AN216

DC/DC Converter Controller Using a PICmicro® Microcontroller

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INTRODUCTION

In many applications, a DC/DC Converter is used to produce a regulated voltage or current, derived from an unregulated power supply, or from a battery. Examples of these applications include battery chargers, electronic air purifiers, emergency exit signs, and distributed power systems.

In some of those applications, a dedicated Switched Mode Power Supply (SMPS) Controller IC is used in conjunction with a microcontroller. In other applications, however, a dedicated SMPS Controller IC may be overkill. An alternative approach is to generate a low cost SMPS function in a smart microcontroller, such as the PIC16C620A. This Application Note shows a method of using the microcontroller to perform simple SMPS control functions.

Two circuits were built for evaluation. One circuit provides a Constant Voltage output, the other a Constant Current output.

DC/DC CONVERTER

There are several popular DC/DC Converter topologies, such as the Boost and Fly-back Converter topologies. The DC/DC Converter used in this example is a Buck (or step down) Converter, which is also a popular topology. In Figure 3, the Buck Converter consists of transistor Q1, diode D1, inductor L1, and capacitor C1. Transistor Q2 is used as a level translator for the PICmicro device PORTB output to turn Q1 on or off.

Application Note AN701 explains how a Buck Converter works. It also provides a general guideline on component selection.

In any type of DC/DC Converter circuit, the power device selections are very important. The key parameters to look for in the transistor Q1 are the switching time and current rating. These two parameters greatly affect the maximum switching frequency of the converter, and also how much current the converter can be designed for. The diode D1 should either be a Schottky, or ultra fast diode, in order to minimize switching losses in the converter. The type of capacitor C1 is also very important to minimize the ripple on the converter output. An electrolytic capacitor with a low ESR (Equivalent Series Resistance) is desirable for capacitor C1.

In some cases, the output ripple of the converter may still be higher than desired, even with the proper inductor and capacitor selections. In this case, an additional inductor and capacitor may be used as a low pass filter at the converter output.

A DC/DC Converter is normally chosen because of its high efficiency in converting the input power to output power. Unlike a linear regulator, the efficiency measure of a DC/DC Converter generally increases as its load increases. A properly designed DC/DC Converter can yield an efficiency measure of greater than 90% at full load. The efficiency of a DC/DC Converter is expressed as the ratio of output power and input power. The following equations can be used to determine efficiency.

$$Efficiency = {}^{P_{OUT}}/_{P_{IN}} * 100\%$$

or

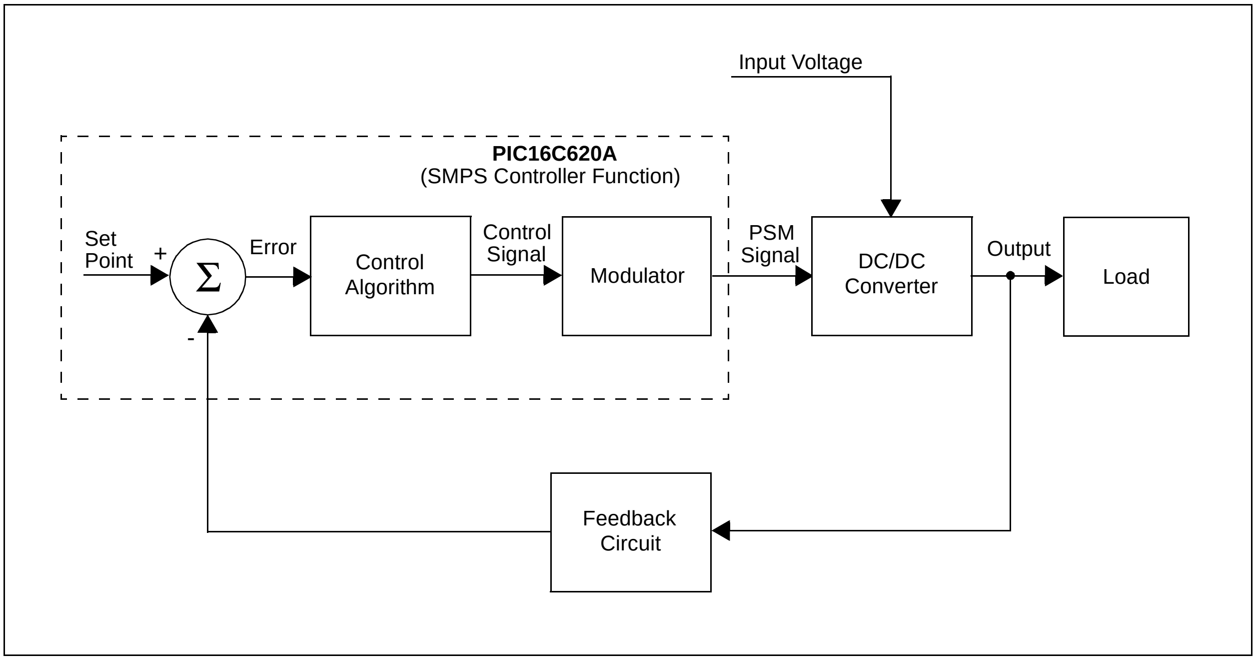
$$Efficiency = {}^{V_{OUT} * I_{OUT}}/_{(V_{IN} * I_{IN})} * 100\%$$

The selection of the DC/DC Converter components, in many cases, is a trade-off between cost, performance, and size. In this Application Note, the component selections were made to simply provide a DC/DC Converter that can be used to demonstrate the PIC16C620A capability to perform SMPS controller function. The DC/DC Converter discussed here is not optimized for any particular parameter.

SMPS CONTROLLER FUNCTION

The DC/DC Converter circuit is merely a power processor. It transforms the available input voltage and current into the output voltage and current, based on the command of the SMPS controller. The SMPS controller looks at the converter output, compares the output to a set point, performs a control algorithm and finally, applies the algorithm output to a modulator. The modulator output is then used to drive the DC/DC Converter. Figure 1 shows a simplified block diagram of a complete DC/DC Converter system. In this Application Note, the PIC16C620A is used to implement the SMPS controller function, which includes the following functions: set point generation, error amplifier, control algorithm, and the modulator. These functions are shown inside the dashed box in Figure 1.

