Tufts University
Department of Electrical Engineering
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NERD GIRLS
Maximum Power Point Tracker

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Senior Design Project 2003
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TABLE OF CONTENTS

1. PURPOSE

The objective of the project was to design a Maximum Power Point Tracker (MPPT) for a solar-powered vehicle. This component optimized the amount of power obtained from the photovoltaic array and charged the power supply. The solar car will be constructed by the 2003/2004 Nerd Girls Team and will incorporate the Maximum Power Point Tracker unit into the final design.

2. INTRODUCTION

Developed by Professor Karen Panetta, the Tufts University Nerd Girls Project brings together a team of multidisciplinary undergraduate female engineers. Their mission is to build and race a solar-powered vehicle in Fall 2003 and to use it as an outreach tool to introduce engineering to young students.

2.1 PHOTOVOLTAIC CELLS AND ARRAY RESEARCH

Photovoltaic cells are devices that absorb sunlight and convert that solar energy into electrical energy.

Solar cells are commonly made of silicon, one of the most abundant elements on Earth. Pure silicon, an actual poor conductor of electricity, has four outer valence electrons that form tetrahedral crystal lattices.

The electron clouds of the crystalline sheets are stressed by adding trace amounts of elements that have three or five outer shell electrons that will enable electrons to move. The nuclei of these elements fit well in the crystal lattice, but with only three outer shell electrons, there are too few electrons to balance out, and "positive holes" float in the electron cloud. With five outer shell electrons, there are too many electrons. The process of adding these impurities on purpose is called "doping." When doped with an element with five electrons, the resulting silicon is called N-type ("n" for negative) because of the prevalence of free electrons. Likewise, when doped with an element of three electrons, the silicon is called P-type. The absence of electrons (the "holes") define P-type.

The combination of N-type and P-type silicon cause an electrostatic field to form at the junction. At the junction, electrons from the sides mix and form a barrier, making it hard for electrons on the N side to cross to the P side. Eventually equilibrium is reached, and an electric field separates the sides.

When photons (sunlight) hit a solar cell, its energy frees electron-holes pairs. The electric field will send the free electron to the N side and hole to the P side. This causes further disruption of electrical neutrality, and if an external current path is provided, electrons will flow through the path to their original side (the P side) to unite with holes that the electric field sent there, doing work for us along the way. The electron flow provides the current, and the cell's electric field causes a voltage. With both current and voltage, we have power, which is the product of the two.

Three solar cell types are currently available: monocrystalline, polycrystalline, and thin film, discerned by material, efficiency, and composition.

By wiring solar cells in series, the voltage can be increased; or in parallel, the current. Solar cells are wired together to form a solar panel. Solar panels can be joined to create a solar array.

2.2 Power Supply Research

A battery is a source portable electric power. A storage battery is a reservoir, which may be used repeatedly for storing energy. Energy is charged and drained from the reservoir in the form of electricity, but it is stored as chemical energy. The most common storage battery is the lead-acid battery that is widely used in automobiles. They represent about 60% of all batteries sold worldwide and are usually more economical and have a high tolerance for abuse. Lead-acid batteries are inexpensive, relatively safe and easily recyclable, but have a low energy-to-weight ratio, which is a serious limitation when trying to build lightweight vehicles.

New battery technologies are constantly being explored that can offer better energy-to-weight ratios, lower costs and increased battery life. The nickel-metal-hydride battery has received a great deal of attention as a near future solution. Nickel-metal-hydride batteries offer about twice the energy capacity for the same weight as a current lead-acid battery. Another battery type with an even greater energy density is Lithium ion.

2.3 MPPT Research

The Maximum Power Point Tracker (MPPT) is needed to optimize the amount of power obtained from the photovoltaic array to the power supply.

The output of a solar module is characterized by a performance curve of voltage versus current, called the I-V curve. See Figure 1. The maximum power point of a solar module is the point along the I-V curve that corresponds to the maximum output power possible for the module. This value can be determined by finding the maximum area under the current versus voltage curve.

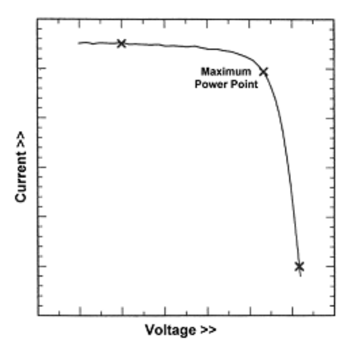


Figure 1: I-V Curve

3. BASIC DESIGN

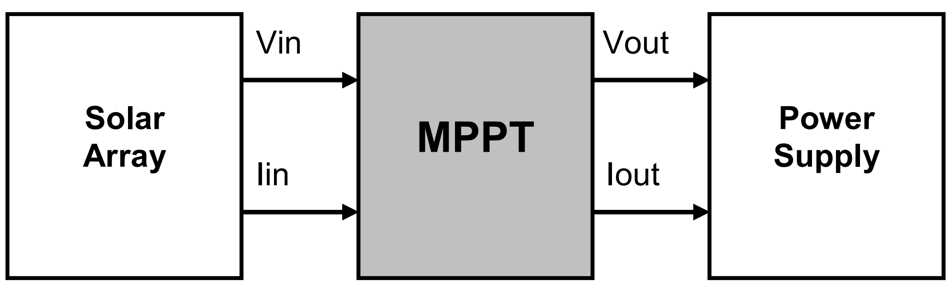
3.1 WHY ARE WE BUILDING A MPPT?

There are commericially available MPPTs which are typically used for home solutions and buildings. These are not designed to withstand the harsh, fast-changing environmental conditions of solar car racing. Design of the customized MPPT will ensure that the system operates as closely to the Maximum Power Point (MPP) while being subjected to the varying lighting and temperature.

3.2 HOW DOES IT WORK?

The inputs of the MPPT consisted of the photovoltaic voltage and current outputs. The adjusted voltage and current output of the MPPT charges the power supply. See Figure 2.

A microcontroller was utilized to regulate the integrated circuits (ICs) and calculate the maximum power point, given the output from the solar array. Hardware and software integration was necessary for the completion of this component.



4. IMPLEMENTATION

4.1 OVERALL DESIGN CONSIDERATIONS

Many factors influenced the component selection and the design of the MPPT.

- In terms of optimal functionality, the theory of power conservation needed to be applied. The input and output voltage and current were calculated such that the power into and out of the MPPT was equal.

- To protect the photovoltaic array from damage, protection diodes were employed.

- Two 48V lead acid battery banks were utilized. Only one battery bank will be charged at a time. (The other will be employed to run other components of the car).

- In order to trickle charge the batteries, a voltage exceeding 48V must be fed to the bank. In this design, 50V was chosen to charge the power supply.

- To prevent damage and overcharging of the power supply, a FET was employed.

4.2 HARDWARE

The MPPT circuitry consisted of three sections – Voltage Control, Charging Unit, and Solar Array Protection. See Appendix 7.1.1. The Voltage Control block consisted of two DC to DC converters that stepped down the solar array voltage. The converters supplied the necessary voltage to run the various components of the system. Secondly, the Charging Unit consisted of the PIC microcontroller, PWM, MOSFET, and protection diodes. It computed the maximum power point and regulated the various integrated circuits that charged the 48V power supply. Lastly, the Solar Array Protection block consisted of the protection diodes used to prevent solar panel damage.

4.2.1 COMPONENTS

Table 1 shows the components used for each of the three sections of the hardware design. See Appendix 7.4 for datasheets.

COMPONENT	PART NUMBER
PIC Microcontroller	PICF458
DC to DC Converter (5V)	PT4122A
DC to DC Converter (12V)	TPS6734IP
Pulse Width Modulator (PWM)	TL598CN
Diode	16CTU04S
Digital to Analog Converter (DAC)	LTC1451CN8
MOSFET	IXFX90N20Q
MOSFET driver	MAX4420CPA

Table 1: Components

4.2.2 VOLTAGE CONTROL

The DC/DC Buck Converter stepped down the solar array output voltage (approximately 48V) to 5v in order to power the PIC, DACs, and RS-232. The DC/DC Boost Converter stepped up the 5v output from the Buck Converter to 12v in order to power the PWM.

4.2.3 CHARGING UNIT

The charging unit consisted of multiple components, which worked together to power the battery array. This unit contained the ADCs, DACs, PIC microcontroller, PWM, MOSFET, MOSFET driver, inductor, and protection diodes.

The ADC changed the analog output of the solar array into a digital signal to be manipulated by the PIC microcontroller. The DAC worked in the opposite direction of the ADC. It changed the digital output from the PIC to an analog signal, which regulated the PWM.

The PIC microcontroller performed all of the calculations necessary to obtain the maximum power point. The PIC received the input voltage directly from the solar array and converted the value to a digital signal via the ADCs. In order to determine the input current, the output voltage of the voltage divider was sent to the PIC as a digital signal via the ADCs. From there, knowing the resistance of the voltage divider, the calculations were performed within the PIC. Having both the input voltage (V) and current (I) from the solar array, the power could be determined (P=V*I). Keeping the theory of power conservation in mind, the output power from the PIC needed to equal the input power from the solar array. At the same time, the charging voltage must exceed the battery array voltage, 48V; therefore 50V was assumed for the output voltage. The output current was calculated using the input power and the output voltage. This value was then converted to an analog signal via the DACs and sent to the PWM.

The PWM received the adjusted voltage and current from the PIC, and changed its duty cycle accordingly. This duty cycle controlled the MOSFET.

The MOSFET acted like a switch. When it was on, it closed the circuit and sent the power to ground, preventing the overcharging of the battery array. At this time, current built up in the inductor and it was able to charge. When it was off, the circuit opened, and the power was sent through the protection diodes to the battery array. At this time, the inductor discharged.

The protection diodes prevented current from flowing back from the batteries and potentially damaging the solar array. By placing the diodes in parallel, the overall resistance decreased, and allowed a greater amount of current to pass through.

4.2.4 Solar Array Protection Block

The voltage divider took the voltage from the solar array and stepped it down to a maximum voltage of 4.08V. This prevented the ADC from “blowing out.” Without the voltage divider, the solar array would send too large of a voltage for the ADC to handle. Protection diodes were utilized to prevent the current from flowing back to the solar array and causing damage to it.

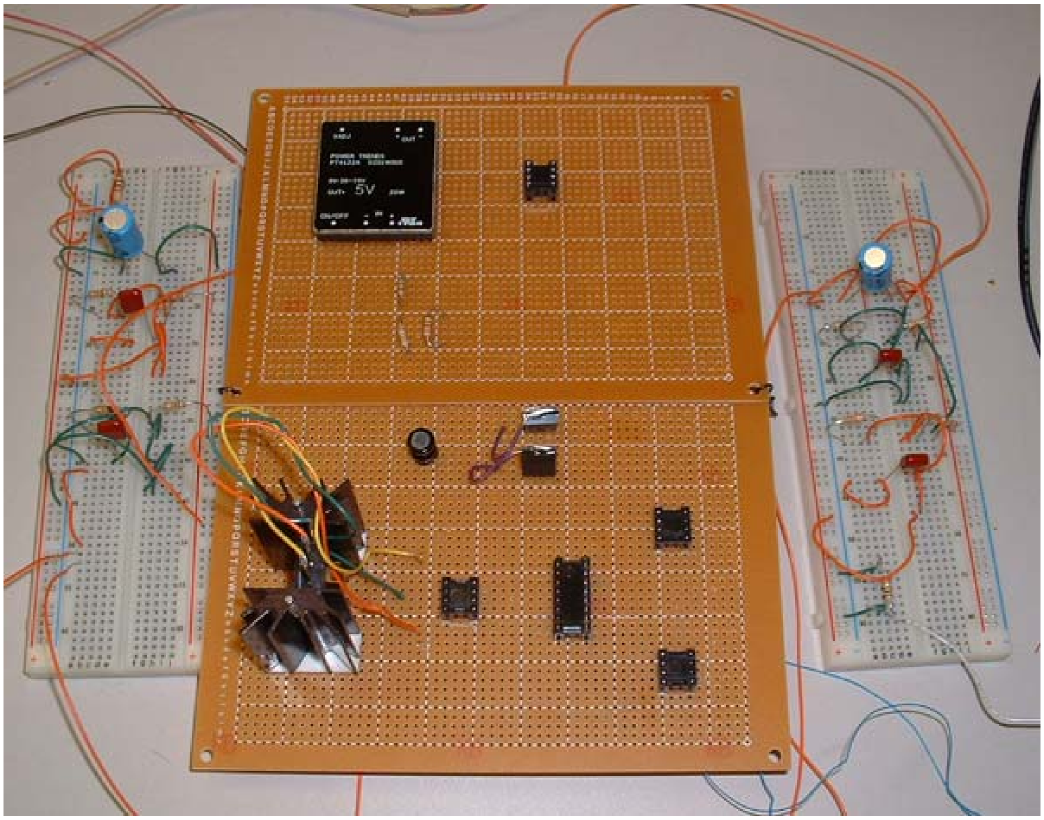


Figure 4: MPPT Circuit Board

4.3 SOFTWARE

The PIC Microcontroller chosen had sufficient memory to meet the demands of the design. The ADCs were also included in the PIC, which reduced the amount of additional external parts.

