6.115 Final Project

PCB Mill

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Overview of PCB Mill Document

1. Introduction

1.1 What is a PCB Mill?

A PCB Mill is a device that etches out a pattern on a copper clad board such that it makes a Printed Circuit Board (PCB). PCBs are used everywhere in the field of electrical engineering to connect electrical components to one another. Typically, after a board is designed, the layout files are sent to a manufacturer who then makes the board and ships it back to the customer. When prototyping, the delay and setup costs associated with sending a layout to a manufacturer can often mean days of down time. While this may not seem costly at first, it can prove to be a significant nuisance since most boards contain a wiring bug that was overlooked or misunderstood and must then be remade.

The advantage of the PCB Mill is its ability to create a prototype in less than a couple hours and at a much reduced cost compared to outsourcing. The current price of a commercial PCB Milling device is around $3000 US which is a significant investment for most small labs or individuals wishing to quickly prototype. The solution: Make a PCB Mill from scratch using everyday parts.

1.2 Design Concepts

The main concepts commonly used to make a milling device consist of a threaded travel mechanism, a combination X-axis and Y-axis, a precisely controlled motor (either a stepper motor or a DC motor with a position encoder), and a controller for the milling mechanism to correctly position it. For each axis - X,Y, and Z – a motor is connected to the threaded travel mechanism. As the motor turns the screw-like device, a guide on top of the thread moved back and forth in a straight 1-dimensional line. Combining the X-axis and the Y-axis, an XY-plane is created. This allows a platform to be positioned anywhere in a 2-dimensional plane. The Z axis, either mounted as port of the XY plane or separately above it, allows for a 3rd dimension.

With the help of a controller, the medium to be cut can be correctly placed in the XY-plane and the Z-axis, connected to a drilling device, can be raised or lowered to cut the desired path. With a well designed mill, accuracy of better than one thousandth of an inch can be achieved.

1.3 Proposed Design

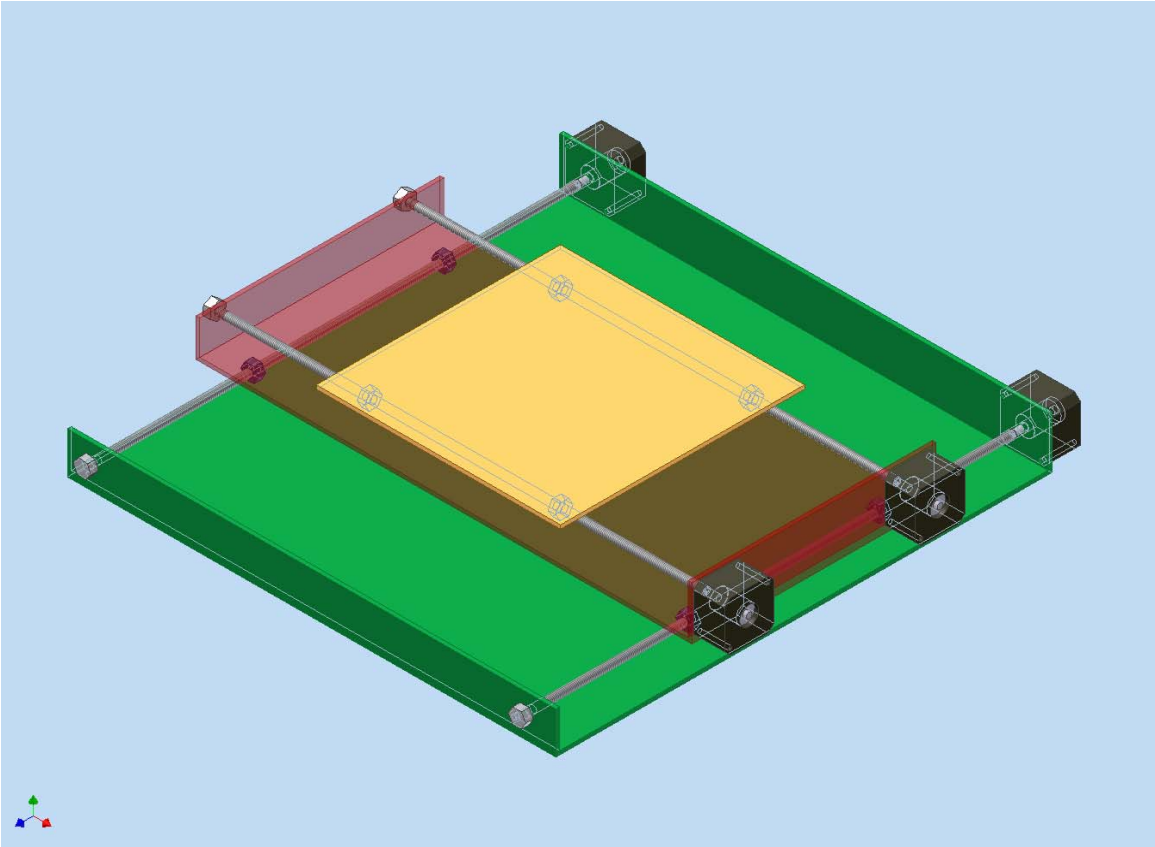
The design I am proposing uses 6 stepper motors to control the 3 axis of operation. (2 motors per axis) This is used instead of one motor per axis to minimize the likelihood of binding under a working load. Each stepper motor is connected to a push-pull driver chip which is controlled by a PIC16F877 microcontroller. The PIC chip displays the current position on an LCD and gets the desired position from the R31JP 805x microcontroller board. The operating system on the R31JP allows the user to download .kmf mill files and then command the system to carry out the milling operation. A PCB Milling program written in C++ is used to display, draw, and convert the standard HPGL plotter files to the .kmf milling file format.

2. The Mechanical System

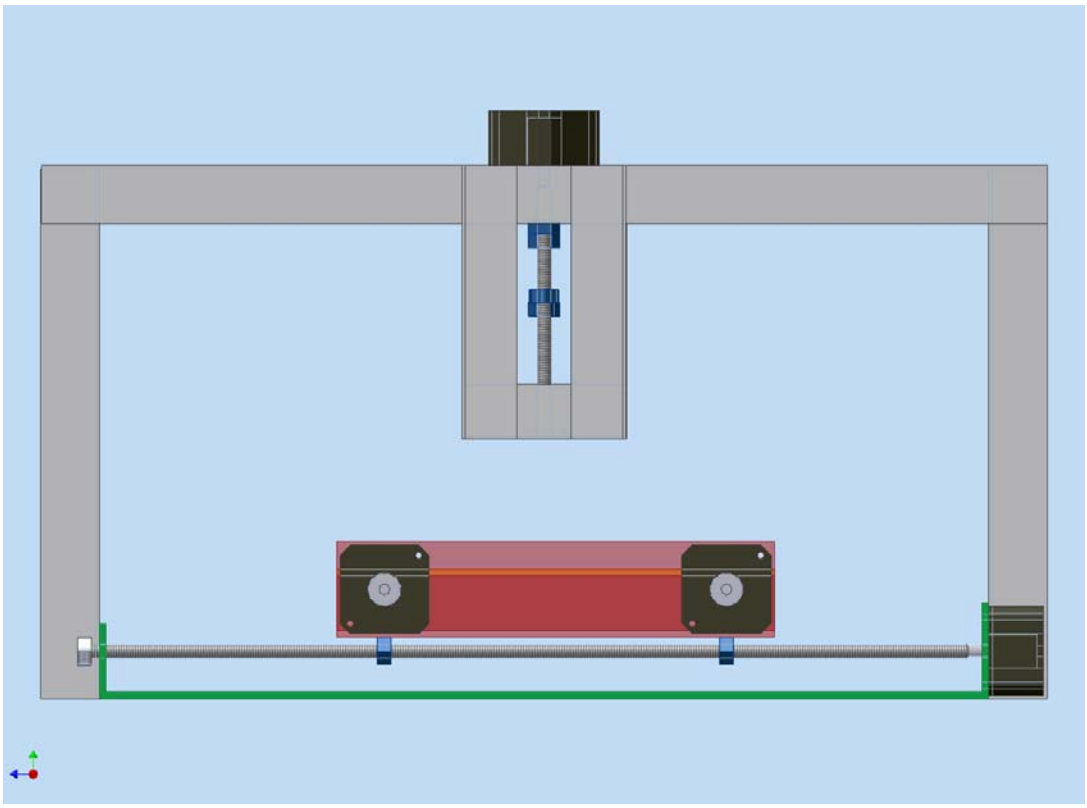
2.1 Mechanical Design

The complete mechanical system was designed in a 3D solid working environment using Autodesk Inventor. Due to its light weight, strength, and cost, aluminum was chosen as the primary framing metal. This includes the main chassis of the mill which supports the X axis, the Y-axis, the 8" x 8" work area, and the Z-axis overhead support. Chassis connections were made with ¼" bolts where possible. The long threaded rod, or all-thread, is made of stainless steel to allow for moderately heavy loads on the work area. To couple the stepper motors to the threaded shaft, ¼" vinyl tubing and a hose clamp was used. This allows for some flexibility in the coupling and reduces non-torsional stresses which can needlessly overwork the motor. Uni-polar stepper motors were used, but could have easily been replaced with Bipolar stepper motors if desired. An AC motor is mounted on the Z-axis to perform the drilling operation. Ideally, a precision ¼" drill chuck would be mounted on the shaft of the AC drill motor for easy bit changing when necessary.

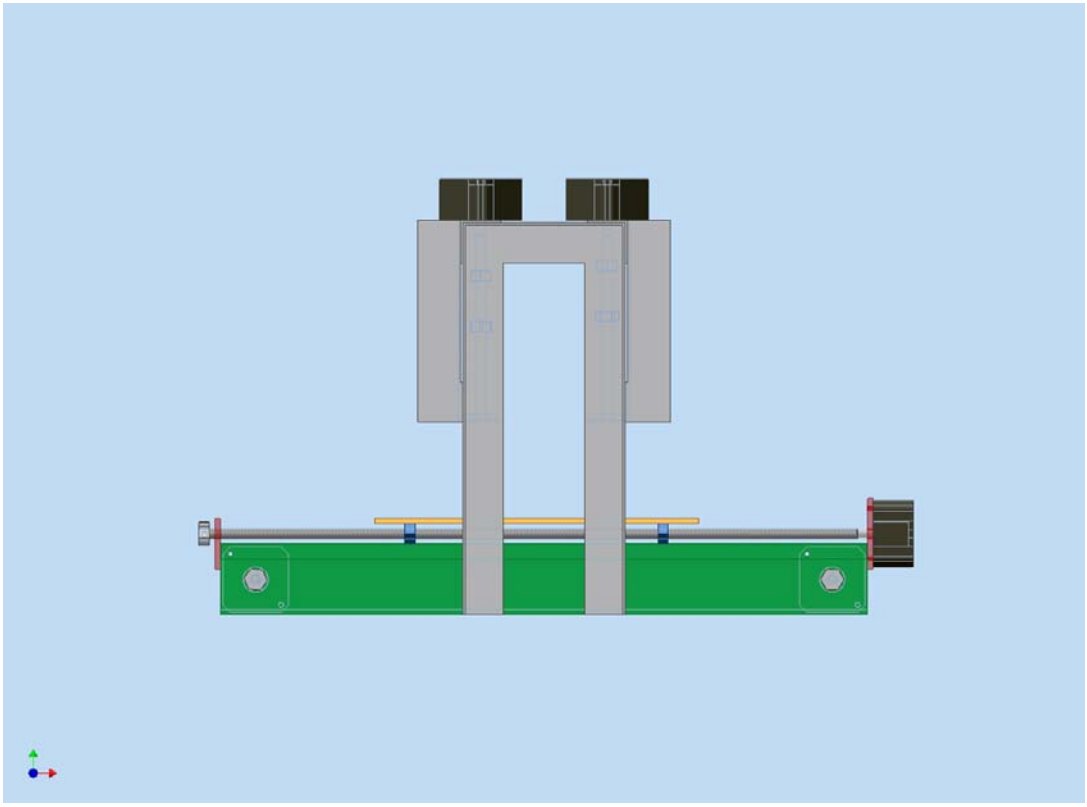
2.2 Mechanical Design Models



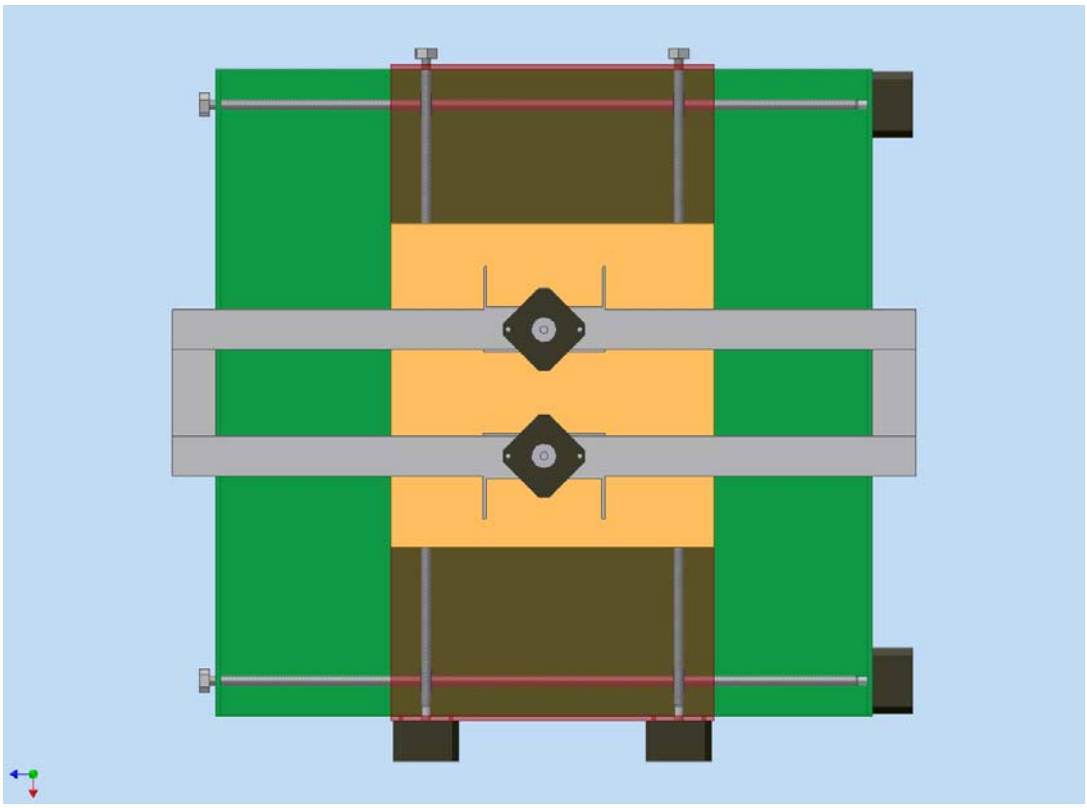
XY-Plane Design - Isometric View



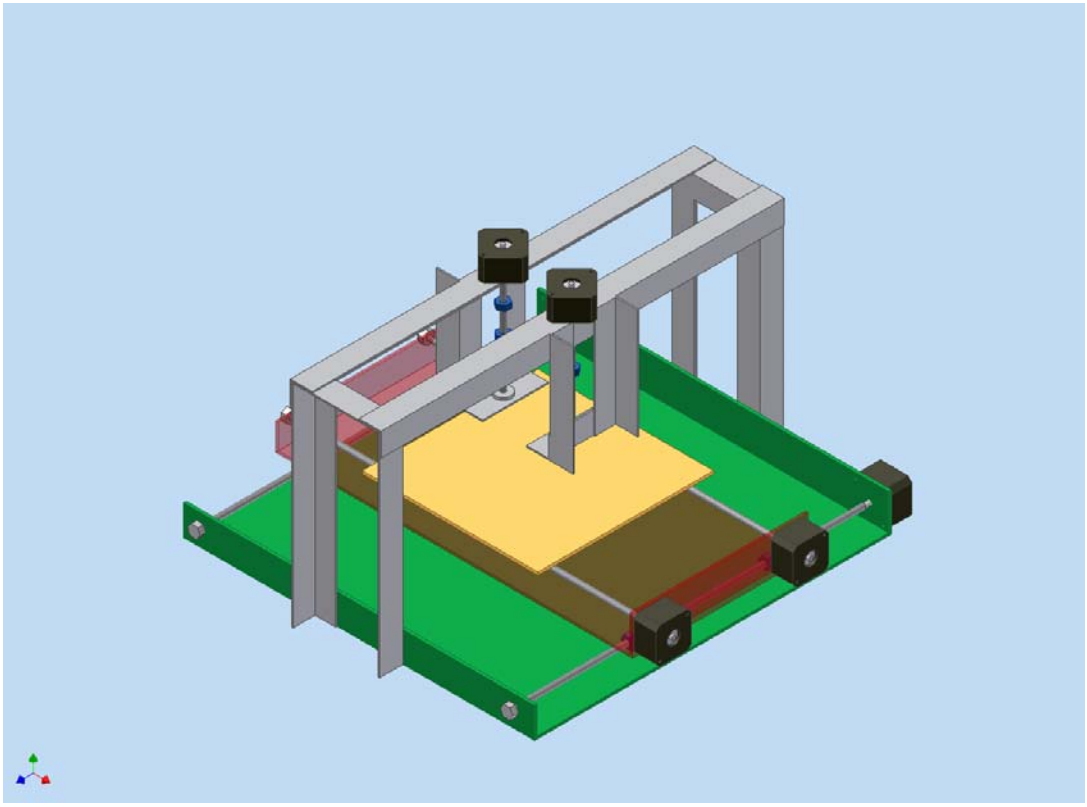
Final Design - Front View



Final Design - Left View



Final Design - Top View



Final Design - Isometric View

2.3 Tools/Supplies

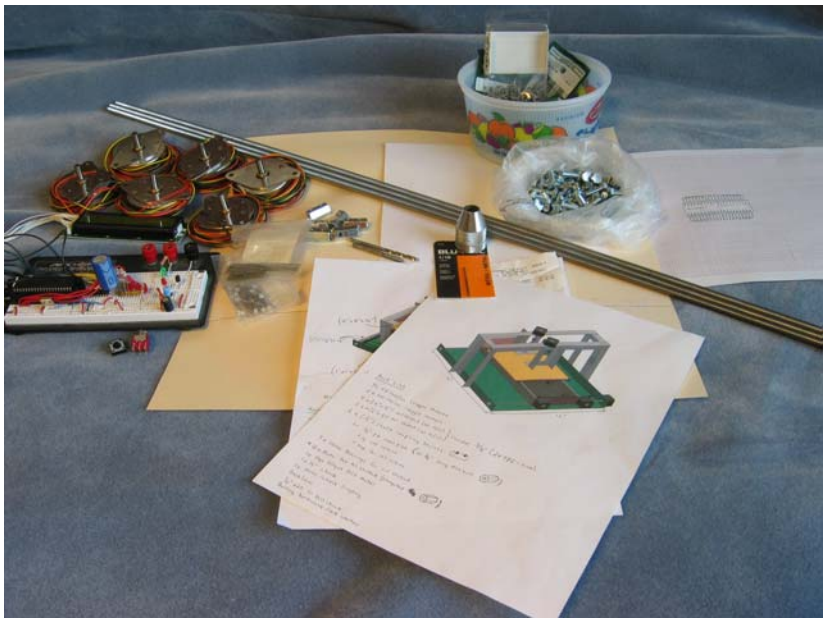
Supplies List:

- 6 x 48 steps/rev Stepper motors
- ¼" Vinyl tubing
- 6 x ¼" Hose clamps
- 8x32 Bolts/Nuts/Washers
- ¼" Bolts/Nuts/Lock-Washers
- .25"x8"x8" Aluminum Plate (for work area)
- 2"x2"x.125" Angle (4' for side supports of chassis)
- 1"x1"x.125" Angle (10' for other parts of chassis)
- 1"x.125" Rectangle (for AC motor U-bracket)
- 3 x 3'x5/16 Threaded Rod
- 14 x 5/16"x7/8" Hex Nut (for threaded rod mounting)

Tools List:

- Hand Drill
- Drill Bits (1/16" – 3/8")
- Hacksaw
- Hacksaw Blades (18 TPI for fast aluminum cutting)
- Dial Caliper (for precision measurements)
- Pliers
- Wrenches (1/4 – 7/16)
- Clamps to hold materials while working
- Bastard File for de-burring cuts
- Screwdrivers
- 8x32 Tap and Tap Wrench
- A Lot of Patience

