MICROCHIP

AN701

Switch Mode Battery Eliminator Based on a PIC16C72A

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OVERVIEW

The PIC16C72A is a member of the PICmicro® Mid-Range Family of 8-bit, high-speed microcontrollers. The PIC16C72 provides the following features:

- 5 Channel, 8-bit Analog-to-Digital Converter (A/D)
- CCP Module to generate a PWM output
- I^2C™/SPI™ Module
- 3 Timers
- 8 Interrupt sources

This application note shows how to combine the A/D and CCP modules with suitable software to produce a Switch Mode Battery Eliminator (SMBE) providing 3.0, 4.5, 5.0, 6.0, 7.5 and 9.0 volt output voltages at up to 1 Amp with an AC or DC input between 12.6V and 30V peak.

HARDWARE

The system makes use of the A/D to read the input and output voltages, the Capture/Compare/Pulse module to generate a PWM output, and Timer2 to regulate how fast the program runs. External hardware includes a switching power converter and a suitable output filter. Six LEDs on PORTB indicate the output voltage as set by two push buttons on PORTA.

Optional components not installed in this project include a serial EEPROM to store the last voltage setting and a level translator to convert TTL to RS-232 for communications with a PC.

In-Circuit Serial Programming™ (ICSP) support has also been provided. LEDs D7 and D8 share clock and data lines required for ICSP. These LEDs indicate error conditions and are optional.

Analog-to-Digital Converter Module

The A/D converts an input voltage between ground and V_{DD} to an 8-bit value presented in ADRES. In this application, the switching converter input and output voltages are sampled. Provisions have been included to read the setting of a potentiometer.

Capture/Compare/Pulse Width Modulation Module

The CCP module produces the PWM signal that controls the series pass switching transistor. Depending on the PWM period and F_{OSC}, any number of bits between 2 and 10 bits may be used to specify the PWM on-time. The CCP module requires the use of Timer2, the Timer2 prescaler, and the PR2 register to produce a PWM output.

Timer2 Postscaler

Timer2 drives the CCP module to control the PWM period and also drives the Timer2 postscaler. The postscaler is incremented when Timer2 is reset at the end of each PWM cycle and will generate an interrupt when the postscaler overflows.

External Hardware

The switching buck converter relies on three components to function:

- Series pass switch (Q1)
- Inductor (L1)
- Commutating diode (D10).

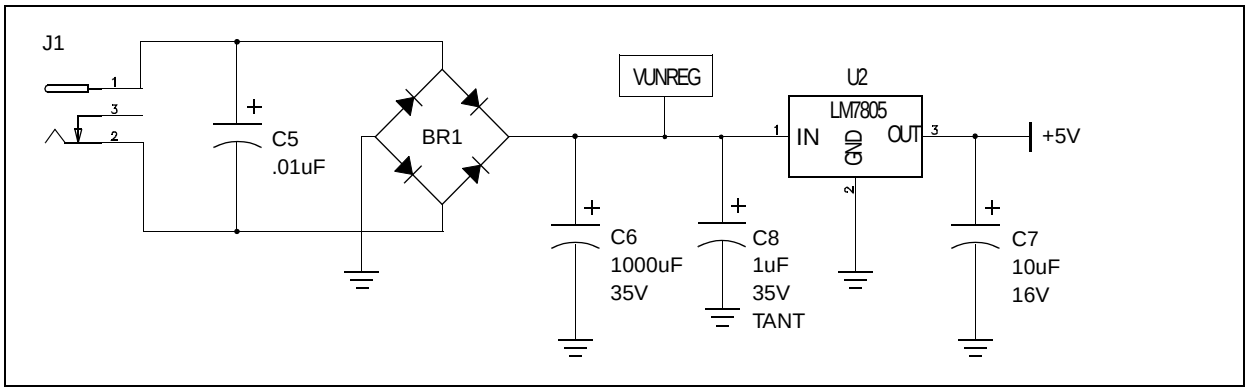
These devices form the core of all switch mode buck converters.

Power Input Circuit

This circuit is a conventional linear power supply that accepts AC or DC power with a peak voltage of 30V (limited by the 78L05). The converter operates off the unregulated bulk power, while the regulator supplies power and a voltage reference to the controller.

Figure 1 shows the Power Input Circuit. Bridge rectifier BR1 rectifies the raw power input that may be AC or DC. Capacitor C6 provides rough filtering to reduce ripple in the input voltage. Capacitor C8 provides the short current pulses drawn by transistor Q1 when it is turned on. Capacitor C7 provides filtering of regulator U2 output.

FIGURE 1: POWER INPUT CIRCUIT



Power Converter

Figure 2 shows the switching buck converter with drive circuits. Unregulated DC is provided at the emitter of transistor Q1. Q1, inductor L1 and diode D10 form the basic buck switching converter. The output appears at connector J4.

When RC2 (PWM output) is high, transistor Q2 is turned on, pulling Q2's collector to ground. This draws current from Q1's base, turning Q1 on. When Q1 is on, current from capacitors C6 and C8 charge L1 through the load. Resistor R19 limits the current drawn from the base of Q1. Resistor R17 ensures that Q1 switches off quickly. Resistor R20 ensures that transistor Q2 switches off quickly. Resistor R18 limits Q2's base current.

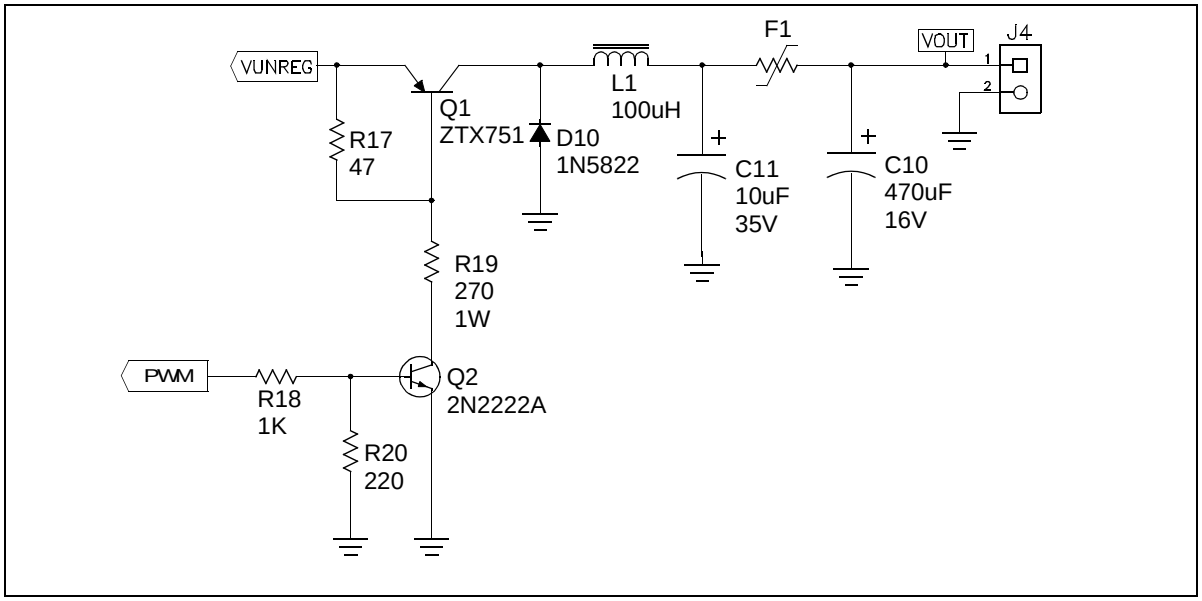
When RC2 is low, R20 turns off Q2 and R17 turns off Q1. When Q1 is off, the current through L1 continues to flow through L1, D10 and the load, discharging L1. When the current through L1 becomes less than the current drawn by the load, C10 provides the additional current and reduces output voltage ripple.