Programming was completed in MPASM Assembly. See Appendix 7.2 and 7.3 for Software flowcharts and code.

4.3.1 MENU STRUCTURE

The PIC contains a LCD screen, which enabled us to display the input and output voltages and currents. This enabled us to confirm the results of the calculations performed by the PIC. The structure of the LCD output was laid out as a menu. There were four main menu items, Voltage input from the solar array, current input from the solar array, voltage output from the MPPT and current output from the MPPT. See Figure 5.

Initially, the welcoming note was displayed on the LCD followed by the voltage input from the solar array menu item. A register called which_menu was used to organize the information about which menu item the user was viewing. Bit 0 of the which_menu register indicated whether or not the user was within the first menu item. If the bit value was 1, this meant the user was looking at the input voltage from the solar array. A 0 bit value meant the user was not within this menu item. The same system was set up for the rest of the menu items. Bit 1 was allocated to the input current from the solar array menu item. Bit 2 was allocated to the output voltage from the MPPT menu item. Finally, bit 3 was allocated to the output current from the MPPT menu item.

By pressing RA4, the user could scroll through the main menu items. By pushing RB0, the user could view the submenu of each main menu item. For example, if the user wanted to see the changing input voltage values, the user would scroll through the menu (using the RA4 button) until the Vin Solar menu item was displayed. Then, the user would select this (pushing RB0) and the voltage would be displayed on the LCD. The user could return to the main menu by pushing RB0 again. The which_menu register bit values were used to determine the return location on the main menu.

The final design was set up to perform the calculations to determine the output power each time the user selected the output current from the MPPT menu item. In order to test the functionality of the calculation code, values were hard-coded for the input voltage, input current and output voltage. For example, if the voltage input was 5V and the current input was 10mA, the two values were multiplied together to determine the power. If we wanted a 2V output, this value would be hard-coded as the output voltage. The input power would be divided by the 2V and the result would be the output current. So, in this example, the output current would be displayed as 25mA. This way the power output from the MPPT remained the same as the power input from the solar panels, but the voltage and current were adjusted so that enough voltage would be sent to a power supply to charge it. See Appendix 7.2.1.

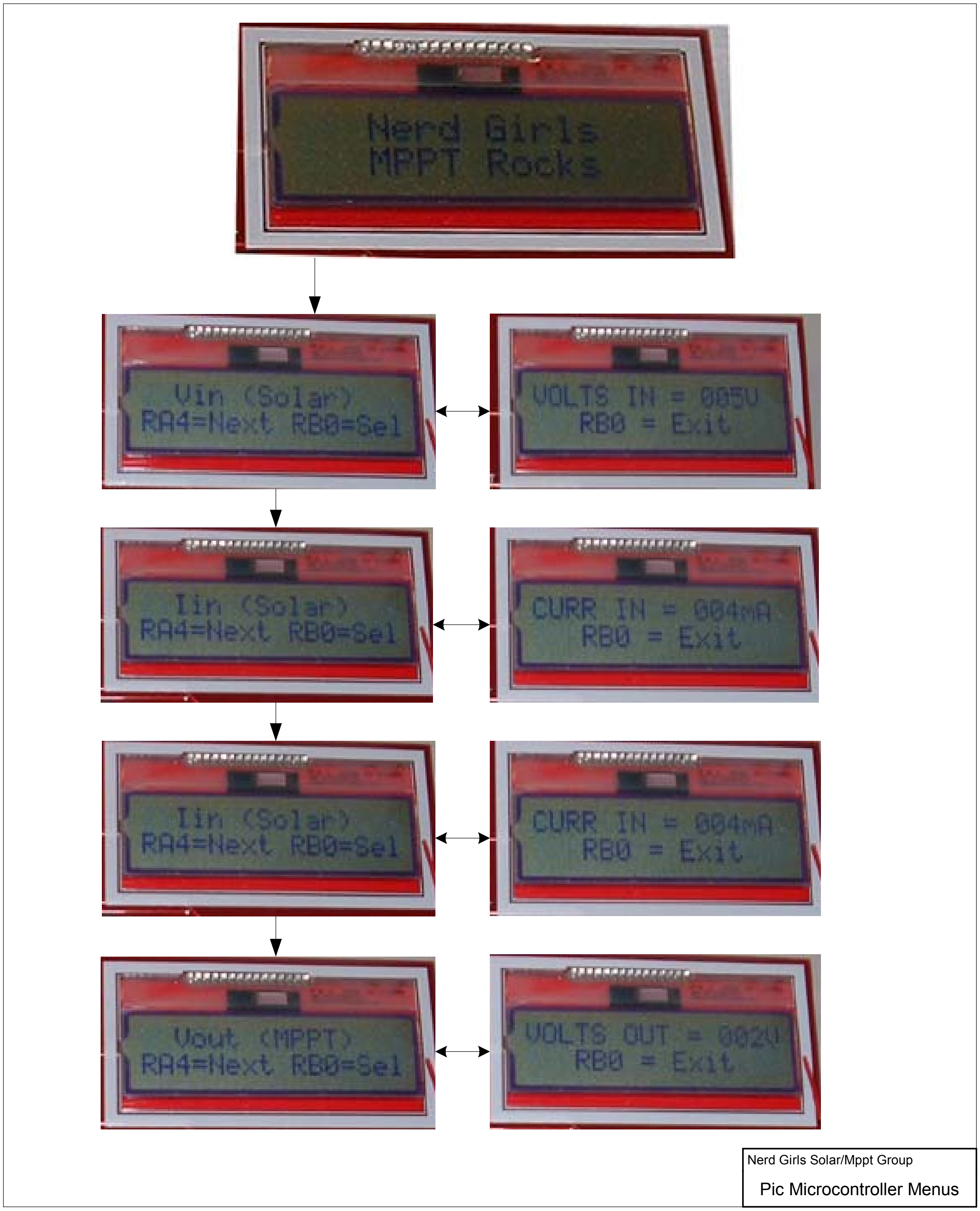


Figure 5: PIC Microcontroller LCD Menu Display
The topmost figure shows the welcome screen. The left screens are the scrollable main menus that display a submenu containing input/output data if RBO is selected. Sample inputs were used to test the calculation algorithm, as shown.

4.3.2 ALGORITHM

When the program started running, the first steps taken were to configure the PIC ports being used for inputs and outputs and to set the A/D conversion information. See Appendix 7.2.2. From there, the output voltage was given a set value. This value should be 50V, as this was the amount of voltage needed to charge the 48V battery array.

The welcome note was then displayed to inform the user that the program was running. Following this, the first item on the main menu was displayed (Vin Solar). At this point the user had the option to either select the item using the RB0 button (and the value would be displayed on the LCD) or to scroll through the four menu items using the RA4 button.

When the user selected one of the menu items by pressing RB0, the program first cleared the which_menu bit that was previously 1 (indicating the last menu item that was viewed). See Appendix 7.2.3. The label was then displayed on the LCD screen and the which_menu bit allocated to the current menu item was set to 1.

The program then took the data and either converted the value to a digital signal (if the data was received from port A) and stored the value in a register, or just stored the hard-coded value in a register. This was the only information needed to display the values for the first three menu items.

If the user selected the current output of the MPPT menu item, the output current was calculated using the input voltage, input current and output voltage values stored in the registers. The result was then printed to the LCD screen.

In order to return to the correct menu item, the program checked the bit values of the which_menu. For example, if bit 0 of which_menu was equal to the value of 1, the program would return to the first menu item, Vin Solar.

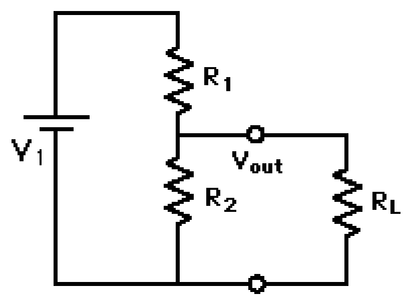
5. ASSESSMENT

5.1 HARDWARE

DIP packaging was used because they are easier to wire wrap. Wire wrapping for a majority of the circuitry was chosen instead soldering because it will facilitate future changes.

Chip sockets were used instead of wire wrapping directly to the chip; thus if the chip goes bad, it can be replaced and the does not have to be rewired.

The voltage divider circuitry was determined by assuming that the maximum output voltage of the solar array is 75V, and the maximum input of the ADC is 5 volts. See Figure 6. The following resistor values were used in order to obtain a maximum output of 4.08V: R_1=620KΩ, R_2=68KΩ, R_L=75KΩ



$$V_{out} = \frac{V_1(R_2||R_L)}{(R_1 + R_2||R_L)}$$

Figure 6: Voltage Divider Circuitry

Extra diodes were not needed for the Solar Protection Array. Diode protection to V_{DD} and V_{SS} were included in the ADCs on the PIC microcontroller.

The capacitors used do not support high voltages for an extended period of time, therefore they will have a short lifespan**.**

The packaging for the MOSFET and diodes made it difficult to attach to the circuit board.

The circuitry was placed on multiple boards. This made it easier to visualize the layout, but greatly increased the overall size of the complete device. If the final the device was packaged, the wiring and chips would be protected from damage. Also, the input and output wires would be easily accessible.

Figure 4: PIC Microcontroller

5.2 SOFTWARE

The calculation section of the program worked with only a few flaws. We were able to calculate the input power and then determine the output current knowing the output voltage desired and the input power. However, the code produced incorrect results once the test values were increased to numbers large enough to produce results greater than 256. The multiplication function was set up to multiply an 8-bit number by another 8-bit number and the result would be 16 bits total, stored in two 8-bit registers. When the two numbers being multiplied produced a result greater than 256, the value stored in the high bit register was incorrect. At the same time, we came across problems when the result of the division function included a fraction. The code was set up to print three decimal values to the LCD (up to 256). Several different steps were taken in an attempt to print out correct results with fractions; however, the goal was never achieved.

The design was set up so that the PIC would receive an input voltage and current from the solar array. However, there were difficulties when it came to reading the input values. Knowing port A was the port used for A/D conversions, it was set up so that there could be two inputs for voltage and current. There were two registers used to configure the A/D conversion information, ADCON0 and ADCON1. ADCON0 bit 0 was set to enable the A/D conversion and bits 3-5 were used to determine the channel from which the PIC was reading the input to convert. Eventually, it should be set up so that bits 5-3 are switched between 000 and 001, taking turns reading the input from channel 0 and channel 1. In order to test this, however, the bits were hard-coded to 000. ADCON1 bits 3-0 were set for two inputs (1101). With two inputs, there needed to be voltage references to ground and +5V. Ideally, with this test, an input between 0 and 5 volts would be used as the voltage input from the solar array (smaller test values at first). However, the program constantly shutdown when this design was attempted.