FIGURE 1: DC/DC CONVERTER SYSTEM



MODULATOR - PULSE SKIPPING MODULATION (PSM)

One of the simplest modulation techniques used for controlling a DC/DC Converter is Pulse Skipping Modulation (PSM), which is also known as Pulsed Frequency Modulation. In a PSM system, the modulator generates a train of pulses to turn the converter power switch on and off. The pulses have a fixed pulse width, as well as period. As long as the converter output is below the desired target, the PSM pulses continue to run the converter switch. Once the converter output reaches or exceeds the target, the next PSM pulse is skipped. This operation will result in decreasing pulse density as the converter output reaches its target, or as the output loading decreases. When the converter output falls below the target, or as the output loading increases, the PSM pulse density will increase.

The theoretical limit of the maximum output voltage is determined by the input voltage to the DC/DC Converter and the maximum duty cycle of the PSM signal, which is the duty cycle of the PSM signal when it is continuously running (not skipping pulses). This relationship can be expressed as follows:

$$V_{OUTMAX} = V_{IN} * d_{max}$$

This formula does not take into account the conduction and switching losses of the converter components. The discussion of non-ideal DC/DC Converter is beyond the scope of this Application Note. However, many papers and text books are available on this subject.

In this application, the PIC16C620A microcontroller performs the modulator function in firmware. This firmware modulator generates the PSM pulses on the RB7 pin (PORTB, bit 7), to drive transistor Q2 of the DC/DC Converter. When the DC/DC Converter output is below the desired value, the firmware continuously sends out PSM pulses to increase the converter output. Once the DC/DC Converter output exceeds the target, the controller will skip the PSM pulses until the output voltage, or current, falls below the threshold and the control cycle repeats.

Timer0 of the microcontroller is used to generate a time base for the firmware modulator. Timer0 is enabled and the TMR0 register is loaded with a reload value. When Timer0 overflows, an interrupt occurs. In the interrupt routine, TMR0 is again loaded with the reload value. The reload value determines the time base of the PSM signal. In this application, the TMR0 reload value is chosen to produce a time base of 50 microseconds when the microcontroller runs from a 16 MHz crystal. Other crystal frequencies may be used; however, the 16 MHz was selected to give plenty of instruction cycles in between Timer0 interrupts, for the firmware execution. When the actual application requirements are well defined, the operating frequency can be adjusted to a lower frequency to save power.

FEEDBACK CIRCUIT

For the SMPS controller to work properly, the DC/DC Converter system must include a feedback circuit. The feedback circuit provides information to the SMPS controller of the converter output.

Feedback Circuit for Constant Voltage DC/DC Converter

The first circuit is a Constant Voltage DC/DC Converter. The feedback requirement for a Constant Voltage control is a voltage proportional to the output voltage. In Figure 3, this feedback circuit consists of R5 and R6. The output of the R5-R6 divider is applied to the AN1 input pin of the C2 comparator in the PIC16C620A. The two resistors simply scale down the output voltage to equal the reference voltage. The formula to calculate R5 and R6 is shown below.

$$R6 = R5 * {}^{V_{REF}}/_{(V_{OUT}-V_{REF})}$$

The parallel combination value of R5 and R6 should be less than 10 kΩ to minimize errors due to input leakage current from the AN1 pin.

Some applications require that the feedback voltage can be trimmed to compensate for the V_{REF} variations over process. If this capability is required, then a potentiometer can be added to allow trimming. To get the most accurate results, the adjustment of the trim potentiometer should be performed when the system is running.

Feedback Circuit for Constant Current DC/DC Converter

The second circuit is a Constant Current DC/DC Converter. The feedback requirement for this circuit is a voltage proportional to the output current.

For the Constant Current circuit in Figure 4, the feedback consists of simply R6. The voltage on R6 is then presented to the AN1 input pin of the C2 comparator in the PIC16C620A. Resistor R7 is added to provide ESD protection to the AN1 pin, since the load will be connected to R6 directly. The formula to calculate R6 is:

$$R6 = {}^{V_{REF}}/_{I_{OUT}}$$

$$\text{Power dissipation on } R6 = V_{REF} * I_{OUT}$$

For applications where the output current is high, a very small current sense resistor, R6, is required to minimize power dissipation. In this case, an operation amplifier may be required to amplify the small voltage on R6 to the size of V_{REF}.

Similar to the Constant Voltage applications, depending on the need, a trimming potentiometer may be required in the Constant Current application as well. Since potentiometers are generally not designed to dissipate power, it is very important to make sure that the potentiometer does not carry the load current, for reliability and control drift minimization reasons.

Output Load Connections for the Constant Current DC/DC Converter

For the circuit shown in Figure 4, the load connections for the Constant Current circuit can not be grounded. If the load is grounded, then the current sense resistor R6 is shorted to ground and the SMPS controller can not sense the load current. If a grounded load is required in the system, the method for current sensing must be modified. The following are possible solutions to allow a ground referenced load:

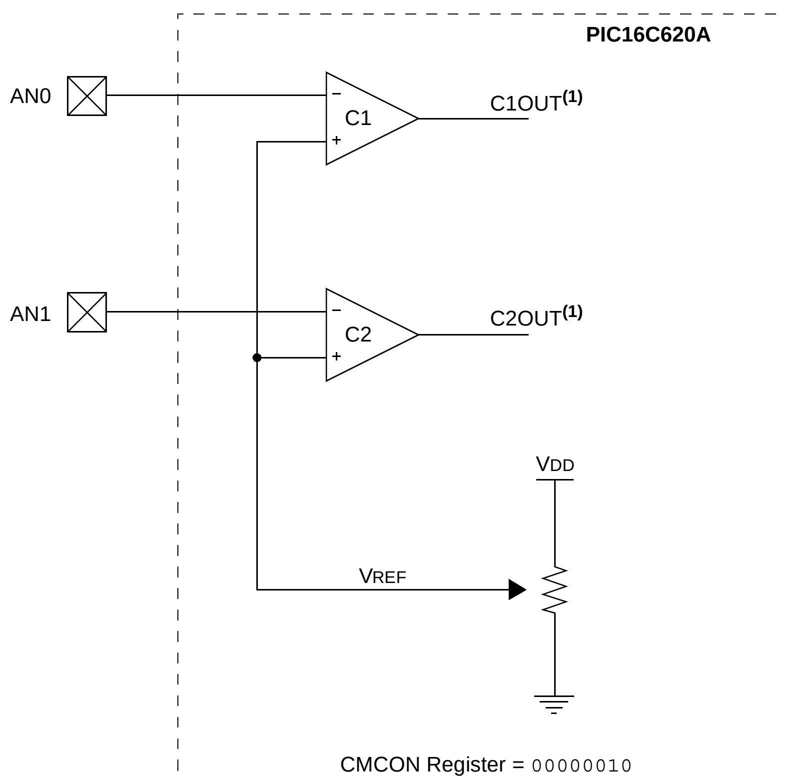
1. Ground the load and float the PICmicro microcontroller ground.
2. Move the current sense resistor to the output of the DC/DC Converter and use an op-amp to level shift the voltage on R6 to a ground referred signal.