To ensure that Q1 remains cool during operation, it must be driven well into saturation. When driving transistors as digital switches, divide their h_{FE} (small signal gain) by 5 and use the resulting gain for your calculations. This ensures that the transistor switches through its linear region quickly to prevent significant heat generation in the transistor.

As the unregulated input voltage decreases, the drive applied to Q1 decreases to the point where Q1 starts operating in its linear region, producing heat. Continued operation in the linear region will cause Q1 to overheat and fail. Q1 usually shorts, causing the input voltage to appear at the converter output. R19 was selected to allow Q1 to operate safely as long as VUNREG is above 10V. The controller software will shut down the converter if VUNREG falls below 10V.

The converter output contains a considerable amount of noise. Capacitors C10 and C11 provide filtering to reduce that noise. F1 is a PTC resistor acting as a 1 Amp, self-resetting fuse.

FIGURE 2: SWITCHING BUCK CONVERTER WITH DRIVE AND OUTPUT CIRCUITS



Microcontroller Circuits

The microcontroller, analog inputs and digital outputs are shown in Figure 3.

The LEDs indicate the output voltage (D1-6) and converter faults (D7-8). Switches S1 and S2 allow the user to select the desired output voltage. Resistors R3, R4 and capacitor C4 form the voltage feedback circuit. Resistors R15, R16 and capacitor C13 form the voltage source sense circuit. PWM is output at pin RC2.

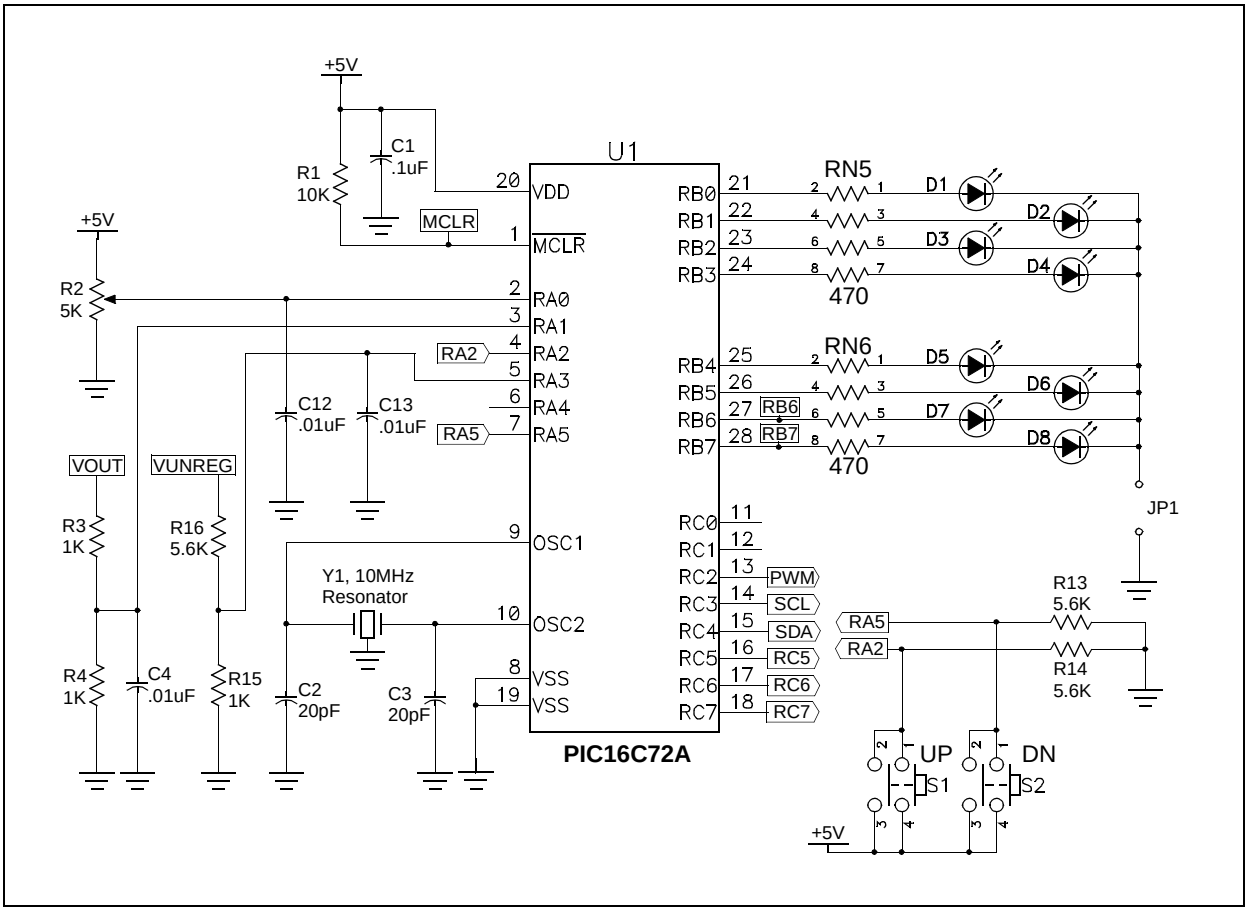
Register packs RN5 and RN6 limit current through LEDs D1-D8. LEDs D7 and D8 share clock and data lines required for ICSP. Jumper J1 disables all LEDs.

When programming the controller using ICSP, J1 should be removed. If ICSP does not function properly, D7 and D8 or RN6 should be installed after programming.

S1 is the decrease voltage button and S2 is the increase voltage button. R13 and R14 are pull down resistors.

Resonator Y1, and capacitors C2 and C3 set Fosc for the controller. If Y1 is a ceramic resonator with internal capacitors, C2 and C3 are not required. Resistor R1 pulls $\overline{MCLR}$ to +5V while allowing the controller to be programmed using ICSP. In addition, connecting pins 1 and 3 of connector J2 causes a remote reset of the controller. (See figure 5.)

FIGURE 3: MICROCONTROLLER, ANALOG INPUTS AND DIGITAL INPUTS AND OUTPUTS



FIRMWARE

Initialization

The controller is first initialized by configuring the A/D, CCP and Timer2 peripherals, followed by clearing the RAM required for variables and initializing some variables. Controller pins are configured as required for each of the modules, or as digital outputs if they are not being used.

A/D

Pins RA0, RA1 and RA3 are configured as analog inputs. Pins RA2 and RA5 are used as digital inputs. The controller VDD is used as VREF for the A/D.

The conversion clock source TAD is selected to be between 1.6usec and 6.4usec. Since Tosc = 0.1usec (Fosc = 10MHz), 32Tosc = 3.2usec. The A/D module is turned on and pin RA1 (VOUT) is sampled for conversion later in the loop.

TRISA configures pin RA4 as an output and all others as inputs.

CCP (PWM)

The CCP module is set to PWM mode. Timer2 is enabled with a 1:1 prescaler. PR2 is set to 63 (0x3F). The resulting PWM frequency is 39.063KHz. (TPWM=25.6msec). The CCP module uses 8-bit data to control the PWM duty cycle. The PWM duty cycle is set to 0, ensuring that the PWM output is turned off.

All pins on PORTC are configured as outputs, including RC2 which is the controller PWM output.

Timer2 postscaler

Since Timer2 will also control the frequency that the main loop will execute, the Timer2 postscaler is set to a 1:1 ratio and the Timer2 postscaler interrupt is enabled. This will cause one interrupt for each PWM cycle.

RAM

RAM required for variables is cleared. The 3.0V LED on PORTB is lit. The variable `set_pt` is initialized to produce the 3.0V output. Button debounce counters are initialized.