In order to show how the A/D conversion would work, though, the potentiometer values were used as the voltage input. The potentiometer was defaulted with a link to channel 0 of port A and it seemed that this was the only way to test the A/D conversions. It was set to convert numbers 0 through 15. So, in the final design, the user could rotate the knob of the potentiometer to test different values (from 0 to 15) that acted as the input voltage.

Overall, the program was able to meet the requirements of the design, but only to a certain degree. The final integration of the hardware and software was unable to work due to the troubles encountered when attempting to input or output a voltage to or from the PIC. The A/D conversion and the calculations could be tested with the final program however. The finished program consisted of a hard-coded value of 4mA for the input current and 2V for the output voltage. The user could test the program by rotating the potentiometer value (acting as the input voltage) and the result could be viewed under the Iout MPPT menu item. For example, the user could turn the potentiometer so that the value of the input voltage was 5V. The program would calculate the power using this and the 4mA hard-coded. The output current would then be determined using this power value and the output voltage of 2V. The result in this case would be 10mA.

6. CONCLUSION

In order to charge a power source at its maximum efficiency, a Maximum Power Point Tracker (MPPT) device is utilized. The MPPT design incorporated three systems - the Voltage Divider, Charging Unit, and Solar Array Protection.

Although the final MPPT did not completely function as planned, the software algorithm did complete the correct calculation to find the Maximum Power Point. As the project came to an end, various changes could have been made which could benefit the design and implementation process. A smaller output range of the solar array would have helped to design a more efficient MPPT. Allowance of ample time is necessary. Many problems with the component purchasing and software were encountered.

There were a few weaknesses in the code. First, the PIC was not programmed to continuously loop. A program that automatically checks and updates the maximum power point could improve the design. Secondly, the program did not successfully communicate with the hardware. Working communication is absolutely crucial in the final device that will be incorporated into the solar-powered vehicle.

Use of space in the car is also an important factor, as it can be critical to the overall design. A more organized circuitry layout on only one board would enable the device to be simply set into the car.

6.1 FUTURE WORK

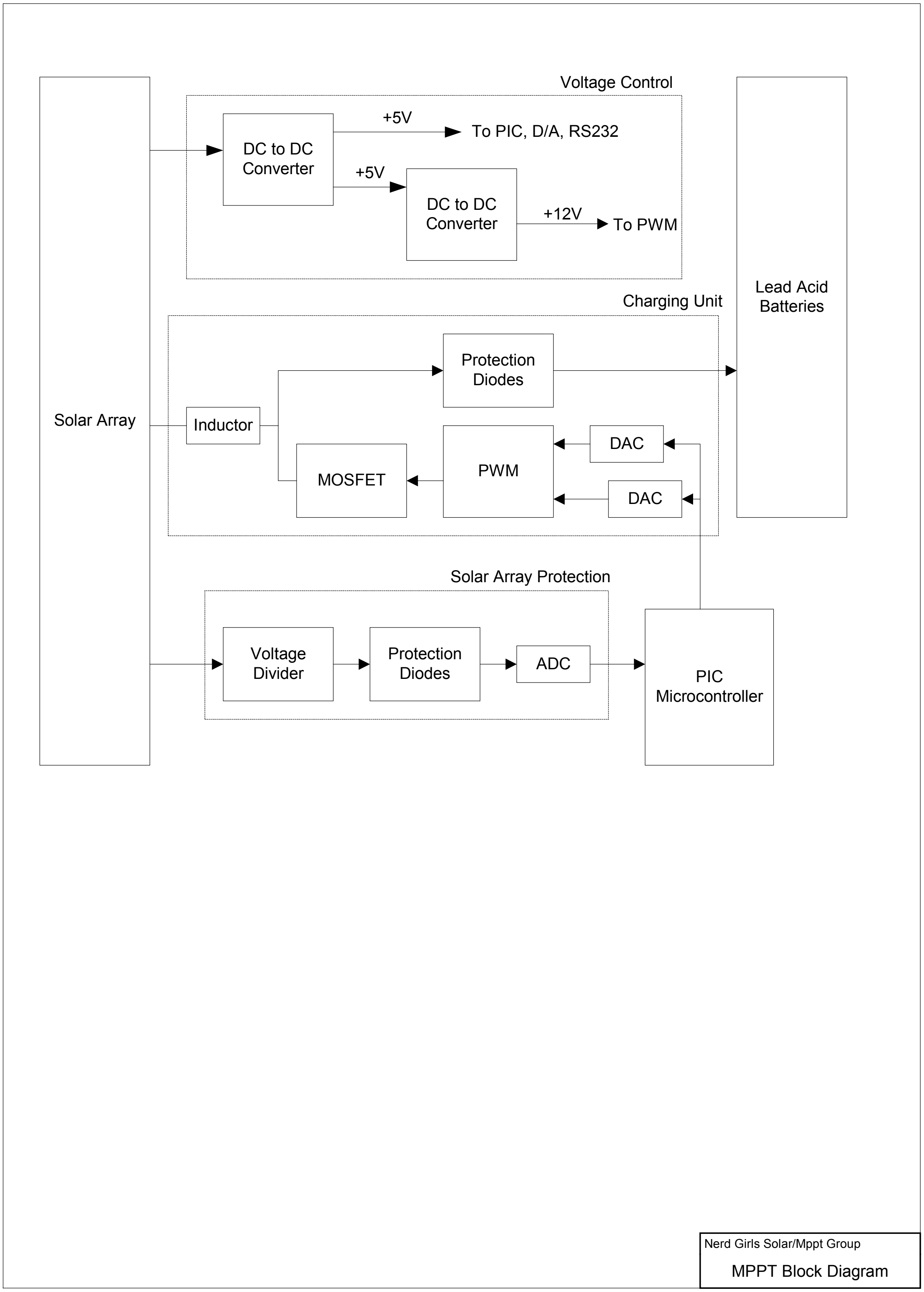
Fast-switching components are necessary to operate the device intended for solar car racing. The component choice is key in the design of the MPPT. High power efficiency is attained by carefully researching and selected the right components.