2.4 Building the PCB Mill

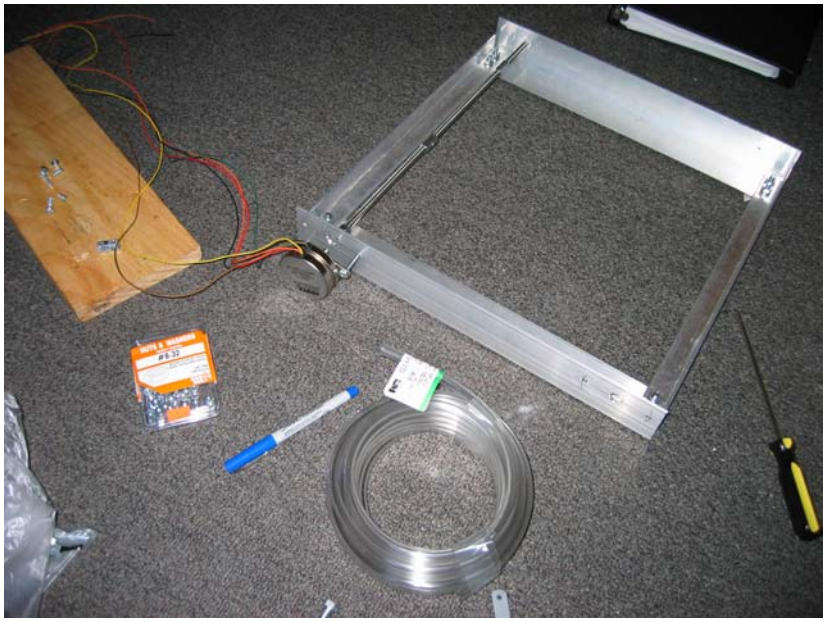


Laying out the parts

Measure twice, cut once…

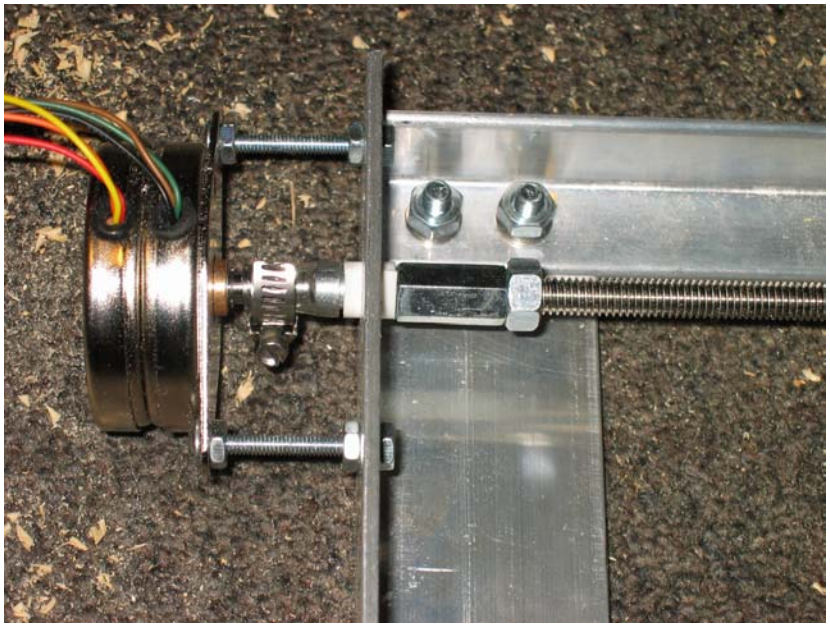
Sizing up the chassis

Squaring things up



One motor mounted

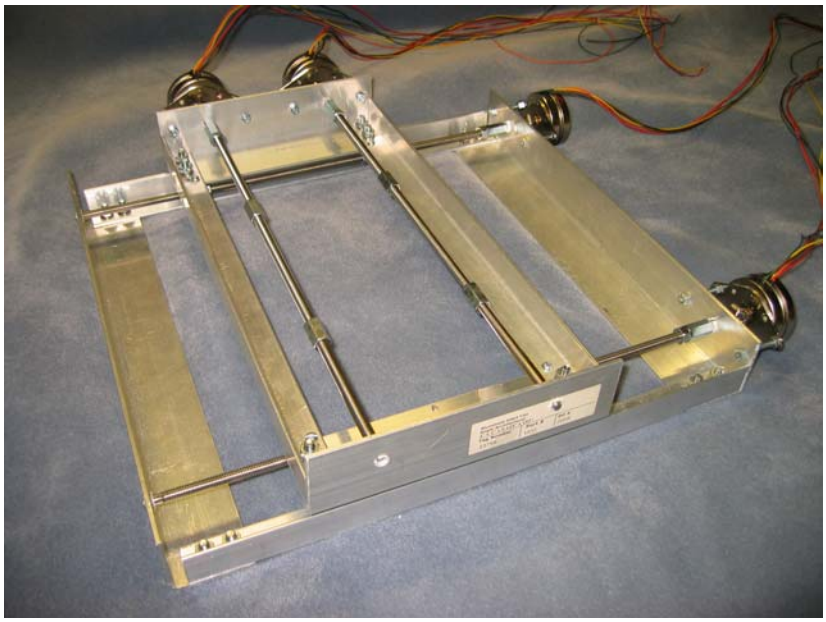
Double checking alignment



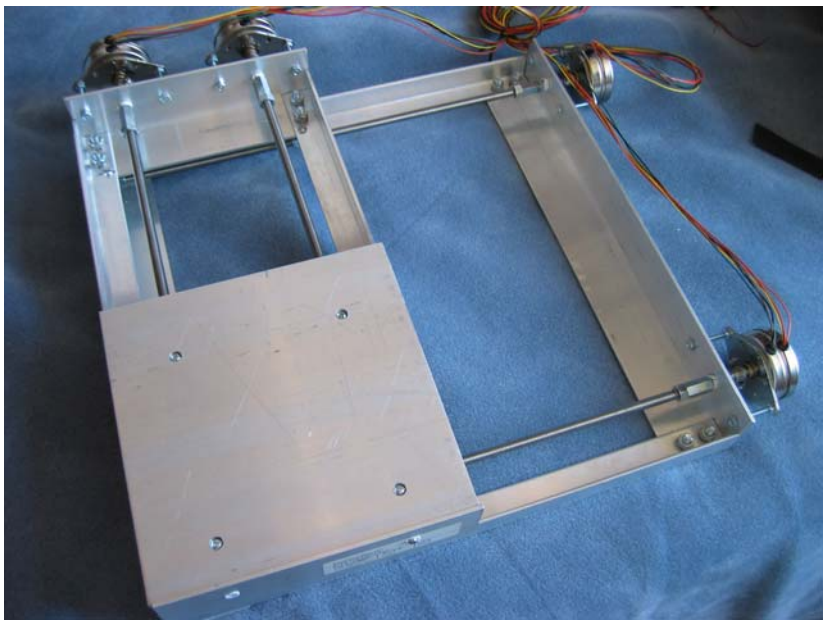
The flexible vinyl coupling and hose clamp

Tapping holes in the hex guide nuts

It’s easy to be happy with a design before it’s tested…

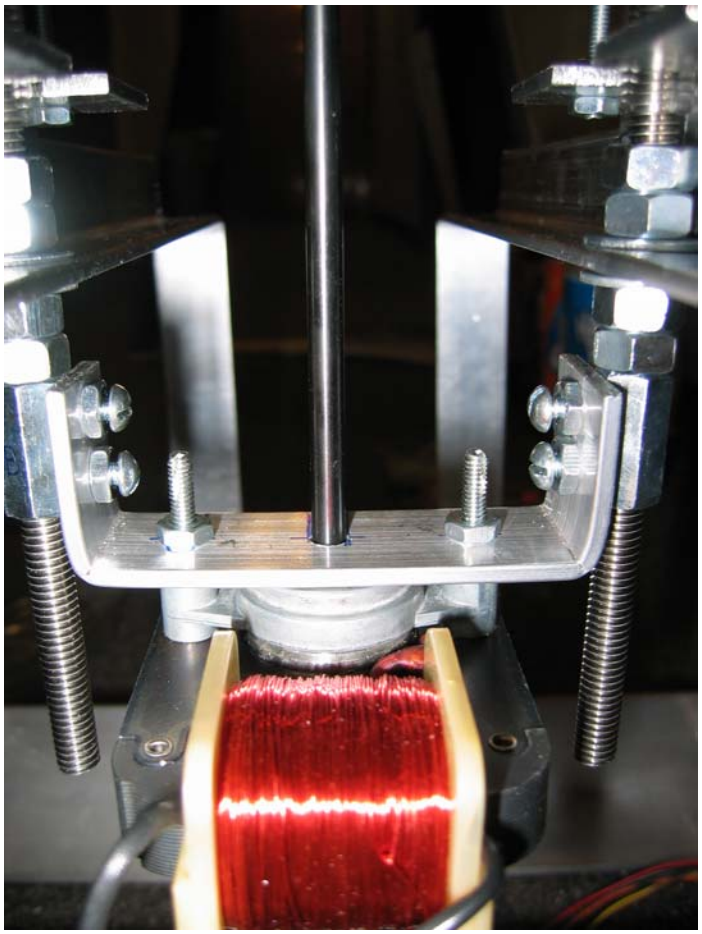


Y-axis mounted onto X-Axis

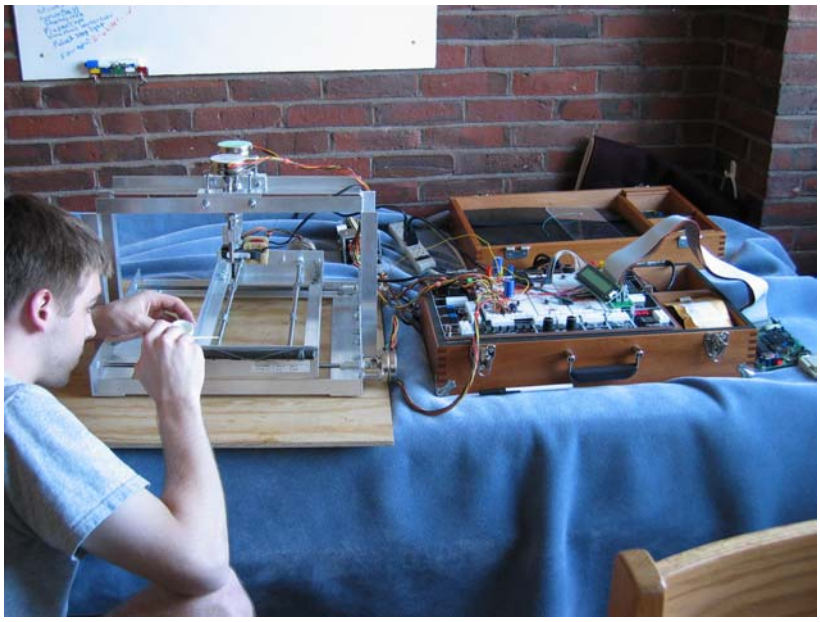


Work plate mounted on top of Y axis

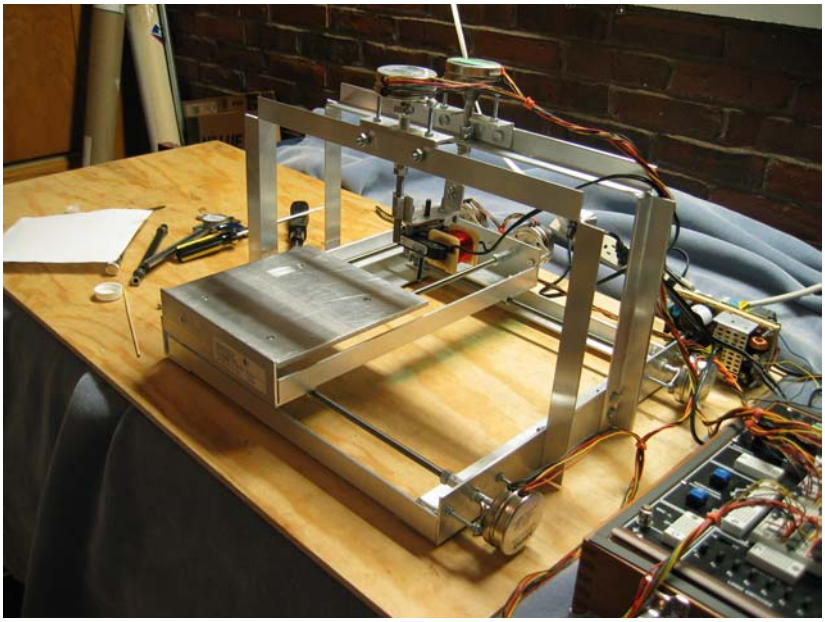
Bending both Z-axis supports at the same time to keep them identical



The AC motor mounted to the hex guide nuts for the Z-axis



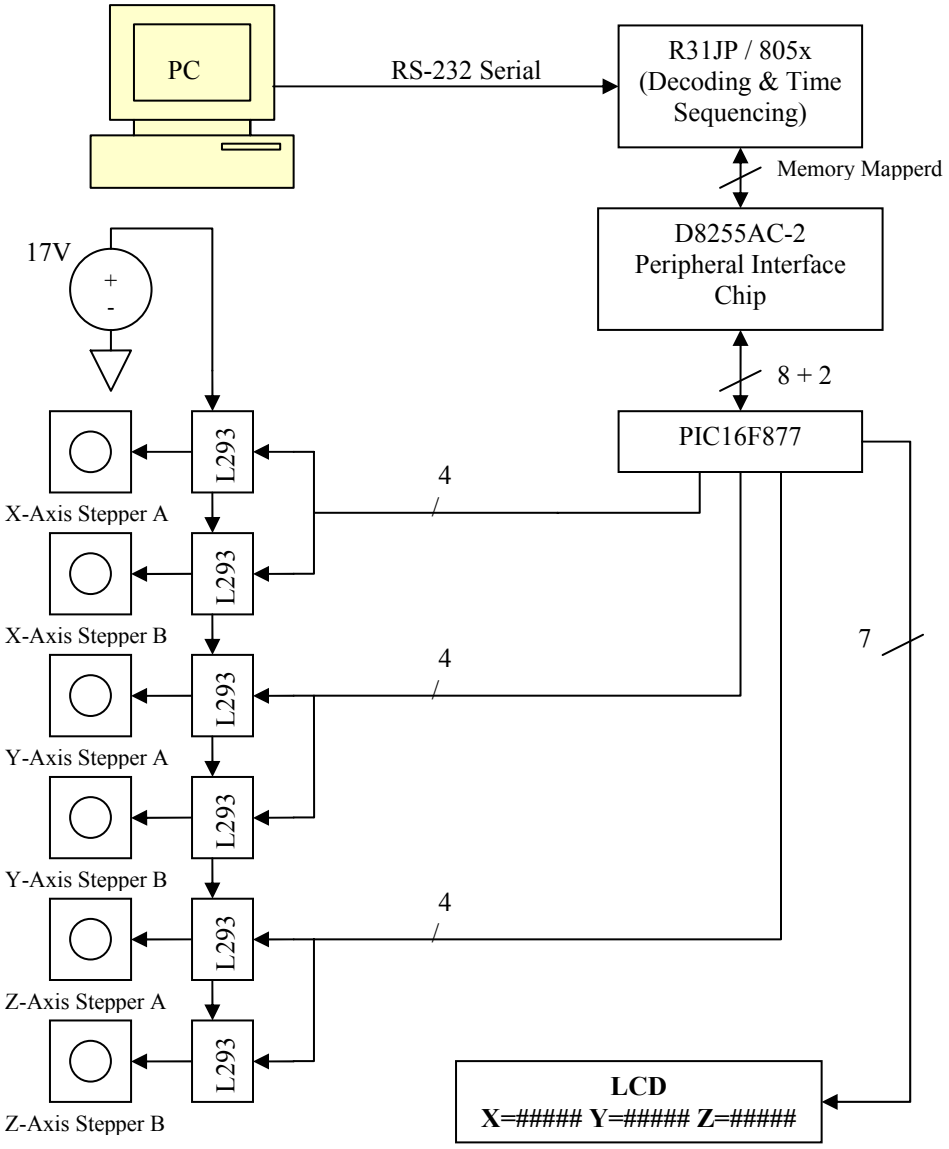
Oiling the threaded rods to reduce friction



The complete Mechanical PCB Mill System

3. The Electrical System

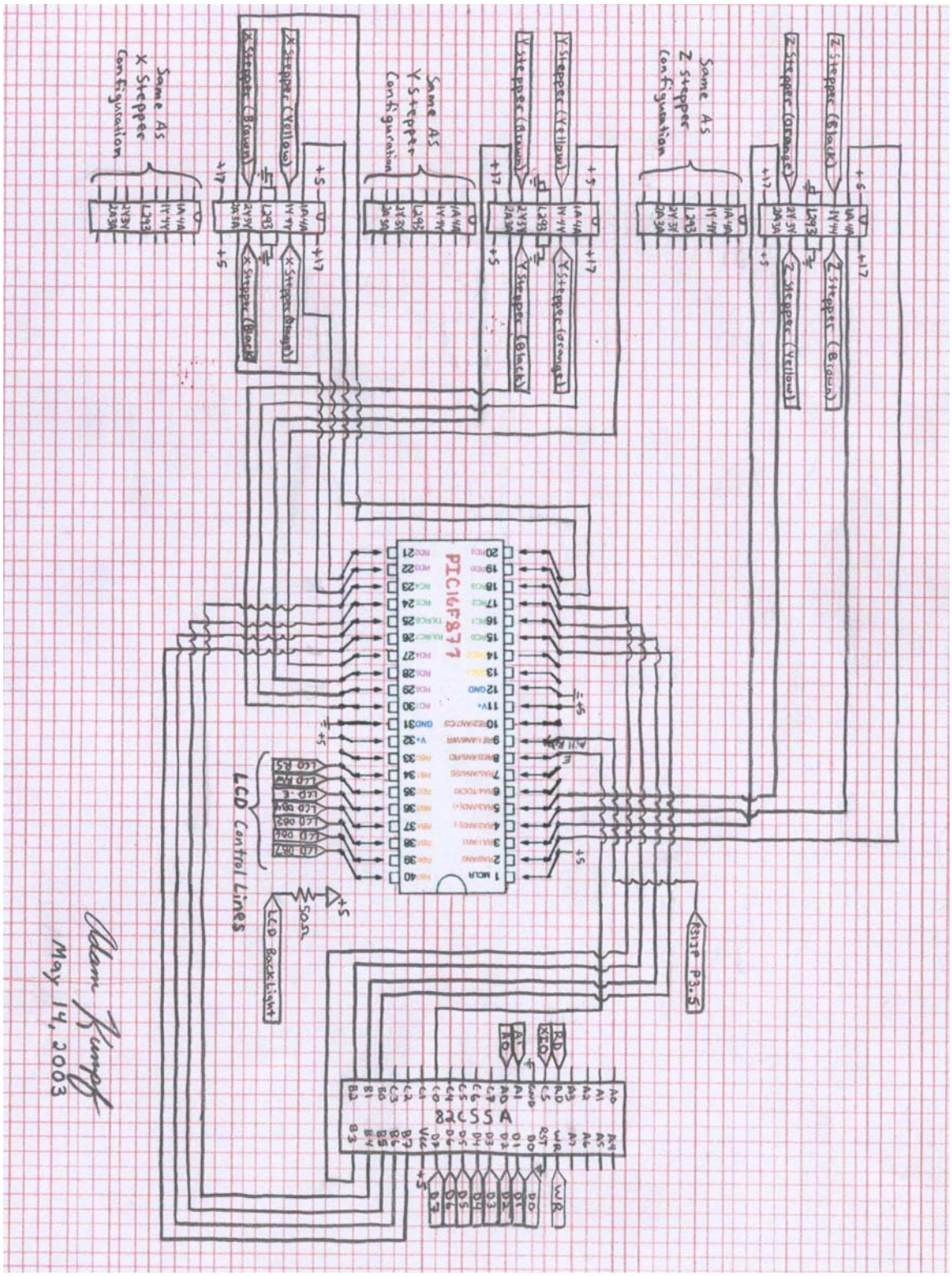
3.1 Circuit Block Diagram



3.2 Integrated Circuits Used

R31JP microcontroller board (Intel 805x)
PIC16F877 microcontroller
6 x L293 Push Pull Driver
D8255AC-2 Peripheral Interface Chip
LCD Controller w/ LCD