Main loop

For a digital control loop to function as well as an analog controller, the digital control loop should repeat at least 30 times faster than the fastest expected transient.

The ripple frequency at capacitor C7 is 120Hz, or twice the AC power line frequency. In this application, the loop must be executed at least 120 x 30, or 3600 times a second to adequately respond to the bulk power ripple. Transients at the converter output are also handled, but less effectively with increasing frequency.

The Timer2 postscaler generates interrupts that are counted by the interrupt service routine. When 8 interrupts have occurred, the main loop is allowed to execute once. This causes the main loop to execute 4883 times a second.

The A/D starts a conversion on RA1/AN1 (VOUT). The program loops wait for the conversion to complete. The 8-bit result is placed in VOUT. The A/D is then set to sample the input voltage (VUNREG).

PID Controller

The control algorithm is a software implementation of a Proportional-Integral-Differential (PID) controller. The only input to this controller is the difference between the desired output voltage and the actual output voltage, and is known as the error signal.

The first module produces the error signal by finding the difference between `set_pt` and VOUT. The result is saved in the low byte of a 2 byte signed variable `e0h:e0`. The high byte is set to reflect a negative value if needed. The difference is selected to produce a positive result if `set_pt` is greater than VOUT.

```
e0 = set_pt - vout
```

if `e0<7>=0` , `e0h = 0x00`, else `e0h = 0xFF`

A proportional term is generated from the present error signal. This is simply the signed error multiplied by some factor Kp. The 2 byte signed result is saved as `proh:pro`.

```
proh:pro = Kp * e0h:e0
Kp = proportional factor
```

The difference between the present and previous error is found and saved as the 2 byte signed result `difh:dif`. The previous error `e1h:e1` is simply the error result found in the execution of the previous loop. The difference between errors is multiplied by some factor (Kd) and saved as `difh:dif.`

```
difh:dif = Kd * (e1h:e1 – e0h:e0)
Kd=difference factor
```

The integral component is nothing more than a total of all the errors produced since the last reset. The present error is multiplied by some factor (Ki) before being added to the running 2 byte unsigned total `inth:int`.

```
inth:int = inth:int + Ki * e0h:e0
Ki = integral factor
```

The proportional, integral and difference terms are summed together. The result of the sum is saved as the 2 byte signed result `pwmh:pwm`.

```
pwmh:pwm = proh:pro + difh:dif
             + inth:int
```

The result is never greatly positive, but can sometimes cause the result to underflow. When pwmh:pwm underflows (as it does when the load is disconnected), the PWM drive signal must be forced to zero or the converter output becomes unpredictable. The overload LED is also lit.

If pwmh<7> = 1, then pwmh:pwm = 0x0000 and turn on the OVLD LED, else turn off OVLD LED.

PWM Generator

The PWM generator module (software, not the peripheral) discards the 3 least and 5 most significant bits, and uses the remaining 8 bits to generate PWM with a desired on time. Of the remaining 8 bits, the 2 least significant bits are loaded into CCP1CON<5:4>. The last 6 bits (with 2 leading zeros to form a byte) are loaded into CCP1RL.

Conversion of the input voltage V_{UNREG} is started.

Reading Buttons

The LED data at PORTB is copied to a temporary variable.

The down button is read. If it is closed, its debounce counter is incremented. If no overflow occurs, execution proceeds to reading the up button. If an overflow does occur, the LED data is shifted right one bit, unless bit 0 is already set. Overflows occur approximately every half second.

The up button is read and processed similar to the down button. If it is closed, its debounce counter is incremented. If no overflow occurs, execution proceeds to convert V_{IN}. If an overflow does occur, the LED data is shifted left one bit, unless bit 5 is already set. Overflows occur approximately every half second.

The LED data is copied back to PORTB to light the corresponding LED. The LED data is also used to find the proper index to use prior to calling a look-up table.

A call to the lookup table is performed. The lookup table routine adds the index in the W register to the program counter. The next instruction performed is a "retlw" instruction that places the new set_pt in the W register and returns to the next instruction after the call to the look-up table. The value returned is saved as the new set_pt.

Both button debounce counters are reset.

The conversion result of V_{IN} is retrieved from the A/D and vin is subtracted from 0xC1 (10V set point). If the result is positive, V_{IN} is less than 10V and program execution is directed to a safety shutdown module. Otherwise, program execution continues normally.

```
If (0xC1 – vin) is positive, go to shutdown.
```

The present error, e0h:e0, replaces the previous error, e1h:e1.

Program execution then returns to the top of the loop to wait for Timer2 postscaler interrupts.

Interrupts

The Interrupt Service Routine saves the state of the W and STATUS registers, increments the interrupt counter and restores the STATUS and W registers.

Safety Shutdown

The safety shutdown module has been included to turn off the converter and to light the trip LED. Once entered, there is no exit from this module except by resetting the controller.

Gain constants Kp, Kd, and Ki

Constants Kp, Ki, and Kd were determined experimentally. The goal was to maintain V_{OUT} between 4.75V and 5.25V when the 5V output was selected. V_{OUT} should remain within this band, regardless of changes in the load current. This specifically includes 10% changes in current, unloaded to full-load, and full-load to unloaded step changes. Other step changes in loading were also examined.

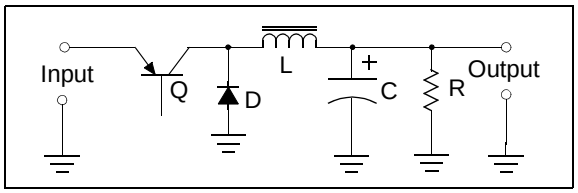
Constants determined for a 5V output were then used for other voltage outputs.

Only resistive loads were considered. Some degradation of output performance may be expected with inductive or capacitive loads.

APPENDIX A: SWITCH MODE BUCK CONVERTER

A switch mode buck converter performs a voltage reduction by periodically charging an inductor from a high voltage source, then allowing the charged inductor to transfer its stored energy to the load at a lower voltage. This energy transfer occurs with little loss.

FIGURE 4: SWITCH MODE BUCK CONVERTER TOPOLOGY



In the ideal buck converter, the average output power equals the average input power. The switch is operated at a constant frequency, but the duty cycle (on time / cycle time) controls the output voltage.

When the switch Q (a transistor or MOSFET) is closed, current from the source flows through the inductor L, through the load R and back to the source. Energy is being stored in the inductor by increasing inductor current and building up a magnetic field.

When the switch is open, the source no longer supplies energy. The energy stored in the magnetic field is transferred to the load as the magnetic field collapses. Inductor current is decreasing as current flows from the inductor through the load R and diode D and back to the inductor L.

No energy is lost in the inductor during this conversion. The majority of losses occur in the switching device as it switches though its linear region, and the commutation diode when it conducts due to its forward voltage drop. Most electrolytic filter capacitors also have high resistance to the high frequency ripple current.

If current flows through the inductor at all times, the converter is operating in the continuous mode. The average inductor current is the same as the load current. If the load current is constant, variations in the inductor current average to zero. The peak inductor current will be no greater than twice the average current, and can be reduced by raising the switching frequency. This is normally the desired operating mode.

If the current through the inductor stops, the converter is operating in the discontinuous mode. All the current that flows through the load continuously must flow through the switch and charge the inductor during the time the switch is turned on. This can result in very high currents in both the switch and inductor and risks saturating the inductor. When the inductor is saturated, its inductance decreases drastically. Considerable noise is also produced as large currents are switched, requiring a greater amount of filtering. This mode is normally used only when there is very light loading of the converter, but it is easier to stabilize than the continuous mode converter.

