EEDatWrite(KP, kp);  // Store value in EEPROM
                  break;

        case 'I': ki = atoi(inpbuf);   // integral gain change
                  EEDatWrite(KI, ki);  // Store value in EEPROM
                  break;

        case 'D': kd = atoi(inpbuf);   // differential gain change
                  EEDatWrite(KD, kd);  // Store value in EEPROM
                  break;

        case 'G': firstseg = (char)(atoi(inpbuf));
                  break;
                                       // Get the first segment in
                                       // the range to be executed.

        case 'L': firstseg = (char)(atoi(inpbuf));
                  break;

        default: break;
        }
    }

else if(comcount == 2)
    {
    if(!stat.run)                      // If no profile is executing
        {
        if(parameter < 4)              // If this was a segment parameter
            {                          // change.
            if(segnum < 12)
                {
                // Write the segment paramater into data memory
                segment1[segnum][parameter] = atoi(inpbuf);
                // Compute EEPROM address and write data to EEPROM
                eeadr = (segnum << 3) + (parameter << 1);
                EEDatWrite(eeadr, segment1[segnum][parameter]);
                }

            else if(segnum < 24)
                // Write segment parameter data into data memory
                segment2[segnum - 12][parameter] = atoi(inpbuf);
            }
        else switch(parameter)
            {
            case 'G': lastseg = (char)(atoi(inpbuf)); // Get value for
                      segnum = firstseg;              // last segment.
                      stat.loop = 0;
                      stat.run = 1;                   // Start profile.
                      break;

            case 'L': lastseg = (char)(atoi(inpbuf)); // Get value for
                      segnum = firstseg;              // last segment.
                      stat.loop = 1;                  // Enable looping
                      stat.run = 1;                   // Start profile
                      break;

            default: break;
            }
        }
    }
```



```
else;
}


//----------------------------------------------------------------------
// putrsUSART()
//
// Puts a string of characters in program memory to the USART
//----------------------------------------------------------------------

void putrsUSART(const char *data)
{
    do
    {
        while(!(TXSTA & 0x02));
        TXREG = *data;
    } while( *data++ );
}

//----------------------------------------------------------------------
// EEDatWrite()
//
// Writes an integer value to the 16F877 data EEPROM memory at
// the specified address.
//----------------------------------------------------------------------

void EEDatWrite(unsigned char address, int data)
{
union INTVAL temp;

temp.i = data;

while(WR);                          // If write in progress, wait until done.
EEADR = address;                    // Load address to be written.
EEDATA = temp.b[0];                 // Load data to be written.
EEPGD = 0;                          // Point to data memory.
WREN = 1;                           // Enable writes.
GIE = 0;                            // Disable interrupts.
EECON2 = 0x55;                      // Required write sequence.
EECON2 = 0xaa;                      //             "
WR = 1;                             // Do the write.

while(WR);                          // If write in progress, wait until done.
EEADR++;                            // Increment address.
EEDATA = temp.b[1];                 // Load data to be written.
EECON2 = 0x55;                      // Required write sequence.
EECON2 = 0xaa;                      // Required write sequence.
WR = 1;                             // Do the write.
while(WR);                          // Wait for write to finish.
GIE = 1;                            // Reenable interrupts.
WREN = 0;                           // Disable writes.
}

//----------------------------------------------------------------------
// EEDatRead()
//
// Reads an integer value as two bytes from the 16F877 data EEPROM at
// the specified address location
//----------------------------------------------------------------------

int EEDatRead(unsigned char address)
{
union INTVAL data;

EEADR = address;// Load the address.
```

```
EEPGD = 0;                          // Point to data memory.
RD = 1;                             // Do the read.
data.b[0] = EEDATA;// Get the data.
EEADR++;                            // Point to next address.
RD = 1;                             // Do the read.
data.b[1] = EEDATA;// Get the data.