7. APPENDIX

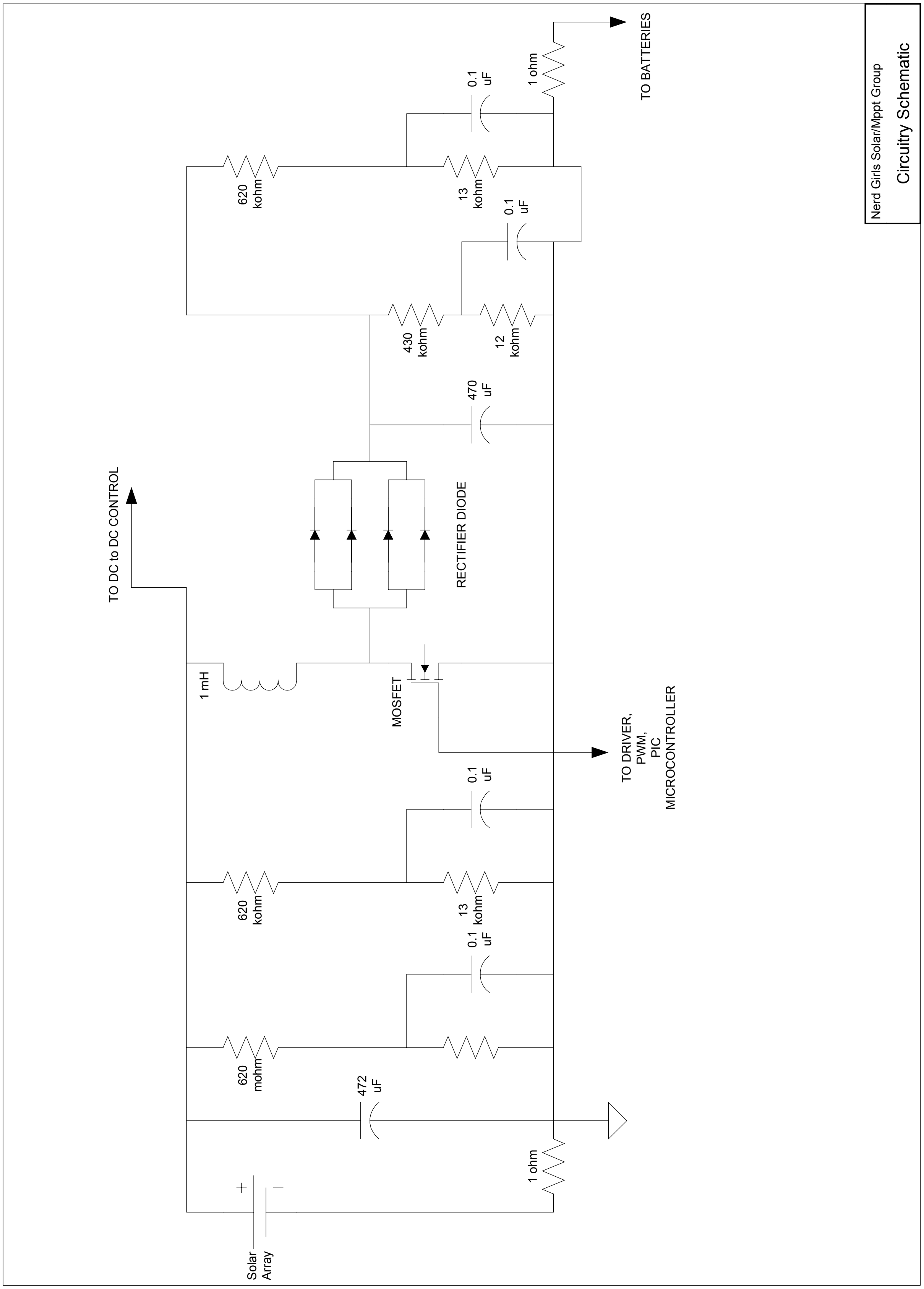
CONTENTS

APPENDIX 7.1 HARDWARE SCHEMATICS

APPENDIX 7.1.1 MPPT BLOCK DIAGRAM

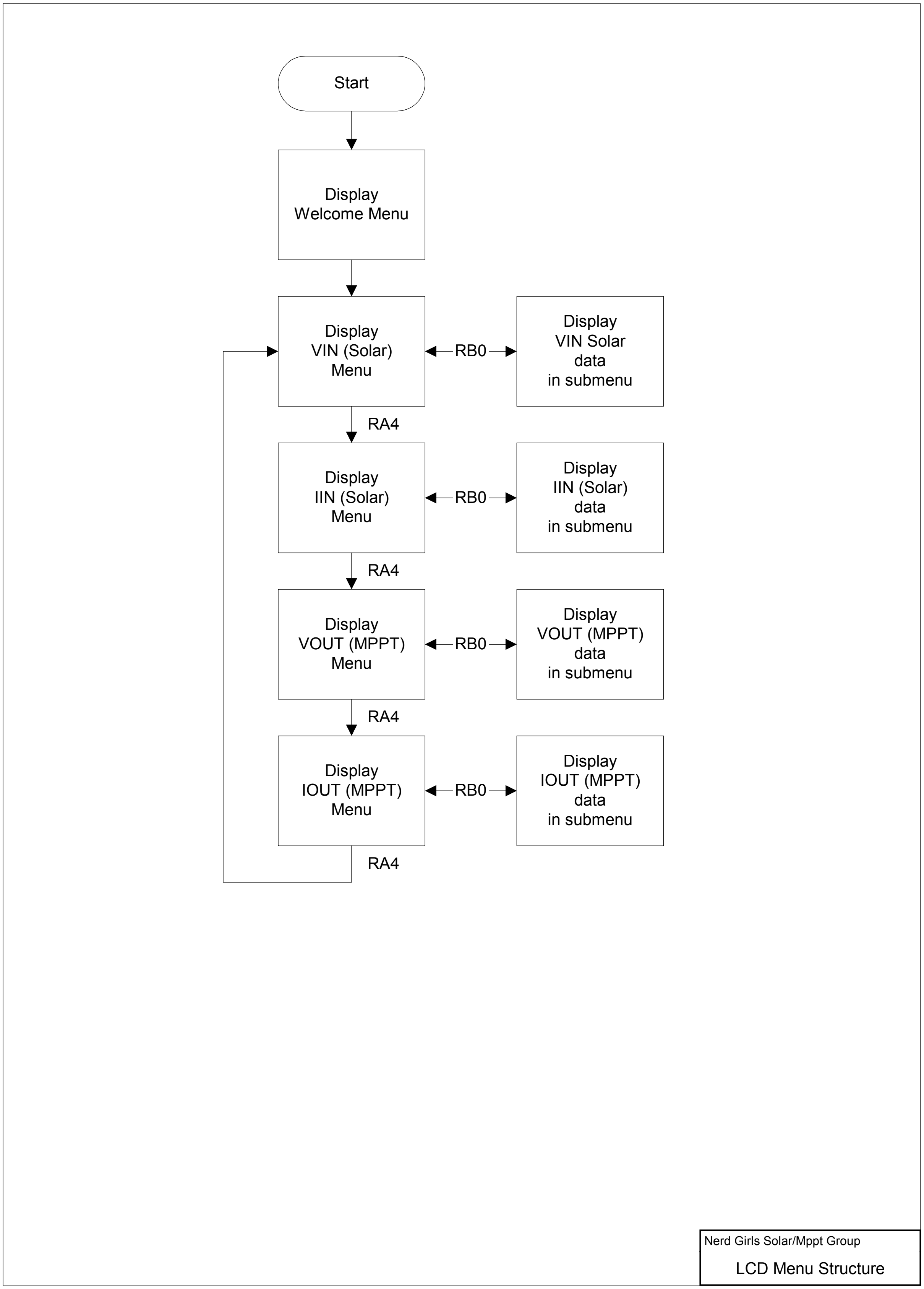


APPENDIX 7.1.2 CIRCUITRY SCHEMATIC

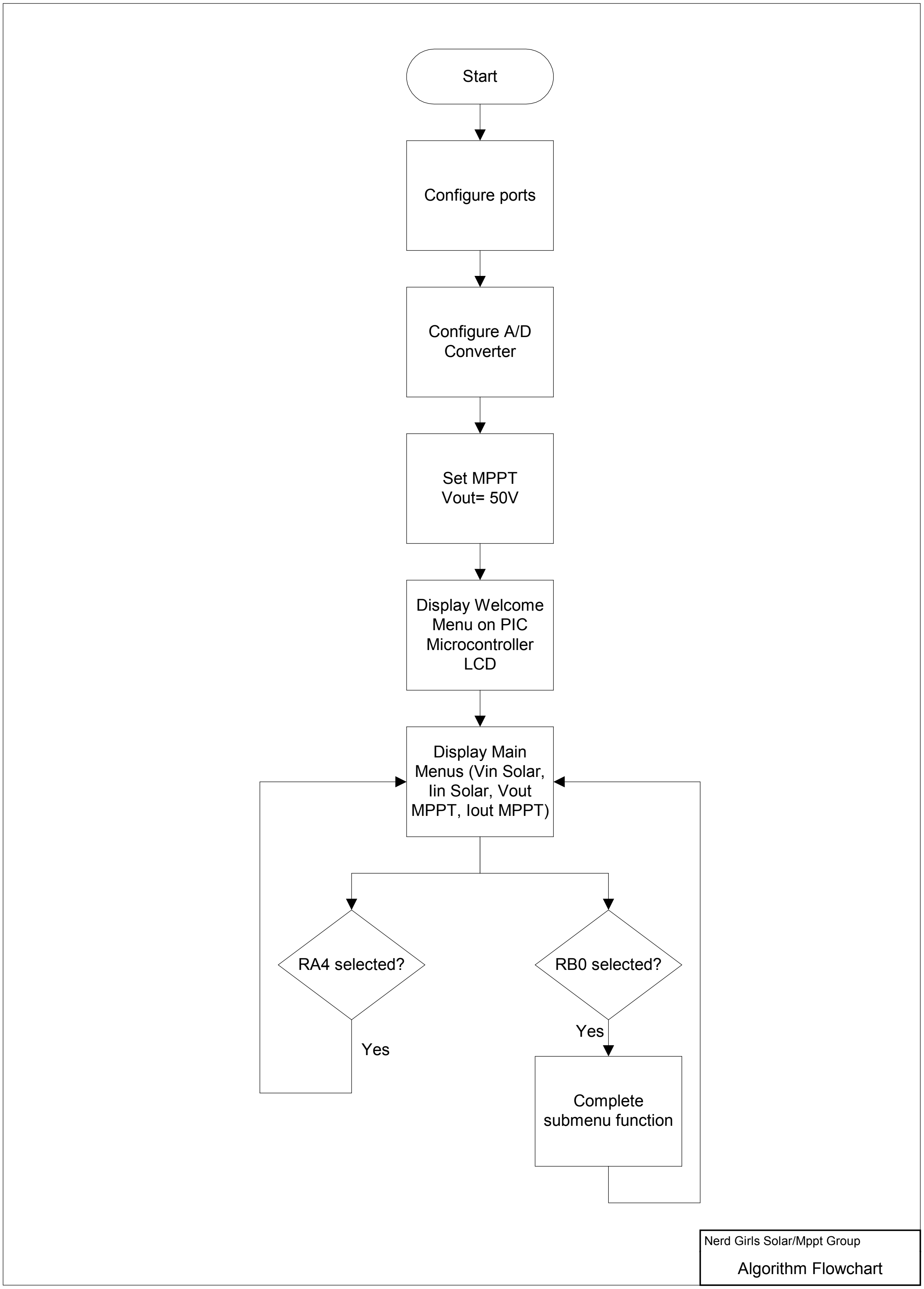


APPENDIX 7.2 SOFTWARE FLOWCHARTS

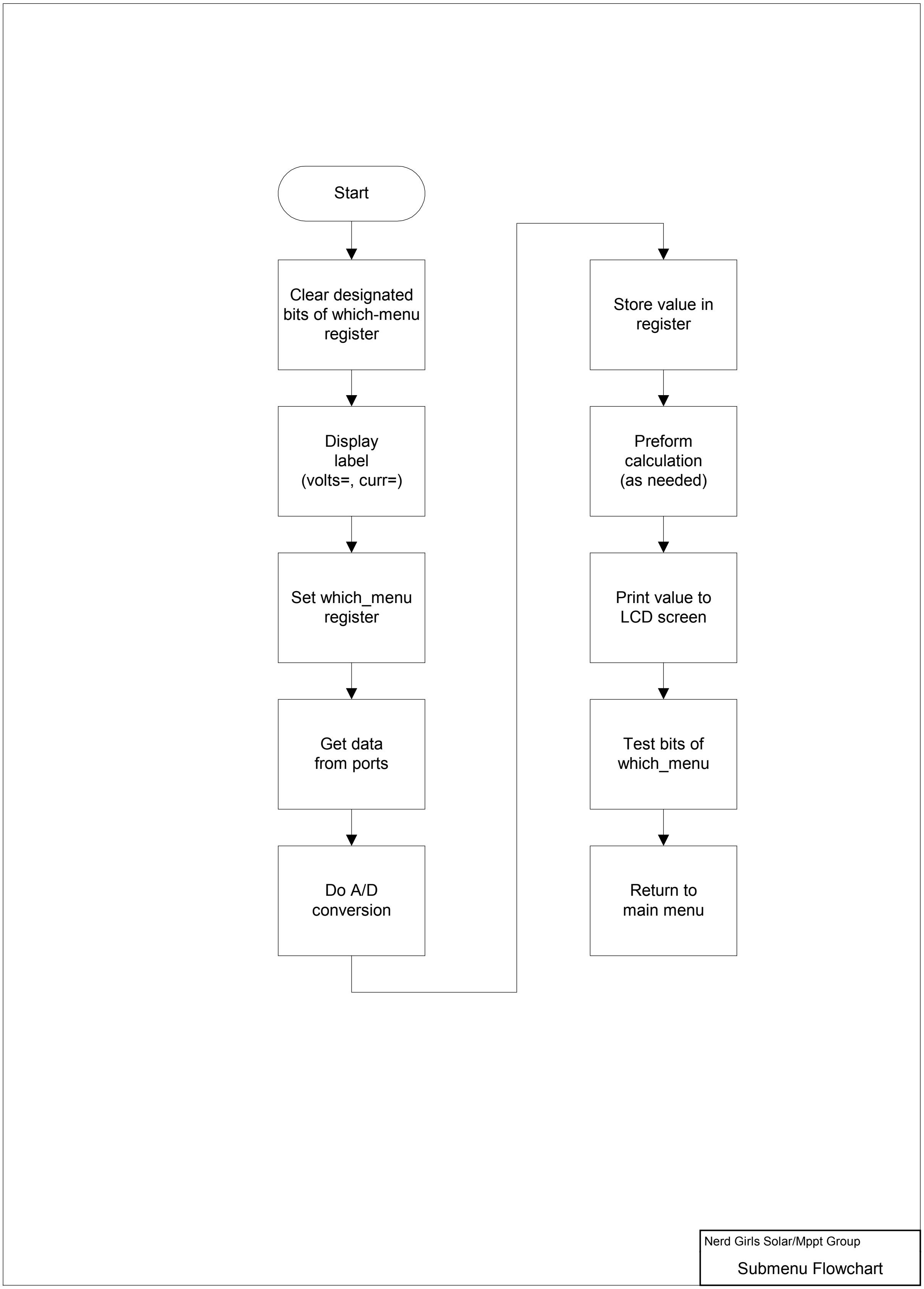
APPENDIX 7.2.1 MENU STRUCTURE



APPENDIX 7.2.2 ALGORITHM



APPENDIX 7.2.3 ALGORITHM SUBMENU FUNCTION



APPENDIX 7.3 CODE

APPENDIX 7.3.1 SOLARGIRLS.ASM

```
;***********************************************************************
;*          Microchip Technology Inc. 2002
;*          Assembler version: 2.0000
;*          Filename:
;*                  solargirls.asm (main routine)
;*          Dependents:
;*                  p18lcd.asm
;*                  p18math.asm
;*                  16f877.lkr

;***********************************************************************
;MAXIMUM POWER POINT TRACKER PIC CODE
;STEPHANIE, KATIE, JEANELL
;***********************************************************************
        list p=18f452
        #include p18f452.inc
;Program Configuration Registers
        __CONFIG    _CONFIG2L, _BOR_OFF_2L & _PWRT_ON_2L
        __CONFIG    _CONFIG4L, _STVR_OFF_4L & _LVP_OFF_4L & _DEBUG_OFF_4L
        __CONFIG    _CONFIG5L, _CP0_OFF_5L & _CP1_OFF_5L & _CP2_OFF_5L & _CP3_OFF_5L
        __CONFIG    _CONFIG6L, _WRT0_OFF_6L & _WRT1_OFF_6L & _WRT2_OFF_6L & _WRT3_OFF_6L
        __CONFIG    _CONFIG7L, _EBTR0_OFF_7L & _EBTR1_OFF_7L & _EBTR2_OFF_7L & _EBTR3_OFF_7L


        #define  scroll_dir      TRISA,4
        #define  scroll          PORTA,4             ;Push-button RA4 on PCB
        #define  select_dir      TRISB,0
        #define  select          PORTB,0             ;Push-button RB0 on PCB

        EXTERN          LCDInit, temp_wr, d_write, i_write, LCDLine_1, LCDLine_2
        EXTERN          UMUL0808L, UDIV1608L, AARGB0, AARGB1, BARGB0, BARGB1, AARGB5, REMB0,
REMB1, TEMP

ssprw   macro                           ;check for idle SSP module routine
        movlw   0x00
        andwf   SSPCON2,W
        sublw   0x00
        btfss   STATUS,Z
        bra     $-8

        btfsc   SSPSTAT,R_W
        bra     $-2
        endm

variables       UDATA
which_menu  RES 1
ptr_pos         RES 1
ptr_count       RES 1
temp_1          RES 1
temp_2          RES 1
temp_3          RES 1
cmd_byte        RES 1
temperature     RES 1
LSD             RES 1
MsD             RES 1
MSD             RES 1
seconds         RES 1
```

```
minutes         RES 1
hours           RES 1

NumH            RES 1
NumL            RES 1
TenK            RES 1
Thou            RES 1
Hund            RES 1
Tens            RES 1
Ones            RES 1

volt_in         RES 1
curr_in                 RES 1
batt_volt       RES 1
batt_curr       RES 1

STARTUP CODE
        NOP
        goto    start
        NOP
        NOP
        NOP
PROG1   CODE

stan_table                              ;table for standard code
        ;       "XXXXXXXXXXXXXXXX"
        ;                               ptr:
        data    "  Vin (Solar)   "    ;0
        data    "  Iin (Solar)   "    ;16
        data    "  Vout (MPPT)   ";32
        data    "  Iout (MPPT)   " ;48
        data    "RA4=Next RB0=Sel"      ;64
        data    "   Nerd Girls   " ;80
        data    "   MPPT Rocks   "      ;96
        data    "RA4=Set RB0=Menu"      ;112
        data    "RA4= --> RBO= ++"      ;128
        data    "   RB0 = Exit       "  ;144
        data    "Volts = "      ;160
        data    "Current =      "   ;176
        data    "               "   ;192

start
        call LCDInit

        movlw   B'10100100'             ;initialize USART
        movwf   TXSTA                   ;8-bit, Async, High Speed
        movlw   .25
        movwf   SPBRG                   ;9.6kbaud @ 4MHz
        movlw   B'10010000'
        movwf   RCSTA

        bcf     TRISC,2         ;configure CCP1 module for buzzer
;       bcf     TRISC,6
        movlw   0x80
        movwf   PR2                     ;initialize PWM period
        movlw   0x80                    ;initialize PWM duty cycle
        movwf   CCPR1L
        bcf     CCP1CON,CCP1X
        bcf     CCP1CON,CCP1Y
```

```
        movlw   0x05                    ;postscale 1:1, prescaler 4, Timer2 ON
        movwf   T2CON

        bsf     TRISA,4         ;make switch RA4 an Input

        ;ADDITIONS FOR A/D CONVERTING
        clrf    PORTB                   ;Clear PORTB
        clrf    TRISB                   ;PORTB all outputs, display 4 MSB's
                                        ;of A/D result on LEDs
        bsf     TRISB,0         ;make switch RB0 an Input
        movlw   B'01000001'     ;Fosc/8, A/D enabled
        movwf   ADCON0
        movlw   B'00001110'             ;B'00001110';Left justify,1 analog channel
        movwf   ADCON1                  ;VDD and VSS references


; test register value print by putting a value into curr_in

;       movlw   B'00000011'     ; put value in register W (35)
;       movwf   volt_in   ; put value of reg. W into volt_in

        movlw   B'00000100'             ;B'01100100'
        movwf   curr_in   ; put value of reg. W into curr_in

        movlw  B'00000010'      ; put value 50 (50v output to batt) in reg. W
        movwf  batt_volt        ;put value of reg. W (50) into batt_volt reg.



;**************** STANDARD CODE MENU SELECTION *****************
                        ;Introduction
        movlw   .80                     ;send "Nerd Girls" to LCD
        movwf   ptr_pos
        call    stan_char_1

        movlw   .96                     ;send "MPPT Rocks" to LCD
        movwf   ptr_pos
        call    stan_char_2
        call    delay_1s                ;delay for display
        call    delay_1s                ;delay for display
        call    delay_1s                ;delay for display
        call    delay_1s                ;delay for display
menu
;------------------ VOLTAGE IN (SOLAR)----------------------------
        bcf which_menu, 3               ;bit 3 of register which_menu is cleared to 0
        btfss   scroll          ;wait for RA4 release
        goto    $-2
        btfss   select          ;wait for RB0 release
        goto    $-2

        movlw   0x00                    ;Displays "Solar Vout" (.0) to LCD
        movwf   ptr_pos
        call    stan_char_1

        movlw   .64                     ;RA4=Next  RB0=Sel
        movwf   ptr_pos
        call    stan_char_2
v_wait
        bsf which_menu, 0
        btfss   select          ;voltmeter measurement ??
```

```
        bra     voltmeter
        btfsc   scroll          ;next mode ??
        bra     v_wait          ;NO
        btfss   scroll          ;YES
        bra     $-2                     ;wait for RA4 release
;-------------- SOLAR CURRENT OUTPUT -------------------------------
menu_buz
   bcf which_menu, 0        ;bit 0 of register which_menu is cleared to 0
        btfss   scroll          ;wait for RA4 release
        goto    $-2
        btfss   select          ;wait for RB0 release
        bra     $-2


        movlw   .16                     ;Displays "Solar Iout" to LCD
        movwf   ptr_pos
        call    stan_char_1

        movlw   .64                     ;RA4=Next  RB0=Sel
        movwf   ptr_pos
        call    stan_char_2
b_wait
        bsf which_menu, 1
        btfss select            ;current measurement??
        bra voltmeter
        btfsc scroll            ;next mode??
        bra b_wait                      ;NO
        btfss scroll            ;YES
        bra $-2                 ;wait for RA4 release

;---------------- MPPT VOLTAGE OUTPUT ----------------------
menu_temp
        bcf which_menu, 1               ;bit 1 of register which_menu is cleared to 0
        btfss   scroll          ;wait for RA4 release
        bra     $-2
        btfss   select          ;wait for RB0 release
        bra     $-2

        movlw   .32                       ;Display "MPPT Vout" to LCD
        movwf   ptr_pos
        call    stan_char_1

        movlw   .64                       ;RA4=Next  RB0=Sel
        movwf   ptr_pos
        call    stan_char_2
t_wait
        bsf which_menu, 2
        btfss select                    ;current measurement??
        bra voltmeter
        btfsc scroll                    ;next mode??
        bra t_wait                              ;NO
        btfss scroll                    ;YES
        bra $-2                         ;wait for RA4 release

;------------- -- MPPT CURRENT OUTPUT ----------------------------------
menu_clock
        bcf which_menu, 2               ;bit 2 of register which_menu is cleared to 0
        btfss   scroll          ;wait for RA4 release
        bra     $-2
        btfss   select          ;wait for RB0 release
```

```
        bra     $-2

        movlw   .48                     ;Display "MPPT Iout" to LCD
        movwf   ptr_pos
        call    stan_char_1

        movlw   .64                     ;RA4=Next  RB0=Sel
        movwf   ptr_pos
        call    stan_char_2
;--------------------don't need clock stuff-------------------
c_wait
        bsf which_menu, 3
        btfss select                    ;current measurement??
        bra voltmeter
        btfsc scroll                    ;next mode??
        bra c_wait                              ;NO
        btfss scroll                    ;YES
        bra $-2                                 ;wait for RA4 release
;       btfss   select                  ;goto time ??
;       bra     clock                   ;YES
;       btfsc   scroll                  ;NO, next mode ??
;       bra     c_wait                  ;NO
;       btfss   scroll                  ;YES
;       bra     $-2                     ;wait for release
;---------------- ---end of clock stuff-----------------------

        bra     menu                    ;begining of menu
        return


;************* STANDARD USER CODE *****************************
;------------- Voltmeter--------------------------------------
voltmeter
        btfss   select                  ;wait for RB0 release
        bra     $-2

;---------------------------- --------------------------------


;ADDITIONS FOR A/D CONVERTING
        ;write in 001 for bits 5-3 of adcon0
        bsf     ADCON0,GO       ;Start A/D conversion (changes bit 2 of ADCON0 to 1)
Wait
        btfss   PIR1,ADIF       ;Wait for conversion to complete
        goto    Wait

        swapf   ADRESH,W        ;Swap A/D result nibbles
        andlw   0x0f            ;Mask off lower 4 bits
        movwf   volt_in ;Write A/D result to PORTB

;*************************************************************

;perform calculations
   btfsc  which_menu, 0   ;if selected solar voltage output (bit 0 of reg. which_menu would then be 1)
   goto   temp_inputvoltprint
        btfsc  which_menu, 2    ;if selected mppt voltage output (bit 2 of reg. which_menu would then be 1)
        goto    temp_outputvoltprint
   btfsc  which_menu, 1   ;if selected solar current output (bit 1 of reg. which_menu would then be 1)
        goto    temp_inputcurrprint
        btfsc  which_menu, 3    ;if selected mppt current output (bit 3 of reg. which_menu would then be 1)
        goto    temp_outputcurrprint    ;send "Current = " to the LCD
```

```
        movwf   ptr_pos
        call    stan_char_1
temp_inputvoltprint
        call    LCDLine_1
        ;movlw  0x20             ;space
        ;movwf  temp_wr
        ;call   d_write
        ;movlw  0x20             ;space
        ;movwf  temp_wr
        ;call   d_write
        movlw   A'V'                     ;print "V"
        movwf   temp_wr
        call    d_write
        movlw   A'O'                     ;print "O"
        movwf   temp_wr
        call    d_write
        movlw   A'L'
        movwf   temp_wr
        call    d_write
        movlw   A'T'
        movwf   temp_wr
        call    d_write
        movlw   A'S'