In both continuous and discontinuous modes, charging or discharging a filter capacitor at the converter output makes up the difference between the inductor and load currents. This filter capacitor also reduces output ripple voltage and noise that switching converters produce.

The equations presented here assume an ideal circuit, but actual circuits have similar results.

The approximate duty cycle D.C. can be approximated by:

$$D.C. = \frac{V_{OUT}}{V_{IN}} = \frac{I_{IN}}{I_{OUT}} = \frac{T_{ON}}{T_{PWM}}$$

Where V_{OUT} = output voltage,
I_{IN} = average input current,
T_{ON} = switch on time
V_{IN} = input voltage,
I_{OUT} = output current,
T_{PWM} = PWM period = $1/F_{PWM}$

The ripple current magnitude due to switching is approximated by:

$$I_{RIPPLE} = \frac{(V_{IN}-V_{OUT}) * D.C. * T_{PWM}}{L}$$

Where L = inductor inductance,
I_{RIPPLE} = ripple current peak-to-peak
F_{PWM} = PWM frequency

The ripple current is absorbed by the output filter capacitor C, but produces a small output ripple voltage that is approximated by:

$$V_{RIPPLE} = \frac{I_{RIPPLE} * D.C. * T_{PWM}}{C}$$

Where V_{RIPPLE} = output voltage ripple peak-to-peak

EXAMPLE 1: CAPACITOR AND INDUCTOR SELECTION

Given: V_{UNREG} = 20V, V_{OUT} = 6V,
V_{RIPPLE} = 0.1V, I_{RIPPLE} = 1A,
F_{PWM} = 39.063KHz

Solution:

$$D.C. = \frac{V_{OUT}}{V_{IN}} = \frac{6}{20} = 0.30$$

$$T_{PWM} = \frac{1}{F_{PWM}} = \frac{1}{39KHz} = 25.6uS$$

$$C = \frac{I_{RIP}*D.C.*T_{PWM}}{V_{RIPPLE}} = \frac{(1A)(.3)(25.6uS)}{0.1V}$$

$$= 76.8uF$$

$$I_{RIP} = \frac{(V_{IN}-V_{OUT})*D.C.*T_{PWM}}{L}$$

$$L = \frac{(V_{IN}-V_{OUT})*D.C.*T_{PWM}}{I_{RIP}}$$

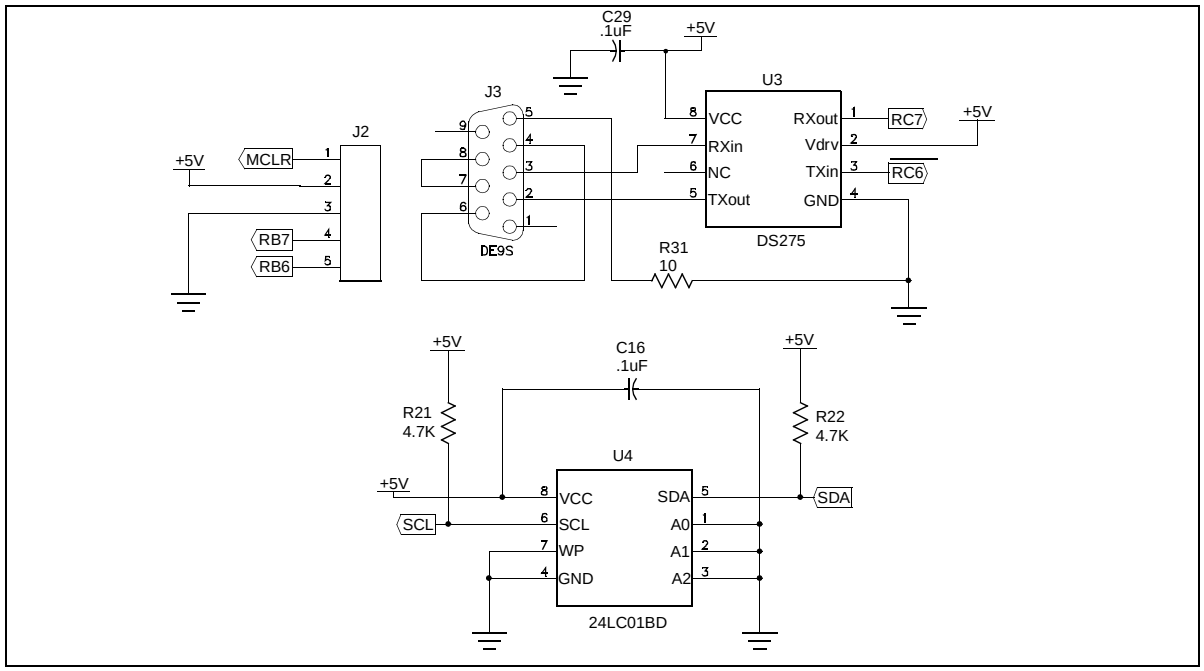
$$= \frac{(20V-6V)(0.30)(25.6uS)}{1A}$$

$$= 107.5uH$$

APPENDIX B: ACCESSORY COMPONENTS

These accessory component are not installed on the board, but can provide additional capabilities. Connector J2 provides for In-Circuit Serial Programming (ICSP) and offers a remote $\overline{MCLR}$ reset by connecting pins 1 and 3. Integrated circuit U3 and connector J3 provide RS-232 communications with the controller. Integrated circuit U4 is a serial EEPROM that communicates with the controller using the I^2C™ protocol.