return data.i;
}
```

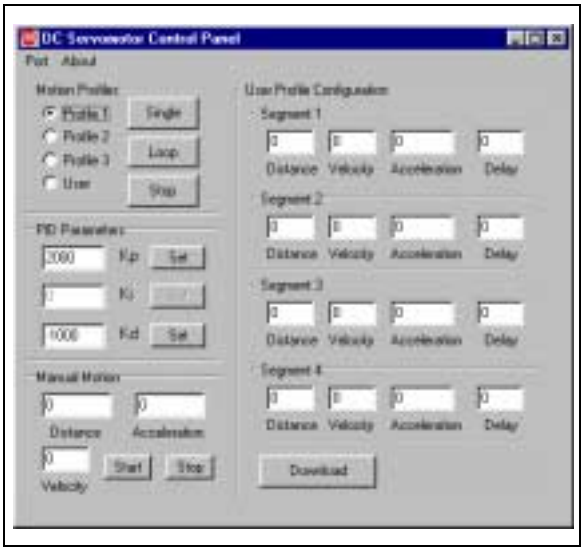

APPENDIX C: OPERATION WITH WINDOWS SOFTWARE

For convenience, a custom Windows® application is provided to control the servomotor. The control software for the servomotor is installed by copying the following files into a new directory on your PC.

- `Servo.exe`
- `vcl35.bpl`
- `zcommobj.bpl`
- `cp3240mt.dll`
- `borlndmm.dll`

Start the application by running `Servo.exe`. The following window should appear (see Figure C-1):

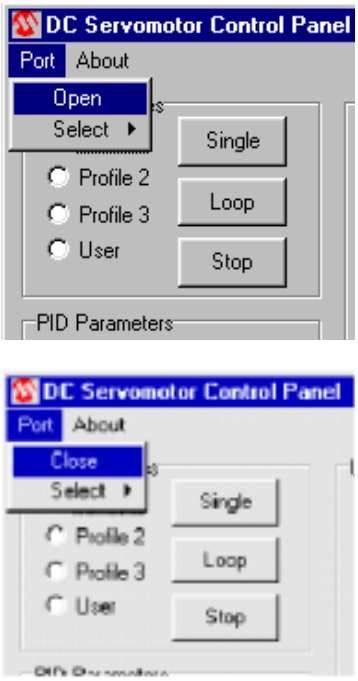
FIGURE C-1: DC SERVOMOTOR CONTROL PANEL



The control software uses COM2 as the default COM port. If the servomotor is connected to a different COM port, you will need to change the setting to the appropriate port. If you point to **Port** in the menu bar, a drop-down menu appears (see Figure C-2). If the **Close** option is seen, you should close the current port and reopen the menu. Otherwise, point to the **Select** option, which provides a list of available COM ports. Choose the appropriate port and click **Open**.

Select one of the three motion profiles listed in the **Motion Profiles** section of the control window and click **Single** to test the software. The motor will execute a motion and stop after a few seconds. Click the **Loop** button to perform the motions repeatedly.

FIGURE C-2: PORT MENU OPTIONS



Programming a Single Motion Segment

A single motion segment may be programmed and executed using the **Manual Motion** section of the control window. For example, enter the following values into the appropriate data windows and click **Start**.

- **Distance**: `2950`
- **Velocity**: `128`
- **Acceleration**: `1024`

You should observe that the motor shaft slowly rotates, then stops. Table C-1 summarizes the data value limits for all values in the control software.

TABLE C-1: SERVOMOTOR PARAMETER LIMITS

Parameter	Min. Value	Max. Value	Comments
Distance	-32000	32000	1 Shaft Revolution = 2950
Velocity	0	4096	
Acceleration	0	32000	
Delay	0	32000	Number of servo update periods
Kp	0	6000	
Kd	-32000	32000	

Programming Up to Four Motion Segments

The **User Profile Configuration** area of the software control window allows four motion segments to be programmed into the motor and executed. A delay value is specified in servo update periods and determines the amount of idle time between consecutive motion segments.

You can enter the motion profile data for each motion segment into the appropriate data windows. The following are suggested starting values.

Data Window	Seg 1	Seg 2	Seg 3	Seg 4
Distance:	2950	2950	29500	29500
Velocity:	128	1024	128	512
Acceleration:	1024	1024	1024	1024
Delay:	2000	2000	2000	2000

Click the **Download** button to transfer the parameters to the servomotor. Then, click the **User** radio button in the **Motion Profiles** box and either the **Single** or **Loop** button to start the profile.

NOTES:

Note the following details of the code protection feature on PICmicro® MCUs.

- The PICmicro family meets the specifications contained in the Microchip Data Sheet.
- Microchip believes that its family of PICmicro microcontrollers is one of the most secure products of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the PICmicro microcontroller in a manner outside the operating specifications contained in the data sheet. The person doing so may be engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as “unbreakable”.
- Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our product.

If you have any further questions about this matter, please contact the local sales office nearest to you.

DNV Certification, Inc. USA — ANSI-RAB QMS ACCREDITED — DNV MSC The Netherlands Accredited by the RvA — DNV — ISO 9001 / QS-9000 REGISTERED FIRM