3.3 Schematic/Layout



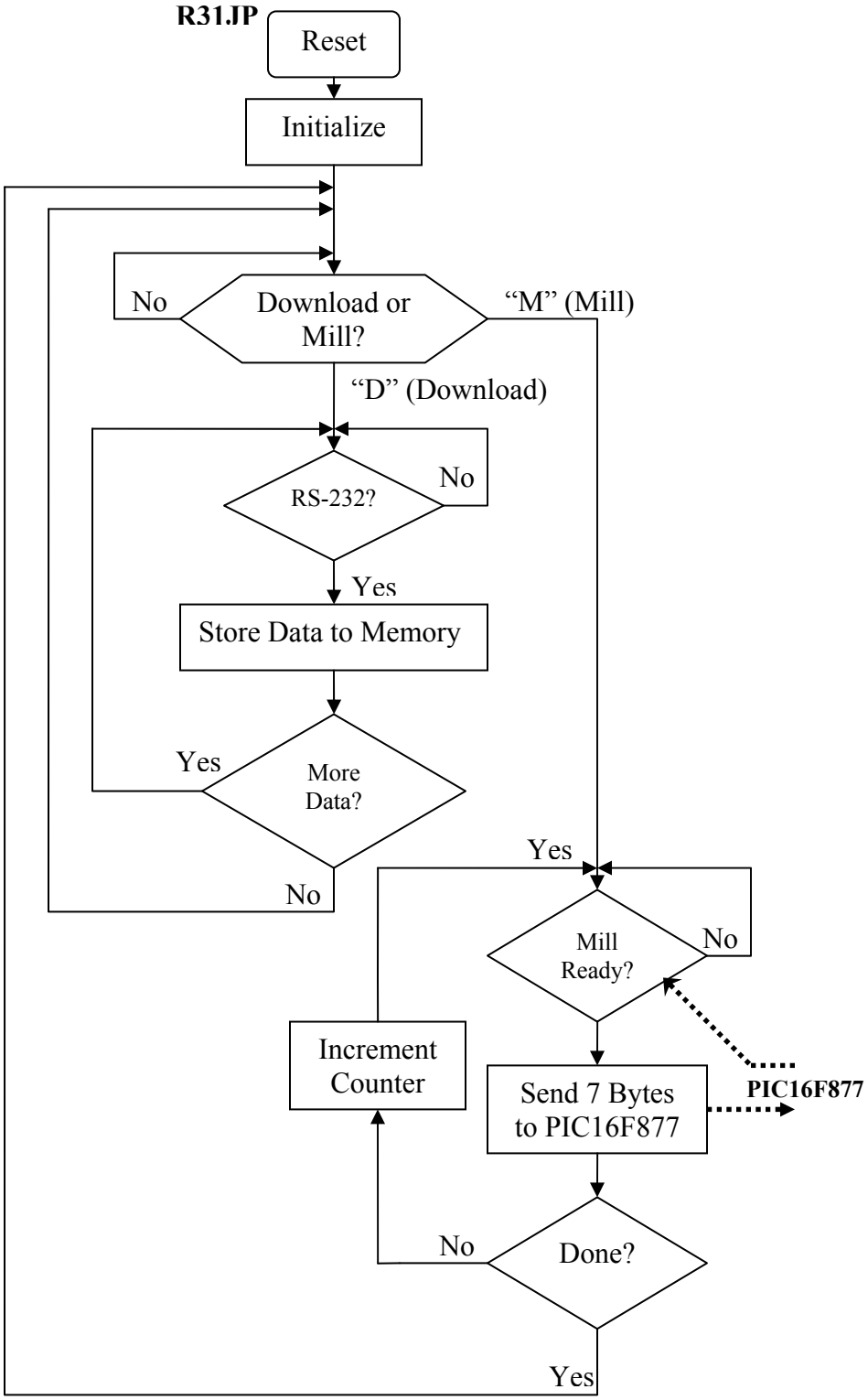
4. Implementing the Intel 805x/R31JP

4.1 Purpose

The purpose of using the Intel 805x/R31JP microcontroller board is to provide the user with an Operating System interface via the serial port and to allow the user to store the desired milling routine in external RAM. The device can then be asked by the user to carry out the milling process. To do this the R31JP communicates with the PIC16F877 through the D8255AC-2 Peripheral Interface Chip. Eight data lines and two control lines are used to send information. The Enable control lines is used to clock position data into the PIC16F877 and the MillReady line is driven high by the PIC microcontroller when it is ready for a new position.

4.2 R31JP Flowchart

(Section of Operating System that handles Downloading and Milling)



4.3 Explanation

The R31JP program is based on the MinMon Operating System with a couple new commands that allow for downloading .KMF mill files and carrying out the actuall milling procedure. The R31JP is connected to a PC via a serial cable and communicates at a baud rate of 9600 bps to a communication window on the host computer. When the microcontroller is turned on, a welcome screen is printed and the device initializes local variables and the Peripheral Interface chip. If the user presses the "D" key, a prompt will be given instructing the user to send the .KMF file to the device. This can be done by treating the file as plain text and sending it over the RS-232 serial port.

Since the .KMF mill file is very similar to the standard Intel Hex file, the operating system handles this routine nicely and sends a "." handshake after each line is read. Each new mill position is stored in external RAM using only 5 bytes and can be retrieved at any time as long as power remains on to the device.

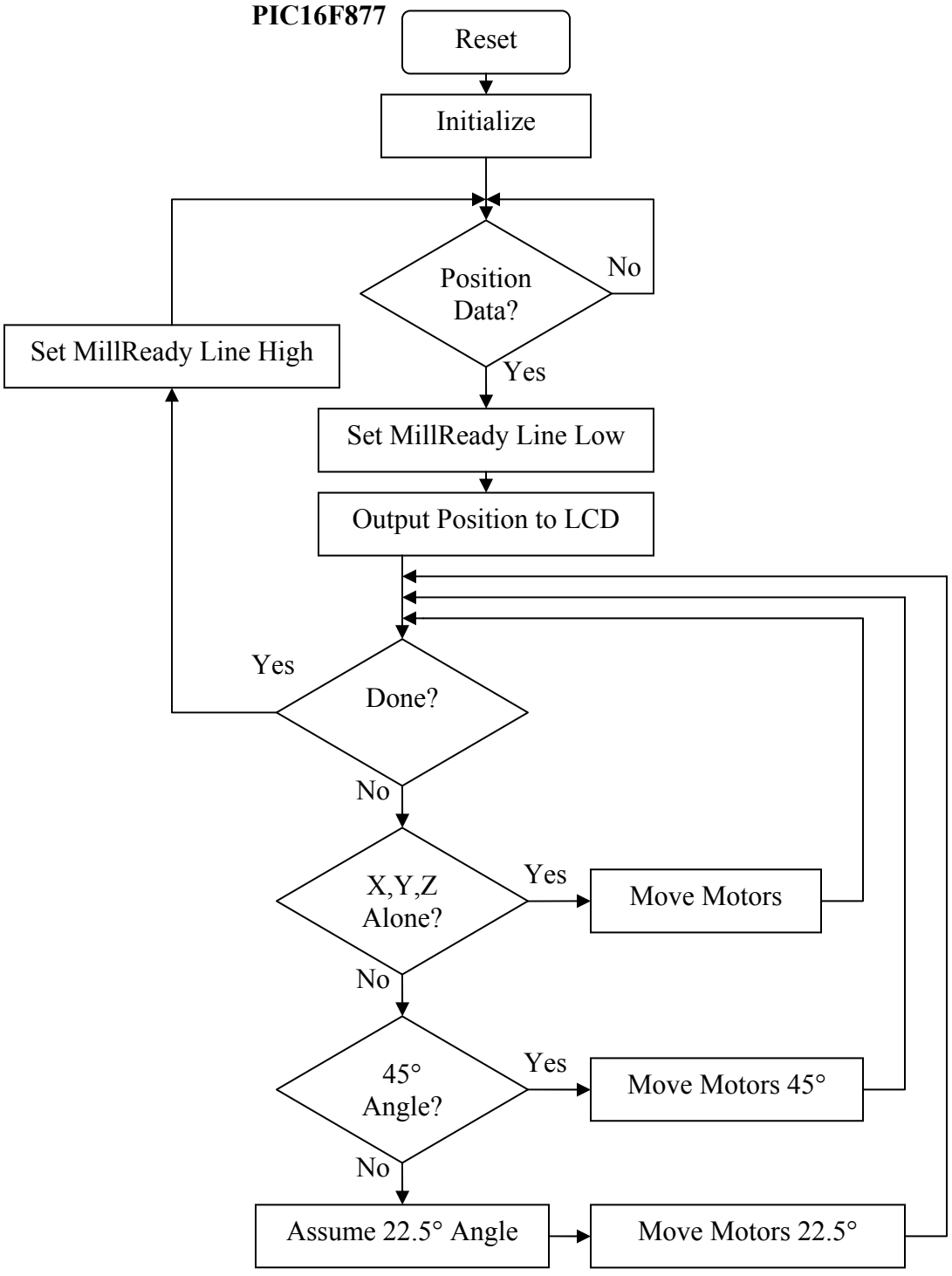
After a .KMF mill file has been loaded into the external RAM, pressing the "M" key will cause the R31JP to begin the milling process. The microcontroller waits until the MillReady line goes high, signifying that the mill is awaiting it's next command, and then sends 7 bytes of data to the PIC16F877 though the D8255AC-2 Peripheral Interface chip. The first byte is an instruction byte and currently does not affect the mill. The next six bytes correspond to the X, Y, and Z coordinates. For each axis, the most significant byte is sent first and is then folled by the least significant byte. See *Appendix C: PIC16F877 Timing Diagram,* for more information about how data is sent to the PIC16F877. Once all mill position data has been sent, a (0,0,0) position is sent to reset the mill to the origin and the user is returned to the main command dialog.

5. Implementing the PIC16F877

5.1 Purpose

The purpose of the PIC16F877 is to abstract away the complexities of moving the stepper motors to a position linearly, controlling an LCD, and handling 12 stepper motor control lines. This allows the R31JP to simply send the desired position to the PIC16F877 and let the PIC do the rest of the calculations and movement control. Since the PIC chip runs at nearly 5 times the speed of the R31JP (5MHz machine clock of the PIC compared to the 1MHz machine clock of the R31JP) it also allows for more timing flexibility than the R31JP can handle alone.

5.2 PIC16F877 Flowchart



5.3 Explanation

On startup, the mill assumes the position (0,0,0). All positions thereafter are relative to the startup position. Once all variables are initialized, the LCD is configured and the MillReady line is driven high to notify the R31JP that it is ready for a new position. Once a "goto" position has been received, the MillReady line is driven low and the LCD prints the desired destination.

The mill first moves to the (X,Y) position and then changes the Z-axis position if needed. Since most PCB HPGL files try to make all angles between coordinates a multiple of 22.5°, there are 3 basic routines that the PIC16F877 can choose from to most accurately trace out a linear path. If the difference between the "goto" position and the current postion only differs along a single axis, the motors responsible for that axis are the only ones that are driven. If the absolute value of the difference of both X and Y are the same, a multiple of 45° is chosen appropriately. This involves turning both the X and Y stepper motors at the same rate, but possibly different directions.

The last angular choice is 22.5°. Since the stepper motors now driven at different rates, an approximation is made. That is, since the arctan(2/5) is 21.8° with an error of only 0.7°, one axis is stepped 5 times for every 2 times that the other axis is stepped. This however does not result in an incorrect final placement since the algorithm chosen continuously calculates the difference between the current position and the "goto" position and responds accordingly. Thus, if an angle of 35° is desired, the mill will trace out a 22.5° angle until a 45° angle exists between the current and "goto" position. The mill will then move at 45° until it has successfully come to rest at the exact desired position.

Once the correct position has been achieved, the MillReady line is driven high to allow for the next postion to be sent from the R31JP. Since the R31JP always sends an origin vector (0,0,0) after the entire trace has been sent to the mill, the mill can be restarted and still retain the correct relative starting point.

6. PCB Mill Software (C++)

6.1 Purpose

The purpose of the PCB Mill software is to provide a graphical environment that allows the user to easily create, modify, visualize, and convert HPGL plotter files. Once the desired layout has been achieved it can be saved as either as a .HPGL file for later use or as a .KMF file which can be sent to the mill over the serial cable. The program also allows for error checking such as negative coordinates or improperly using a drill layer to draw a PCB trace.

6.2 Design Concepts

This piece of software was developed in Visual C++ due to the simplicity of implementing Graphical User Interfaces (GUIs). The graphical portion of the application was designed around a PaintBox object which uses the Canvas property to display an image. The core of the program focuses around a simple HPGL parser and interpreter. Since string manipulation is one of the drawbacks of C++, computation time while

parsing can be lengthy when processing long HPGL files. A 2x Zoom feature was also created to allow the user to more precisely inspect their design.

6.3 .KMF Mill File Format

The Kumpf Mill File (.KMF) format is very similar to the Intel Hex file format to allow for easy downloading to the R31JP. The main difference is that all data lines are the same length. (5 bytes)

:05[Adr-MSB][Adr-LSB][R][I][X-MSB][X-LSB][Y-MSB][Y-LSB][Checksum]

Adr-MSB = Load Address Most Significant Byte
Adr-LSB = Load Address Least Significant Byte
R = Record Type (00 = data; 01 = end)
I = Instruction (01 = move XY only;
02 = move XY, then move Z Up;
Else = move XY, then move Z Down to 'I')
X-MSB = X position Most Significant Byte
X-LSB = X position Least Significant Byte
Y-MSB = Y position Most Significant Byte
Y-LSB = Y position Least Significant Byte
Checksum = 2's compliment of sum of all preceding bytes (except ":")

6.4 HPGL (.PLT) Plotter File Format

The Hewlett-Packard Graphics Language (HPGL) is used to store 2-D drawings in an intuitive format that resembles picking-up, moving, and putting down a collection of pens. HPGL files are often saved with the extension .PLT to signify that they are used for plotting.

The basic HPGL commands:

SP# = Select Pen #
PU = Pen Up
PD = Pen Down
PA[X],[Y] = Position Absolute X,Y
(move to a position relative to the origin)
; = command terminator

The position of the plotter is specified in "plu"s. (plotter units)
1 Inch = 1016 plu's.

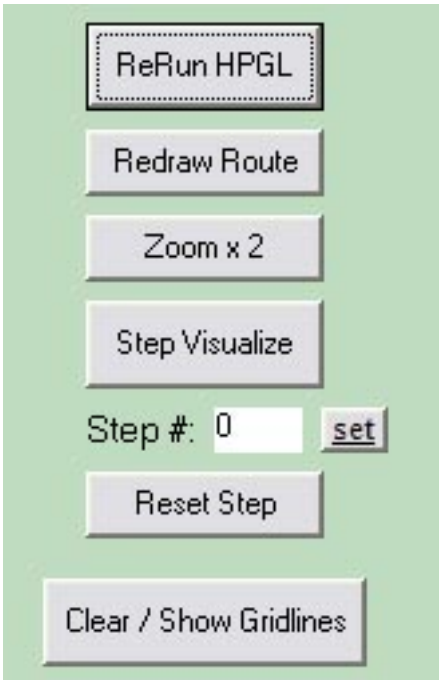
HPGL example:

```
SP3;
PA2540,6096;PD;
PA2286,5080;
PA2032,4953;
PA2032,4953;PU;
```

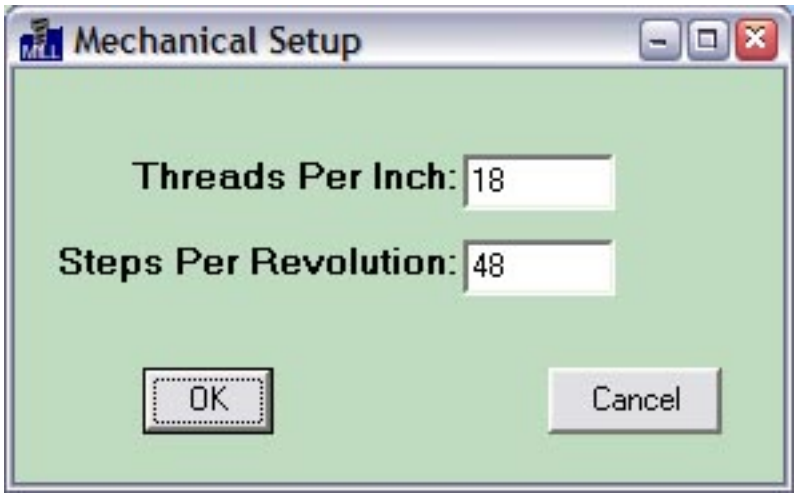
6.5 Features

- 8”x8” work area identical to the Mill
- Error checking for negative coordinates
- Visual window to display trace and drilling of the mill
- Ability to step through HPGL files
- 1/8” snap grid and guidelines for easy alignment
- Save both KMF and HPGL files
- Ability to override milling depth and snap grid coordinates
- Customize Threads per Inch and Steps per Revolution
- Zoom by a factor of 2 and move in real-time
- Print out traces and drills to scale

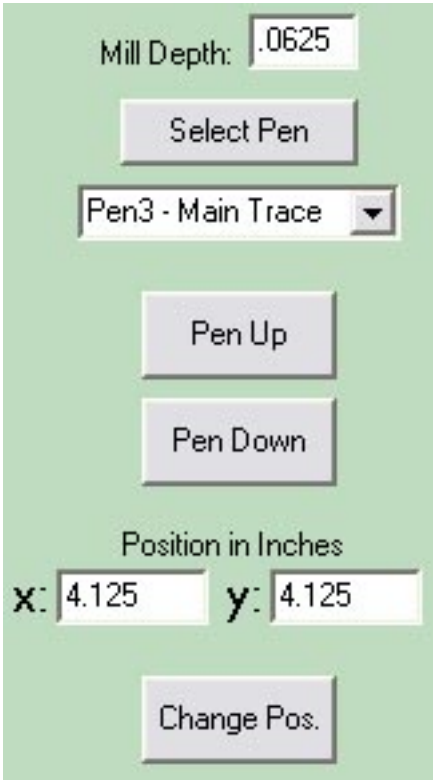
6.6 Screenshots



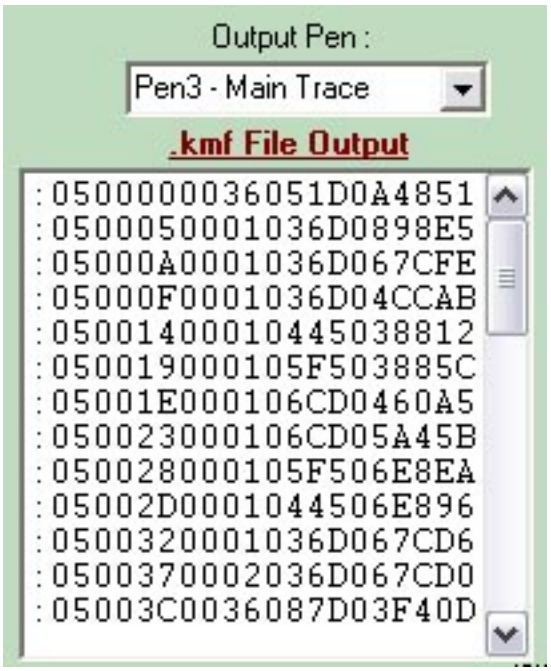
Visualization Control Panel



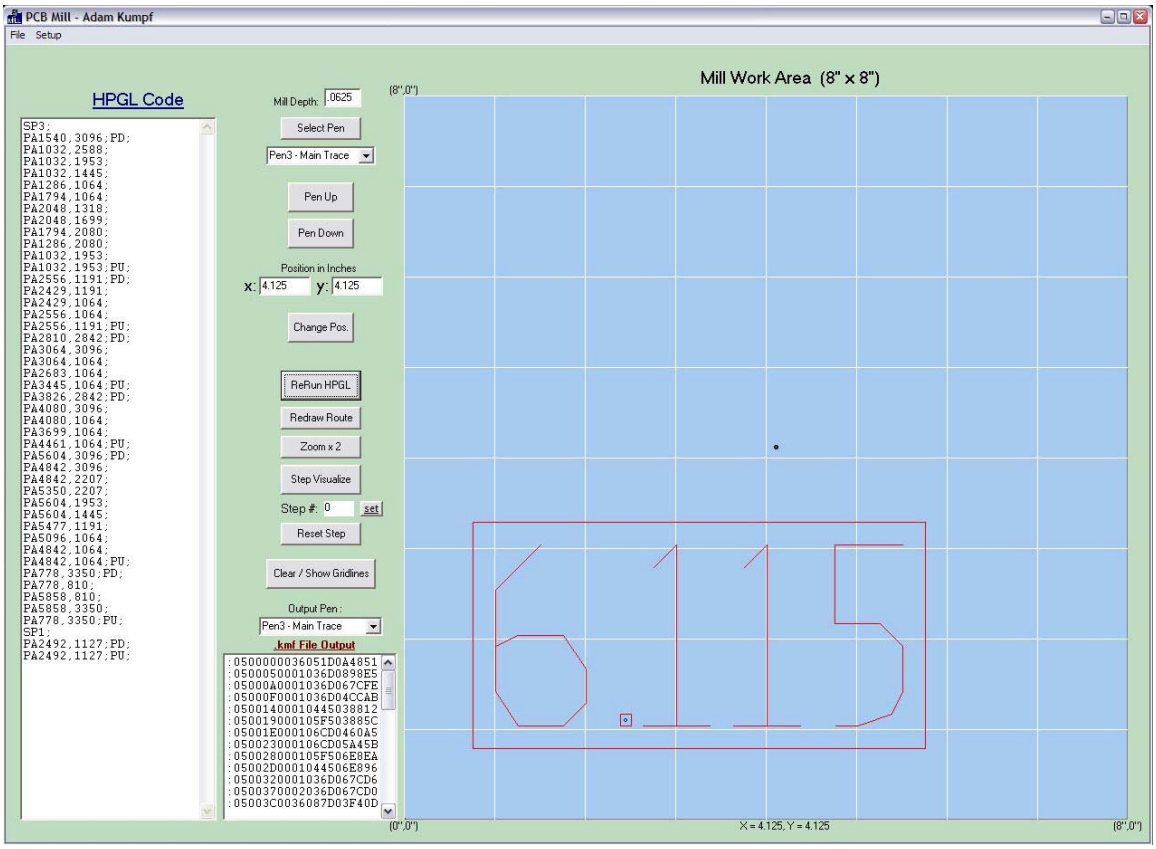
Mechanical Setup Dialog



Position Control Layout



.KMF File Output Window



Entire PCB Mill Application Window

7. Problems and Improvement Ideas

The main problems I encountered with the PCB Mill were related to the mechanical system. It seems as though the threaded rods that I used had a slight bend to them. This causes the 8"x8" work area platform to move in a sinusoidal manner as the stepper motors turn. If the rods were straight, I believe the mill would work much better than it currently does.