FIGURE 5: ACCESSORY COMPONENTS



APPENDIX C: CODE

```
MPASM 02.20 Released         SW_REG1A.ASM   3-9-1999  19:28:40


LOC  OBJECT CODE     LINE SOURCE TEXT
  VALUE

                     00001
;*******************************************************************************
                     00002 ;*   Filename: APPNOTE.ASM
                     00003
;*******************************************************************************
                     00004 ;*       Author:      Brett Duane
                     00005 ;*       Company:     Microchip Technology
                     00006 ;*       Revision:    Rev 1.0
                     00007 ;*       Date:        3-9-99
                     00008 ;*       Assembled using MPASM rev 4.00.00
                     00009
;*******************************************************************************
                     00010 ;*       Include files: p16c72a.inc Rev 1.01
                     00011
;*******************************************************************************
                     00012 ;*
                     00013 ;*       Switching buck regulator using 16C72A using A/D,
                     00014 ;*       PWM (CCP) and timer2 modules.
                     00015 ;*
                     00016 ;*       PID control loop implementation.
                     00017 ;*       Executes 4883 loops per second.
                     00018 ;*       Spends most of its time looping waiting for timer2 overflows.
                     00019 ;*
                     00020 ;*       A/D inputs and PWM output are 8 bits,
                     00021 ;*       with internal calculations done in 16 bits
                     00022 ;*
                     00023 ;*       Timer2 postscaler (1:16) generates an interrupt.
                     00024 ;*
                     00025 ;*       RA0 converts a 0-5V input from trimmer, but is not used.
                     00026 ;*       RA1 monitors VOUT.
                     00027 ;*       RA2 is the up voltage push button input.
                     00028 ;*       RA3 monitors VUNREG.
                     00029 ;*       RA5 is the down voltage push button input.
                     00030 ;*
                     00031 ;*       RB<5:0> drives LEDs to indicate the output voltage.
                     00032 ;*       RB<7:6> drives LEDs to indicate overload or shutdown.
                     00033 ;*
                     00034 ;*       RC2 is the PWM source for the switching converter.
                     00035 ;*
                     00036 ;*
                     00037 ;*       Configuration Bit Settings
                     00038 ;*           Brown-out detect is off
                     00039 ;*           Code protect is off
                     00040 ;*           Power-up timer is enabled
                     00041 ;*           Watchdog timer is disabled
                     00042 ;*           10MHz resonator is driven in XT mode
                     00043 ;*
                     00044 ;*       Program Memory Words Used:   230
                     00045 ;*       Program Memory Words Free:  1818
                     00046 ;*
                     00047 ;*       Data Memory Bytes Used:       24
                     00048 ;*       Data Memory Bytes Free:      104
                     00049 ;*
                     00050
;*******************************************************************************
                     00051 ;*       What's Changed
                     00052 ;*
                     00053 ;*       Date        Description of Change
```

```
                  00054 ;*
                  00055 ;*   3-3-99      This is the initial release.
                  00056 ;*
                  00057
;***************************************************************************
                  00058
                  00059      list p=16c72a
                  00060      #include    <p16c72a.inc>
                  00001      LIST
                  00002 ; P16C72A.INC Standard Header File,Version 1.01 Microchip Technology, Inc.
                  00249      LIST
                  00061
2007 3FB1         00062      __config _BODEN_OFF & _CP_OFF & _PWRTE_ON & _WDT_OFF & _XT_OSC
                  00063
                  00064
                  00065          cblock  0x020
                  00066
  00000020        00067              UPCL     ;up button debounce
  00000021        00068              UPCH     ;up button debounce
  00000022        00069              DNCL     ;down button debounce
  00000023        00070              DNCH     ;down button debounce
  00000024        00071              SETPOINT ;voltage setpoint - RA0 result (unsigned)
  00000025        00072              VOUT     ;output voltage feedback - RA1 result
  00000026        00073              VUNREG   ;source voltage feedback - RA3 result
  00000027        00074              TEMPA    ;temp variable
  00000028        00075              TEMPB    ;temp variable
  00000029        00076              INT      ;integral component
  0000002A        00077              INTH     ;integral component
  0000002B        00078              PRO      ;proportional component
  0000002C        00079              PROH     ;proportional component
  0000002D        00080              DIF      ;difference component
  0000002E        00081              DIFH     ;difference component
  0000002F        00082              PWM      ;PWM drive
  00000030        00083              PWMH     ;PWM drive
  00000031        00084              E0       ;present error
  00000032        00085              E0H      ;present error
  00000033        00086              E1       ;past error
  00000034        00087              E1H      ;past error
  00000035        00088              T2POST   ;postscaler interrupt counter
  00000036        00089              ISRS     ;isr variable
  00000037        00090              ISRW     ;isr variable
                  00091
                  00092          endc
                  00093
  000000F9        00094 DEL1     equ 0xf9     ;text equate - debounce delay
  00000089        00095 AVOUT    equ 0x89     ;text equate - select VOUT channel
  00000099        00096 AVUNREG  equ 0x99     ;text equate - select VUNREG channel
                  00097
                  00098
;***************************************************************************
                  00099 ;*       Reset vector
                  00100 ;*           This is the reset vector
                  00101 ;*
                  00102
;***************************************************************************
                  00103
0000              00104          org     0x00    ;reset vector
0000 280E         00105          goto    Main    ;program start
                  00106
                  00107
                  00108
;***************************************************************************
                  00109 ;*       INTERRUPT SERVICE ROUTINE
                  00110 ;*           This ISR counts timer2 interrupts
                  00111 ;*
                  00112 ;*       Input Variables:
```

```
                  00113 ;*       T2POST       Counts overflow interrupts
                  00114 ;*
                  00115 ;*   Output Variables:
                  00116 ;*       T2POST       Counts overflow interrupts
                  00117 ;*
                  00118
;*****************************************************************************
                  00119
0004              00120      org     0x04     ;interrupt service routine
                  00121
0004 00B7         00122      movwf   ISRW     ;save W
0005 0E03         00123      swapf   STATUS,W ;get status
0006 00B6         00124      movwf   ISRS     ;save status
                  00125
0007 108C         00126      bcf     PIR1,TMR2IF;clear interrupt request flag
                  00127
0008 0AB5         00128      incf    T2POST,F ;increment interrupt counter
                  00129
0009 0E36         00130      swapf   ISRS,W   ;get status
000A 0083         00131      movwf   STATUS   ;restore status
000B 0EB7         00132      swapf   ISRW,F   ;restore W
000C 0E37         00133      swapf   ISRW,W   ;restore W
                  00134
000D 0009         00135      retfie           ;return from interrupt
                  00136
                  00137
;*****************************************************************************
                  00138 ;*   Main    Beginning of main loop
                  00139 ;*           First segment of code initializes controller
                  00140
;*****************************************************************************
                  00141
000E              00142 Main
000E 1303         00143      bcf     STATUS,RP1;bank1 initialization
000F 1683         00144      bsf     STATUS,RP0;bank1
                  00145 ;adc
0010 3004         00146      movlw   0x04     ;RA0,1,3 analog, RA2,5 digital, Vref=Vdd
0011 009F         00147      movwf   ADCON1
                  00148
0012 302F         00149      movlw   0x2f     ;RA0,1,3 analog in; RA2,5 digital in, RA4 dig out
0013 0085         00150      movwf   TRISA
                  00151 ;PWM
0014 30FF         00152      movlw   0xFF     ;set portC to all inputs
0015 0087         00153      movwf   TRISC
0016 1107         00154      bcf     TRISC,2  ;make RC2/PWM output
                  00155