SET POINT AND VOLTAGE CONTROL ALGORITHM

The PIC16C620A has an on-board voltage reference, VREF, and two comparators, C1 and C2 (see Figure 2 for illustration). The VREF module is used to provide a set point to the system. If so desired, the set point voltage can be adjusted via firmware. In this application, the VREF set point is set to VDD/2.

The comparators have several configurations, some of which allow the comparators to compare external voltage(s) to the VREF voltage. The configuration that is used for this application example is shown in Figure 2. To select this configuration, the comparator control register CMCON must be set to `b'00000010'`.

FIGURE 2: PIC16C620A COMPARATOR AND VREF SELECTED CONFIGURATION



Note 1: C1OUT and C2OUT can be read by the firmware in the CMCON Register.

In this application, only the C2 comparator of the PIC16C620A is used to compare the feedback voltage on the AN1 pin to the internal voltage reference VREF. If the DC/DC Converter output is lower than the desired value, then the feedback voltage presented on AN1 is lower than VREF. In this case, the comparator output, C2OUT, is high. If the DC/DC Converter output is higher than the desired value, then the comparator output is low. The firmware uses the comparator output state to determine whether the DC/DC Converter output needs to be increased or not.

The Voltage Control Algorithm performed in firmware becomes very simple:

- If the voltage on AN1 pin is lower than VREF, then produce PSM output pulse
- Else (voltage on AN1 pin is higher than VREF), then skip PSM output pulse

Because the PIC16C620A and the firmware monitors and controls the voltage on the AN1 pin, regardless of whether the voltage is derived from either the Constant Voltage or Constant Current feedback circuit, this firmware can be used for either the Constant Voltage or Constant Current circuit implementation without any changes.

Integrating the Voltage Control and Modulator

The Voltage Control Algorithm is executed every time Timer0 interrupts. After the firmware reloads TMR0, it checks the comparator output to determine whether the output pulse should be active or not, on the next PSM cycle. Once this decision is made, a flag bit is set or cleared depending on the decision, and the output pulse is turned off. After several microseconds delay, before leaving the interrupt routine, the output pulse is activated again, depending on the status of the flag bit. If the output is set, this pulse will stay active until the next Timer0 interrupt occurs. If the output is clear, then the PSM pulse is skipped until the next Timer0 interrupt occurs, and the control sequence repeats. Figure 5 shows the flowchart of the Firmware SMPS Controller.