A solution to the problem might be to add a few guide rails that keep each axis running straight and true. A simple felt-lined wooden shim may be all that's needed to minimize the undesired vertical and horizontal movements.

Another problem was making a drill chuck for the AC motor that was relatively precise. If the milling/drill bit is not centered well, the resulting cut will be too large and the vibrations caused by it may drastically shorten the life of the machine.

Perhaps the best way to solve this problem would be to make sure the AC motor shaft used has the same diameter as the drill chuck such that they can be easily coupled. It is also important to balance the drill chuck to minimize vibrations.

One final improvement would be to take out one of the microcontrollers to simplify the design. Since the R31JP controller board contains many components and is fairly large in size, I think it would be good to try doing everything on the PIC16F877. The system could then be practical enough that people from all over could reproduce this project fairly easily.

Appendixes:

Appendix A: R31JP Code

```
;   ************************************************
;   *                                              *
;   *  MINMON - The Minimal 8051 Monitor Program   *
;   *                                              *
;   *  Portions of this program are courtesy of    *
;   *  Rigel Corporation, of Gainesville, Florida  *
;   *                                              *
;   *  Modified for 6.115                          *
;   *  Massachusetts Institute of Technology       *
;   *  January, 2001  Steven B. Leeb               *
;   *  May 2003, Adam A. Kumpf                     *
;   *                                              *
;   ************************************************
stack  equ  2fh           ; bottom of stack
                          ; - stack starts at 30h -
errorf equ   0            ; bit 0 is error status
TXdata equ  90            ; Data to be transmitted to the PIC
InstByte equ 91           ; Instruction byte
LastZcoor equ 92    ; Hold last value of Z Position.
;=====================================================================
; 8032 hardware vectors
;=====================================================================
   org 00h                ; power up and reset vector
   ljmp start
   org 03h                ; interrupt 0 vector
   ljmp start
   org 0bh                ; timer 0 interrupt vector
   ljmp start
   org 13h                ; interrupt 1 vector
   ljmp start
   org 1bh                ; timer 1 interrupt vector
   ljmp start
   org 23h                ; serial port interrupt vector
   ljmp start
   org 2bh                ; 8052 extra interrupt vector
   ljmp start
;=====================================================================
; begin main program
;=====================================================================
   org     100h           ; 100h     ;;; CHANGE FOR ROM!!!!!!
start:
   clr     ea             ; disable interrupts
   lcall   init           ; initialize hardware
   lcall   print          ; print welcome message
   db 0ah, 0dh, 0ah, 0dh, 0ah, 0dh
   db "                                  | |                ", 0ah, 0dh
   db "                                  |z|          y     ", 0ah, 0dh
   db "     +------------------+    +--\\|/--------+       ", 0ah, 0dh
   db "     |      6.115       |   /    V        /+       ", 0ah, 0dh
   db   "     |     PCB Mill     |  /  .__/       //        ", 0ah, 0dh
   db "     |    Adam Kumpf    | +_____________+/         ", 0ah, 0dh
   db   "     +------------------+ +=============+ ->x      ", 0ah, 0dh
```

```
   db   "                                                          ", 0ah, 0dh
   db "(Download/Mill/Goto/Read/Write/Vector)", 0h

monloop:
   mov     sp,#stack      ; reinitialize stack pointer
   clr     ea             ; disable all interrupts
   clr     errorf         ; clear the error flag
   lcall   print          ; print prompt
   db 0dh, 0ah,"PCB Mill:> ", 0h
   clr     ri             ; flush the serial input buffer
   lcall   getcmd         ; read the single-letter command
   mov     r2, a          ; put the command number in R2
   ljmp    nway           ; branch to a monitor routine
endloop:                  ; come here after command has finished
   sjmp monloop           ; loop forever in monitor loop
;=================================================================
; subroutine init
; this routine initializes the hardware
; set up serial port with a 11.0592 MHz crystal,
; use timer 1 for 9600 baud serial communications
;=================================================================
init:
   mov   tmod, #20h       ; set timer 1 for auto reload - mode 2
   mov   tcon, #41h       ; run counter 1 and set edge trig ints
   mov   th1,  #0fdh      ; set 9600 baud with xtal=11.059mhz
   mov   scon, #50h       ; set serial control reg for 8 bit data
                          ; and mode 1
   mov   DPTR, #0xfe03h   ; DPTR = Peripheral Chip (control)
   mov       a, #0x80h    ;
   movx @DPTR, a    ; Set all Ports A,B,C as Outputs.
   ret
;=================================================================
; monitor jump table
;=================================================================
jumtab:
   dw badcmd              ; command '@' 00
   dw badcmd              ; command 'a' 01
   dw badcmd              ; command 'b' 02
   dw badcmd              ; command 'c' 03
   dw downld              ; command 'd' 04 Download
   dw badcmd              ; command 'e' 05
   dw badcmd              ; command 'f' 06
   dw goaddr              ; command 'g' 07 goto
   dw badcmd              ; command 'h' 08
   dw badcmd              ; command 'i' 09
   dw badcmd              ; command 'j' 0a
   dw badcmd              ; command 'k' 0b
   dw badcmd              ; command 'l' 0c
   dw mill                ; command 'm' 0d Mill
   dw badcmd              ; command 'n' 0e
   dw badcmd              ; command 'o' 0f
   dw badcmd              ; command 'p' 10
   dw badcmd              ; command 'q' 11
   dw readbt              ; command 'r' 12 read
   dw badcmd              ; command 's' 13
   dw badcmd              ; command 't' 14
   dw badcmd              ; command 'u' 15
```

```
   dw vectwr              ; command 'v' 16 vector wite
   dw writebt             ; command 'w' 17 write
   dw badcmd              ; command 'x' 18
   dw badcmd              ; command 'y' 19
   dw badcmd              ; command 'z' 1a

;****************************************************************
; monitor command routines
;****************************************************************
;================================================================
; command goaddr  'g'
; this routine branches to the 4 hex digit address which follows
;================================================================
goaddr:
   lcall getbyt           ; get address high byte
   mov   r7, a            ; save in R7
   lcall prthex
   lcall getbyt           ; get address low byte
   push  acc              ; push lsb of jump address
   lcall prthex
   lcall crlf
   mov   a, r7            ; recall address high byte
   push  acc              ; push msb of jump address
   ret                    ; do jump by doing a ret
;================================================================
; command downld  'd'
; this command reads in an Intel hex file from the serial port
; and stores it in external memory.
;================================================================
downld:
   lcall   print        ; print "Ready to Receive .kmf File"
   db 0ah, 0dh, "Ready to Receive .kmf File", 0h
   lcall crlf
   mov   a, #'>'          ; acknowledge by a '>'
   lcall sndchr
dl:
   lcall getchr           ; read in ':'
   cjne  a,  #':', dl
   lcall getbytx          ; get hex length byte
   jz    enddl            ; if length=0 then return
   mov   r0, a            ; save length in r0
   lcall getbytx          ; get msb of address
   setb  acc.7            ; make sure it is in RAM
   mov   dph, a           ; save in dph
   lcall getbytx          ; get lsb of address
   mov   dpl, a           ; save in dpl
   lcall getbytx          ; read in special purpose byte (ignore)
dloop:
   lcall getbytx          ; read in data byte
   movx  @dptr, a         ; save in ext mem
   inc   dptr             ; bump mem pointer
   djnz  r0, dloop        ; repeat for all data bytes in record
   lcall getbytx          ; read in checksum, but ignore
   mov   a,  #'.'
   lcall sndchr           ; handshake '.'
   sjmp  dl               ; read in next record
enddl:
```

```
   lcall getbytx          ; read in remainder of the
   lcall getbytx          ; termination record
   lcall getbytx
   lcall getbytx
   mov   a,  #'.'
   lcall sndchr           ; handshake '.'
   mov a, #0x00h    ; store "zero" byte to end download.
   movx  @dptr, a         ; save in ext mem
   ljmp  endloop          ; return
getbytx:
   lcall getbyt
   jb    errorf, gb_err
   ret
gb_err:
   ljmp badpar

;***************************************************************
; monitor support routines
;***************************************************************
badcmd:
   lcall print
   db 0dh, 0ah," bad command ", 0h
   ljmp endloop
badpar:
   lcall print
   db 0dh, 0ah," bad parameter ", 0h
   ljmp endloop
;===============================================================
; subroutine getbyt
; this routine reads in an 2 digit ascii hex number from the
; serial port. the result is returned in the acc.
;===============================================================
getbyt:
   lcall getchr           ; get msb ascii chr
   lcall ascbin           ; conv it to binary
   swap  a                ; move to most sig half of acc
   mov   b,  a            ; save in b
   lcall getchr           ; get lsb ascii chr
   lcall ascbin           ; conv it to binary
   orl   a,  b            ; combine two halves
   ret
;===============================================================
; subroutine getcmd
; this routine gets the command line.  currently only a
; single-letter command is read - all command line parameters
; must be parsed by the individual routines.
;
;===============================================================
getcmd:
   lcall getchr           ; get the single-letter command
   clr   acc.5            ; make upper case
   lcall sndchr           ; echo command
   clr   C                ; clear the carry flag
   subb  a, #'@'          ; convert to command number
   jnc   cmdok1           ; letter command must be above '@'
   lcall badpar
cmdok1:
```

```
   push  acc              ; save command number
   subb  a, #1Bh          ; command number must be 1Ah or less
   jc    cmdok2
   lcall badpar           ; no need to pop acc since badpar
                          ; initializes the system
cmdok2:
   pop   acc              ; recall command number
   ret
;===============================================================
; subroutine nway
; this routine branches (jumps) to the appropriate monitor
; routine. the routine number is in r2
;===============================================================
nway:
   mov   dptr, #jumtab    ;point dptr at beginning of jump table
   mov   a, r2            ;load acc with monitor routine number
   rl    a                ;multiply by two.
   inc   a                ;load first vector onto stack
   movc  a, @a+dptr       ;         "          "
   push  acc              ;         "          "
   mov   a, r2            ;load acc with monitor routine number
   rl    a                ;multiply by two
   movc  a, @a+dptr       ;load second vector onto stack
   push  acc              ;         "          "
   ret                    ;jump to start of monitor routine


;*****************************************************************
; general purpose routines
;*****************************************************************
;===============================================================
; subroutine sndchr
; this routine takes the chr in the acc and sends it out the
; serial port.
;===============================================================
sndchr:
   clr  scon.1            ; clear the tx  buffer full flag.
   mov  sbuf,a            ; put chr in sbuf
txloop:
   jnb  scon.1, txloop    ; wait till chr is sent
   ret
;===============================================================
; subroutine getchr
; this routine reads in a chr from the serial port and saves it
; in the accumulator.
;===============================================================
getchr:
   jnb  ri, getchr        ; wait till character received
   mov  a,  sbuf          ; get character
   anl  a,  #7fh          ; mask off 8th bit
   clr  ri                ; clear serial status bit
   ret
;===============================================================
; subroutine print
; print takes the string immediately following the call and
; sends it out the serial port.  the string must be terminated
; with a null. this routine will ret to the instruction
```

```
; immediately following the string.
;=============================================================
print:
   pop   dph              ; put return address in dptr
   pop   dpl
prtstr:
   clr  a                 ; set offset = 0
   movc a,  @a+dptr       ; get chr from code memory
   cjne a,  #0h, mchrok   ; if termination chr, then return
   sjmp prtdone
mchrok:
   lcall sndchr           ; send character
   inc   dptr             ; point at next character
   sjmp  prtstr           ; loop till end of string
prtdone:
   mov   a,  #1h          ; point to instruction after string
   jmp   @a+dptr          ; return
;=============================================================
; subroutine crlf
; crlf sends a carriage return line feed out the serial port
;=============================================================
crlf:
   mov   a,  #0ah         ; print lf
   lcall sndchr
cret:
   mov   a,  #0dh         ; print cr
   lcall sndchr
   ret
;=============================================================
; subroutine prthex
; this routine takes the contents of the acc and prints it out
; as a 2 digit ascii hex number.
;=============================================================
prthex:
   push acc
   lcall binasc           ; convert acc to ascii
   lcall sndchr           ; print first ascii hex digit
   mov   a,  r2           ; get second ascii hex digit
   lcall sndchr           ; print it
   pop acc
   ret
;=============================================================
; subroutine binasc
; binasc takes the contents of the accumulator and converts it
; into two ascii hex numbers.  the result is returned in the
; accumulator and r2.
;=============================================================
binasc:
   mov   r2, a            ; save in r2
   anl   a,  #0fh         ; convert least sig digit.
   add   a,  #0f6h        ; adjust it
   jnc   noadj1           ; if a-f then readjust
   add   a,  #07h
noadj1:
   add   a,  #3ah         ; make ascii
   xch   a,  r2           ; put result in reg 2
   swap  a                ; convert most sig digit
```

```
   anl   a,  #0fh         ; look at least sig half of acc
   add   a,  #0f6h        ; adjust it
   jnc   noadj2           ; if a-f then re-adjust
   add   a,  #07h
noadj2:
   add   a,  #3ah         ; make ascii
   ret

;===============================================================
; subroutine ascbin
; this routine takes the ascii character passed to it in the
; acc and converts it to a 4 bit binary number which is returned
; in the acc.
;===============================================================
ascbin:
   clr   errorf
   add   a,  #0d0h        ; if chr > 30 then error
   jnc   notnum
   clr   c                ; check if chr is 0-9
   add   a,  #0f6h        ; adjust it
   jc    hextry           ; jmp if chr not 0-9
   add   a,  #0ah         ; if it is then adjust it
   ret
hextry:
   clr   acc.5            ; convert to upper
   clr   c                ; check if chr is a-f
   add   a,  #0f9h        ; adjust it
   jnc   notnum           ; if not a-f then error
   clr   c                ; see if char is 46 or less.
   add   a,  #0fah        ; adjust acc
   jc    notnum           ; if carry then not hex
   anl   a,  #0fh         ; clear unused bits
   ret
notnum:
   setb  errorf           ; if not a valid digit
   ljmp  endloop


;===============================================================
; mon_return is not a subroutine.
; it simply jumps to address 0 which resets the system and
; invokes the monitor program.
; A jump or a call to mon_return has the same effect since
; the monitor initializes the stack.
;===============================================================
mon_return:
   ljmp  0


;===============================================================
; command readbt  'R'
; this routine reads the 4 hex digit address which follows
;===============================================================
readbt:
   lcall getbyt           ; get address high byte
   mov   dph, a           ; put in DPH
   lcall prthex
```

```
   lcall getbyt           ; get address low byte
   mov       dpl, a             ; put in DPL
   lcall prthex
   lcall crlf
   movx  a, @DPTR         ; move data from RAM (at DPTR)
   lcall prthex           ; get hex digits and prints them
   ljmp  endloop

;=================================================================
; command readbt  'W'
; this routine Writes data into the 4 hex digit address
;=================================================================
writebt:
   lcall getbyt           ; get address high byte
   mov   dph, a           ; put in DPH
   lcall prthex
   lcall getbyt           ; get address low byte
   mov       dpl, a             ; put in DPL
   lcall prthex
   mov a, #3dh            ; print "="
   lcall  sndchr
   lcall getbyt           ; get data to be written
   lcall prthex
   movx  @DPTR, a         ; move data to External RAM
   ljmp  endloop

;=================================================================
; command readbt  'V'
; this routine Writes 256 data byte into the 4 hex digit address (+256)
;=================================================================
vectwr:
   lcall   print        ; print "Ready for Hex Address of Vector Write"
   db 0ah, 0dh, "Ready for Hex Address of Vector Write", 0ah, 0dh, "*",
0h
   lcall getbyt         ; get address high byte
   mov dph, a           ; put in DPH
   lcall prthex         ; print value
   lcall getbyt         ; get address low byte
   mov       dpl, a           ; put in DPL
   lcall prthex         ; print value
   mov r6, #00h         ; set loop to 256 times

vectloop:
   lcall crlf           ; carraige return, new line
   mov a, dph           ; get DPH
   lcall prthex         ; print it
   mov a, dpl           ; get DPL
   lcall prthex         ; print it
   mov a, #3dh          ; print "="
   lcall  sndchr

   lcall getbyt         ; get data to be written
   lcall prthex
   movx  @DPTR, a       ; move data to External RAM
   inc DPTR             ; move to next location
   djnz r6, vectloop    ; JMP when r6 != 0
   ljmp endloop         ; otherwise, goto endloop
```

```
;=============================================================
; command readbt  'M'
; this routine Runs the Mill
;=============================================================
mill:
   lcall   print        ; print " Milling"
   db 0ah, 0dh, " Milling:", 0h
   lcall mill_init      ; Setup Mill

mill_loop
   jnb P3.5, mill_loop  ; Wait for Mill Ready line to go high

   movx a, @DPTR
   mov InstByte, a
   jnz keep_milling     ; is value zero?
   lcall   print        ; print " Milling Complete - Returning to
Origin"
   db 0ah, 0dh, " Milling Complete - Returning to Origin", 0ah, 0dh, 0h
   ljmp lastmill
keep_milling:
   lcall mill_send      ; send Instruction Byte (currently not used.)
   inc DPTR             ; Get and Send XgotoH
   movx a, @DPTR
   mov TXdata, a
   lcall mill_send
   inc DPTR             ; Get and Send XgotoL
   movx a, @DPTR
   mov TXdata, a
   lcall mill_send
   inc DPTR             ; Get and Send YgotoH
   movx a, @DPTR
   mov TXdata, a
   lcall mill_send
   inc DPTR             ; Get and Send YgotoL
   movx a, @DPTR
   mov TXdata, a
   lcall mill_send
   mov TXdata, #0x00h   ; write ZgotoH (zero for now)
   lcall mill_send

   mov a, InstByte                  ; move Instruction Byte to Accum
   cjne  a,  #0x01h, mill_newZ      ; Simply change x&y position (no Z
movement)

   mov a, LastZcoor     ; write ZgotoL (LastZcoor)
   mov TXdata, a
   lcall mill_send
   ljmp milling_shake   ; send handshake (skip mill_newZ)

mill_newZ:
   mov a, InstByte      ; ZgotoL (Instruction)

   cjne a, #0x02h, mill_Zdown ; check to see if mill is going down/up

   mov LastZcoor, #0x00h      ; Mill going up - set position to Zero.
   mov TXdata, #0x00h
```

```
   lcall mill_send      ; write ZgotoL (Zero)
   ljmp milling_shake   ; send handshake (skip mill_Zdown)

mill_Zdown:
   mov a, InstByte      ; ZgotoL (Instruction)
   mov LastZcoor, a     ; save Z coor for next time through
   mov TXdata, a        ; write ZgotoL (Instruction)
   lcall mill_send

milling_shake:
   mov   a,  #'*'
   lcall sndchr         ; handshake '.'
   inc DPTR
   ljmp mill_loop       ; repeat until finished


lastmill:

   lcall mill_send      ; send Instruction Byte (currently not used.)
   mov TXdata, #0x00h
   lcall mill_send      ; Send XgotoH = 0 (origin)
   lcall mill_send      ; Send XgotoL = 0 (origin)
   lcall mill_send      ; Send YgotoH = 0 (origin)
   lcall mill_send      ; Send YgotoL = 0 (origin)
   lcall mill_send      ; Send ZgotoH = 0 (origin)
   lcall mill_send      ; Send ZgotoL = 0 (origin)
lastmill_wait:
   jnb P3.5, lastmill_wait    ; Wait for Mill Ready line to go high

   lcall   print        ; print "Mill Ready...
(Download/Mill/Goto/Read/Write/Vector)"
   db "Mill Ready...",0ah, 0dh,
"(Download/Mill/Goto/Read/Write/Vector)", 0h

   ljmp endloop         ; return to main prompt.




mill_init:
   mov DPTR, #0x8000h   ; Set DPTR to first location in RAM
   ret

mill_send:
  push dph
  push dpl

  mov DPTR, #0xfe01h
  mov a, TXdata
  movx @DPTR, a         ; Move data to PORTB
  nop
  nop
  mov DPTR, #0xfe02h
  mov a, #0x01h
  movx @DPTR, a         ; set enable high
  nop
  nop
```

```
  mov a, #0x00h
  movx @DPTR, a          ; set enable low

  pop dpl
  pop dph
  ret
```