0017 303F         00156      movlw   .63      ;PWM period =  78.125KHz (8 bit resolution)
0018 0092         00157      movwf   PR2
                  00158
                  00159 ;timer2
0019 148C         00160      bsf     PIE1,TMR2IE;enable timer2 postscaler interrupts
                  00161
                  00162 ;display
001A 0186         00163      clrf    TRISB    ;make PORTB all outputs
                  00164
001B 1283         00165      bcf     STATUS,RP0;select bank0
                  00166 ;adc
001C 3089         00167      movlw   AVOUT    ;(10MHz osc)set A/D conv clock(Fosc/32),
001D 009F         00168      movwf   ADCON0   ;select RA1(AN1), turn on A/D
                  00169 ;PWM
001E 1217         00170      bcf     CCP1CON,4;clear ls bits of PWM duty cycle
001F 1297         00171      bcf     CCP1CON,5
0020 0195         00172      clrf    CCPR1L   ;set PWM to 0 (turn off PWM)
                  00173
0021 3004         00174      movlw   0x04     ;enable timer2, set prescale=1:1,
                                                    postscale=1:1
```

```
0022 0092      00175          movwf   T2CON
0023 300C      00176          movlw   0x0C     ;set CCP1 to PWM mode
0024 0097      00177          movwf   CCP1CON
               00178
               00179 ;*************************************************************************
               00180 ;*       Restart Clears memory
               00181 ;*
               00182 ;*           Initializes display LEDs, desired output voltage,
               00183 ;*           debounce counters
               00184 ;*
               00185 ;*           Enables interrupts
               00186 ;*
               00187 ;*       Output Variables:
               00188 ;*           SETPOINT    desired output voltage, set to 3.0V
               00189 ;*           DNCL, DNCH  Down voltage button debounce counter
               00190 ;*           UPCL, UPCH  Up voltage button debounce counter
               00191 ;*
               00192 ;*************************************************************************
               00193
0025 3020      00194 Restart  movlw   0x20     ;clear memory from 0x20 to 0x3f
0026 0084      00195          movwf   FSR
0027 0180      00196 ClrMem   clrf    INDF
0028 0A84      00197          incf    FSR,F
0029 1F04      00198          btfss   FSR,6
002A 2827      00199          goto    ClrMem
               00200
002B 3001      00201          movlw   0x01     ;light 3.0V LED
002C 0086      00202          movwf   PORTB
               00203
002D 304D      00204          movlw   0x4d     ;initial 3.0V setting
002E 00A4      00205          movwf   SETPOINT
               00206
002F 01A2      00207          clrf    DNCL     ;clear down button debounce counter
0030 01A0      00208          clrf    UPCL     ;clear up button debounce counter
               00209
0031 30F9      00210          movlw   DEL1
0032 00A3      00211          movwf   DNCH     ;preset down button debounce counter byte
0033 00A1      00212          movwf   UPCH     ;preset up button debounce counter high byte
               00213
0034 170B      00214          bsf     INTCON,PEIE ;enable peripheral interrupt sources
0035 178B      00215          bsf     INTCON,GIE  ;enable all interrupts
               00216
               00217 ;*************************************************************************
               00218 ;*
               00219 ;*       Again   Top of main loop
               00220 ;*
               00221 ;*               Waits for 8 timer2 interrupts
               00222 ;*
               00223 ;*               A/D converts VOUT
               00224 ;*
               00225 ;*               Acquires VUNREG channel
               00226 ;*
               00227 ;*       Input Variables:
               00228 ;*               T2POST      Timer2 interrupt counter
               00229 ;*
               00230 ;*       Output Variables:
               00231 ;*               VOUT        Conversion result
               00232 ;*
               00233 ;*************************************************************************
               00234
0036           00235 Again
0036 1DB5      00236          btfss   T2POST,3   ;long delay
0037 2836      00237          goto    Again      ;try again
               00238
0038 01B5      00239          clrf    T2POST     ;clear counter
               00240
```

```
                00241 ;--- start conversion - feedback
0039 151F       00242       bsf     ADCON0,GO_DONE ;start conversion
003A 0000       00243       nop
003B 191F       00244 Wc2   btfsc   ADCON0,GO_DONE ;test if done
003C 283B       00245       goto    Wc2            ;no, wait some more
003D 081E       00246       movf    ADRES,W        ;get conversion result
003E 00A5       00247       movwf   VOUT           ;save result
                00248 ;--- end conversion
003F 3099       00249       movlw   AVUNREG        ;select VUNREG channel
0040 009F       00250       movwf   ADCON0
                00251
                00252
;*****************************************************************************
                00253 ;*    FErr    Finds difference (error) between SETPOINT and VOUT
                00254 ;*    E0H:E0 = SETPOINT - VOUT
                00255 ;*
                00256 ;*    Input Variables:
                00257 ;*            SETPOINT    Desired output voltage
                00258 ;*
                00259 ;*    Output Variables:
                00260 ;*            E0H:E0      Signed error
                00261
;*****************************************************************************
                00262
0041            00263 FErr
0041 01B2       00264       clrf    E0H            ;clear error high byte
                00265
0042 0825       00266       movf    VOUT,W
0043 0224       00267       subwf   SETPOINT,W     ;f-w=d
0044 00B1       00268       movwf   E0             ;save new error
                00269
0045 1C03       00270       btfss   STATUS,C       ;was there a borrow?
0046 09B2       00271       comf    E0H,F          ;yes
                00272
                00273
;*****************************************************************************
                00274 ;*    Ppp     Produces proportional term by multiplying E0H:E0 by Kp
                00275 ;*
                00276 ;*            PROH:PRO = E0H:E0 * Kp
                00277 ;*            Kp = 2^3 - Produced by 3 left shifts
                00278 ;*
                00279 ;*            This term forces the output close to the desired output
                00280 ;*            quickly, but will never completely eliminate the error.
                00281 ;*
                00282 ;*    Input Variables:
                00283 ;*            E0H:E0      Error found at top of loop
                00284 ;*            Kp          Proportional gain factor (constant)
                00285 ;*
                00286 ;*    Output Variables:
                00287 ;*            PROH:PRO    Proportional component
                00288 ;*
                00289
;*****************************************************************************
                00290
0047            00291 Ppp
0047 0831       00292       movf    E0,W           ;move E0 to temp space
0048 00A7       00293       movwf   TEMPA
0049 0832       00294       movf    E0H,W
004A 00A8       00295       movwf   TEMPB
                00296
004B 1003       00297       bcf     STATUS,C       ;mult E0 by 2
004C 0DA7       00298       rlf     TEMPA,F
004D 0DA8       00299       rlf     TEMPB,F
                00300
004E 1003       00301       bcf     STATUS,C       ;mult E0 by 2
004F 0DA7       00302       rlf     TEMPA,F
```

```
0050 0DA8      00303      rlf    TEMPB,F
               00304
0051 1003      00305      bcf    STATUS,C       ;mult E0 by 2
0052 0DA7      00306      rlf    TEMPA,F
0053 0DA8      00307      rlf    TEMPB,F
               00308
0054 0827      00309 PppD movf   TEMPA,W        ;move result in temp space to pro
0055 00AB      00310      movwf  PRO
0056 0828      00311      movf   TEMPB,W
0057 00AC      00312      movwf  PROH
               00313
               00314
;*****************************************************************************
               00315 ;*   DifCom  Computes differential component
               00316 ;*
               00317 ;*       Finds difference between this loop error and previous
                             loop error
               00318 ;*   DIFH:DIF = (E1H:E1 - E0H:E0) * Kd
               00319 ;*
               00320 ;*       Kd = 2^3 - Produced by 3 left shifts
               00322 ;*       This term tends to slow controller response.
               00323 ;*
               00324 ;*   Input Variables:
               00325 ;*       E1H:E1      Previous loop error
               00326 ;*       E0H:E0      Present loop error
               00327 ;*       Kd          Differential gain factor (constant)
               00328 ;*
               00329 ;*   Output Variables:
               00330 ;*       DIFH:DIF    differential component
               00331 ;*
               00332
;*****************************************************************************
               00333
0058           00334 DifCom
0058 0834      00335      movf   E1H,W          ;get prev error high byte
0059 0232      00336      subwf  E0H,W          ;f-w=d   E0-E1=w
005A 00AE      00337      movwf  DIFH           ;save difference high byte