FIGURE 3: VOLTAGE SOURCE DC/DC CONVERTER USING PIC16C620A

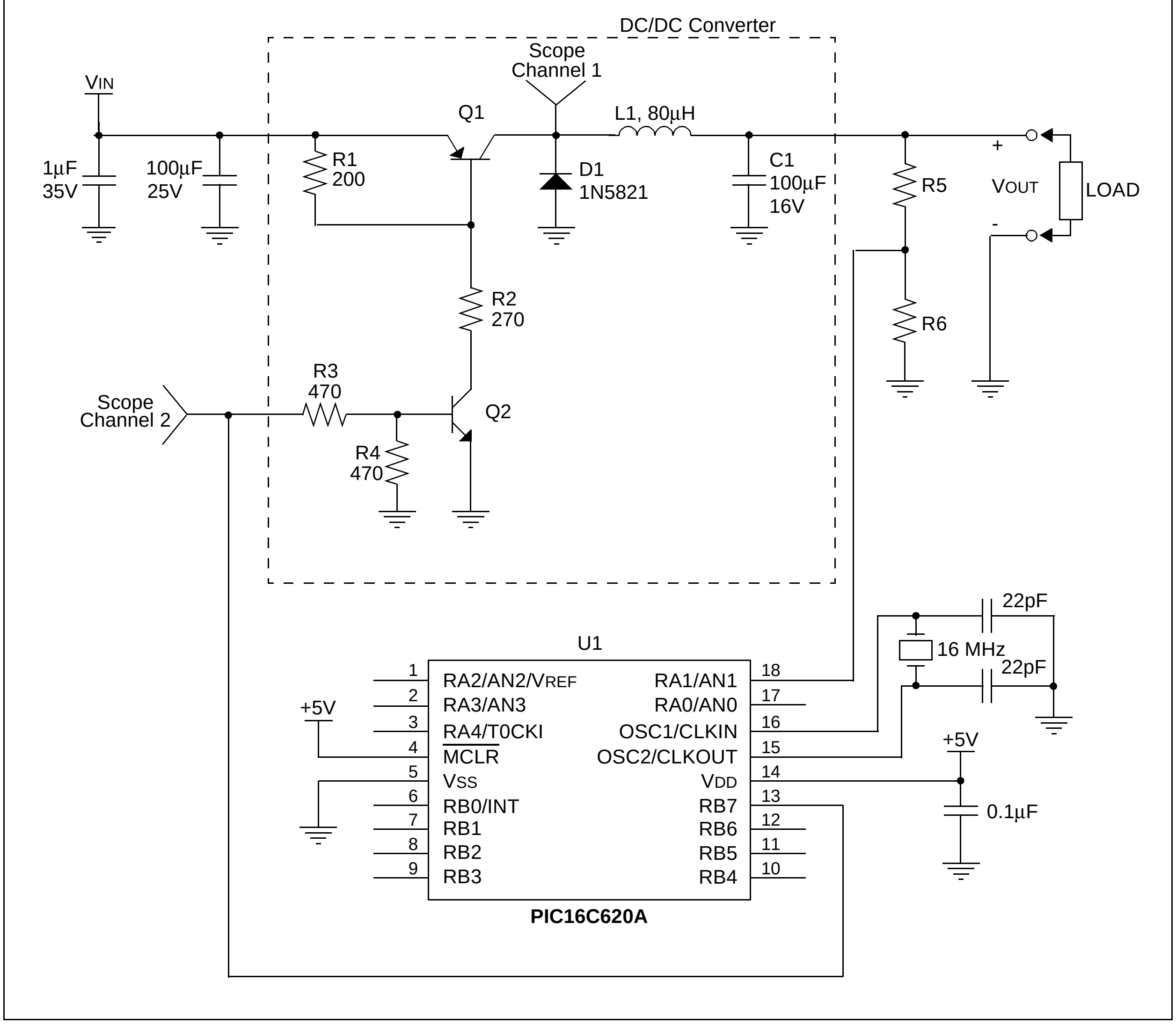


FIGURE 4: CURRENT SOURCE DC/DC CONVERTER USING PIC16C620A

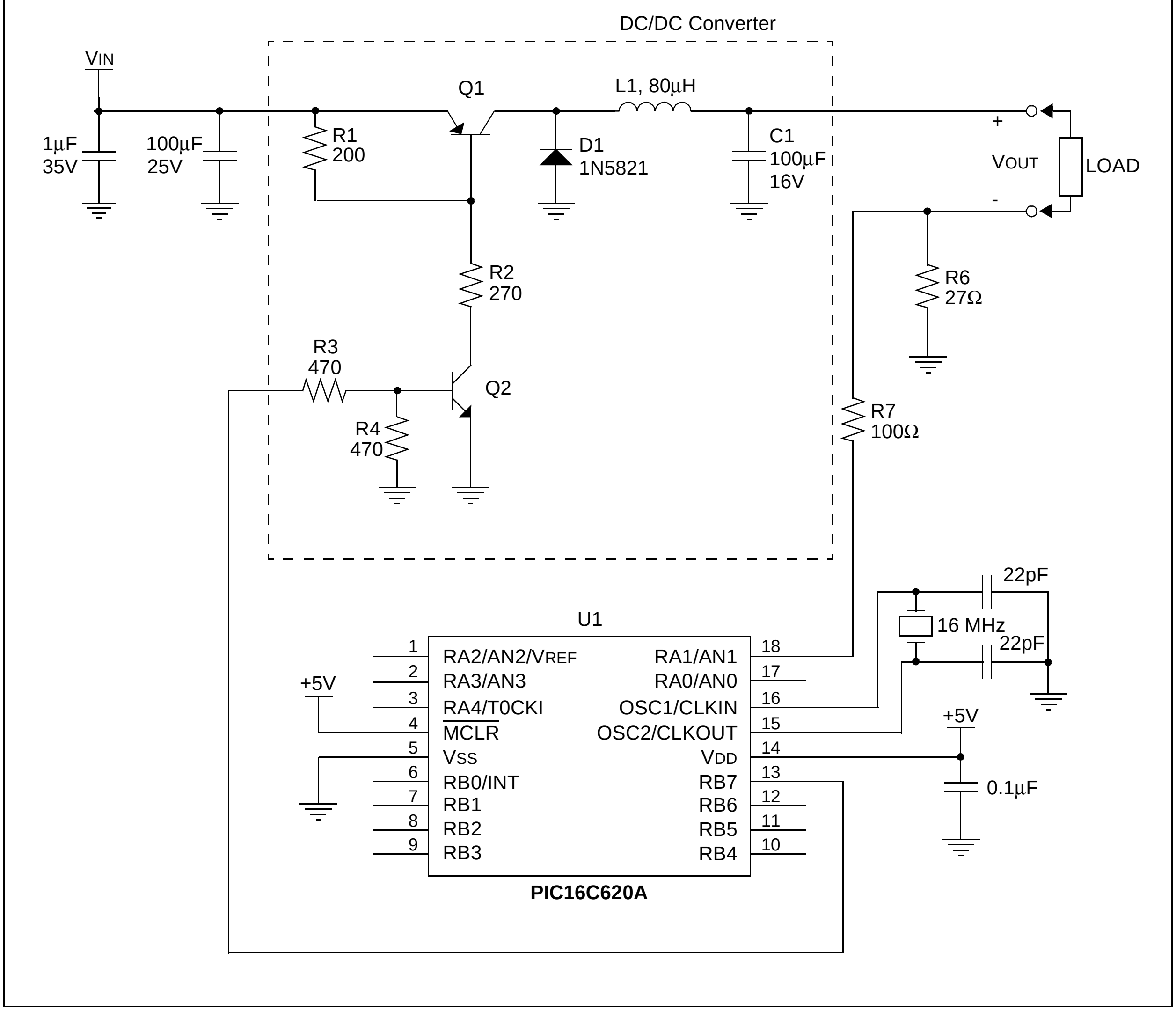


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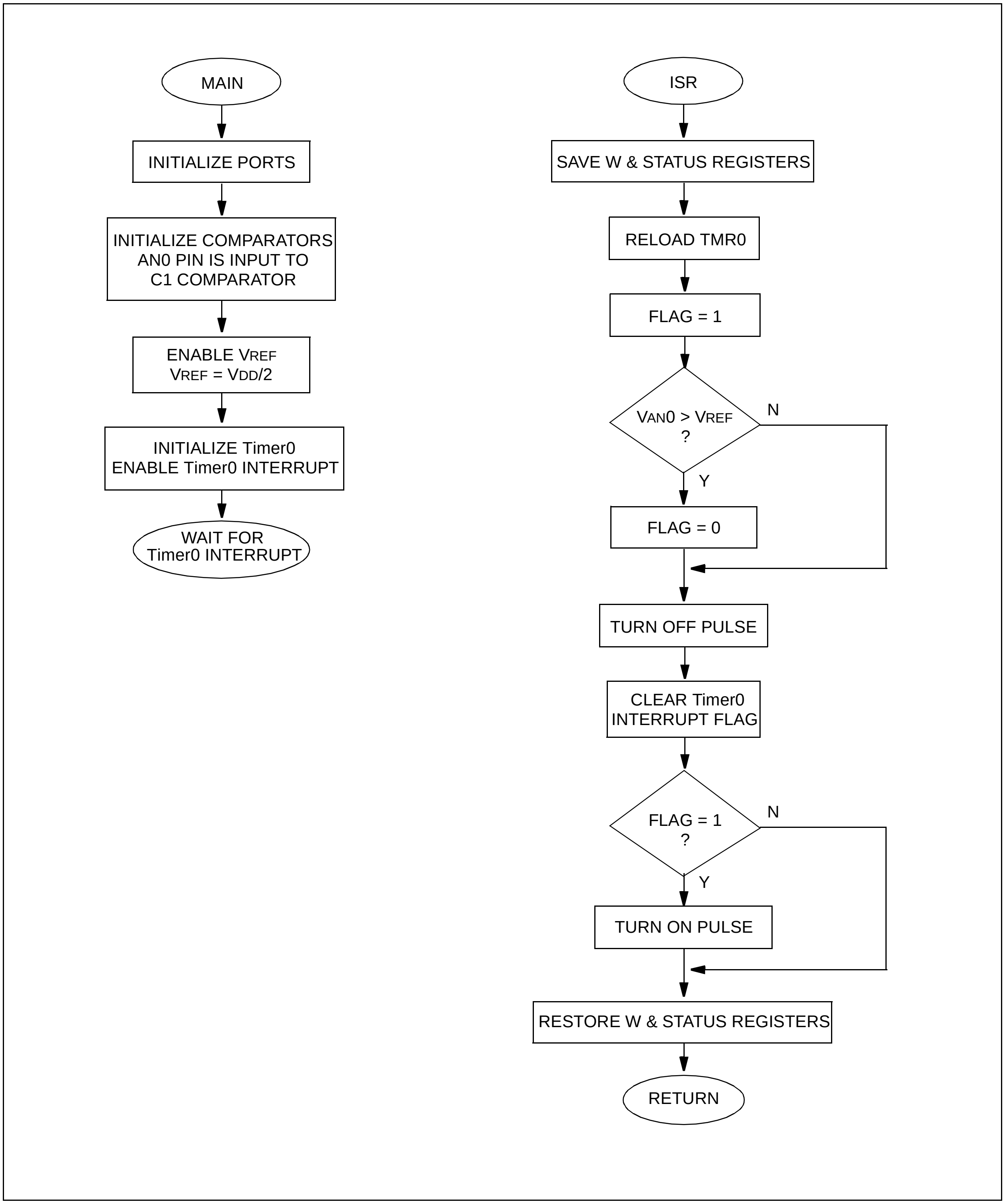
FIGURE 5: FIRMWARE SMPS CONTROLLER FLOW CHART



WAVEFORMS FROM THE VOLTAGE SOURCE CIRCUIT

To see how the DC/DC Converter circuit works, voltage waveforms of the PSM output on RB7 and the Q1 switch output are captured for 3 different input voltage levels, while the output load is kept constant at 4.2 V, 100 mA. The RB7 PSM output voltage is shown as Channel 1, while the Q1 switch output voltage is shown as Channel 2. The waveforms are captured at the following input voltage levels:

1. V_{IN} = 8.8 V. See Figure 6.
2. V_{IN} = 10.8 V. See Figure 7.
3. V_{IN} = 12.8 V. See Figure 8.

When the RB7 output is high, the Q1 switch turns on. The switch output voltage immediately rises to the input voltage, i.e., 8.8 V on Figure 6. At this time, the inductor current increases. The inductor current is flowing to the capacitor C1 and the DC/DC Converter load. Once the RB7 output goes low, the Q1 switch turns off. The inductor current, however, needs a low impedance path to continue its flow. This causes the switch output voltage to fall until diode D1 turns on. The inductor current now flows through the diode from the system ground. Figure 6 shows that the voltage at the output of the switch drops to approximately -0.7V. At this time, the voltage across the inductor reverses its polarity, causing the inductor current to drop. When the inductor current reaches zero, diode D1 turns off, and the voltage on the inductor collapses to zero. This can be seen by the Q1 switch output going from -0.7V to the DC/DC Converter output voltage.

Note that although the waveform seems repetitive, the frequency is not constant. Once in a while, the distance between pulses changes. This change happens when the Voltage Control Algorithm determines that additional pulses should be skipped for that PSM cycle.

The waveforms on Figure 6, Figure 7 and Figure 8, were taken with the same voltage and time scales. It is obvious from looking at the three plots, as the ratio of V_{IN}/V_{OUT} increases, the pulse density on the RB7 pin decreases. At higher input voltages, each switching of the Q1 transistor will deliver higher charge to the DC/DC Converter output.

For a constant input voltage, the PSM pulse density on the RB7 pin will also vary as a function on the output load. In the Constant Voltage circuit, as the output current decreases, the PSM pulse density on the RB7 pin also decreases.