Appendix B: PIC16F877 Code

```
;#####################################################################
;#                                                                   #
;#             This Program takes in 3 16-bit values and sends       #
;#             the correct output to stepper motors (x, y, z)        #
;#             which can then be used to control a Milling Machine.  #
;#                                                                   #
;#                                                                   #
;#####################################################################

;; Definitions: format "[7,6,5,4,3,2,1,0]"
;;      PORTB(output) = [DB7,DB6,DB5,DB4,E,R/W,RS,x] (LCD)
;;  PORTA(output) = [x,x,x,x,Zd,Zc,Zb,Za]
;;  PORTD(output) = [Yd,Yc,Yb,Ya,Xd,Xc,Xb,Xa]
;;  PORTC(Input)  = [d7,d6,d5,d4,d3,d2,d1,d0] (From R31JP)
;;  PORTE(In/Out) = [x,x,x,x,x,x,MillReady(o),Enable(i)]



       list p=16f877
       include <p16F877.inc>


;########################################
;#  Variable Declarations (0x20 - 0x7f)  #
;########################################

d0      equ     0x20           ; General Temp Varaible
d1      equ     0X21           ; General Temp Varaible
d2      equ     0x22           ; General Temp Varaible
d3      equ     0x23           ; General Temp Varaible
d4      equ     0x24           ; General Temp Varaible

XcoorL  equ     0x25    ; Current X Coordinate (LSB)
XcoorH  equ     0x26    ; Current X Coordinate (MSB)
YcoorL  equ     0x27    ; Current Y Coordinate (LSB)
YcoorH  equ     0x28    ; Current Y Coordinate (MSB)
ZcoorL  equ     0x29    ; Current Z Coordinate (LSB)
ZcoorH  equ     0x2a    ; Current Z Coordinate (MSB)

XgotoL  equ     0x2b    ; goto X Coordinate (LSB)
XgotoH  equ     0x2c    ; goto X Coordinate (MSB)
YgotoL  equ     0x2d    ; goto Y Coordinate (LSB)
YgotoH  equ     0x2e    ; goto Y Coordinate (MSB)
ZgotoL  equ     0x2f    ; goto Z Coordinate (LSB)
ZgotoH  equ     0x30    ; goto Z Coordinate (MSB)

Xcurstep equ 0x31      ; X stepper motor position
Ycurstep equ 0x32      ; Y stepper motor position
Zcurstep equ 0x33      ; Z stepper motor position

NumH equ 0x34          ; variables for BCD conversion
NumL equ 0x35          ; variables for BCD conversion
TenK equ 0x36          ; Ten Thousands place
```

```
Thou equ 0x37          ; Thousands place
Hund equ 0x38          ; Hundreds place
Tens equ 0x39          ; Tens place
Ones equ 0x3a          ; Ones place

tmp0    equ     0x3b    ; LCD temp varaible
tmp1    equ     0x3c    ; LCD temp varaible
tmp2    equ     0x3d    ; LCD temp varaible
tmp3    equ     0x3e    ; LCD temp varaible

Xpostemp equ 0x3f      ; X position temp variable
Ypostemp equ 0x40      ; Y position temp variable
Zpostemp equ 0x41      ; Z position temp variable

XdifL   equ     0x42    ; delta X Coordinate (LSB)
XdifH   equ     0x43    ; delta X Coordinate (MSB)
YdifL   equ     0x44    ; delta Y Coordinate (LSB)
YdifH   equ     0x45    ; delta Y Coordinate (MSB)
ZdifL   equ     0x46    ; delta Z Coordinate (LSB)
ZdifH   equ     0x47    ; delta Z Coordinate (MSB)

XYZdifFlags equ 0x48   ; X diff Flags [(all are zero),(x & y are
zero),(Z=neg),(Y=neg),(X=neg),(Z is Zero=1),(Y is Zero=1),(X is Zero=1)]

Angletmp1 equ 0x49     ; Temp Variable for Angle Decider
XposL   equ 0x4a       ; abs(XdifL)
XposH   equ 0x4b       ; abs(XdifH)
YposL   equ 0x4c       ; abs(YdifL)
YposH   equ 0x4d       ; abs(YdifH)
XnegL   equ 0x4e       ; Negative of XposL
XnegH   equ 0x4f       ; Negative of XposH

MillReady equ 0x50     ; Set to 1 when Mill is Ready for next instruction.
MillInst  equ 0x51     ; Mill Instruction from R31JP

;########################################
;#           Control Byte                           #
;########################################
        __CONFIG _CP_OFF & _DEBUG_OFF & _WRT_ENABLE_OFF & _CPD_OFF & _LVP_OFF & _BODEN_OFF
& _HS_OSC & _PWRTE_OFF & _WDT_OFF

;########################################
;#        Beginning of Program                    #
;########################################
start
        org     0x00    ; Reset Vector
start
        call setup
        goto Main

        org 0x04        ; Interrupt Vector

        org 0x100
Main
        bcf             STATUS, C
        movlw   0x60    ;f              = -> 1
        movwf   tmp1    ;               w>f, ->0
        movlw   0x50    ;w              w<f, ->1
        subwf   tmp1, w
        nop



        call    p_ready                 ; Print   " Ready... " to LCD firstline
        call    p_position              ; Print current position to LCD secondline
        call    Delay
        call    p_going                 ; print   "  Going to... " to LCD firstline
        call    p_gotopos               ; print position device is going to, LCD secondline
Main_MoveMill
        call    Find_Difs               ; Compute X,Y,Z difference from current values
        call    CalcDifBits             ; calculate X,Y,Z differnce flag bits(neg/Zero)
```

```
        call    MoveMotors
        call    step_delay              ; stepper motor delay
        btfss   MillReady, 0            ; Check if Mill is done working.
        goto    Main_MoveMill

Main_newPos1
        bsf     PORTE, 1                ; Ready for instruction...
        btfss   PORTE, 0                ; Wait for Instruction from R31JP
        goto    Main_newPos1
Main_newPos2
        movf    PORTC, w                ; get Mill Instruction
        movwf   MillInst
        bcf     MillReady, 0
        bcf     PORTE, 1                ; Clear MillReady bit for next time.
Main_newPos3
        btfsc   PORTE, 0                ; wait for Enable to clear.
        goto    Main_newPos3
Main_newPos4
        btfss   PORTE, 0                ; wait for Enable to go High.
        goto    Main_newPos4
Main_newPos5
        movf    PORTC, w                ; get Mill XgotoH
        movwf   XgotoH
Main_newPos6
        btfsc   PORTE, 0                ; wait for Enable to clear.
        goto    Main_newPos6

Main_newPos7
        btfss   PORTE, 0                ; wait for Enable to go High.
        goto    Main_newPos7
Main_newPos8
        movf    PORTC, w                ; get Mill XgotoL
        movwf   XgotoL
Main_newPos9
        btfsc   PORTE, 0                ; wait for Enable to clear.
        goto    Main_newPos9

Main_newPos10
        btfss   PORTE, 0                ; wait for Enable to go High.
        goto    Main_newPos10
Main_newPos11
        movf    PORTC, w                ; get Mill YgotoH
        movwf   YgotoH
Main_newPos12
        btfsc   PORTE, 0                ; wait for Enable to clear.
        goto    Main_newPos12

Main_newPos13
        btfss   PORTE, 0                ; wait for Enable to go High.
        goto    Main_newPos13
Main_newPos14
        movf    PORTC, w                ; get Mill YgotoL
        movwf   YgotoL
Main_newPos15
        btfsc   PORTE, 0                ; wait for Enable to clear.
        goto    Main_newPos15

Main_newPos16
        btfss   PORTE, 0                ; wait for Enable to go High.
        goto    Main_newPos16
Main_newPos17
        movf    PORTC, w                ; get Mill ZgotoH
        movwf   ZgotoH
Main_newPos18
        btfsc   PORTE, 0                ; wait for Enable to clear.
        goto    Main_newPos18

Main_newPos19
        btfss   PORTE, 0                ; wait for Enable to go High.
        goto    Main_newPos19
Main_newPos20
```

```
        movf    PORTC, w              ; get Mill ZgotoL
        movwf   ZgotoL
Main_newPos21
        btfsc   PORTE, 0              ; wait for Enable to clear.
        goto    Main_newPos21

        call    p_going               ; print   "  Going to... " to LCD firstline
        call    p_gotopos             ; print position device is going to, LCD secondline
        goto    Main_MoveMill  ; Everything's ok.. Move the Mill.



setup
        bsf     STATUS, RP0           ; Control Page
        movlw   b'00000000'
        movwf   TRISB                 ; Set PORTB = Output to LCD display
        movwf   TRISD                 ; Set PORTD = Output of x & y stepper motors
        movwf   TRISA                 ; Set PORTA = Output of z stepper
        movlw   b'11111111'
        movwf   TRISC                 ; Set PORTE = Input data from R31JP
        movlw   b'00000101'
        movwf   TRISE                 ; Set PORTE = Input E line and Output MillReady
        movlw   b'00000111'
        movwf   ADCON1                ; allow PORTE to be used an digital inputs.
        bcf     STATUS, RP0           ; Clear Control Page
        movlw   b'01110111'
        movwf   PORTD
        bsf     PORTE, 1
        bcf     PORTE, 1              ; not ready for instruction yet.
        call    initialize            ; Setup LCD
        movlw   0x00
        movwf   XcoorL                ; startup with pos = (0,0,0)
        movwf   XcoorH                ; startup with pos = (0,0,0)
        movlw   0x00
        movwf   YcoorL                ; startup with pos = (0,0,0)
        movwf   YcoorH                ; startup with pos = (0,0,0)
        movlw   0x00
        movwf   ZcoorL                ; startup with pos = (0,0,0)
        movwf   ZcoorH                ; startup with pos = (0,0,0)
        movlw   0x00
        movwf   XgotoL                ; startup with goto pos = (0,0,0)
        movwf   XgotoH                ; startup with goto pos = (0,0,0)
        movwf   YgotoL                ; startup with goto pos = (0,0,0)
        movwf   YgotoH                ; startup with goto pos = (0,0,0)
        movwf   ZgotoL                ; startup with goto pos = (0,0,0)
        movwf   ZgotoH                ; startup with goto pos = (0,0,0)
        movlw   b'01110111'
        movwf   Xcurstep              ; startup with current stepper pos = 0x77
        movwf   Ycurstep              ; startup with current stepper pos = 0x77
        movwf   Zcurstep              ; startup with current stepper pos = 0x77

        clrf    XdifL                 ; Set difference values to 0 at startup
        clrf    XdifH                 ; Set difference values to 0 at startup
        clrf    YdifL                 ; Set difference values to 0 at startup
        clrf    YdifH                 ; Set difference values to 0 at startup
        clrf    ZdifL                 ; Set difference values to 0 at startup
        clrf    ZdifH                 ; Set difference values to 0 at startup
        clrf    MillReady             ; start mill off not ready yet.
        return


;########################################
;#      Inc/Dec Move Loop Routines      #
;########################################

MoveMotors
        btfsc   XYZdifFlags, 7        ; Are all differences zero?
        goto    motors_all_zero
        btfsc   XYZdifFlags, 6        ; Are just X and Y zero? (Z may be non-zero here)
        goto    motors_just_z
                                      ; Must be X or Y or both here... (Z not allowed)
```

```
        btfsc   XYZdifFlags, 0          ; Is X zero?
        goto    motors_y_alone          ; Must be Y difference Alone

        btfsc   XYZdifFlags, 1          ; Is Y zero? (if so, then X is difference alone)
        goto    motors_x_alone
                                        ; Must be Both X And Y movement!
                                        ; (no X & Y & Z allowed)


        movf    XdifH, w
        movwf   XposH
        movf    XdifL, w
        movwf   XposL
        movf    YdifH, w
        movwf   YposH
        movf    YdifL, w
        movwf   YposL

                                        ; Calculate Absolute value of Xdif and Ydif
        btfss   XdifH, 7
        goto    Xnotneg
                                        ; 2's Compliment to get Positive value!
        bcf     STATUS, C               ; clear the carry flag
        comf    XdifL,w                 ; calculate the 1's complement of the LSB for
subtraction
        movwf   XposL
        comf    XdifH,w                 ; calculate the 1's complement of the MSB for
subtraction
        movwf   XposH
        movf    XposL,w
        addlw   0x01                    ; add 1 to the LSB 1st complement to get the 2's
complement
        movwf   XposL
        btfsc   STATUS,C                ; test the carry flag, if a carry occurred
        incf    XposH,f                 ; add 1 to the MSB register if Carry occured
Xnotneg
        btfss   YdifH, 7
        goto    Ynotneg
                                        ; 2's Compliment to get Positive value!
        bcf     STATUS, C               ; clear the carry flag
        comf    YdifL,w                 ; calculate the 1's complement of the LSB for
subtraction
        movwf   YposL
        comf    YdifH,w                 ; calculate the 1's complement of the MSB for
subtraction
        movwf   YposH
        movf    YposL,w
        addlw   0x01                    ; add 1 to the LSB 1st complement to get the 2's
complement
        movwf   YposL
        btfsc   STATUS,C                ; test the carry flag, if a carry occurred
        incf    YposH,f                 ; add 1 to the MSB register if Carry occured
Ynotneg

        movf    XposL, w
        andlw   0xfc                    ; only keep highest 5 bits of XdifL for compare.
        movwf   XposL                   ; store for later
        movf    YposL, w
        andlw   0xfc                    ; only keep highest 5 bits of YdifL for compare.
        movwf   YposL                   ; store for later

sub16comp
        bcf     STATUS, C               ; clear the carry flag
        comf    XposL,w                 ; calculate the 1's complement of the LSB for
subtraction
        movwf   XnegL
        comf    XposH,w                 ; calculate the 1's complement of the MSB for
subtraction
        movwf   XnegH
        movf    XnegL,w
```

```
        addlw   0x01                    ; add 1 to the LSB 1st complement to get the 2's
complement
        movwf   XnegL
        btfsc   STATUS,C                ; test the carry flag, if a carry occurred
        incf    XnegH,f                 ; add 1 to the MSB register if Carry occured
add16comp
        bcf     STATUS,C
        movf    YposH, w
        addwf   XnegH, f
        bcf     STATUS, C
        movf    YposL, w
        addwf   XnegL, f
        btfsc   STATUS,C                ; test the carry flag, if a carry occurred
        incf    XnegH,f                 ; add 1 to the MSB register if Carry occured
                                        ; XnegH:XnegL not contains zero if 45 degrees
        bcf     STATUS, C
        movf    XnegL, w
        addlw   0x00
        btfss   STATUS, Z
        goto    motor_not45
        bcf     STATUS, C
        movf    XnegH, w
        addlw   0x00
        btfsc   STATUS, Z
        goto    motors_x_and_y45

                                        ; assume 22.5 degree angle
motor_not45
        btfss   XnegH, 7
        goto    motor_22_y_big          ; if XnegH is positive, x < y @ 22.5 degree
        goto    motor_22_x_big          ; if XnegH is negative, x > y @ 22.5 degree
motor_22_x_big
        call    motors_x_alone
        call    step_delay
        call    motors_x_alone
        call    motors_y_alone
        call    step_delay
        call    motors_x_alone
        call    step_delay
        call    motors_x_alone
        call    motors_y_alone
        call    step_delay
        call    motors_x_alone
        return
motor_22_y_big
        call    motors_y_alone
        call    step_delay
        call    motors_x_alone
        call    motors_y_alone
        call    step_delay
        call    motors_y_alone
        call    step_delay
        call    motors_x_alone
        call    motors_y_alone
        call    step_delay
        call    motors_y_alone
        return



motors_x_and_y45                        ; 45degree angle setup
        call    motors_x_alone          ; use the stack return to call X
        goto    motors_y_alone          ; and also call Y, then return to main.
motors_x_alone
        btfsc   XYZdifFlags, 3          ; is it negative?
        goto    motors_x_alone_neg
motors_x_alone_pos
        call    stepxup
        return
motors_x_alone_neg
        call    stepxdown
```

```
        return

motors_y_alone
        btfsc   XYZdifFlags, 4          ; is it negative?
        goto    motors_y_alone_neg
motors_y_alone_pos
        call    stepyup
        return
motors_y_alone_neg
        call    stepydown
        return

motors_just_z
        btfsc   XYZdifFlags, 5          ; is it negative?
        goto    motors_just_z_neg
motors_just_z_pos
        call    stepzup
        call    step_delay              ; double delay time for Z axis
        return
motors_just_z_neg
        call    stepzdown
        call    step_delay              ; double delay time for Z axis
        return
motors_all_zero                         ; Do Nothing!
        call    p_ready                 ; Print "Ready..." to LCD
        call    p_position              ; print position

        bsf             MillReady, 0    ; Mill Is done Working!
        return

;########################################
;#      Stepper Motor Routines          #
;########################################

stepxup
        incfsz  XcoorL, f
        goto    stepxup2
        incf    XcoorH, f
stepxup2
        incf    XdifL, f                ;# decrease Z difference data by subtracting 1
        decfsz  XdifL, f                ;#
        goto    stepxup3                ;#
        decf    XdifH, f                ;#
stepxup3
        decf    XdifL, f                ;#
        bcf     STATUS, C
        rlf     Xcurstep, w
        btfsc   STATUS, C               ; keep carry bit as bit 0 of Register
        addlw   d'1'
        movwf   Xcurstep
        andlw   0x0f                    ; only keep lowest 4 bits
        movwf   Xpostemp
        movf    PORTD, w
        andlw   0xf0
        addwf   Xpostemp, w             ; add on lowest 4 bits
        movwf   PORTD
        return


stepxdown
        incf    XcoorL, f
        decfsz  XcoorL, f
        goto    stepxdown2
        decf    XcoorH, f
stepxdown2
        decf    XcoorL, f
        incfsz  XdifL, f                ;# decrease Z difference data by adding 1
        goto    stepxdown3              ;#
        incf    XdifH, f                ;#
stepxdown3
        bcf     STATUS, C
```

```
        rrf     Xcurstep, w
        btfsc   STATUS, C               ; keep carry bit as bit 0 of Register
        addlw   d'128'
        movwf   Xcurstep
        andlw   0x0f                    ; only keep lowest 4 bits
        movwf   Xpostemp
        movf    PORTD, w
        andlw   0xf0
        addwf   Xpostemp, w             ; add on lowest 4 bits
        movwf   PORTD
        return


stepyup
        incfsz  YcoorL, f
        goto    stepyup2
        incf    YcoorH, f
stepyup2
        incf    YdifL, f                ;# decrease Z difference data by subtracting 1
        decfsz  YdifL, f                ;#
        goto    stepyup3                ;#
        decf    YdifH, f                ;#
stepyup3
        decf    YdifL, f                ;#
        bcf     STATUS, C
        rlf     Ycurstep, w
        btfsc   STATUS, C               ; keep carry bit as bit 0 of Register
        addlw   d'1'
        movwf   Ycurstep
        andlw   0xf0                    ; only keep highest 4 bits
        movwf   Ypostemp
        movf    PORTD, w
        andlw   0x0f
        addwf   Ypostemp, w             ; add on highest 4 bits
        movwf   PORTD
        return


stepydown
        incf    YcoorL, f
        decfsz  YcoorL, f
        goto    stepydown2
        decf    YcoorH, f
stepydown2
        decf    YcoorL, f
        incfsz  YdifL, f                ;# decrease Z difference data by adding 1
        goto    stepydown3              ;#
        incf    YdifH, f                ;#
stepydown3
        bcf     STATUS, C
        rrf     Ycurstep, w
        btfsc   STATUS, C               ; keep carry bit as bit 0 of Register
        addlw   d'128'
        movwf   Ycurstep
        andlw   0xf0                    ; only keep highest 4 bits
        movwf   Ypostemp
        movf    PORTD, w
        andlw   0x0f
        addwf   Ypostemp, w             ; add on highest 4 bits
        movwf   PORTD
        return


stepzup
        incfsz  ZcoorL, f
        goto    stepzup2
        incf    ZcoorH, f
stepzup2
        incf    ZdifL, f                ;# decrease Z difference data by subtracting 1
        decfsz  ZdifL, f                ;#
        goto    stepzup3                ;#
```

```
        decf    ZdifH, f                ;#
stepzup3
        decf    ZdifL, f                ;#
        bcf     STATUS, C
        rlf     Zcurstep, w
        btfsc   STATUS, C               ; keep carry bit as bit 0 of Register
        addlw   d'1'
        movwf   Zcurstep
        andlw   0x0f                    ; only keep lowest 4 bits
        movwf   Zpostemp
        movf    PORTA, w
        andlw   0xf0
        addwf   Zpostemp, w             ; add on lowest 4 bits
        movwf   PORTA
        return


stepzdown
        incf    ZcoorL, f
        decfsz  ZcoorL, f
        goto    stepzdown2
        decf    ZcoorH, f
stepzdown2
        decf    ZcoorL, f
        incfsz  ZdifL, f                ;# decrease Z difference data by adding 1
        goto    stepzdown3              ;#
        incf    ZdifH, f                ;#
stepzdown3
        bcf     STATUS, C
        rrf     Zcurstep, w
        btfsc   STATUS, C               ; keep carry bit as bit 0 of Register
        addlw   d'128'
        movwf   Zcurstep
        andlw   0x0f                    ; only keep lowest 4 bits
        movwf   Zpostemp
        movf    PORTA, w
        andlw   0xf0
        addwf   Zpostemp, w             ; add on lowest 4 bits
        movwf   PORTA
        return


;########################################
;#            MATH Routines             #
;########################################

Find_Difs
sub16x
        bcf     STATUS, C               ; clear the carry flag
        comf    XcoorL,w                ; calculate the 1's complement of the LSB for
subtraction
        movwf   XdifL
        comf    XcoorH,w                ; calculate the 1's complement of the MSB for
subtraction
        movwf   XdifH
        movf    XdifL,w
        addlw   0x01                    ; add 1 to the LSB 1st complement to get the 2's
complement
        movwf   XdifL
        btfsc   STATUS,C                ; test the carry flag, if a carry occurred
        incf    XdifH,f                 ; add 1 to the MSB register if Carry occured
add16x
        bcf     STATUS,C
        movf    XgotoH, w
        addwf   XdifH, f
        bcf     STATUS, C
        movf    XgotoL, w
        addwf   XdifL, f
        btfsc   STATUS,C                ; test the carry flag, if a carry occurred
        incf    XdifH,f                 ; add 1 to the MSB register if Carry occured
sub16y
```

```
        bcf     STATUS, C               ; clear the carry flag
        comf    YcoorL,w                ; calculate the 1's complement of the LSB for
subtraction
        movwf   YdifL
        comf    YcoorH,w                ; calculate the 1's complement of the MSB for
subtraction
        movwf   YdifH
        movf    YdifL,w
        addlw   0x01                    ; add 1 to the LSB 1st complement to get the 2's
complement
        movwf   YdifL
        btfsc   STATUS,C                ; test the carry flag, if a carry occurred
        incf    YdifH,f                 ; add 1 to the MSB register if Carry occured
add16y
        bcf     STATUS,C
        movf    YgotoH, w
        addwf   YdifH, f
        bcf     STATUS, C
        movf    YgotoL, w
        addwf   YdifL, f
        btfsc   STATUS,C                ; test the carry flag, if a carry occurred
        incf    YdifH,f                 ; add 1 to the MSB register if Carry occured
sub16z
        bcf     STATUS, C               ; clear the carry flag
        comf    ZcoorL,w                ; calculate the 1's complement of the LSB for
subtraction
        movwf   ZdifL
        comf    ZcoorH,w                ; calculate the 1's complement of the MSB for
subtraction
        movwf   ZdifH
        movf    ZdifL,w
        addlw   0x01                    ; add 1 to the LSB 1st complement to get the 2's
complement
        movwf   ZdifL
        btfsc   STATUS,C                ; test the carry flag, if a carry occurred
        incf    ZdifH,f                 ; add 1 to the MSB register if Carry occured
add16z
        bcf     STATUS,C
        movf    ZgotoH, w
        addwf   ZdifH, f
        bcf     STATUS, C
        movf    ZgotoL, w
        addwf   ZdifL, f
        btfsc   STATUS,C                ; test the carry flag, if a carry occurred
        incf    ZdifH,f                 ; add 1 to the MSB register if Carry occured
        return

CalcDifBits
        clrf    XYZdifFlags             ; start XYZdifFlags from zero
        movf    XdifL, w
        bcf     STATUS, C
        sublw   0x00
        btfss   STATUS, C
        goto    calcdifb2               ; X-L was not zero..
        movf    XdifH, w                ; X-L was zero, check X-H
        bcf     STATUS, C
        sublw   0x00
        btfsc   STATUS, C
        bsf     XYZdifFlags, 0          ; X-H was zero, set to 1
calcdifb2
        movf    YdifL, w
        bcf     STATUS, C
        sublw   0x00
        btfss   STATUS, C
        goto    calcdifb3               ; Y-L was not zero..
        movf    YdifH, w                ; Y-L was zero, check X-H
        bcf     STATUS, C
        sublw   0x00
        btfsc   STATUS, C
        bsf     XYZdifFlags, 1          ; Y-H was zero, set to 1
calcdifb3
```

```
        movf    ZdifL, w
        bcf     STATUS, C
        sublw   0x00
        btfss   STATUS, C
        goto    calcdifb4               ; Z-L was not zero..
        movf    ZdifH, w                ; Z-L was zero, check X-H
        bcf     STATUS, C
        sublw   0x00
        btfsc   STATUS, C
        bsf     XYZdifFlags, 2          ; Z-H was zero, set to 1
calcdifb4
        btfsc   XdifH, 7
        bsf     XYZdifFlags, 3          ; Xdif is negative
        btfsc   YdifH, 7
        bsf     XYZdifFlags, 4          ; Ydif is negative
        btfsc   ZdifH, 7
        bsf     XYZdifFlags, 5          ; Zdif is negative

        btfss   XYZdifFlags, 0
        goto    calcdifnotz
        btfss   XYZdifFlags, 1
        goto    calcdifnotz
        bsf     XYZdifFlags, 6          ; X and Y are both Zero
        btfsc   XYZdifFlags, 2
        bsf     XYZdifFlags, 7          ; All numbers are Zero
calcdifnotz
        return


;########################################
;#             LCD Commands             #
;########################################
initialize
        movlw   b'00110011'             ; begin(still in 8-bit mode)
        call    wr_setup
        movlw   b'00110010'             ; switch to 4-bit mode. Function Set.
        call    wr_setup
        movlw   b'00101000'             ; another Function Set.
        call    wr_setup
        movlw   b'00001000'             ;Display Off
        call    wr_setup
        movlw   b'00001111'             ;Display On with Blinking Cursor
        call    wr_setup
        movlw   b'00001111'             ;Display On with Blinking Cursor
        call    wr_setup
        movlw   b'00000110'             ;Entry Mode
        call    wr_setup
        movlw   b'00101011'             ;Fix Display.. makes display darker.
                                        ;N(3) = problem..  only one line!!!
        call    wr_setup
        return

LCD_firstline
        movlw   b'10000000'             ; move to 1st line
        call    wr_setup
        return

LCD_secondline
        movlw   b'11000000'             ; move to 2nd line
        call    wr_setup
        return

LCD_multispace                          ;set number of spaces desired in w register.
        movwf   tmp3;
LCD_msloop
        movlw   b'00100000'             ;write " "
        call    wr_letter
        decfsz  tmp3, f
        goto    LCD_msloop
        return
```

```
wr_setup
        movwf   tmp1
        movf    tmp1, w
        movwf   tmp2
        BCF     tmp2, 0                 ;use first nibble(d4-d7)
        BCF     tmp2, 1
        BCF     tmp2, 2
        BSF     tmp2, 3
        movf    tmp2, w

        movwf   PORTB                   ;send data (enable=1)
        call    s_delay
        BCF     PORTB, 3                ;end send, (enable=0)
        call    s_delay

         rlf     tmp1, w                ;get next nibble (d0-d3)
        movwf   tmp1
         rlf     tmp1, w
        movwf   tmp1
         rlf     tmp1, w
        movwf   tmp1
         rlf     tmp1, w
        movwf   tmp2

        BCF     tmp2, 0
        BCF     tmp2, 1
        BCF     tmp2, 2
        BSF     tmp2, 3
        movf    tmp2, w

        movwf   PORTB                   ;send data (enable=1)
        call    s_delay
        BCF     PORTB, 3                ;end send, (enable=0)
        call    s_delay

        return

wr_letter
        movwf   tmp1
        movf    tmp1, w
        movwf   tmp2
        BCF     tmp2, 0                 ;use first nibble(d4-d7)
        BSF     tmp2, 1
        BCF     tmp2, 2
        BSF     tmp2, 3
        movf    tmp2, w

        movwf   PORTB                   ;send data (enable=1)
        call    let_delay
        BCF     PORTB, 3                ;end send, (enable=0)
        call    let_delay

         rlf     tmp1, w                ;get next nibble (d0-d3)
        movwf   tmp1
         rlf     tmp1, w
        movwf   tmp1
         rlf     tmp1, w
        movwf   tmp1
         rlf     tmp1, w
        movwf   tmp2

        BCF     tmp2, 0
        BSF     tmp2, 1
        BCF     tmp2, 2
        BSF     tmp2, 3
        movf    tmp2, w

        movwf   PORTB                   ;send data (enable=1)
        call    let_delay
        BCF     PORTB, 3                ;end send, (enable=0)
```

```
        call    let_delay
        return

LCD_wr_bcd
        bsf     TenK, 4                 ;Convert decimal numbers into ASCII format for LCD
        bsf     TenK, 5
        bsf     Thou, 4
        bsf     Thou, 5
        bsf     Hund, 4
        bsf     Hund, 5
        bsf     Tens, 4
        bsf     Tens, 5
        bsf     Ones, 4
        bsf     Ones, 5
        movf TenK, w
        call    wr_letter
        movf Thou, w
        call    wr_letter
        movf Hund, w
        call    wr_letter
        movf Tens, w
        call    wr_letter
        movf Ones, w
        call    wr_letter
        retlw 0


;#########################################
;#         LCD  Write Routines           #
;#########################################

p_ready
        call    LCD_firstline
        movlw   d'8'
        call    LCD_multispace
        movlw   a'R'
        call    wr_letter
        movlw   a'e'
        call    wr_letter
        movlw   a'a'
        call    wr_letter
        movlw   a'd'
        call    wr_letter
        movlw   a'y'
        call    wr_letter
        movlw   a'.'
        call    wr_letter
        movlw   a'.'
        call    wr_letter
        movlw   a'.'
        call    wr_letter
        movlw   d'8'
        call    LCD_multispace
        call    LCD_secondline
        movlw   d'24'
        call    LCD_multispace
        return

p_position
        call    LCD_secondline
        movlw   a'X'
        call    wr_letter
        movlw   a'='
        call    wr_letter
        movf    XcoorL, w
        movwf   NumL
        movf    XcoorH, w
        movwf   NumH
        call    BCD                     ; convert to Decimal
        call    LCD_wr_bcd              ;print out BCD of X position
        movlw   a' '
```

```
        call    wr_letter
        movlw   a'Y'
        call    wr_letter
        movlw   a'='
        call    wr_letter
        movf    YcoorL, w
        movwf   NumL
        movf    YcoorH, w
        movwf   NumH
        call    BCD                     ; convert to Decimal
        call    LCD_wr_bcd              ;print out BCD of Y position
        movlw   a' '
        call    wr_letter
        movlw   a'Z'
        call    wr_letter
        movlw   a'='
        call    wr_letter
        movf    ZcoorL, w
        movwf   NumL
        movf    ZcoorH, w
        movwf   NumH
        call    BCD                     ; convert to Decimal
        call    LCD_wr_bcd              ;print out BCD of Z position
        movlw   a' '
        call    wr_letter
        return

p_going
        call    LCD_firstline
        movlw   d'8'
        call    LCD_multispace
        movlw   a'G'
        call    wr_letter
        movlw   a'o'
        call    wr_letter
        movlw   a'i'
        call    wr_letter
        movlw   a'n'
        call    wr_letter
        movlw   a'g'
        call    wr_letter
        movlw   a' '
        call    wr_letter
        movlw   a't'
        call    wr_letter
        movlw   a'o'
        call    wr_letter
        movlw   a'.'
        call    wr_letter
        movlw   a'.'
        call    wr_letter
        movlw   a'.'
        call    wr_letter
        movlw   d'5'
        call    LCD_multispace
        call    LCD_secondline
        movlw   d'24'
        call    LCD_multispace
        return

p_gotopos
        call    LCD_secondline
        movlw   a'X'
        call    wr_letter
        movlw   a'='
        call    wr_letter
        movf    XgotoL, w
        movwf   NumL
        movf    XgotoH, w
        movwf   NumH
        call    BCD                     ; convert to Decimal
```