Microchip received QS-9000 quality system certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona in July 1999. The Company’s quality system processes and procedures are QS-9000 compliant for its PICmicro® 8-bit MCUs, KEELOQ® code hopping devices, Serial EEPROMs and microperipheral products. In addition, Microchip’s quality system for the design and manufacture of development systems is ISO 9001 certified.

WORLDWIDE SALES AND SERVICE

AMERICAS

Corporate Office
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200 Fax: 480-792-7277
Technical Support: 480-792-7627
Web Address: http://www.microchip.com

Rocky Mountain
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7966 Fax: 480-792-7456

Atlanta
500 Sugar Mill Road, Suite 200B
Atlanta, GA 30350
Tel: 770-640-0034 Fax: 770-640-0307

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, Indiana 46902
Tel: 765-864-8360 Fax: 765-864-8387

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

New York
150 Motor Parkway, Suite 202
Hauppauge, NY 11788
Tel: 631-273-5305 Fax: 631-273-5335

San Jose
Microchip Technology Inc.
2107 North First Street, Suite 590
San Jose, CA 95131
Tel: 408-436-7950 Fax: 408-436-7955

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

ASIA/PACIFIC

Australia
Microchip Technology Australia Pty Ltd
Suite 22, 41 Rawson Street
Epping 2121, NSW
Australia
Tel: 61-2-9868-6733 Fax: 61-2-9868-6755

China - Beijing
Microchip Technology Consulting (Shanghai) Co., Ltd., Beijing Liaison Office
Unit 915
Bei Hai Wan Tai Bldg.
No. 6 Chaoyangmen Beidajie
Beijing, 100027, No. China
Tel: 86-10-85282100 Fax: 86-10-85282104

China - Chengdu
Microchip Technology Consulting (Shanghai) Co., Ltd., Chengdu Liaison Office
Rm. 2401, 24th Floor,
Ming Xing Financial Tower
No. 88 TIDU Street
Chengdu 610016, China
Tel: 86-28-6766200 Fax: 86-28-6766599

China - Fuzhou
Microchip Technology Consulting (Shanghai) Co., Ltd., Fuzhou Liaison Office
Unit 28F, World Trade Plaza
No. 71 Wusi Road
Fuzhou 350001, China
Tel: 86-591-7503506 Fax: 86-591-7503521

China - Shanghai
Microchip Technology Consulting (Shanghai) Co., Ltd.
Room 701, Bldg. B
Far East International Plaza
No. 317 Xian Xia Road
Shanghai, 200051
Tel: 86-21-6275-5700 Fax: 86-21-6275-5060

China - Shenzhen
Microchip Technology Consulting (Shanghai) Co., Ltd., Shenzhen Liaison Office
Rm. 1315, 13/F, Shenzhen Kerry Centre,
Renminnan Lu
Shenzhen 518001, China
Tel: 86-755-2350361 Fax: 86-755-2366086

Hong Kong
Microchip Technology Hongkong Ltd.
Unit 901-6, Tower 2, Metroplaza
223 Hing Fong Road
Kwai Fong, N.T., Hong Kong
Tel: 852-2401-1200 Fax: 852-2401-3431

India
Microchip Technology Inc.
India Liaison Office
Divyasree Chambers
1 Floor, Wing A (A3/A4)
No. 11, O'Shaugnessey Road
Bangalore, 560 025, India
Tel: 91-80-2290061 Fax: 91-80-2290062

Japan
Microchip Technology Japan K.K.
Benex S-1 6F
3-18-20, Shinyokohama
Kohoku-Ku, Yokohama-shi
Kanagawa, 222-0033, Japan
Tel: 81-45-471- 6166 Fax: 81-45-471-6122

Korea
Microchip Technology Korea
168-1, Youngbo Bldg. 3 Floor
Samsung-Dong, Kangnam-Ku
Seoul, Korea 135-882
Tel: 82-2-554-7200 Fax: 82-2-558-5934

Singapore
Microchip Technology Singapore Pte Ltd.
200 Middle Road
#07-02 Prime Centre
Singapore, 188980
Tel: 65-334-8870 Fax: 65-334-8850

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

EUROPE

Denmark
Microchip Technology Nordic ApS
Regus Business Centre
Lautrup hoj 1-3
Ballerup DK-2750 Denmark
Tel: 45 4420 9895 Fax: 45 4420 9910

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

Germany
Microchip Technology GmbH
Gustav-Heinemann Ring 125
D-81739 Munich, Germany
Tel: 49-89-627-144 0 Fax: 49-89-627-144-44

Italy
Microchip Technology SRL
Centro Direzionale Colleoni
Palazzo Taurus 1 V. Le Colleoni 1
20041 Agrate Brianza
Milan, Italy
Tel: 39-039-65791-1 Fax: 39-039-6899883

United Kingdom
Arizona Microchip Technology Ltd.
505 Eskdale Road
Winnersh Triangle
Wokingham
Berkshire, England RG41 5TU
Tel: 44 118 921 5869 Fax: 44-118 921-5820

01/18/02