FIGURE 6: WAVEFORMS OF RB7 AND Q1 SWITCH OUTPUT VOLTAGES, V_{IN} = 8.8 V, V_{OUT} = 4.2 V, I_{OUT} = 100 mA

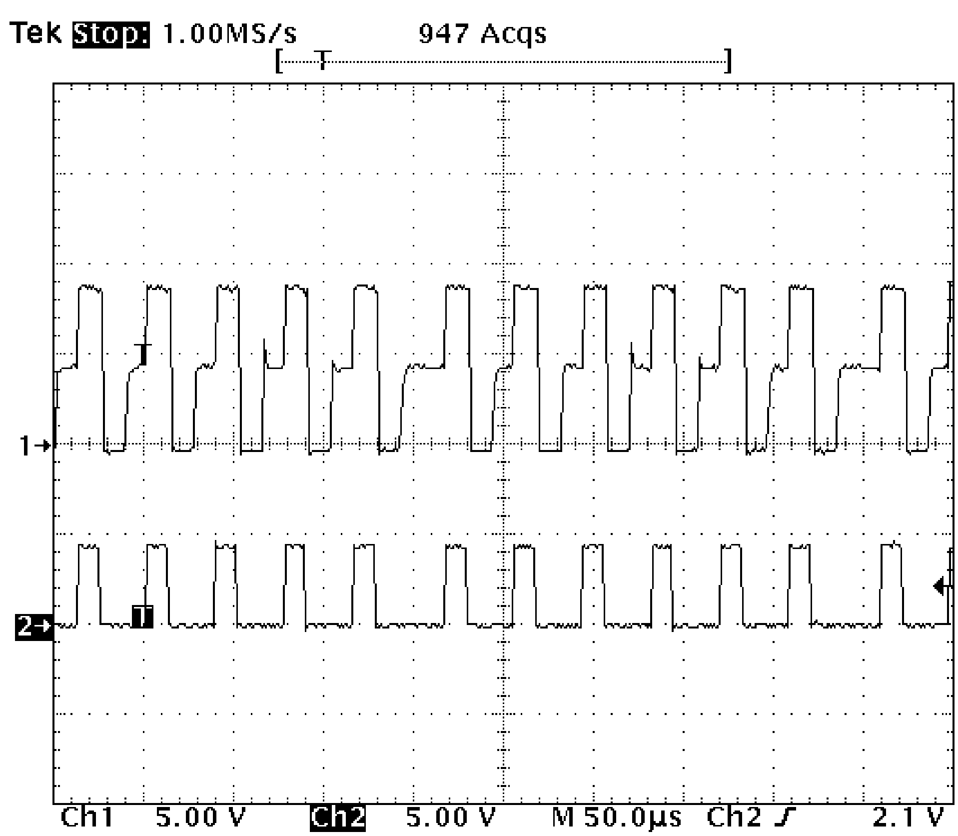


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FIGURE 7: WAVEFORMS OF RB7 AND Q1 SWITCH OUTPUT VOLTAGES, V_{IN} = 10.8 V, V_{OUT} = 4.2 V, I_{OUT} = 100 mA

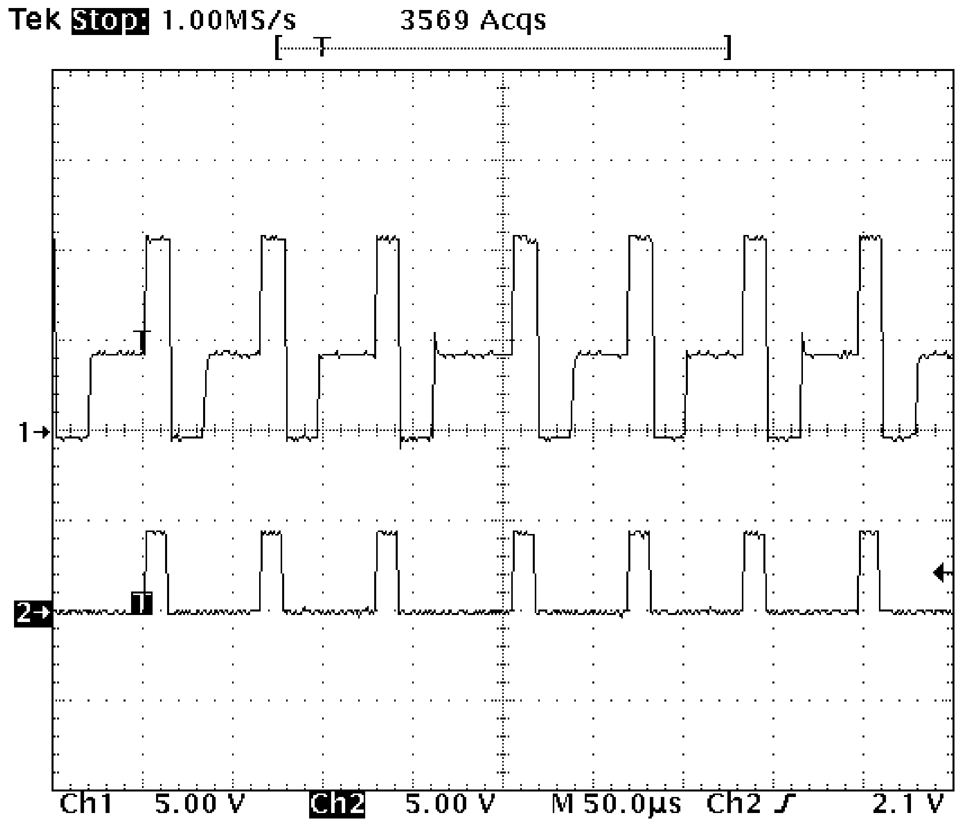
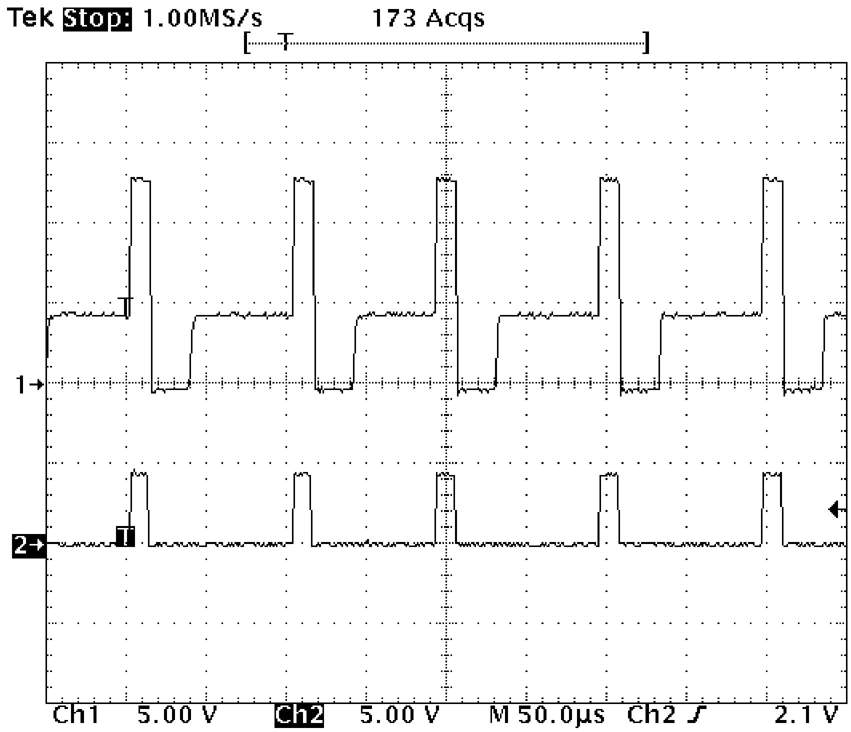