        movwf   temp_wr
        call    d_write
        movlw   0x20                     ;space
        movwf   temp_wr
        call    d_write
        movlw   A'I'
        movwf   temp_wr
        call    d_write
        movlw   A'N'
        movwf   temp_wr
        call    d_write
        movlw   0x20                     ;space
        movwf   temp_wr
        call    d_write
        movlw   A'='                     ;print "="
        movwf   temp_wr
        call    d_write
        movlw   0x20                     ;space
        movwf   temp_wr
        call    d_write
        movf    volt_in, W               ;print Digital Input test value
        call    bin_bcd          ;get temp ready for LCD
        movf    MSD,W                    ;send high digit
        movwf   temp_wr
        call    d_write
        movf    MsD,W                    ;send middle digit
        movwf   temp_wr
        call    d_write
        movf    LSD,W                    ;send low digit
        movwf   temp_wr
        call    d_write
        movlw   A'V'
        movwf   temp_wr
        call    d_write
        movlw   0x20                     ;space
        movwf   temp_wr
        call    d_write
```

```
        ;end of sending unit to LCD
        movwf   temp_wr
        call    d_write
        goto    volts_again

;-------------------------------------------
temp_inputcurrprint
        call    LCDLine_1
        ;movlw  0x20            ;space
        ;movwf  temp_wr
        ;call   d_write
        ;movlw  0x20            ;space
        ;movwf  temp_wr
        ;call   d_write
        movlw   A'C'                    ;print "C"
        movwf   temp_wr
        call    d_write
        movlw   A'U'                    ;print "U"
        movwf   temp_wr
        call    d_write
        movlw   A'R'
        movwf   temp_wr
        call    d_write
        movlw   A'R'
        movwf   temp_wr
        call    d_write
        ;movlw  A'E'
        ;movwf  temp_wr
        ;call   d_write
        movlw   0x20                    ;space
        movwf   temp_wr
        call    d_write
        movlw   A'I'
        movwf   temp_wr
        call    d_write
        movlw   A'N'
        movwf   temp_wr
        call    d_write
        movlw   0x20                    ;space
        movwf   temp_wr
        call    d_write
        movlw   A'='                    ;print "="
        movwf   temp_wr
        call    d_write
        movlw   0x20                    ;space
        movwf   temp_wr
        call    d_write
        movf    curr_in, W              ;print Digital Input test value
        call    bin_bcd                 ;get temp ready for LCD
        movf    MSD,W                   ;send high digit
        movwf   temp_wr
        call    d_write
        movf    MsD,W                   ;send middle digit
        movwf   temp_wr
        call    d_write
        movf    LSD,W                   ;send low digit
        movwf   temp_wr
        call    d_write
        movlw   A'm'
        movwf   temp_wr
```

```
        call    d_write
        movlw   A'A'
        movwf   temp_wr
        call    d_write
        movlw   0x20                ;space
        movwf   temp_wr
        call    d_write
        ;end of sending unit to LCD
        movwf   temp_wr
        call    d_write
        goto    volts_again

;------------------------------------

;-------------------------------------------
temp_outputvoltprint
        call    LCDLine_1
        ;movlw  0x20                ;space
        ;movwf  temp_wr
        ;call   d_write
        ;movlw  0x20                ;space
        ;movwf  temp_wr
        ;call   d_write
        movlw   A'V'                        ;print "C"
        movwf   temp_wr
        call    d_write
        movlw   A'O'                        ;print "U"
        movwf   temp_wr
        call    d_write
        movlw   A'L'
        movwf   temp_wr
        call    d_write
        movlw   A'T'
        movwf   temp_wr
        call    d_write
        movlw   A'S'
        movwf   temp_wr
        call    d_write
        movlw   0x20                        ;space
        movwf   temp_wr
        call    d_write
        movlw   A'O'
        movwf   temp_wr
        call    d_write
        movlw   A'U'
        movwf   temp_wr
        call    d_write
        movlw   A'T'
        movwf   temp_wr
        call    d_write
        movlw   0x20                        ;space
        movwf   temp_wr
        call    d_write
        movlw   A'='                        ;print "="
        movwf   temp_wr
        call    d_write
        movlw   0x20                        ;space
        movwf   temp_wr
        call    d_write
        movf    batt_volt, W        ;print Digital Input test value
```

```
        call    bin_bcd                 ;get temp ready for LCD
        movf    MSD,W                   ;send high digit
        movwf   temp_wr
        call    d_write
        movf    MsD,W                   ;send middle digit
        movwf   temp_wr
        call    d_write
        movf    LSD,W                   ;send low digit
        movwf   temp_wr
        call    d_write
        movlw   A'V'
        movwf   temp_wr
        call    d_write
        movlw   0x20                    ;space
        movwf   temp_wr
        call    d_write
        ;end of sending unit to LCD
        movwf   temp_wr
        call    d_write
        goto    volts_again

;------------------------------------


;-------------------------------------------
temp_outputcurrprint
        call    LCDLine_1
        ;movlw  0x20                    ;space
        ;movwf  temp_wr
        ;call   d_write
        ;movlw  0x20                    ;space
        ;movwf  temp_wr
        ;call   d_write
        movlw   A'C'                    ;print "C"
        movwf   temp_wr
        call    d_write
        movlw   A'U'                    ;print "U"
        movwf   temp_wr
        call    d_write
        movlw   A'R'
        movwf   temp_wr
        call    d_write
        movlw   A'R'
        movwf   temp_wr
        call    d_write
        ;movlw  A'E'
        ;movwf  temp_wr
        ;call   d_write
        movlw   0x20                    ;space
        movwf   temp_wr
        call    d_write
        movlw   A'O'
        movwf   temp_wr
        call    d_write
        movlw   A'U'
        movwf   temp_wr
        call    d_write
        movlw   A'T'
        movwf   temp_wr
        call    d_write
```

```
        movlw   0x20                    ;space
        movwf   temp_wr
        call    d_write
        movlw   A'='                    ;print "="
        movwf   temp_wr
        call    d_write
        movlw   0x20                    ;space
        movwf   temp_wr
        call    d_write
        movf    volt_in, W
        movwf   AARGB0                  ;voltage in
        movf    curr_in, W
        movwf   BARGB0                  ;current in
        call    UMUL0808L               ;multiply BARGB0 by AARGB0 (result stored in BARGB1 (high) and
AARGB1 (low)

        movf    BARGB1, W               ;high bit register result of mult stored in BARGB0
        movwf   BARGB0
        movf    AARGB1, W               ;low bit register result of mult stored in AARGB0
        movwf   AARGB0
        movf    batt_volt, W            ;store 50V (volt. output to batteries) in BARGB1
        movwf   BARGB1
        call    UDIV1608L               ;[BARGB0][AARGB0]/[BARGB1] result stored in AARGB1
        movf    AARGB1, W               ;storing result in AARGB1 and sending to reg. W to print


    call    bin_bcd
        movf    MSD,W
        movwf   temp_wr
        call    d_write
        movf    MsD,W
        movwf   temp_wr
        call    d_write
        movf    LSD,W                   ;send high digit from the LSD #.xx
        movwf   temp_wr
        call    d_write



;       movf    volt_in, W              ;moves input voltage into reg. W
;       mulwf   curr_in                 ;multiplies the input volt. and input curr, stores result in W
;       movf    PRODL, W
;       movwf   AARGB0
;       movf    PRODH, W
;       movwf   AARGB1
;       movf    batt_volt, W    ;6
;       movwf   BARGB0
;       call    UDIV1608L

        ;movf   AARGB0, W               ;prepare for 16-bit binary to BCD
        ;movwf  NumH
        ;movf   AARGB1, W
        ;movwf  NumL
        ;call   bin16_bcd               ;get volts ready for LCD

;       call    LCDLine_2               ;display A/D result on 2nd line
        ;movf   Hund,W                  ;get hunds
        ;call   bin_bcd
        ;movf   MsD,W
        ;movwf  temp_wr
```

```
        ;call     d_write
        ;movf     LSD,W                  ;send high digit from the LSD #.xx
        ;movwf    temp_wr
        ;call     d_write


;       movf      AARGB1, W
;       call   bin_bcd

;       movf      MSD,W                  ;send high digit
;       movwf     temp_wr
;       call      d_write
;       movf      MsD,W                  ;send middle digit
;       movwf     temp_wr
;       call      d_write
;       movf      LSD,W                  ;send low digit
;       movwf     temp_wr
;       call      d_write
        movlw     A'm'
        movwf     temp_wr
        call      d_write
        movlw     A'A'
        movwf     temp_wr
        call      d_write
        movlw     0x20                   ;space
        movwf     temp_wr
        call      d_write
        ;end of sending unit to LCD
        movwf     temp_wr
        call      d_write
        goto      volts_again

;------------------------------------


volts_again
        movlw     .144                   ;Display "RB0 = Exit" to LCD
        movwf     ptr_pos
        call      stan_char_2
        movlw     "\r"                   ;move data into TXREG
        movwf     TXREG                  ;carriage return
        btfss     TXSTA,TRMT             ;wait for data TX
        bra       $-2

        btfsc     select    ;exit volt measurement ?? - if register select is 0, then skip next instruction and exit
        bra          voltmeter          ;NO, do conversion again
        btfsc  which_menu, 0            ;YES, if bit 0 of register which_menu is 0, then skip next instruction
        bra          menu                ; branches to next menu item (solar current output)
        btfsc  which_menu, 1            ;YES, if bit 1 of reg. which_menu is 0, skips next instr
        bra    menu_buz                 ; branches to next menu item (mppt voltage output)
        btfsc  which_menu, 2            ;YES, if bit 2 of reg. which_menu is 0, skips next instr
        bra    menu_temp                 ; branches to next menu item (mppt current output)
        btfsc  which_menu, 3            ;YES, if bit 3 of reg. which_menu is 0, skips next instr
        bra    menu_clock

;----------------- CLOCK -----------------------------------------

clock
        btfss     select                ;wait for RB0 button release
        bra       $-2
```

```
        movlw   0x0F                    ;intitialize TIMER1
        movwf   T1CON
        clrf    seconds
        clrf    minutes
        clrf    hours
overflow
        bcf     PIR1,TMR1IF
        movlw   0x80
        movwf   TMR1H                   ;load regs for 1 sec overflow
        clrf    TMR1L

        incf    seconds,F               ;increment seconds
        movf    seconds,W
        sublw   .60
        btfss   STATUS,Z                ;increment minutes ?
        bra     clk_done
        incf    minutes,F
        clrf    seconds

        movf    minutes,W
        sublw   .60
        btfss   STATUS,Z                ;increment hours ?
        bra     clk_done
        incf    hours,F
        clrf    minutes

        movf    hours,W
        sublw   .13
        btfss   STATUS,Z
        bra     clk_done
        movlw   .1                      ;start a new 12 hour period
        movwf   hours
clk_done
        movf    hours,W                 ;send hours to LCD