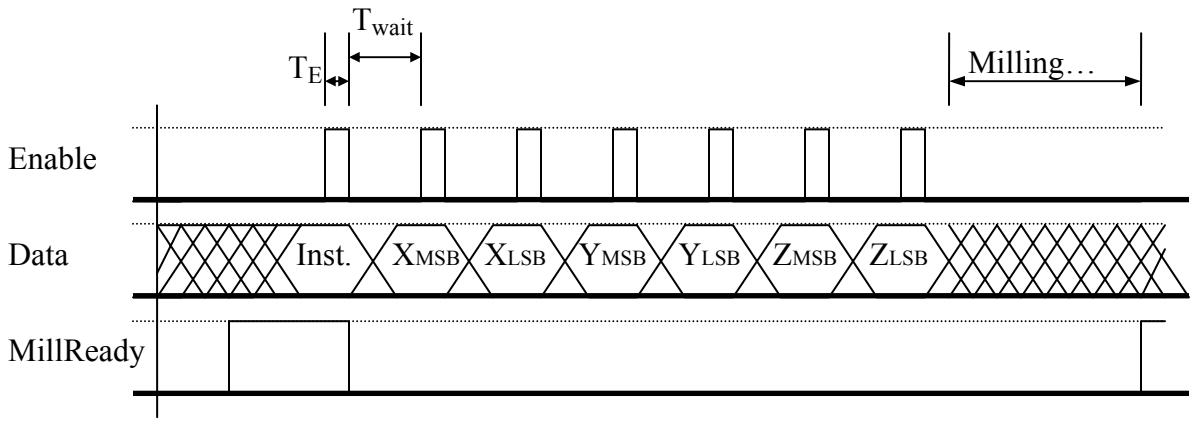
```
        call    LCD_wr_bcd              ;print out BCD of X position
        movlw   a' '
        call    wr_letter
        movlw   a'Y'
        call    wr_letter
        movlw   a'='
        call    wr_letter
        movf    YgotoL, w
        movwf   NumL
        movf    YgotoH, w
        movwf   NumH
        call    BCD                     ; convert to Decimal
        call    LCD_wr_bcd              ;print out BCD of Y position
        movlw   a' '
        call    wr_letter
        movlw   a'Z'
        call    wr_letter
        movlw   a'='
        call    wr_letter
        movf    ZgotoL, w
        movwf   NumL
        movf    ZgotoH, w
        movwf   NumH
        call    BCD                     ; convert to Decimal
        call    LCD_wr_bcd              ;print out BCD of Z position
        movlw   a' '
        call    wr_letter
        return

p_error
        call    LCD_firstline
        movlw   d'8'
        call    LCD_multispace
        movlw   a'*'
        call    wr_letter
        movlw   a'*'
        call    wr_letter
        movlw   a' '
        call    wr_letter
        movlw   a'E'
        call    wr_letter
        movlw   a'r'
        call    wr_letter
        movlw   a'r'
        call    wr_letter
        movlw   a'o'
        call    wr_letter
        movlw   a'r'
        call    wr_letter
        movlw   a' '
        call    wr_letter
        movlw   a'*'
        call    wr_letter
        movlw   a'*'
        call    wr_letter
        movlw   d'5'
        call    LCD_multispace
        call    LCD_secondline
        movlw   d'24'
        call    LCD_multispace
        return

;########################################
;#       Binary Converted Decimal       #
;########################################
BCD
        ;input
        ;=A3*163 + A2*162 + A1*161 + A0*160
        ;=A3*4096 + A2*256 + A1*16 + A0
        ;NumH            EQU AD3M        ;A3*16+A2
        ;NumL            EQU AD3L     ;A1*16+A0
```

```
        ;share variables
        ;=B4*104 + B3*103 + B2*102 + B1*101 + B0*100
        ;=B4*10000 + B3*1000 + B2*100 + B1*10 + B0
        ;TenK            EQU LOOPER      ;B4
        ;Thou            EQU D2              ;B3
        ;Hund            EQU D1              ;B2
        ;Tens            EQU R2              ;B1
        ;Ones            EQU R1              ;B0

        swapf   NumH,w  ;w  = A2*16+A3
         andlw   0x0F     ;w  = A3
         addlw   0xF0   ;w  = A3-16
         movwf   Thou   ;B3 = A3-16
         addwf   Thou,f ;B3 = 2*(A3-16) = 2A3 - 32
         addlw   d'226' ;w  = A3-16 - 30 = A3-46
         movwf   Hund   ;B2 = A3-46
         addlw   d'50'  ;w  = A3-46 + 50 = A3+4
         movwf   Ones   ;B0 = A3+4

         movf    NumH,w ;w  = A3*16+A2
         andlw   0x0F   ;w  = A2
         addwf   Hund,f ;B2 = A3-46 + A2 = A3+A2-46
         addwf   Hund,f ;B2 = A3+A2-46  + A2 = A3+2A2-46
         addwf   Ones,f ;B0 = A3+4 + A2 = A3+A2+4
         addlw   d'233' ;w  = A2 - 23
         movwf   Tens   ;B1 = A2-23
         addwf   Tens,f ;B1 = 2*(A2-23)
         addwf   Tens,f ;B1 = 3*(A2-23) = 3A2-69 (Doh! thanks NG)

         swapf   NumL,w ;w  = A0*16+A1
         andlw   0x0F   ;w  = A1
         addwf   Tens,f ;B1 = 3A2-69 + A1 = 3A2+A1-69 range -69...-9
         addwf   Ones,f ;B0 = A3+A2+4 + A1 = A3+A2+A1+4
                        ;and Carry = 0 (thanks NG)
         rlf     Tens,f ;B1 = 2*(3A2+A1-69) + C = 6A2+2A1-138 and
                        ;Carry is now 1 as tens register had to be negitive
         rlf     Ones,f ;B0 = 2*(A3+A2+A1+4) + C = 2A3+2A2+2A1+9
                        ;(+9 not +8 due to the carry from prev line, Thanks NG)
         comf    Ones,f ;B0 = ~(2A3+2A2+2A1+9) = -2A3-2A2-2A1-10
                        ;(ones complement plus 1 is twos complement. Thanks SD)
         rlf     Ones,f ;B0 = 2*(-2A3-2A2-2A1-10) = -4A3-4A2-4A1-20
         movf    NumL,w ;w  = A1*16+A0
         andlw   0x0F   ;w  = A0
         addwf   Ones,f ;B0 = -4A3-4A2-4A1-20 + A0 = A0-4(A3+A2+A1)-20
                        ;range -215...-5 Carry=0
         rlf     Thou,f ;B3 = 2*(2A3 - 32) = 4A3 - 64

         movlw   0x07   ;w  = 7
         movwf   TenK   ;B4 = 7

         movlw   d'10'  ;w  = 10
Lb1:                    ;do
         addwf   Ones,f ; B0 += 10
         decf    Tens,f ; B1 -= 1
         btfss   3,0

          goto   Lb1    ; while B0 < 0
Lb2:                    ;do
         addwf   Tens,f ; B1 += 10
         decf    Hund,f ; B2 -= 1
         btfss   3,0
          goto   Lb2    ; while B1 < 0
Lb3:                    ;do
         addwf   Hund,f ; B2 += 10
         decf    Thou,f ; B3 -= 1
         btfss   3,0
          goto   Lb3    ; while B2 < 0
Lb4:                    ;do
         addwf   Thou,f ; B3 += 10
         decf    TenK,f ; B4 -= 1
         btfss   3,0
```

```
        goto   Lb4     ; while B3 < 0
        retlw   0


;#########################################
;#            Delay Routines             #
;#########################################

;###  s_delay is used to allow the correct amount of time to
;     pass when instructions are sent to the LCD.

; Setup_Delay = 0.005 seconds
; Clock frequency = 20 MHz
; Actual delay = 0.005 seconds = 25000 cycles
; Error = 0 %
s_delay                         ;24921 cycles
       movlw   0x59
       movwf   d1
s_delay_00
       movlw   0x5c
       movwf   d2
s_delay_01
       decfsz  d2, f
       goto    s_delay_01
       decfsz  d1, f
       goto    s_delay_00      ;73 cycles
       movlw   0x18
       movwf   d1
s_delay_10
       decfsz  d1, f
       goto    s_delay_10      ;2 cycles
       nop
       nop                     ;4 cycles (including call)
       return



; Let_Delay = 0.0001 seconds
; Clock frequency = 20 MHz
; Actual delay = 0.0001 seconds = 500 cycles
; Error = 0 %
let_delay
                               ;496 cycles
       movlw   0xa5
       movwf   d1
let_delay_00
       decfsz  d1, f
       goto    let_delay_00
                               ;4 cycles (including call)
       return



; Delay = 1 seconds
; Clock frequency = 20 MHz
; Actual delay = 1 seconds = 5000000 cycles
; Error = 0 %
Delay                          ;4963001 cycles
       movlw   0x7d
       movwf   d1
Delay_00
       movlw   0x64
       movwf   d2
Delay_01
       movlw   0x83
       movwf   d3
Delay_02
       decfsz  d3, f
       goto    Delay_02
       decfsz  d2, f
```

```
        goto    Delay_01
        decfsz  d1, f
        goto    Delay_00        ;36981 cycles
        movlw   0x56
        movwf   d1
Delay_10
        movlw   0x8e
        movwf   d2
Delay_11
        decfsz  d2, f
        goto    Delay_11
        decfsz  d1, f
        goto    Delay_10        ;13 cycles
        movlw   0x04
        movwf   d1
Delay_20
        decfsz  d1, f
        goto    Delay_20        ;1 cycle
        nop                     ;4 cycles (including call)
        return


;###  step_delay is used to create the delay between stepper motor cycles.

; Delay = 0.015 seconds
; Clock frequency = 20 MHz
; Actual delay = 0.015 seconds = 75000 cycles
; Error = 0 %

step_delay                      ;74993 cycles
        movlw   0x96
        movwf   d1
        movlw   0x3B
        movwf   d2
step_delay_0
        decfsz  d1, f
        goto    $+2
        decfsz  d2, f
        goto    step_delay_0    ;3 cycles
        goto    $+1
        nop                     ;4 cycles (including call)
        return


; Delay = 1248 instruction cycles
; Clock frequency = 20 MHz
; Actual delay = 0.0002496 seconds = 1248 cycles
; Error = 0 %
sub_delay                       ;1243 cycles
        return
        movlw   0xF8
        movwf   d1
        movlw   0x01
        movwf   d2
sub_delay_0
        decfsz  d1, f
        goto    $+2
        decfsz  d2, f
        goto    sub_delay_0     ;1 cycle
        nop                     ;4 cycles (including call)
        return
        END
```

Appendix C: PIC16F877 Timing Diagram



T_{wait} > 1.0 uSec
T_E > 1.8 uSec

Inst. = Instruction Byte (currently not used)
X_{MSB} = X position Most Significant Byte
X_{LSB} = X position Least Significant Byte
Y_{MSB} = Y position Most Significant Byte
Y_{LSB} = Y position Least Significant Byte
Z_{MSB} = Z position Most Significant Byte
Z_{LSB} = Z position Least Significant Byte

MillReady is driven High by the PIC16F877 when it is ready for a new mill position. The R31JP can then set the appropriate Data byte on the Databus. To clock in the data, the Enable line is pulled high by the R31JP for a minimum of 1.0 uSeconds. The Enable line can then be lower and after a delay of T_{wait} (greater than 1.8 uSeconds), the process can be repeated to clock in the remaining Data bytes.