FIGURE 8: WAVEFORMS OF RB7 AND Q1 SWITCH OUTPUT VOLTAGES, V_{IN} = 12.8 V, V_{OUT} = 4.2 V, I_{OUT} = 100 mA



BENCH MEASUREMENTS DATA

To quantitatively evaluate performance, each circuit was tested in the lab. Several key parameters relevant to power supply circuits were measured. Those parameters are:

1. **Line Regulation:** both Constant Voltage and Constant Current circuits.
   Line regulation is the amount of change on the output as a function of the input voltage. For the Constant Voltage circuit, the units for line regulation are V/V, while for the Constant Current they are A/V (or mA/V).
2. **Load Regulation:** both Constant Voltage and Constant Current circuits.
   Load regulation is the amount of change on the output as a function of the load. For the Constant Voltage circuit, the units for load regulation are V/A (or mV/mA), while for the Constant Current they are A/V (or mA/V).
3. **Output Ripple Noise:** Constant Voltage only.
   The output ripple noise is measured in mV rms.
4. **Power Conversion Efficiency:** Constant Voltage only.
   The Efficiency is measured as the ratio of power delivered to the load and power delivered to the DC/DC Converter.

Bench Measurement Data of the Constant Voltage DC/DC Converter

The following table is a summary of the Constant Voltage DC/DC Converter performance.

TABLE 1: CONSTANT VOLTAGE DC/DC CONVERTER PERFORMANCE

Parameter	Value	Conditions
Line Regulation	< 3 mV/V	V_{IN} = 8.8 V to 14.8 V, V_{OUT} = 4.2 V, I_{OUT} = 100 mA
	< 5 mV/V	V_{IN} = 8.8 V to 14.8 V, V_{OUT} = 4.2 V, I_{OUT} = 520 mA
Load Regulation	-0.06 mV/mA	V_{IN} = 8.8 V, V_{OUT} = 4.2 V, I_{OUT} = 0 mA to 100 mA
	-0.04 mV/mA	V_{IN} = 8.8 V, V_{OUT} = 4.2 V, I_{OUT} = 100 mA to 520 mA
Output Ripple	< 5.2 mV rms	V_{IN} = 8.8 V, V_{OUT} = 4.2 V, I_{OUT} = 0 mA to 100 mA
	< 12.3 mV rms	V_{IN} = 8.8 V, V_{OUT} = 4.2 V, I_{OUT} = 100 mA to 520 mA
Efficiency	67%	V_{IN} = 8.8 V, V_{OUT} = 4.2 V, I_{OUT} = 100 mA
	72%	V_{IN} = 8.8 V, V_{OUT} = 4.2 V, I_{OUT} = 520 mA
	45%	V_{IN} = 14.8 V, V_{OUT} = 4.2 V, I_{OUT} = 100 mA
	62%	V_{IN} = 14.8 V, V_{OUT} = 4.2 V, I_{OUT} = 520 mA

Bench Measurement Data of the Constant Current DC/DC Converter

The following table is a summary of the Constant Current DC/DC Converter performance. The output ripple current of this circuit was not measured. The Efficiency parameter was also not measured. The Efficiency measure, however, should be identical to that of the Constant Voltage DC/DC Converter for a given similar input and output condition to the circuit.

TABLE 2: CONSTANT CURRENT DC/DC CONVERTER PERFORMANCE

Parameter	Value	Conditions
Line Regulation	< 0.02 mA/V	V_{IN} = 7.8 V to 14.8 V, V_{OUT} = 4.0 V, I_{OUT} = 90 mA
Load Regulation	-0.26 mA/V	V_{IN} = 14.8 V, V_{OUT} = 4 V to 14.8 V, I_{OUT} = 90 mA
	-0.52 mA/V	V_{IN} = 14.8 V, V_{OUT} = 2 V to 4 V, I_{OUT} = 90 mA

EXPANDING THE APPLICATION

The use of the PIC16C620A in DC/DC Converter circuits can be expanded to the following applications:

1. Constant Voltage with Current Limit DC/DC Converters.
   Since the PIC16C620A has two comparators, one comparator can be used for the voltage feedback, and the other for detecting current limit.
2. Other power converter topologies.
   The control methodology can be used for Boost and Fly-back topologies, as well. The feedback circuitry, more than likely, must be modified to include the power switch current sensing.
3. Firmware programmable output voltage or current.
   The V_{REF} voltage can be changed in firmware. This capability allows user to change the output voltage or current as needed by the application.
4. The use of other modulation techniques, i.e., Pulse Width Modulation (PWM).
   A PWM control can be implemented, instead of the PSM technique used in this example. In addition to Timer0 interrupt, the comparator interrupt is also enabled. In this case, the comparator interrupt determines when to turn off the RB7 output pulse as soon as the control threshold is reached. In this type of PWM control, however, it is possible for the PWM signal to oscillate when the duty cycle is greater than 50%, due to a phenomenon called the Right Half Plane Zero. Under this condition, a slope compensation is required to stabilize the PWM control signal.

The detailed implementations of any of those applications are left as an exercise to the readers' creativity.

CONCLUSION

This Application Note has demonstrated that the PIC16C620A can be used to perform simple SMPS controller functions, such as Constant Voltage, Constant Current, or Constant Voltage with current limit. The program example can be used with any of the PICmicro family members, which has on-board comparators.