        call    bin_bcd

        call    LCDLine_1               ;place time on line 1

        movf    MsD,W                   ;send middle digit
        movwf   temp_wr
        call    d_write
        movf    LSD,W                   ;send low digit
        movwf   temp_wr
        call    d_write
        movlw   0x3A                    ;send  :   colon
        movwf   temp_wr
        call    d_write

        movf    minutes,W               ;send minutes to LCD
        call    bin_bcd

        movf    MsD,W                   ;send middle digit
        movwf   temp_wr
        call    d_write
        movf    LSD,W                   ;send low digit
        movwf   temp_wr
        call    d_write
        movlw   0x3A                    ; send :   colon
        movwf   temp_wr
        call    d_write
```

```
        movf    seconds,W               ;send seconds to LCD
        call    bin_bcd

        movf    MsD,W                   ;send middle digit
        movwf   temp_wr
        call    d_write
        movf    LSD,W                   ;send low digit
        movwf   temp_wr
        call    d_write

        movlw   0x20                    ;send 3 spaces after 00:00:00
        movwf   temp_wr
        call    d_write
        movlw   0x20
        movwf   temp_wr
        call    d_write
        movlw   0x20
        movwf   temp_wr
        call    d_write

        movlw   .112                    ;send "RA4=Dn RB0=Menu" to LCD
        movwf   ptr_pos
        call    stan_char_2

        btfss   scroll          ;set time ??
        bra     set_time

        btfss   select          ;return to main menu ??
        bra     menu

        btfss   PIR1,TMR1IF             ;has timer1 overflowed ?
        bra     $-2                     ;NO, wait til overflow
        bra     overflow        ;YES

        return
;****************************** *******************************


;************************** ROUTINES *************************
;**************************************************************
;**************************************************************

;----Standard code, Place characters on line-1----------------------
stan_char_1
        call    LCDLine_1               ;move cursor to line 1
        movlw   .16                     ;1-full line of LCD
        movwf   ptr_count
        movlw   UPPER stan_table
        movwf   TBLPTRU
        movlw   HIGH stan_table
        movwf   TBLPTRH
        movlw   LOW stan_table
        movwf   TBLPTRL
        movf    ptr_pos,W
        addwf   TBLPTRL,F
        clrf    WREG
        addwfc  TBLPTRH,F
        addwfc  TBLPTRU,F
```

```
stan_next_char_1
        tblrd   *+
        movff   TABLAT,temp_wr
        call    d_write                 ;send character to LCD

        decfsz  ptr_count,F             ;move pointer to next char
        bra     stan_next_char_1

        movlw   "\n"                    ;move data into TXREG
        movwf   TXREG                   ;next line
        btfss   TXSTA,TRMT              ;wait for data TX
        goto    $-2
        movlw   "\r"                    ;move data into TXREG
        movwf   TXREG                   ;carriage return
        btfss   TXSTA,TRMT              ;wait for data TX
        goto    $-2

        return

;----Standard code, Place characters on line-2----------------------
stan_char_2
        call    LCDLine_2               ;move cursor to line 2
        movlw   .16                     ;1-full line of LCD
        movwf   ptr_count
        movlw   UPPER stan_table
        movwf   TBLPTRU
        movlw   HIGH stan_table
        movwf   TBLPTRH
        movlw   LOW stan_table
        movwf   TBLPTRL
        movf    ptr_pos,W
        addwf   TBLPTRL,F
        clrf    WREG
        addwfc  TBLPTRH,F
        addwfc  TBLPTRU,F

stan_next_char_2
        tblrd   *+
        movff   TABLAT,temp_wr
        call    d_write                 ;send character to LCD

        decfsz  ptr_count,F             ;move pointer to next char
        bra     stan_next_char_2

        movlw   "\n"                    ;move data into TXREG
        movwf   TXREG                   ;next line
        btfss   TXSTA,TRMT              ;wait for data TX
        goto    $-2
        movlw   "\r"                    ;move data into TXREG
        movwf   TXREG                   ;carriage return
        btfss   TXSTA,TRMT              ;wait for data TX
        goto    $-2

        return
;-------------------------------------------- --------------------


;------------------ 100ms Delay -----------------------------
delay_100ms
        movlw   0xFF
```

```
        movwf   temp_1
        movlw   0x83
        movwf   temp_2

d100l1
        decfsz  temp_1,F
        bra     d100l1
        decfsz  temp_2,F
        bra     d100l1
        return

;---------------- 1s Delay --------------------------------
delay_1s
        movlw   0xFF
        movwf   temp_1
        movwf   temp_2
        movlw   0x05
        movwf   temp_3
d1l1
        decfsz  temp_1,F
        bra     d1l1
        decfsz  temp_2,F
        bra     d1l1
        decfsz  temp_3,F
        bra     d1l1
        return

;---------------- Set Current Time -------------------------
set_time
        movlw   .128                    ;send "RA4= --> RBO= ++" to LCD
        movwf   ptr_pos
        call    stan_char_2
set_time_again
        btfss   scroll          ;wait for button release
        bra     $-2

        call    LCDLine_1               ;start at 0x00 on LCD

        btfss   select          ;wait for RB0 button release
        bra     $-2
        call    delay_100ms
        btfss   select  ;increment hours (tens) ?
        bra     inc_hours
        bra     next_digit
inc_hours
        incf    hours
        movf    hours,W         ;check if hours has passed 12 ?
        sublw   .13
        btfss   STATUS,Z
        bra     next_digit
        clrf    hours                   ;YES, reset hours to 00
next_digit
        btfss   scroll          ;move to next digit
        bra     inc_mins
        movf    hours,W

        call    bin_bcd         ;get hours ready for display

        movf    MsD,W                   ;send tens digit
        movwf   temp_wr
```

```
        call    d_write
        movf    LSD,W                   ;send ones digit
        movwf   temp_wr
        call    d_write
        movlw   0x3A                    ;send  :  colon
        movwf   temp_wr
        call    d_write

        bra     set_time_again

inc_mins
        btfss   scroll          ;wait for RA4 button release
        bra     $-2
        call    LCDLine_1
        movlw   0x14                    ;shift cursor to right 3 places
        movwf   temp_wr
        call    i_write
        movlw   0x14
        movwf   temp_wr
        call    i_write
        movlw   0x14
        movwf   temp_wr
        call    i_write

        btfss   select          ;wait for RB0 button release
        bra     $-2
        call    delay_100ms
        btfss   select  ;increment minutes (tens) ?
        bra     inc_minutes
        bra     next_digit?
inc_minutes
        incf    minutes
        movf    minutes,W               ;check if hours has passed 12 ?
        sublw   .60
        btfss   STATUS,Z
        bra     next_digit?
        clrf    minutes
next_digit?
        btfss   scroll                  ;move to next digit
        bra     set_time_done
        movf    minutes,W

        call    bin_bcd                 ;get minutes ready for display

        movf    MsD,W                   ;send tens digit
        movwf   temp_wr
        call    d_write
        movf    LSD,W                   ;send ones digit
        movwf   temp_wr
        call    d_write
        movlw   0x3A                    ;send  :  colon
        movwf   temp_wr
        call    d_write
        bra     inc_mins

set_time_done
        btfss   scroll          ;wait for RA4 button release
        bra     $-2
        bra     overflow
```

```
;---------------- Binary (8-bit) to BCD ------------------
;                 255 = highest possible result
bin_bcd
        clrf    MSD
        clrf    MsD
        movwf   LSD             ;move value to LSD
ghundreth
        movlw   .100            ;subtract 100 from LSD
        subwf   LSD,W
        btfss   STATUS,C        ;is value greater than 100
        bra     gtenth          ;NO goto tenths
        movwf   LSD             ;YES, move subtraction result into LSD
        incf    MSD,F           ;increment hundreths
        bra     ghundreth
gtenth
        movlw   .10             ;take care of tenths
        subwf   LSD,W
        btfss   STATUS,C
        bra     over            ;finished conversion
        movwf   LSD
        incf    MsD,F           ;increment tenths position
        bra     gtenth
over                            ;0 - 9, high nibble = 3 for LCD
        movf    MSD,W           ;get BCD values ready for LCD display
        xorlw   0x30            ;convert to LCD digit
        movwf   MSD
        movf    MsD,W
        xorlw   0x30            ;convert to LCD digit
        movwf   MsD
        movf    LSD,W
        xorlw   0x30            ;convert to LCD digit
        movwf   LSD
        retlw   0

;---------------- Binary (16-bit) to BCD -----------------------
;                 xxx = highest possible result
bin16_bcd
                        ; Takes number in NumH:NumL
                    ; Returns decimal in
                    ; TenK:Thou:Hund:Tens:Ones
    swapf   NumH,W
    andlw   0x0F
    addlw   0xF0
    movwf   Thou
    addwf   Thou,F
    addlw   0xE2
    movwf   Hund
    addlw   0x32
    movwf   Ones

    movf    NumH,W
    andlw   0x0F
    addwf   Hund,F
    addwf   Hund,F
    addwf   Ones,F
    addlw   0xE9
    movwf   Tens
    addwf   Tens,F
    addwf   Tens,F
```

```
        swapf   NumL,W
        andlw   0x0F
        addwf   Tens,F
        addwf   Ones,F

        rlcf    Tens,F
        rlcf    Ones,F
        comf    Ones,F
        rlcf    Ones,F

        movf    NumL,W
        andlw   0x0F
        addwf   Ones,F
        rlcf    Thou,F

        movlw   0x07
        movwf   TenK

        movlw   0x0A                    ; Ten
Lb1:
        decf    Tens,F
        addwf   Ones,F
        btfss   STATUS,C
         bra    Lb1
Lb2:
        decf    Hund,F
        addwf   Tens,F
        btfss   STATUS,C
         bra    Lb2
Lb3:
        decf    Thou,F
        addwf   Hund,F
        btfss   STATUS,C
         bra    Lb3
Lb4:
        decf    TenK,F
        addwf   Thou,F
        btfss   STATUS,C
         bra    Lb4

        retlw   0


;---------------------------- EEPROM WRITE -----------------------------
write_eeprom
                bsf     SSPCON2,SEN             ;start bit
                btfsc   SSPCON2,SEN
                goto    $-2
                movlw   B'10100000'             ;send control byte (write)
                movwf   SSPBUF
                ssprw
                btfsc   SSPCON2,ACKSTAT                 ;ack?
                goto    $-2

                movlw   0x00                    ;send slave address HIGH byte
                movwf   SSPBUF
                ssprw
                btfsc   SSPCON2,ACKSTAT                 ;ack?
                goto    $-2
```

```
        movlw   0x05                    ;send slave address LOW byte(0x0005)
        movwf   SSPBUF
        ssprw
        btfsc   SSPCON2,ACKSTAT                 ;ack?
        goto    $-2

        movf    temperature,w           ;send slave DATA = temperature
        movwf   SSPBUF
        ssprw
        btfsc   SSPCON2,ACKSTAT                 ;ack?
        goto    $-2

        bsf     SSPCON2,PEN             ;stop bit
        btfsc   SSPCON2,PEN
        goto    $-2

        bcf     PIR1,TMR1IF             ;clear TIMER1 overflow flag
        clrf    TMR1L                   ;clear registers for next overflow
        clrf    TMR1H

        return

;***************************** *****************************
        end
```