Appendix D: C++ Code

(This is not the full program as there are many other files that control the visual layout, linking, etc..)

```
#include <vcl.h>
#pragma hdrstop

#include "Unit1.h"
#include "Unit2.h"
//---------------------------------------------------------------------------
#pragma package(smart_init)
#pragma resource "*.dfm"
TForm1 *Form1;
//---------------------------------------------------------------------------
__fastcall TForm1::TForm1(TComponent* Owner)
        : TForm(Owner)
{
//  Setup Stepper Motor Info Here
ThreadsperInch = 18;
Stepsperrev = 48;

currentcoorx = 0;
currentcoory = 0;
plotterup = 1;
stepvisualize = 0;

ComboBox1->ItemIndex = 3;
ComboBox2->ItemIndex = 3;



}
//---------------------------------------------------------------------------

void __fastcall TForm1::Button1Click(TObject *Sender)
{
int hpglx = 0;
int hpgly = 0;
AnsiString temp = 0;
temp = Edit1->Text * 1016;
hpglx = atoi(temp.c_str());             //1016 Plotter Units per inch
temp = Edit2->Text * 1016;
hpgly = atoi(temp.c_str());             //1016 Plotter Units per inch
currentcoorx = hpglx;
currentcoory = hpgly;
Memo1->Lines->Text = Memo1->Lines->Text + "PA" + currentcoorx + "," + currentcoory + ";PU;\r\n";
Memo1->Perform(EM_LINESCROLL,0 ,Memo1->Lines->Count);
}
//---------------------------------------------------------------------------
void __fastcall TForm1::Button2Click(TObject *Sender)
{
int hpglx = 0;
int hpgly = 0;
AnsiString temp = 0;
temp = Edit1->Text * 1016;
hpglx = atoi(temp.c_str());             //1016 Plotter Units per inch
temp = Edit2->Text * 1016;
hpgly = atoi(temp.c_str());             //1016 Plotter Units per inch
currentcoorx = hpglx;
currentcoory = hpgly;
Memo1->Lines->Text = Memo1->Lines->Text + "PA" + currentcoorx + "," + currentcoory + ";PD;\r\n";
Memo1->Perform(EM_LINESCROLL,0 ,Memo1->Lines->Count);
}
//---------------------------------------------------------------------------
void __fastcall TForm1::Button4click(TObject *Sender)
{
Label12->Caption = "Starting";
Label12->Update();
zoom = 0;
Button4->Caption = "Please Wait";
makegrid();
PaintBox1->Canvas->Pen->Color = 0x0000ff;   //Red Pen color
Label10->Caption = "";

String input = Memo1->Text;
Label12->Caption = "Parsing: 1st Pass";
Label12->Update();
stringreplace(input,"\r","");   // Get rid of carraige returns and line breaks
Label12->Caption = "Parsing: 2nd Pass";
Label12->Update();
stringreplace(input,"\n","");
Label12->Caption = "Computing";
Label12->Update();
                                // We are now left a single line,  seperated by ";" and
                                // each entry beginning with a letter.
                                // A=position, U=plotter Up, D=Plotter Down

for(int q=0; q < 10000; q++){   // clear out result array.
        result[q] = "";
        }
```

```
Split(input,';',result);        // result is an array of data example..  (A300,500; D; A500,500; U)

stepvisualize = 0;
plotterup = 1;
int index=0;

float divider;
divider = (Stepsperrev * ThreadsperInch);
divider = 1016/divider;         // divider = number to divide HPGL by...

LoadAddress = 0;
kmfFILE = "";   //Start Output file from scratch
result[0].Delete(1,1);      // get rid of first character

while(index<9999){
        result[index+1].Delete(1,1);      // get rid of first character
        if(result[index].Pos("A")){     //Move Plotter Position
                int xreturn;
                int yreturn;
                splitXY(result[index], xreturn, yreturn);
                        // Output to KMF Array !!
                        if(xreturn < 0 || yreturn < 0){
                                Label10->Caption = "Error! Negative Position Encountered @ Instruction:";
                                Label10->Caption = Label10->Caption + index;
                                kmfFILE += "-#ERROR#-\r\n";
                                if(xreturn < 0){
                                        xreturn = 0;
                                        }
                                if(yreturn < 0){
                                        yreturn = 0;
                                        }
                                int negpos = Memo1->Text.Pos("-");
                                Memo1->SelStart = negpos-1;
                                Memo1->SelLength = 1;
                                Memo1->SetFocus();
                                }
                        if(PenNumber == ComboBox1->ItemIndex){
                                int checksum;
                                char *chAdd=result[index+1].c_str();    //look at next piece of data
                                                                        //for Up/Down commands
                                int Instruction;
                                switch(*chAdd){
                                        case 'A':
                                                Instruction = 1;
                                                break;
                                        case 'U':
                                                Instruction = 2;
                                                break;
                                        case 'D':
                                                int Ztravel = Edit4->Text * 10000;
                                                Instruction = (ThreadsperInch * Stepsperrev * Ztravel)/10000;
                                                break;
                                        }
                                kmfFILE += ":05";                 // for Intel Hex File, :=RecordMark, 05=5
                                                                  // bytes of Info
                                kmfFILE += IntToHex(LoadAddress,4);  // Load Address
                                kmfFILE += "00";                     //  Store as type "data"
                                if(Instruction < 16){
                                        kmfFILE += "0" + IntToHex(Instruction,1); // Append the Instruction character;
                                        }
                                if(Instruction >= 16 && Instruction < 256){
                                        kmfFILE += IntToHex(Instruction,2);     // Append the Instruction character;
                                        }
                                if(Instruction >=256){
                                        kmfFILE += "ff";                      // Append the Instruction character;
                                        Instruction = 255;
                                        Label10->Caption = "Error! Z Axis Travel Greater than ";
                                        float extreme = (255 * 1000)/ (Stepsperrev * ThreadsperInch);
                                        Label10->Caption = Label10->Caption + extreme;
                                        Label10->Caption = Label10->Caption + " (Thousandths of an Inch)";
                                        }
                                kmfFILE += IntToHex(int(xreturn/divider),4);         // print x Hex values
                                kmfFILE += IntToHex(int(yreturn/divider),4);         // print y Hex Values
                                checksum = (5 + Instruction + int(LoadAddress/256) + int(LoadAddress%256) +
int((int(xreturn/divider))/256) + int((int(xreturn/divider))%256) + int((int(yreturn/divider))/256) +
int((int(yreturn/divider))%256));
                                checksum = checksum % 256;  // only keep one byte of information.  (LSB)
                                checksum = 256 - checksum;
                                checksum = checksum % 256;
                                kmfFILE += IntToHex(checksum,2);
                                kmfFILE += "\r\n";                      // newline

                                LoadAddress = LoadAddress + 5;
                                }
                        // End KMF Array Operations
                xreturn = xreturn / 10.16;
                yreturn = yreturn / 10.16;
                if(plotterup == 1){     // plotter is up, do not draw.
                        PaintBox1->Canvas->MoveTo(xreturn,(800-yreturn));
                        currentcoorx = xreturn;
                        currentcoory = (800-yreturn);
                        }
                if(plotterup == 0){     //plotter is down, draw line
                        PaintBox1->Canvas->LineTo(xreturn,(800-yreturn));
                        currentcoorx = xreturn;
```

```
                        currentcoory = (800-yreturn);
                        }
                }
        if(result[index].Pos("U")){     // Plotter Up
                plotterup = 1;
                }
        if(result[index].Pos("D")){     // Plotter Down
                plotterup = 0;
                if(PenNumber == 1 || PenNumber == 2 || PenNumber == 5){
                        PaintBox1->Canvas->Ellipse(currentcoorx+2, currentcoory+2,currentcoorx-2, currentcoory-2);
                        }
                }
        if(result[index].Pos("P")){
                String holder = result[index];
                holder.Delete(1,1);      // get rid of P
                PenNumber = atoi(holder.c_str());
                switch(atoi(holder.c_str())){
                        case 0:
                                PaintBox1->Canvas->Pen->Color = 0x007700;
                                break;
                        case 1:
                                PaintBox1->Canvas->Pen->Color = 0xff0000;       // Main Drill
                                break;
                        case 2:
                                PaintBox1->Canvas->Pen->Color = 0x007700;       //drill
                                break;
                        case 3:
                                PaintBox1->Canvas->Pen->Color = 0x0000ff;       //Main Trace
                                break;
                        case 4:
                                PaintBox1->Canvas->Pen->Color = 0x007700;       //??
                                break;
                        case 5:
                                PaintBox1->Canvas->Pen->Color = 0x007700;       //drill
                                break;
                        case 6:
                                PaintBox1->Canvas->Pen->Color = 0x007700;       //short drill?
                                break;
                        case 7:
                                PaintBox1->Canvas->Pen->Color = 0x007700;       // trace?
                                break;
                        default:
                                PaintBox1->Canvas->Pen->Color = 0x000000;       // else - black
                                break;

                        }
                }
        index++;
        }

kmfFILE += ":00000001FF";  // Close kmfFIle with and End byte

Memo2->Text = kmfFILE;
Button4->Caption = "ReRun HPGL";
Button8->Visible=true;
Button6->Visible=true;
Button7->Visible=true;
Button9->Visible=true;
Button11->Visible=true;
Edit3->Visible=true;
Label9->Visible=true;
StaticText2->Visible = false;
Label12->Caption = "";
Label12->Update();
}
//---------------------------------------------------------------------------


void TForm1::makegrid()
{                                       // Make a 1" x 1" grid for reference

long holdx, holdy;
holdx = PaintBox1->Canvas->PenPos.x;
holdy = PaintBox1->Canvas->PenPos.y;
PaintBox1->Refresh();
PaintBox1->Canvas->MoveTo(holdx,holdy);    // keep original cooridinates.

PaintBox1->Canvas->Pen->Color = 0xffffff;
PaintBox1->Canvas->MoveTo(0,800);
PaintBox1->Canvas->LineTo(800,800);
PaintBox1->Canvas->MoveTo(0,700);
PaintBox1->Canvas->LineTo(800,700);
PaintBox1->Canvas->MoveTo(0,600);
PaintBox1->Canvas->LineTo(800,600);
PaintBox1->Canvas->MoveTo(0,500);
PaintBox1->Canvas->LineTo(800,500);
PaintBox1->Canvas->MoveTo(0,400);
PaintBox1->Canvas->LineTo(800,400);
PaintBox1->Canvas->MoveTo(0,300);
PaintBox1->Canvas->LineTo(800,300);
PaintBox1->Canvas->MoveTo(0,200);
PaintBox1->Canvas->LineTo(800,200);
PaintBox1->Canvas->MoveTo(0,100);
PaintBox1->Canvas->LineTo(800,100);
PaintBox1->Canvas->MoveTo(0,0);
```

```
PaintBox1->Canvas->LineTo(800,0);

PaintBox1->Canvas->MoveTo(0,0);
PaintBox1->Canvas->LineTo(0,800);
PaintBox1->Canvas->MoveTo(100,0);
PaintBox1->Canvas->LineTo(100,800);
PaintBox1->Canvas->MoveTo(200,0);
PaintBox1->Canvas->LineTo(200,800);
PaintBox1->Canvas->MoveTo(300,0);
PaintBox1->Canvas->LineTo(300,800);
PaintBox1->Canvas->MoveTo(400,0);
PaintBox1->Canvas->LineTo(400,800);
PaintBox1->Canvas->MoveTo(500,0);
PaintBox1->Canvas->LineTo(500,800);
PaintBox1->Canvas->MoveTo(600,0);
PaintBox1->Canvas->LineTo(600,800);
PaintBox1->Canvas->MoveTo(700,0);
PaintBox1->Canvas->LineTo(700,800);
PaintBox1->Canvas->MoveTo(800,0);
PaintBox1->Canvas->LineTo(800,800);
PaintBox1->Canvas->Pen->Color = 0x0000ff;
PaintBox1->Update();
}
void __fastcall TForm1::Button5click(TObject *Sender)
{
long holdx, holdy;
holdx = PaintBox1->Canvas->PenPos.x;
holdy = PaintBox1->Canvas->PenPos.y;
PaintBox1->Refresh();
makegrid();
PaintBox1->Canvas->MoveTo(holdx,holdy);    // keep original cooridinates.
}
//---------------------------------------------------------------------------
void __fastcall TForm1::Button3Click(TObject *Sender)
{
int hpglx = 0;
int hpgly = 0;
AnsiString temp = 0;
temp = Edit1->Text * 1016;
hpglx = atoi(temp.c_str());             //1016 Plotter Units per inch
temp = Edit2->Text * 1016;
hpgly = atoi(temp.c_str());             //1016 Plotter Units per inch
Memo1->Lines->Text = Memo1->Lines->Text + "PA" + hpglx + "," + hpgly + ";\r\n";
currentcoorx = hpglx;
currentcoory = hpgly;
Memo1->Perform(EM_LINESCROLL,0 ,Memo1->Lines->Count);    // Scroll to bottom
}
//---------------------------------------------------------------------------
void __fastcall TForm1::PaintBox1MouseMove(TObject *Sender,
      TShiftState Shift, int X, int Y)
{
zoomdifx = X;
zoomdify = Y - 800;

X = X + 5;             //center around 1/16" away
Y = Y - 5;
Y = 800 - Y;     //fix cooridinate system
int decx;
int decy;
decx = X % 100;
decy = Y % 100;
decx = decx / 12.5;
decy = decy / 12.5;
decx = decx * 125;    // snap to 1/8"
decy = decy * 125;
X = X / 100;
Y = Y / 100;
gridposition->Caption = "X = ";
gridposition->Caption = gridposition->Caption + X;
gridposition->Caption = gridposition->Caption + "." + decx;
gridposition->Caption = gridposition->Caption + ", Y = " + Y;
gridposition->Caption = gridposition->Caption + "." + decy;



if(result[0] != "" && Shift.Contains(ssLeft)){
        if(zoom != 0){
                Edit1->Text = 0;
                Edit2->Text = 0;
                Button11->Caption = "Redrawing x2";

                makegrid();

                stepvisualize = 0;
                plotterup = 1;
                int index=0;
                while(index<10000){
                        if(result[index].Pos("A")){     //Move Plotter Position
                                int xreturn;
                                int yreturn;
                                splitXY(result[index], xreturn, yreturn);
                                xreturn = xreturn / 10.16;
                                yreturn = yreturn / 10.16;
                                if(plotterup == 1){     // plotter is up, do not draw.
                                        PaintBox1->Canvas->MoveTo(xreturn * 2 - zoomdifx,(800-(yreturn * 2)-zoomdify));
```

```
                                        currentcoorx = xreturn * 2 - zoomdifx;
                                        currentcoory = (800-(yreturn * 2) - zoomdify);
                                        }
                                if(plotterup == 0){     //plotter is down, draw line
                                        PaintBox1->Canvas->LineTo(xreturn * 2 - zoomdifx,(800-(yreturn * 2)-zoomdify));
                                        currentcoorx = xreturn * 2 - zoomdifx;
                                        currentcoory = (800-(yreturn * 2) - zoomdify);
                                        }
                                }
                        if(result[index].Pos("U")){     // Plotter Up
                                plotterup = 1;
                                }
                        if(result[index].Pos("D")){     // Plotter Down
                                plotterup = 0;
                                if(PenNumber == 1 || PenNumber == 2 || PenNumber == 5){
                                        PaintBox1->Canvas->Ellipse(currentcoorx+2, currentcoory+2,currentcoorx-2,
currentcoory-2);
                                        }
                                }
                        if(result[index].Pos("P")){
                                String holder = result[index];
                                holder.Delete(1,1);      // get rid of P
                                PenNumber = atoi(holder.c_str());
                                switch(atoi(holder.c_str())){
                                        case 0:
                                                PaintBox1->Canvas->Pen->Color = 0x007700;
                                                break;
                                        case 1:
                                                PaintBox1->Canvas->Pen->Color = 0xff0000;       // Main Drill
                                                break;
                                        case 2:
                                                PaintBox1->Canvas->Pen->Color = 0x007700;       //drill
                                                break;
                                        case 3:
                                                PaintBox1->Canvas->Pen->Color = 0x0000ff;       //Main Trace
                                                break;
                                        case 4:
                                                PaintBox1->Canvas->Pen->Color = 0x007700;       //??
                                                break;
                                        case 5:
                                                PaintBox1->Canvas->Pen->Color = 0x007700;       //drill
                                                break;
                                        case 6:
                                                PaintBox1->Canvas->Pen->Color = 0x007700;       //short drill?
                                                break;
                                        case 7:
                                                PaintBox1->Canvas->Pen->Color = 0x007700;       // trace?
                                                break;
                                        default:
                                                PaintBox1->Canvas->Pen->Color = 0x000000;       // else - black
                                                break;

                                        }
                                }
                        index++;
                        }
Button11->Caption = "Zoom x 2";
                }
        }

}
//---------------------------------------------------------------------------
void __fastcall TForm1::PaintBox1MouseDown(TObject *Sender,
      TMouseButton Button, TShiftState Shift, int X, int Y)
{
//zoomdifx = X;
//zoomdify = Y - 800;
if(zoom == 0){
        X = X + 5;            //center around 1/16" away
        Y = Y - 5;
        Y = 800 - Y;     //fix cooridinate system
        int decx;
        int decy;
        decx = X % 100;
        decy = Y % 100;
        decx = decx / 12.5;
        decy = decy / 12.5;
        decx = decx * 125;    // snap to 1/8"
        decy = decy * 125;
        X = X / 100;
        Y = Y / 100;
        gridposition->Caption = "X = ";
        gridposition->Caption = gridposition->Caption + X;
        gridposition->Caption = gridposition->Caption + "." + decx;
        gridposition->Caption = gridposition->Caption + ", Y = " + Y;
        gridposition->Caption = gridposition->Caption + "." + decy;
                // Write to Cooridinate Boxes..
        Edit1->Text = X;
        Edit1->Text = Edit1->Text + ".";
        Edit1->Text = Edit1->Text + decx;
        Edit2->Text = Y;
        Edit2->Text = Edit2->Text + ".";
        Edit2->Text = Edit2->Text + decy;
                // Move Position Shape Icon.
        int p;
```

```
        p = X * 100 + (decx / 10) - 3;
        Shape2->Left = p;
        p = (800 - (Y * 100 + (decy / 10))) - 2;
        Shape2->Top = p;
        }
if(result[0] != ""){
        if(zoom != 0){
                Edit1->Text = 0;
                Edit2->Text = 0;
                Button11->Caption = "Redrawing x2";

                makegrid();

                stepvisualize = 0;
                plotterup = 1;
                int index=0;
                while(index<10000){
                        if(result[index].Pos("A")){     //Move Plotter Position
                                int xreturn;
                                int yreturn;
                                splitXY(result[index], xreturn, yreturn);
                                xreturn = xreturn / 10.16;
                                yreturn = yreturn / 10.16;
                                if(plotterup == 1){     // plotter is up, do not draw.
                                        PaintBox1->Canvas->MoveTo(xreturn * 2 - zoomdifx,(800-(yreturn * 2)-zoomdify));
                                        currentcoorx = xreturn * 2 - zoomdifx;
                                        currentcoory = (800-(yreturn * 2) - zoomdify);
                                        }
                                if(plotterup == 0){     //plotter is down, draw line
                                        PaintBox1->Canvas->LineTo(xreturn * 2 - zoomdifx,(800-(yreturn * 2)-zoomdify));
                                        currentcoorx = xreturn * 2 - zoomdifx;
                                        currentcoory = (800-(yreturn * 2) - zoomdify);
                                        }