REFERENCES

1. PIC16C620A Datasheet, DS30235 revision H or newer
2. AN701: Switch Mode Battery Eliminator Based on a PIC16C72A

APPENDIX A: SOURCE CODE

```
MPASM 02.30.07 Intermediate    DC-DC1.ASM   3-1-2000  14:29:37         PAGE  1


LOC  OBJECT CODE     LINE SOURCE TEXT
  VALUE

                      00001 ;File name: dc-dc1.asm
                      00002 ;
                      00003 ;This program demonstrates how a PICmicro with comparator, ie: PIC16C620A,
                      00004 ;can be used to control voltage or current, such as in a switched mode dc/dc
                      00005 ;converter. This example employs the pulse skipping modulation (psm) technique
                      00006 ;to drive the external power converter circuit.
                      00007 ;
                      00008 ;===============================================================================
                      00009 ;author:        Hartono Darmawaskita
                      00010 ;company:       Microchip Technology, Inc.
                      00011 ;date:          02-11-2000
                      00012 ;MPLAB version: 4.12.12
                      00013 ;
                      00014 ;===============================================================================
                      00015         LIST P = 16C620A, F=INHX8M
                      00016         #INCLUDE <P16C620A.INC>
                      00001         LIST
                      00002 ; P16C620A.INC  Standard Header File, Version 1.10    Microchip Technology, Inc.
                      00165         LIST
2007   3FF2           00017         __config _WDT_OFF & _HS_OSC & _BODEN_ON & _PWRTE_ON
                      00018
                      00019 ;Pin definition
```

```
                        00020 #define PULSE   PORTB,7         ;pulse output to the power transistor
                        00021
                        00022 ;Constants
  000000AC              00023 VREF_HI  equ b'10101100'        ;high voltage setpoint, vref = vdd/2
  000000A6              00024 VREF_MID equ b'10100110'        ;mid voltage setpoint, vref = vdd/4
  000000A2              00025 VREF_LO  equ b'10100010'        ;low voltage setpoint, vref = vdd/12
  000000D7              00026 TMR0_RELOAD equ .215            ;reload value for tmr0
                        00027
                        00028 ;RAM
  00000020              00029 FLAG    equ 0x20                ;flag register
                        00030         ;bit0   1=feedback voltage is less than setpoint
  00000024              00031 W_TEMP  equ 0x24                ;temporary w register
  00000025              00032 STATUS_TEMP equ 0x25            ;temporary status register
                        00033
                        00034 ;================================================================================
0000                    00035         org     00
0000   2817             00036         goto    start
                        00037         ;
                        00038 ;isr is the interrupt service routine.
                        00039 ;in this routine tmr0 is reloaded with the TMR0_RELOAD value. tmr0 operates as
                        00040 ;the time base for the psm modulator.
                        00041 ;the voltage on an0 pin is compared to the vref:
                        00042 ;       if an1 > vref, then skip the next psm pulse
                        00043 ;       if an1 < vref, then do not skip psm pulse
                        00044 ;
0004                    00045         org     04
0004   00A4             00046 isr:    movwf   W_TEMP          ;save w and status
0005   0E03             00047         swapf   STATUS,W
0006   1283             00048         bcf     STATUS,RP0
0007   00A5             00049         movwf   STATUS_TEMP
                        00050         ;
0008   30D7             00051         movlw   TMR0_RELOAD     ;reload tmr0
0009   0081             00052         movwf   TMR0
000A   1420             00053         bsf     FLAG,0
000B   1F9F             00054         btfss   CMCON,C2OUT     ;if van1 > vsetpoint,
000C   1020             00055         bcf     FLAG,0          ;       then skip next pulse
000D   1386             00056         bcf     PULSE           ;turn off output pulse
000E   110B             00057         bcf     INTCON,T0IF     ;clear tmr0 interrupt flag
000F   1C20             00058         btfss   FLAG,0          ;if skip pulse,
0010   2812             00059         goto    isr_done        ;       then exit
0011   1786             00060         bsf     PULSE           ;else begin a new output pulse
0012                    00061 isr_done:
0012   0E25             00062         swapf   STATUS_TEMP,W   ;restore w and status, and exit
0013   0083             00063         movwf   STATUS
0014   0EA4             00064         swapf   W_TEMP,F
0015   0E24             00065         swapf   W_TEMP,W
0016   0009             00066         retfie
```

```
                    00067         ;
                    00068         ;
                    00069 ;start is the main program of this firmware smps controller.
                    00070 ;i/o ports are initialized.
                    00071 ;tmr0 is configured to run from the internal oscillator with no prescalar. the
                    00072 ;tmr0 interrupt is also enabled.
                    00073 ;the comparators and vref modules are initialized.
                    00074 ;the rest of this main program is an infinite loop. if the microcontroller is
                    00075 ;used for other non timing critical functions, the code for these functions
                    00076 ;should reside within the main program.
                    00077 ;
0017   1283         00078 start:  bcf     STATUS,RP0      ;bank0
0018   0185         00079         clrf    PORTA
0019   0186         00080         clrf    PORTB
001A   1683         00081         bsf     STATUS,RP0      ;bank1
001B   30FF         00082         movlw   b'11111111'     ;
Message[302]: Register in operand not in bank 0.  Ensure that bank bits are correct.
001C   0085         00083         movwf   TRISA           ;port a lines are all inputs
001D   3000         00084         movlw   b'00000000'
Message[302]: Register in operand not in bank 0.  Ensure that bank bits are correct.
001E   0086         00085         movwf   TRISB           ;port b lines are outputs
001F   30DF         00086         movlw   b'11011111'     ;tmr0 clock is internal, prescaler -> wdt
Message[302]: Register in operand not in bank 0.  Ensure that bank bits are correct.
0020   0081         00087         movwf   OPTION_REG
0021   1283         00088         bcf     STATUS,RP0      ;back to bank0
                    00089         ;
0022   3002         00090         movlw   b'00000010'     ;AN0 to C1, AN1 to C2, Internal Vref
0023   009F         00091         movwf   CMCON
                    00092         ;
0024   30AC         00093         movlw   VREF_HI         ;setpoint is vref high
0025   1683         00094         bsf     STATUS,RP0      ;bank1
Message[302]: Register in operand not in bank 0.  Ensure that bank bits are correct.
0026   009F         00095         movwf   VRCON
0027   1283         00096         bcf     STATUS,RP0      ;back to bank 0
0028   01A0         00097         clrf    FLAG
                    00098         ;
0029   30D7         00099         movlw   TMR0_RELOAD     ;initialize tmr0
002A   0081         00100         movwf   TMR0
002B   30A0         00101         movlw   b'10100000'     ;enable tmr0 interrupt
002C   008B         00102         movwf   INTCON
                    00103         ;
002D   282E         00104 loop:   goto $+1                ;main program for other functions goes here
002E   282D         00105         goto    loop
                    00106         ;
                    00107         END
```

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

0000 : X---XXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXX- ----------------
2000 : -------X-------- ---------------- ---------------- ----------------

All other memory blocks unused.

Program Memory Words Used:    44
Program Memory Words Free:   468


Errors   :     0
Warnings :     0 reported,     0 suppressed
Messages :     4 reported,     0 suppressed
```

 Preliminary

NOTES:

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