APPENDIX 7.3.1 LCD.ASM

```
;*******************************************************************
;*	Microchip Technology Inc. 2002
;*	Assembler version: 2.0000
;*	Filename:
;*		p18lcd.asm (main routine)
;*	Dependents:
;*		p18demo.asm
;*		p18math.asm
;*		16f877.lkr
;*******************************************************************

	list p=18f452
	#include p18f452.inc


#define	LCD_D4		PORTD, 0		; LCD data bits
#define	LCD_D5		PORTD, 1
#define	LCD_D6		PORTD, 2
#define	LCD_D7		PORTD, 3

#define	LCD_D4_DIR	TRISD, 0		; LCD data bits
#define	LCD_D5_DIR	TRISD, 1
#define	LCD_D6_DIR	TRISD, 2
#define	LCD_D7_DIR	TRISD, 3

#define	LCD_E		PORTA, 1		; LCD E clock
#define	LCD_RW			PORTA, 2		; LCD read/write line
#define	LCD_RS		PORTA, 3		; LCD register select line

#define	LCD_E_DIR	TRISA, 1
#define	LCD_RW_DIR	TRISA, 2
#define	LCD_RS_DIR	TRISA, 3

#define	LCD_INS			0
#define	LCD_DATA	1

D_LCD_DATA	UDATA
COUNTER		res	1
delay		res	1
temp_wr		res	1
temp_rd		res	1

	GLOBAL		temp_wr

PROG1	CODE


;*************************************************************************

LCDLine_1
	movlw	0x80
	movwf	temp_wr
	rcall	i_write
	return
	GLOBAL		LCDLine_1

LCDLine_2
```

```
        movlw   0xC0
        movwf   temp_wr
        rcall   i_write
        return
        GLOBAL          LCDLine_2

        ;write data
d_write
        movff   temp_wr,TXREG
        btfss   TXSTA,TRMT
        goto    $-2
        rcall   LCDBusy
        bsf     STATUS, C
        rcall   LCDWrite
        return
        GLOBAL          d_write

        ;write instruction
i_write
        rcall   LCDBusy
        bcf     STATUS, C
        rcall   LCDWrite
        return
        GLOBAL          i_write


rlcd    macro   MYREGISTER
 IF MYREGISTER == 1
        bsf     STATUS, C
        rcall   LCDRead
 ELSE
        bcf     STATUS, C
        rcall   LCDRead
 ENDIF
        endm
;**********************************************************************

; *********************************************************************
LCDInit
        clrf    PORTA

        bcf     LCD_E_DIR               ;configure control lines
        bcf     LCD_RW_DIR
        bcf     LCD_RS_DIR

        movlw   b'00001110'
        movwf   ADCON1

        movlw   0xff                    ; Wait ~15ms @ 20 MHz
        movwf   COUNTER
lil1
        movlw   0xFF
        movwf   delay
        rcall   DelayXCycles
        decfsz  COUNTER,F
        bra     lil1

        movlw   b'00110000'             ;#1 Send control sequence
        movwf   temp_wr
        bcf     STATUS,C
```

```
        rcall   LCDWriteNibble

        movlw   0xff                    ;Wait ~4ms @ 20 MHz
        movwf   COUNTER
lil2
        movlw   0xFF
        movwf   delay
        rcall   DelayXCycles
        decfsz  COUNTER,F
        bra     lil2

        movlw   b'00110000'             ;#2 Send control sequence
        movwf   temp_wr
        bcf     STATUS,C
        rcall   LCDWriteNibble

        movlw   0xFF                    ;Wait ~100us @ 20 MHz
        movwf   delay
        rcall   DelayXCycles

        movlw   b'0011000'              ;#3 Send control sequence
        movwf   temp_wr
        bcf     STATUS,C
        rcall   LCDWriteNibble

                ;test delay
        movlw   0xFF                    ;Wait ~100us @ 20 MHz
        movwf   delay
        rcall   DelayXCycles


        movlw   b'00100000'             ;#4 set 4-bit
        movwf   temp_wr
        bcf     STATUS,C
        rcall   LCDWriteNibble

        rcall   LCDBusy                 ;Busy?

        movlw   b'00101000'             ;#5   Function set
        movwf   temp_wr
        rcall   i_write

        movlw   b'00001101'             ;#6  Display = ON
        movwf   temp_wr
        rcall   i_write

        movlw   b'00000001'             ;#7   Display Clear
        movwf   temp_wr
        rcall   i_write

        movlw   b'00000110'             ;#8   Entry Mode
        movwf   temp_wr
        rcall   i_write

        movlw   b'10000000'             ;DDRAM addresss 0000
        movwf   temp_wr
        rcall   i_write


        return
```

```
        GLOBAL          LCDInit
; *******************************************************************

;*******************************************************************

LCDWriteNibble
        btfss   STATUS, C               ; Set the register select
        bcf     LCD_RS
        btfsc   STATUS, C
        bsf     LCD_RS

        bcf     LCD_RW                          ; Set write mode

        bcf     LCD_D4_DIR              ; Set data bits to outputs
        bcf     LCD_D5_DIR
        bcf     LCD_D6_DIR
        bcf     LCD_D7_DIR

        NOP                             ; Small delay
        NOP

        bsf     LCD_E                   ; Setup to clock data

        btfss   temp_wr, 7                      ; Set high nibble
        bcf     LCD_D7
        btfsc   temp_wr, 7
        bsf     LCD_D7
        btfss   temp_wr, 6
        bcf     LCD_D6
        btfsc   temp_wr, 6
        bsf     LCD_D6
        btfss   temp_wr, 5
        bcf     LCD_D5
        btfsc   temp_wr, 5
        bsf     LCD_D5
        btfss   temp_wr, 4
        bcf     LCD_D4
        btfsc   temp_wr, 4
        bsf     LCD_D4

        NOP
        NOP

        bcf     LCD_E                   ; Send the data

        return
; *******************************************************************

; *******************************************************************
LCDWrite
;       rcall   LCDBusy
        rcall   LCDWriteNibble
        swapf   temp_wr,F
        rcall   LCDWriteNibble
        swapf   temp_wr,F

        return

        GLOBAL          LCDWrite
```

```
; *********************************************************************

LCDRead
        bsf     LCD_D4_DIR              ; Set data bits to inputs
        bsf     LCD_D5_DIR
        bsf     LCD_D6_DIR
        bsf     LCD_D7_DIR

        btfss   STATUS, C               ; Set the register select
        bcf     LCD_RS
        btfsc   STATUS, C
        bsf     LCD_RS

        bsf     LCD_RW                          ;Read = 1

        NOP
        NOP

        bsf     LCD_E                   ; Setup to clock data

        NOP
        NOP
        NOP
        NOP

        btfss   LCD_D7                  ; Get high nibble
        bcf     temp_rd, 7
        btfsc   LCD_D7
        bsf     temp_rd, 7
        btfss   LCD_D6
        bcf     temp_rd, 6
        btfsc   LCD_D6
        bsf     temp_rd, 6
        btfss   LCD_D5
        bcf     temp_rd, 5
        btfsc   LCD_D5
        bsf     temp_rd, 5
        btfss   LCD_D4
        bcf     temp_rd, 4
        btfsc   LCD_D4
        bsf     temp_rd, 4

        bcf     LCD_E                   ; Finished reading the data

        NOP
        NOP
        NOP
        NOP
        NOP
        NOP
        NOP
        NOP

        bsf     LCD_E                   ; Setup to clock data

        NOP
        NOP

        btfss   LCD_D7                  ; Get low nibble
        bcf     temp_rd, 3
```

```
        btfsc   LCD_D7
        bsf     temp_rd, 3
        btfss   LCD_D6
        bcf     temp_rd, 2
        btfsc   LCD_D6
        bsf     temp_rd, 2
        btfss   LCD_D5
        bcf     temp_rd, 1
        btfsc   LCD_D5
        bsf     temp_rd, 1
        btfss   LCD_D4
        bcf     temp_rd, 0
        btfsc   LCD_D4
        bsf     temp_rd, 0

        bcf     LCD_E                   ; Finished reading the data

FinRd
        return
; *******************************************************************

; *******************************************************************
LCDBusy
                                        ; Check BF
        rlcd    LCD_INS
        btfsc   temp_rd, 7
        bra     LCDBusy
        return

        GLOBAL          LCDBusy
; *******************************************************************

; *******************************************************************
DelayXCycles
        decfsz  delay,F
        bra     DelayXCycles
        return
; *******************************************************************


        END
```