                                }
                        if(result[index].Pos("U")){     // Plotter Up
                                plotterup = 1;
                                }
                        if(result[index].Pos("D")){     // Plotter Down
                                plotterup = 0;
                                if(PenNumber == 1 || PenNumber == 2 || PenNumber == 5){
                                        PaintBox1->Canvas->Ellipse(currentcoorx+2, currentcoory+2,currentcoorx-2,
currentcoory-2);
                                        }
                                }
                        if(result[index].Pos("P")){
                                String holder = result[index];
                                holder.Delete(1,1);      // get rid of P
                                PenNumber = atoi(holder.c_str());
                                switch(atoi(holder.c_str())){
                                        case 0:
                                                PaintBox1->Canvas->Pen->Color = 0x007700;
                                                break;
                                        case 1:
                                                PaintBox1->Canvas->Pen->Color = 0xff0000;       // Main Drill
                                                break;
                                        case 2:
                                                PaintBox1->Canvas->Pen->Color = 0x007700;       //drill
                                                break;
                                        case 3:
                                                PaintBox1->Canvas->Pen->Color = 0x0000ff;       //Main Trace
                                                break;
                                        case 4:
                                                PaintBox1->Canvas->Pen->Color = 0x007700;       //??
                                                break;
                                        case 5:
                                                PaintBox1->Canvas->Pen->Color = 0x007700;       //drill
                                                break;
                                        case 6:
                                                PaintBox1->Canvas->Pen->Color = 0x007700;       //short drill?
                                                break;
                                        case 7:
                                                PaintBox1->Canvas->Pen->Color = 0x007700;       // trace?
                                                break;
                                        default:
                                                PaintBox1->Canvas->Pen->Color = 0x000000;       // else - black
                                                break;

                                        }
                                }
                        index++;
                        }
Button11->Caption = "Zoom x 2";
                }
        }


}
//---------------------------------------------------------------------------
void __fastcall TForm1::Edit1Change(TObject *Sender)
{
int q;
if(Edit1->Text >= 0){
 q = (Edit1->Text * 100) - 3;
 Shape2->Left = q;
 }
```

```
}
//---------------------------------------------------------------------------
void __fastcall TForm1::Edit2Change(TObject *Sender)
{
int q;
if(Edit2->Text >= 0){
 q = (Edit2->Text * 100);
 q = (800 - q) - 2;
 Shape2->Top = q;
 }

}
//---------------------------------------------------------------------------

void TForm1::stringreplace(String & WorkOn, String Find, String Replacer)
{
      int len = Find.Length();
      int loc = WorkOn.Pos(Find);
      //String WorkOnHolder = WorkOn;
     while (loc)
         {
         //WorkOnHolder.Delete(loc, len);     // using a seperate WorkOnHolder allows the replacing
         WorkOn.Delete(loc, len);           // string to include something in the find string.
         WorkOn.Insert(Replacer, loc);
         loc = WorkOn.Pos(Find);
         //loc = WorkOnHolder.Pos(Find);
         }
}


void TForm1::Split(String WorkOn, const char Splitter, String Array[10000])
{
        char *chAdd=WorkOn.c_str();
        int index=0;
     while (index<10000)
         {
         while( ( *chAdd!='\0' )&& ( *chAdd!=Splitter ) )
                { // Read a string until a Splitter or end of string is encountered
                Array[ index ]+=*chAdd; // Append the character
                ++chAdd;
                }
        if( *chAdd!='\0' ) ++chAdd; // If we ended at the Splitter, jump over it
        ++index;
        }
}

void TForm1::splitXY(String WorkOn, int & xreturn, int & yreturn)  //grab X and Y coors from comma split AnsiString.
{
         WorkOn.Delete(1, 1);   //get rid of first character (A)
         int delimit = WorkOn.Pos(",");
         String temp;
         temp = WorkOn;
         xreturn = atoi(temp.Delete(delimit,10).c_str());
         yreturn = atoi(WorkOn.Delete(1,delimit).c_str());
}

void __fastcall TForm1::Button6Click(TObject *Sender)   //  STEP Visualization Routine
{
Button6->Caption = "Please Wait";
if(result[stepvisualize].Pos("A")){     //Move Plotter Position
                int xreturn;
                int yreturn;
                splitXY(result[stepvisualize], xreturn, yreturn);
                xreturn = xreturn / 10.16;
                yreturn = yreturn / 10.16;
                if(plotterup == 1){     // plotter is up, do not draw.
                        PaintBox1->Canvas->MoveTo(xreturn,(800-yreturn));
                        currentcoorx = xreturn;
                        currentcoory = (800-yreturn);
                        }
                if(plotterup == 0){     //plotter is down, draw line
                        PaintBox1->Canvas->LineTo(xreturn,(800-yreturn));
                        currentcoorx = xreturn;
                        currentcoory = (800-yreturn);
                        }
                }
        if(result[stepvisualize].Pos("U")){     // Plotter Up
                plotterup = 1;
                }
        if(result[stepvisualize].Pos("D")){     // Plotter Down
                plotterup = 0;
                if(PenNumber == 1 || PenNumber == 2 || PenNumber == 5){
                        PaintBox1->Canvas->Ellipse(currentcoorx+2, currentcoory+2,currentcoorx-2, currentcoory-2);
                        }
                }
        if(result[stepvisualize].Pos("P")){
                String holder = result[stepvisualize];
                holder.Delete(1,1);      // get rid of P
                PenNumber = atoi(holder.c_str());
                switch(atoi(holder.c_str())){
                        case 0:
                                PaintBox1->Canvas->Pen->Color = 0x007700;
                                break;
                        case 1:
```

```
                        PaintBox1->Canvas->Pen->Color = 0xff0000;       // Main Drill
                        break;
                case 2:
                        PaintBox1->Canvas->Pen->Color = 0x007700;       //drill
                        break;
                case 3:
                        PaintBox1->Canvas->Pen->Color = 0x0000ff;       //Main Trace
                        break;
                case 4:
                        PaintBox1->Canvas->Pen->Color = 0x007700;       //??
                        break;
                case 5:
                        PaintBox1->Canvas->Pen->Color = 0x007700;       //drill
                        break;
                case 6:
                        PaintBox1->Canvas->Pen->Color = 0x007700;       //short drill?
                        break;
                case 7:
                        PaintBox1->Canvas->Pen->Color = 0x007700;       // trace?
                        break;
                default:
                        PaintBox1->Canvas->Pen->Color = 0x000000;       // else - black
                        break;

                }
        }
        stepvisualize++;
        if(stepvisualize >= 10000) stepvisualize = 0;
        Edit3->Text = stepvisualize;
        Button6->Caption = "Step Visualize";
}
//---------------------------------------------------------------------------

void __fastcall TForm1::Button7Click(TObject *Sender)
{
plotterup = 1;
stepvisualize = 0;
Edit3->Text = stepvisualize;
}
//---------------------------------------------------------------------------

void __fastcall TForm1::Button8Click(TObject *Sender)    //  Redraw Entire Layout
{
StaticText2->Visible = false;
zoom = 0;
Button8->Caption = "Redrawing";
makegrid();
stepvisualize = 0;
plotterup = 1;
int index=0;
while(index<10000){
        if(result[index].Pos("A")){     //Move Plotter Position
                int xreturn;
                int yreturn;
                splitXY(result[index], xreturn, yreturn);
                xreturn = xreturn / 10.16;
                yreturn = yreturn / 10.16;
                if(plotterup == 1){     // plotter is up, do not draw.
                        PaintBox1->Canvas->MoveTo(xreturn,(800-yreturn));
                        currentcoorx = xreturn;
                        currentcoory = (800-yreturn);
                        }
                if(plotterup == 0){     //plotter is down, draw line
                        PaintBox1->Canvas->LineTo(xreturn,(800-yreturn));
                        currentcoorx = xreturn;
                        currentcoory = (800-yreturn);
                        }
                }
        if(result[index].Pos("U")){     // Plotter Up
                plotterup = 1;
                }
        if(result[index].Pos("D")){     // Plotter Down
                plotterup = 0;
                if(PenNumber == 1 || PenNumber == 2 || PenNumber == 5){
                        PaintBox1->Canvas->Ellipse(currentcoorx+2, currentcoory+2,currentcoorx-2, currentcoory-2);
                        }
                }
        if(result[index].Pos("P")){
                String holder = result[index];
                holder.Delete(1,1);      // get rid of P
                PenNumber = atoi(holder.c_str());
                switch(atoi(holder.c_str())){
                        case 0:
                                PaintBox1->Canvas->Pen->Color = 0x007700;
                                break;
                        case 1:
                                PaintBox1->Canvas->Pen->Color = 0xff0000;       // Main Drill
                                break;
                        case 2:
                                PaintBox1->Canvas->Pen->Color = 0x007700;       //drill
                                break;
                        case 3:
                                PaintBox1->Canvas->Pen->Color = 0x0000ff;       //Main Trace
                                break;
                        case 4:
```

```
                                PaintBox1->Canvas->Pen->Color = 0x007700;       //??
                                break;
                        case 5:
                                PaintBox1->Canvas->Pen->Color = 0x007700;       //drill
                                break;
                        case 6:
                                PaintBox1->Canvas->Pen->Color = 0x007700;       //short drill?
                                break;
                        case 7:
                                PaintBox1->Canvas->Pen->Color = 0x007700;       // trace?
                                break;
                        default:
                                PaintBox1->Canvas->Pen->Color = 0x000000;       // else - black
                                break;

                        }
                }
        index++;
        }
Button8->Caption = "Redraw Route";
Button11->Visible=true;

}
//---------------------------------------------------------------------------



void __fastcall TForm1::Button9Click(TObject *Sender)
{
stepvisualize = atoi(Edit3->Text.c_str());
}
//---------------------------------------------------------------------------

void __fastcall TForm1::Button10Click(TObject *Sender)
{
Memo1->Lines->Text = Memo1->Lines->Text + "SP" + ComboBox2->ItemIndex + ";\r\n";
Memo1->Perform(EM_LINESCROLL,0 ,Memo1->Lines->Count);
}
//---------------------------------------------------------------------------

void __fastcall TForm1::Button11Click(TObject *Sender)
{
StaticText2->Visible = true;
Button11->Visible=false;
makegrid();
zoom = 1;
Button11->Caption = "Redrawing x2";
stepvisualize = 0;
plotterup = 1;
int index=0;
while(index<10000){
        if(result[index].Pos("A")){     //Move Plotter Position
                int xreturn;
                int yreturn;
                splitXY(result[index], xreturn, yreturn);
                xreturn = xreturn / 10.16;
                yreturn = yreturn / 10.16;
                if(plotterup == 1){     // plotter is up, do not draw.
                        PaintBox1->Canvas->MoveTo(xreturn * 2,(800-yreturn * 2));
                        currentcoorx = xreturn * 2;
                        currentcoory = (800-yreturn * 2);
                        }
                if(plotterup == 0){     //plotter is down, draw line
                        PaintBox1->Canvas->LineTo(xreturn * 2,(800-yreturn * 2));
                        currentcoorx = xreturn * 2;
                        currentcoory = (800-yreturn * 2);
                        }
                }
        if(result[index].Pos("U")){     // Plotter Up
                plotterup = 1;
                }
        if(result[index].Pos("D")){     // Plotter Down
                plotterup = 0;
                if(PenNumber == 1 || PenNumber == 2 || PenNumber == 5){
                        PaintBox1->Canvas->Ellipse(currentcoorx+2, currentcoory+2,currentcoorx-2, currentcoory-2);
                        }
                }
        if(result[index].Pos("P")){
                String holder = result[index];
                holder.Delete(1,1);      // get rid of P
                PenNumber = atoi(holder.c_str());
                switch(atoi(holder.c_str())){
                        case 0:
                                PaintBox1->Canvas->Pen->Color = 0x007700;
                                break;
                        case 1:
                                PaintBox1->Canvas->Pen->Color = 0xff0000;       // Main Drill
                                break;
                        case 2:
                                PaintBox1->Canvas->Pen->Color = 0x007700;       //drill
                                break;
                        case 3:
                                PaintBox1->Canvas->Pen->Color = 0x0000ff;       //Main Trace
                                break;
                        case 4:
```

```
                                PaintBox1->Canvas->Pen->Color = 0x007700;       //??
                                break;
                        case 5:
                                PaintBox1->Canvas->Pen->Color = 0x007700;       //drill
                                break;
                        case 6:
                                PaintBox1->Canvas->Pen->Color = 0x007700;       //short drill?
                                break;
                        case 7:
                                PaintBox1->Canvas->Pen->Color = 0x007700;       // trace?
                                break;
                        default:
                                PaintBox1->Canvas->Pen->Color = 0x000000;       // else - black
                                break;
                        }
                }
        index++;
        }
Button11->Caption = "Zoom x 2";
}
//---------------------------------------------------------------------------

void __fastcall TForm1::Exit1Click(TObject *Sender)
{
exit(0);
}
//---------------------------------------------------------------------------

void __fastcall TForm1::SaveKMF1Click(TObject *Sender)
{
SaveDialog1->Title = "Save Kumpf Mill File (.kmf)";
if (SaveDialog1->Execute())
Memo2->Lines->SaveToFile(SaveDialog1->FileName);
}
//---------------------------------------------------------------------------

void __fastcall TForm1::SaveHPLG1Click(TObject *Sender)
{
SaveDialog1->Title = "Save HPGL File (.plt)";
if (SaveDialog2->Execute())
Memo1->Lines->SaveToFile(SaveDialog2->FileName);
}
//---------------------------------------------------------------------------

void __fastcall TForm1::OpenHPGL1Click(TObject *Sender)
{
OpenDialog1->Title = "Open HPGL File (.plt)";
if (OpenDialog1->Execute())
Memo1->Lines->LoadFromFile(OpenDialog1->FileName);

}
//---------------------------------------------------------------------------

void __fastcall TForm1::PrintMillWorkArea1Click(TObject *Sender)
{
if (PrintDialog1->Execute()){
        TPrinter * Prntr = Printer();
        Prntr->BeginDoc();

int pscal = 8128 / 1.696;
 Prntr->Canvas->Pen->Color = 0x000000;
 Prntr->Canvas->MoveTo(0,0);
 Prntr->Canvas->LineTo(pscal,0);
 Prntr->Canvas->LineTo(pscal,pscal);
 Prntr->Canvas->LineTo(0,pscal);
 Prntr->Canvas->LineTo(0,0);

// Make Grid lines.
Prntr->Canvas->Pen->Color = 0x00ff00;
Prntr->Canvas->MoveTo(0,pscal);
Prntr->Canvas->LineTo(pscal,pscal);
Prntr->Canvas->MoveTo(0,(7 * pscal) / 8);
Prntr->Canvas->LineTo(pscal,(7 * pscal) / 8);
Prntr->Canvas->MoveTo(0,(6 * pscal) / 8);
Prntr->Canvas->LineTo(pscal,(6 * pscal) / 8);
Prntr->Canvas->MoveTo(0,(5 * pscal) / 8);
Prntr->Canvas->LineTo(pscal,(5 * pscal) / 8);
Prntr->Canvas->MoveTo(0,pscal / 2);
Prntr->Canvas->LineTo(pscal,pscal / 2);
Prntr->Canvas->MoveTo(0,(3 * pscal) / 8);
Prntr->Canvas->LineTo(pscal,(3 * pscal) / 8);
Prntr->Canvas->MoveTo(0,pscal / 4);
Prntr->Canvas->LineTo(pscal,pscal / 4);
Prntr->Canvas->MoveTo(0,pscal / 8);
Prntr->Canvas->LineTo(pscal,pscal / 8);
Prntr->Canvas->MoveTo(0,0);
Prntr->Canvas->LineTo(pscal,0);

Prntr->Canvas->MoveTo(0,0);
Prntr->Canvas->LineTo(0,pscal);
Prntr->Canvas->MoveTo(pscal / 8,0);
Prntr->Canvas->LineTo(pscal / 8,pscal);
Prntr->Canvas->MoveTo(pscal / 4,0);
Prntr->Canvas->LineTo(pscal / 4,pscal);
Prntr->Canvas->MoveTo((3 * pscal) / 8,0);
```

```
Prntr->Canvas->LineTo((3 * pscal) / 8,pscal);
Prntr->Canvas->MoveTo(pscal / 2,0);
Prntr->Canvas->LineTo(pscal / 2,pscal);
Prntr->Canvas->MoveTo((5 * pscal) / 8,0);
Prntr->Canvas->LineTo((5 * pscal) / 8,pscal);
Prntr->Canvas->MoveTo((6 * pscal) / 8,0);
Prntr->Canvas->LineTo((6 * pscal) / 8,pscal);
Prntr->Canvas->MoveTo((7 * pscal) / 8,0);
Prntr->Canvas->LineTo((7 * pscal) / 8,pscal);
Prntr->Canvas->MoveTo(pscal,0);
Prntr->Canvas->LineTo(pscal,pscal);

Prntr->Canvas->Pen->Color = 0x0000ff;
Prntr->Canvas->Pen->Width = 5;

int index=0;
while(index<10000){
        if(result[index].Pos("A")){     //Move Plotter Position
                int xreturn;
                int yreturn;
                splitXY(result[index], xreturn, yreturn);
                xreturn = xreturn / 1.696;
                yreturn = yreturn / 1.696;
                int pscaler = 8128 / 1.696;
                if(plotterup == 1){     // plotter is up, do not draw.
                        Prntr->Canvas->MoveTo(xreturn,pscaler - yreturn);
                        currentcoorx = xreturn;
                        currentcoory = pscaler - yreturn;
                        }
                if(plotterup == 0){     //plotter is down, draw line
                        Prntr->Canvas->LineTo(xreturn,pscaler - yreturn);
                        currentcoorx = xreturn * 2;
                        currentcoory = pscaler - yreturn;
                        }
                }
        if(result[index].Pos("U")){     // Plotter Up
                plotterup = 1;
                }
        if(result[index].Pos("D")){     // Plotter Down
                plotterup = 0;
                if(PenNumber == 1 || PenNumber == 2 || PenNumber == 5){
                        Prntr->Canvas->Ellipse(currentcoorx+15, currentcoory+15,currentcoorx-15, currentcoory-15);
                        }
                }
        if(result[index].Pos("P")){
                String holder = result[index];
                holder.Delete(1,1);      // get rid of P
                PenNumber = atoi(holder.c_str());
                switch(atoi(holder.c_str())){
                        case 0:
                                Prntr->Canvas->Pen->Color = 0x007700;
                                break;
                        case 1:
                                Prntr->Canvas->Pen->Color = 0xff0000;       // Main Drill
                                break;
                        case 2:
                                Prntr->Canvas->Pen->Color = 0x007700;       //drill
                                break;
                        case 3:
                                Prntr->Canvas->Pen->Color = 0x0000ff;       //Main Trace
                                break;
                        case 4:
                                Prntr->Canvas->Pen->Color = 0x007700;       //??
                                break;
                        case 5:
                                Prntr->Canvas->Pen->Color = 0x007700;       //drill
                                break;
                        case 6:
                                Prntr->Canvas->Pen->Color = 0x007700;       //short drill?
                                break;
                        case 7:
                                Prntr->Canvas->Pen->Color = 0x007700;       // trace?
                                break;
                        default:
                                Prntr->Canvas->Pen->Color = 0x000000;       // else - black
                                break;

                        }
                }
        index++;
        }

        //Prntr->Canvas->TextRect(r, 200, 200, Memo1->Lines->Text);
        Prntr->EndDoc();

        }
}
//---------------------------------------------------------------------------

void __fastcall TForm1::MechanicalSetup1Click(TObject *Sender)
{
Form2->Visible = true;
Form2->BringToFront();
}
//---------------------------------------------------------------------------
```