               00338
005B 0833      00339      movf   E1,W           ;get prev error low byte
005C 0231      00340      subwf  E0,W           ;f-w=d   E0-E1=w
005D 00AD      00341      movwf  DIF            ;save difference low byte
               00342
005E 1C03      00343      btfss  STATUS,C       ;was there a borrow?
005F 03AE      00344      decf   DIFH,F         ;yes
               00345
               00346      ;allow difference to be modified here
               00347
0060 1003      00348      bcf    STATUS,C       ;mult dif by 2
0061 0DAD      00349      rlf    DIF,F
0062 0DAE      00350      rlf    DIFH,F
               00351
0063 1003      00352      bcf    STATUS,C       ;mult dif by 2
0064 0DAD      00353      rlf    DIF,F
0065 0DAE      00354      rlf    DIFH,F
               00355
0066 1003      00356      bcf    STATUS,C       ;mult dif by 2
0067 0DAD      00357      rlf    DIF,F
0068 0DAE      00358      rlf    DIFH,F
               00359
               00360
               00361
               00362
;*****************************************************************************
               00363 ;*   IntCom  Computes integral component
               00364 ;*
               00365 ;*   Multiplies present error by Ki,
```

```
                00366 ;*   adds result to INTH:INT
                00367 ;*
                00368 ;*   INTH:INT = INTH:INT + E0H:E0 * Ki
                00369 ;*
                00370 ;*   Ki = 2^3 -- Produced by 3 left shifts
                00371 ;*
                00372 ;*   This term will eliminate all error,
                00373 ;*   but not quickly
                00374 ;*
                00375 ;*   Input Variables:
                00376 ;*   E0H:E0      Present loop error
                00377 ;*   INTH:INT    Running total of errors
                00378 ;*   Ki          Integral gain factor (constant)
                00379 ;*
                00380 ;*   Output Variables:
                00381 ;*   DIFH:DIF    differential component
                00382
;*************************************************************************
                00383
0069            00384 IntCom
0069 0832       00385       movf    E0H,W       ;move E0 to temp space
006A 00A8       00386       movwf   TEMPB
006B 0831       00387       movf    E0,W
006C 00A7       00388       movwf   TEMPA
                00389
                00390       ;allow error to be modified here before adding to integral
                00391
006D 1003       00392       bcf     STATUS,C
006E 0DA7       00393       rlf     TEMPA,F     ;E0
006F 0DA8       00394       rlf     TEMPB,F     ;E0H
                00395
0070 1003       00396       bcf     STATUS,C
0071 0DA7       00397       rlf     TEMPA,F     ;E0
0072 0DA8       00398       rlf     TEMPB,F     ;E0H
                00399
0073 1003       00400       bcf     STATUS,C
0074 0DA7       00401       rlf     TEMPA,F     ;E0
0075 0DA8       00402       rlf     TEMPB,F     ;E0H
                00403
0076 0827       00404 IntD  movf    TEMPA,W     ;get current error, E0
0077 07A9       00405       addwf   INT,F       ;add to INT, store in INT
0078 1803       00406       btfsc   STATUS,C    ;was there a carry?
0079 0AAA       00407       incf    INTH,F      ;yes, inc INT high byte
                00408
007A 0828       00409       movf    TEMPB,W     ;get E0 high byte, E0H
007B 07AA       00410       addwf   INTH,F
                00411
                00412
;*************************************************************************
                00413 ;*   Total  Sums proportional, integral, and differential terms
                00414 ;*
                00415 ;*       PWMH:PWM = INTH:INT + PROH:PRO + DIFH:DIF
                00416 ;*
                00417 ;*       If the result should ever go negative,
                00418 ;*       the result is forced to 0,and the overload LED is set.
                00419 ;*       (This is an error condition.Can't have a negative PWM.)
                00420 ;*
                00421 ;*   Input Variables:
                00422 ;*       INTH:INT    Integral term
                00423 ;*       PROH:PRO    Proportional term
                00424 ;*       DIFH:DIF    Differential term
                00425 ;*
                00426 ;*   Output Variables:
                00427 ;*       PWMH:PWM    Sum of terms
                00428
;*************************************************************************
```

```
             00429
007C         00430 Total
007C 082C    00431 PCom     movf    PROH,W     ;add in proportional term
007D 00B0    00432          movwf   PWMH
             00433
007E 082B    00434          movf    PRO,W
007F 00AF    00435          movwf   PWM
             00436
0080 082A    00437 ICom     movf    INTH,W     ;add in integral term
0081 07B0    00438          addwf   PWMH,F
             00439
0082 0829    00440          movf    INT,W
0083 07AF    00441          addwf   PWM,F
0084 1803    00442          btfsc   STATUS,C
0085 0AB0    00443          incf    PWMH,F
             00444
0086 082E    00445 DCom     movf    DIFH,W     ;add in differential term
0087 07B0    00446          addwf   PWMH,F
             00447
0088 082D    00448          movf    DIF,W
0089 07AF    00449          addwf   PWM,F
008A 1803    00450          btfsc   STATUS,C
008B 0AB0    00451          incf    PWMH,F
             00452
008C 1BB0    00453 Ovrld    btfsc   PWMH,7     ;did PWM go negative?
008D 2890    00454          goto    NegPwm     ;yes
008E 1306    00455          bcf     PORTB,6    ;no - turn off overload LED
008F 2893    00456          goto    PwmGen
             00457
0090 1706    00458 NegPwm   bsf     PORTB,6    ;turn on overload LED
0091 01B0    00459          clrf    PWMH       ;set PWM to 0
0092 01AF    00460          clrf    PWM
             00461
             00462
;*****************************************************************************
             00463 ;*       PwmGen  Divides PWHM:PWM by 8 (3 right shifts)
             00464 ;*           2 LSbits of PWM sent to 2 LSbits of duty cycle register
             00465 ;*           remaining 6 bits sent to CCPR1L (duty cycle register)
             00466 ;*
             00467 ;*           A/D has been acquiring VUNREG, start conversion.
             00468 ;*
             00469 ;*       Input Variables:
             00470 ;*              PWMH:PWM   PWM drive
             00471
;*****************************************************************************
             00472
009          00473 PwmGen
0093 0CB0    00474          rrf     PWMH,F     ;PWMH
0094 0CAF    00475          rrf     PWM,F      ;PWM
             00476
0095 0CB0    00477          rrf     PWMH,F     ;PWMH
0096 0CAF    00478          rrf     PWM,F      ;PWM
             00479
0097 0CB0    00480          rrf     PWMH,F     ;PWMH - can ignore contents of PWMH now
0098 0CAF    00481          rrf     PWM,F      ;PWM
             00482
0099 1217    00483          bcf     CCP1CON,4  ;clear ls bits of PWM duty cycle
009A 1297    00484          bcf     CCP1CON,5
             00485
009B 0CAF    00486          rrf     PWM,F      ;shift carry INTo PWM, lsbit INTo carry
009C 1803    00487          btfsc   STATUS,C   ;is carry set?
009D 1617    00488          bsf     CCP1CON,4  ;set PWM duty cycle lsb
             00489
009E 0CAF    00490          rrf     PWM,F      ;shift carry INTo PWM, lsbit INTo carry
009F 1803    00491          btfsc   STATUS,C   ;is carry set?
00A0 1697    00492          bsf     CCP1CON,5  ;set PWM duty cycle lsb
```

```
                00493
00A1 082F       00494       movf    PWM,W           ;get PWM
00A2 393F       00495       andlw   0x3f            ;mask off 2 ms bits (78.125KHz)
00A3 0095       00496       movwf   CCPR1L          ;put in PWM duty cycle
                00497
00A4 151F       00498       bsf     ADCON0,2        ;start conversion VUNREG
                00499
                00500
;*******************************************************************************
                00501 ;*    up/dn buttons
                00502 ;*            Debounces UP and DOWN buttons
                00503 ;*                Increments counters once for each pass
                00504 ;*                through the loop when button pressed.
                00505 ;*
                00506 ;*                If button not pressed, counter is reset.
                00507 ;*
                00508 ;*                If a button is successfully debounced,
                00509 ;*                both counters are reset.
                00510 ;*
                00511 ;*                Debounce delay is about 0.5 seconds
                00512 ;*
                00513 ;*            Moves voltage indicator bit as required.
                00514 ;*
                00515 ;*            Finds index into lookup table, and calls table.
                00516 ;*
                00517 ;*            Saves result from lookup table as new SETPOINT
                00518 ;*
                00519 ;*    Input Variables:
                00520 ;*            PORTB           Current indicator data
                00521 ;*            DNCH:DNCL       Down button debounce counter
                00522 ;*            UPCH:UPCL       Up button debounce counter
                00523 ;*
                00524 ;*    Output Variables:
                00525 ;*            PORTB           Current indicator data