APPENDIX 7.3.3 MATH.ASM

```
;***********************************************************************
;*          Microchip Technology Inc. 2002
;*          Assembler version: 2.0000
;*          Filename:
;*                  p18math.asm (main routine)
;*      Designed to run at 4MHz
;*          PICDEM 2 PLUS DEMO code
;***********************************************************************

            list        p=18f452
            #include p18f452.inc

            #define  _C         STATUS,0

MATH_VAR        UDATA
AARGB0                      RES 1
AARGB1                      RES 1
AARGB5                      RES 1
BARGB0                      RES 1
BARGB1                      RES 1
REMB0           RES 1
REMB1           RES 1
TEMP            RES 1
LOOPCOUNT       RES 1

            GLOBAL          AARGB0, AARGB1, BARGB0, BARGB1, REMB0, AARGB5, REMB1, TEMP

PROG2  CODE
;---------------- 8 * 8 UNSIGNED MULTIPLY -----------------------

;       Max Timing:     3+12+6*8+7 = 70 clks
;       Min Timing:     3+7*6+5+3 = 53 clks
;       PM: 19          DM: 4
UMUL0808L
                    CLRF    AARGB1
            MOVLW   0x08
            MOVWF   LOOPCOUNT
            MOVF    AARGB0,W

LOOPUM0808A
            RRCF    BARGB0, F
            BTFSC   _C
            bra     LUM0808NAP
            DECFSZ  LOOPCOUNT, F
            bra     LOOPUM0808A

            CLRF    AARGB0
            RETLW   0x00

LUM0808NAP
            BCF     _C
            bra     LUM0808NA

LOOPUM0808
            RRCF            BARGB0, F
            BTFSC   _C
            ADDWF   AARGB0, F
```

```
LUM0808NA      RRCF    AARGB0, F
            RRCF    AARGB1, F
            DECFSZ        LOOPCOUNT, F
            bra          LOOPUM0808
                    return
                    GLOBAL             UMUL0808L
;----------------  16/8 UNSIGNED DIVIDE           ------------------------

;       Max Timing: 2+7*12+11+3+7*24+23 = 291 clks
;       Min Timing: 2+7*11+10+3+7*17+16 = 227 clks
;       PM: 39                                DM: 7

UDIV1608L
                    GLOBAL                        UDIV1608L
                    CLRF          REMB0                              ;clears contents of register REMB0
            MOVLW         8                       ;moves 8 into register LOOPCOUNT
            MOVWF         LOOPCOUNT

LOOPU1608A     RLCF           AARGB0,W             ;contents of reg. AARGB0 rotated one bit to left through carry
flag (result in W)
            RLCF           REMB0, F              ;contents of reg. REMB0 rotated one bit to left through carry flag
            MOVF           BARGB0,W              ;moves contents of BARGB0 to reg. W
            SUBWF          REMB0, F

            BTFSC          _C
            bra          UOK68A
            ADDWF          REMB0, F
            BCF          _C
UOK68A        RLCF           AARGB0, F

            DECFSZ        LOOPCOUNT, F
            bra          LOOPU1608A

            CLRF          TEMP

            MOVLW         8
            MOVWF         LOOPCOUNT

LOOPU1608B     RLCF           AARGB1,W
            RLCF           REMB0, F
            RLCF           TEMP, F
            MOVF           BARGB0,W
            SUBWF          REMB0, F
            CLRF          AARGB5
            CLRW
            BTFSS          _C
            INCFSZ         AARGB5,W
            SUBWF          TEMP, F

            BTFSC          _C
            bra          UOK68B
            MOVF           BARGB0,W
            ADDWF          REMB0, F
            CLRF          AARGB5
            CLRW
            BTFSC          _C
            INCFSZ         AARGB5,W
            ADDWF          TEMP, F

            BCF          _C
```

```
UOK68B      RLCF        AARGB1, F

            DECFSZ      LOOPCOUNT, F
            bra         LOOPU1608B
                  return
                  GLOBAL        UDIV1608L

                  end
```

APPENDIX 7.3.4 P2PLSP18.LKR

```
// Sample linker command file for 18F452i used with MPLAB ICD 2
// $Id: 18f452i.lkr,v 1.1 2002/02/26 16:55:21 sealep Exp $

LIBPATH  .

CODEPAGE   NAME=vectors  START=0x0        END=0x29       PROTECTED
CODEPAGE   NAME=page     START=0x2A       END=0x7DBF
CODEPAGE   NAME=debug    START=0x7DC0     END=0X7FFF     PROTECTED
CODEPAGE   NAME=idlocs   START=0x200000   END=0x200007   PROTECTED
CODEPAGE   NAME=config   START=0x300000   END=0x30000D   PROTECTED
CODEPAGE   NAME=devid    START=0x3FFFFE   END=0x3FFFFF   PROTECTED
CODEPAGE   NAME=eedata   START=0xF00000   END=0xF000FF   PROTECTED

ACCESSBANK  NAME=accessram  START=0x0      END=0x7F
DATABANK    NAME=gpr0       START=0x80     END=0xFF
DATABANK    NAME=gpr1       START=0x100    END=0x1FF
DATABANK    NAME=gpr2       START=0x200    END=0x2FF
DATABANK    NAME=gpr3       START=0x300    END=0x3FF
DATABANK    NAME=gpr4       START=0x400    END=0x4FF
DATABANK    NAME=gpr5       START=0x500    END=0x5F3
DATABANK    NAME=dbgspr     START=0x5F4    END=0x5FF    PROTECTED
ACCESSBANK  NAME=accesssfr  START=0xF80    END=0xFFF    PROTECTED

SECTION     NAME=STARTUP    ROM=vectors
SECTION     NAME=PROG1      ROM=page
```

APPENDIX 7.4 DATASHEETS

APPENDIX 7.4.1 PIC MICROCONTROLER

APPENDIX 7.4.2 DC/DC CONVERTER PT4122A

APPENDIX 7.4.3 DC/DC CONVERTER TPS6734IP

APPENDIX 7.4.4 PWM TL598CN

APPENDIX 7.4.4 PWM TL598CN

APPENDIX 7.4.5 DIODE 16CTU04S

APPENDIX 7.4.6 LTC DAC 1451CM8

APPENDIX 7.4.7 MOSFET IXFX90N20Q

APPENDIX 7.4.8 MOSFET DRIVER MAX4420CPA

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