                00526 ;*            DNCH:DNCL       Down button debounce counter
                00527 ;*            UPCH:UPCL       Up button debounce counter
                00528 ;*            SETPOINT        New voltage setpoint
                00529
;*******************************************************************************
                00530
00A5 0806       00531       movf    PORTB,W         ;move LED data to temp space
00A6 393F       00532       andlw   0x3f            ;mask off non-voltage LEDs
00A7 00A7       00533       movwf   TEMPA
                00534
00A8 1E85       00535 Dnb   btfss   PORTA,5         ;down
00A9 28B3       00536       goto    Upb             ;down not pushed
00AA 0FA2       00537       incfsz  DNCL,f          ;down is pushed, inc debounce
00AB 28CE       00538       goto    Wc3             ;no carry - go to next module
00AC 0FA3       00539       incfsz  DNCH,f          ;inc debounce counter high byte
00AD 28CE       00540       goto    Wc3             ;no carry - go to next module
                00541                               ;---------------------- select next lower LED
00AE 1003       00542       bcf     STATUS,C        ;select next lower LED
00AF 0CA7       00543       rrf     TEMPA,F         ;shift LED data down 1 voltage
00B0 1803       00544       btfsc   STATUS,C        ;3V LED was set before rotate, so
00B1 1427       00545       bsf     TEMPA,0         ;set it again
                00546
00B2 28BE       00547       goto    Dunb
                00548
00B3 1D05       00549 Upb   btfss   PORTA,2         ;up button
00B4 28C9       00550       goto    Nob             ;up not pushed - no buttons pushed
00B5 0FA0       00551       incfsz  UPCL,f          ;down is pushed, inc debounce
00B6 28CE       00552       goto    Wc3             ;no carry - go to next module
00B7 0FA1       00553       incfsz  UPCH,F          ;inc debounce counter high byte
00B8 28CE       00554       goto    Wc3             ;no carry - go to next module
                00555                               ;-------------------- select next higher LED
00B9 1003       00556       bcf     STATUS,C        ;select next higher voltage LED
```

```
00BA 0DA7      00557      rlf     TEMPA,F      ;shift LED data up 1 voltage
00BB 1B27      00558      btfsc   TEMPA,6      ;if 9V LED was set before,
00BC 16A7      00559      bsf     TEMPA,5      ;set it again, and
00BD 1327      00560      bcf     TEMPA,6      ;clear the overload LED
               00561
00BE 0827      00562 Dunb movf    TEMPA,W      ;move LED data back to PORTB
00BF 0086      00563      movwf   PORTB
               00564
00C0 01A8      00565      clrf    TEMPB
00C1 03A8      00566      decf    TEMPB,F      ;set TEMPB to -1
               00567
00C2 0AA8      00568 NewSetincf   TEMPB,F      ;count up
00C3 0CA7      00569      rrf     TEMPA,F      ;rotate least sig bit INTo carry
00C4 1C03      00570      btfss   STATUS,C     ;is carry set now?
00C5 28C2      00571      goto    NewSet       ;no, try again
               00572
00C6 0828      00573      movf    TEMPB,W      ;yes, put count in w
00C7 20DD      00574      call    Tbl          ;get corresponding value for PWM
00C8 00A4      00575      movwf   SETPOINT     ;put value in SETPOINT
               00576
00C9 01A2      00577 Nob  clrf    DNCL         ;clear down button debounce counter
00CA 01A0      00578      clrf    UPCL         ;clear up button debounce counter
00CB 30F9      00579      movlw   DEL1
00CC 00A3      00580      movwf   DNCH         ;preset down button debounce counter
00CD 00A1      00581      movwf   UPCH         ;preset up button debounce counter high byte
               00582
               00583
;*************************************************************************
               00584 ;*    Wc3     VUNREG has been converted by now,
               00585 ;*            Get result, save in VUNREG.
               00586 ;*
               00587 ;*            Select VOUT to aquire.
               00588 ;*
               00589 ;*            Test VUNREG to see if it has dropped too low.
               00590 ;*            If too low, call protective shut-down.
               00591 ;*
               00592 ;*    Input Variables:
               00593 ;*            VUNREG       Input voltage.
               00594
;*************************************************************************
               00595
00CE           00596 Wc3
00CE 191F      00597      btfsc   ADCON0,GO_DONE ;test if done
00CF 28CE      00598      goto    Wc3            ;no, wait some more
00D0 081E      00599      movf    ADRES,W        ;get conversion result
00D1 00A6      00600      movwf   VUNREG         ;save result
               00601
00D2 3089      00602      movlw   AVOUT          ;select feedback channel to aquire
00D3 009F      00603      movwf   ADCON0
               00604
00D4 0826      00605      movf    VUNREG,W       ;get UNREG
00D5 3C50      00606      sublw   0x50           ;10V-VUNREG=?  C=1 if VUNREG<10V
00D6 1803      00607      btfsc   STATUS,C
00D7 28E4      00608      goto    ShutDn         ;turn off regulator (dies here)
               00609
               00610
               00611
;*************************************************************************
               00612 ;*    Shift   shift errors - save current error as old
               00613 ;*            E1H:E1 = E0H:E0
               00614 ;*
               00615 ;*            Go back to top of loop.
               00616 ;*
               00617 ;*    Input Variables:
               00618 ;*            E0H:E0         Present error
               00619 ;*
```

```
           00620 ;*   Output Variables:
           00621 ;*           E1H:E1          Previous error
           00622
;*****************************************************************************
           00623
00D8       00624 Shift
00D8 0831  00625       movf    E0,W
00D9 00B3  00626       movwf   E1
           00627
00DA 0832  00628       movf    E0H,W
00DB 00B4  00629       movwf   E1H
           00630
00DC 2836  00631       goto    Again
           00632
           00633
;*****************************************************************************
           00634 ;*   Tbl     Look up table.
           00635 ;*
           00636 ;*           Called with an index in W.
           00637 ;*
           00638 ;*           Index is added to program counter.
           00639 ;*
           00640 ;*           Execution jumps to "retlw" which will return
           00641 ;*           to the calling program with table value in w.
           00642 ;*
           00643 ;*   Input Variables:
           00644 ;*           w               Offset index into table
           00645 ;*
           00646 ;*   Output Variables:
           00647 ;*           w               Value from table
           00648
;*****************************************************************************
           00649
00DD       00650 Tbl                          ;call with index in w
00DD 0782  00651       addwf   PCL,F           ;add index to PC
           00652
00DE 344D 3474 3482 00653             dt       0x4d, 0x74, 0x82, 0x9b, 0xc2, 0xea
     349B 34C2 34EA
           00654 ;output voltage               3.0   4.5   5.0   6.0   7.5   9.0
           00655
           00656
;*****************************************************************************
           00657 ;*   ShutDn  Protective shutdown. Entry into this routine is a result
           00658 ;*   of a low input voltage. This turns off the converter
           00659 ;*   before the series pass transistor can overheat.
           00660 ;*
           00661 ;*           PWM on-time is set to 0, turning off the converter.
           00662 ;*
           00663 ;*           The converter trip LED is lit, indicating shutdown.
           00664 ;*
           00665 ;*           Execution then loops without exit. The only exit is to
           00666 ;*           reset the controller.
           00667
;*****************************************************************************
           00668
00E4       00669 ShutDn
00E4 1217  00670       bcf     CCP1CON,4       ;turn off PWM
00E5 1297  00671       bcf     CCP1CON,5
00E6 0195  00672       clrf    CCPR1L
           00673
00E7 1786  00674       bsf     PORTB,7         ;light trip LED
           00675
00E8       00676 Dead
00E8 28E8  00677       goto    Dead            ;stays here
           00678
           00679
           00680             END
```

```
MEMORY USAGE MAP ('X' = Used,  '-' = Unused)

0000 : X---XXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0040 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0080 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
00C0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXX------- ----------------
2000 : -------X-------- ---------------- ---------------- ----------------

All other memory blocks unused.

Program Memory Words Used:   230
Program Memory Words Free:  1818


Errors   :     0
Warnings :     0 reported,     0 suppressed
Messages :     0 reported,     7 suppressed
```

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

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

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

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

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

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