TB3097

Digital SMPS – Buck Converter Using the PIC12F1501 NCO Peripheral

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INTRODUCTION

The digital Switch Mode Power Supply (SMPS) is practically an asynchronous buck converter controlled by the PIC12F1501, and has a very high efficiency at light loads. It also offers hardware output overvoltage protection to avoid damaging the charged device.

The charger is characterized by a very small and simple board and a very short Bill of Materials (BOM), which make it very easy to understand and use.

The features of the PIC12F1501 for this application are:

- Two 10-bit ADC
- One 5-bit DAC
- One Comparator
- One Numerically Controlled Oscillator (NCO)
- One Complementary Waveform Generator (CWG)

All these features are connected into the proper functions by software configuration.

PERFORMANCE SPECIFICATIONS

Electrical specifications over operating range:
8V ≤ VDD ≤ 16V.

TABLE 1: ELECTRICAL SPECIFICATIONS

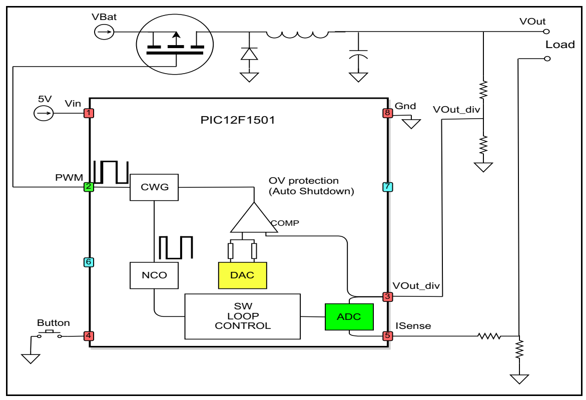
Input Voltage Range	8-16	Volts DC
Output Voltage	5	Volts DC
Output Current	2	Amperes
Output Power	10	Watts
Code Size	452	Words
Ram Size	31	Bytes
Efficiency	88.5%	Measured at 2A
Available Code Size	572	Words
Available RAM Size	33	Bytes

BLOCK DIAGRAM

The control board provides closed-loop proportional control in firmware to maintain the desired output voltage and limit the output current. The PIC® device (PIC12F1501) provides the necessary peripherals for A/D conversion, PWM generation and the amount of memory needed by the algorithm. The control-loop update rate is 4 kHz; the update rate is limited by the ADC acquisition speed.

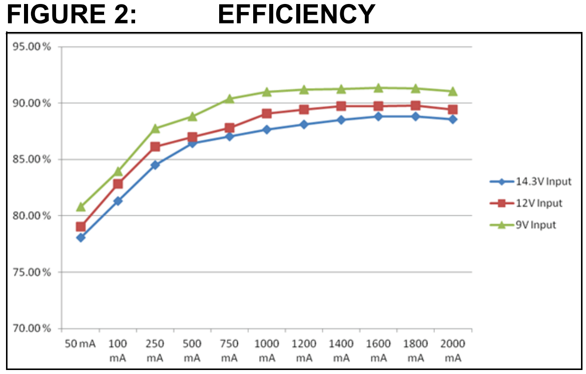
Figure 1 illustrates the block diagram of SMPS.

FIGURE 1: BLOCK DIAGRAM



The overvoltage protection is assured by the CWG module, which is configured to shut down when the output of the comparator is high. The input in the CWG module is received from the NCO module, and the output is CWG1A. Thus, the main purpose of the CWG in this implementation is for auto-shutdown. The NCO module is running in Pulse Frequency mode.

FIGURE 2: EFFICIENCY



FUNCTIONAL DESCRIPTION

The power supply uses a PIC12F1501 for implementing the proportional loop control. The algorithm for adjusting the output voltage and current is done in software, where the information about the output voltage and the load current (10-bit ADC channels) is used for controlling the closed loop. The circuit uses the NCO peripheral to generate a fixed on-time, variable frequency control signal for a buck converter. The "on time" is fixed to 2 µs and the duty cycle is limited in firmware to about 90% at 450 kHz. The NCO frequency step is about 16 Hz using a 16 MHz clock source.

The control loop modifies the NCO frequency (essentially modifying duty cycle – fixed on-time, different period) to regulate the converter output. The decisions are made based on the ADC values read from the output voltage resistor divider and the output current shunt.

Since only one control loop is running for both voltage and current regulation, a special function decides on each update which of the two needs to be regulated. In normal operating conditions, the control loop tries to match the output voltage to the reference. If the output current goes over the limit, the loop tries to match the output current to the maximum-allowed value by reducing the output voltage. A special counter prevents erratic behavior when transitioning from one mode to the other.

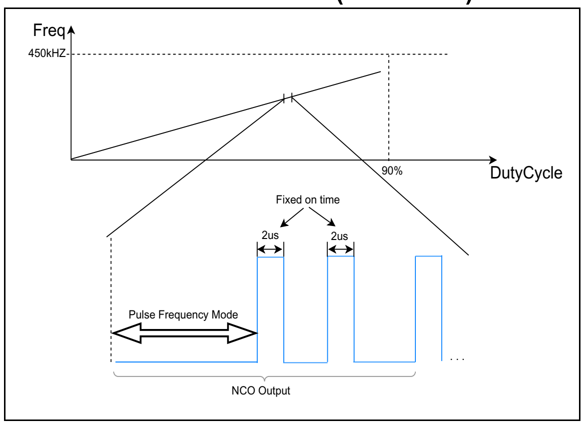
APPLICATIONS

The power supply uses digital proportional control for regulating the output but the update rate is only 4 kHz. This makes it slow to respond to sudden load variations and input voltage changes. For this reason, output voltage is clamped by a very fast comparator-based, overvoltage protection mechanism.

On the other hand, a digital power supply has huge advantages. Output current and voltage can be modified during run-time by the application and complex algorithms like multi-step battery charging algorithms can be easily implemented. The peripheral configuration allows 15 bits of duty-cycle resolution for the transistor control signal, which enables very fine control of output voltage and current.

The main application areas of this power supply are battery chargers, LED drivers, thermoelectric cell drivers, programmable bias generators, and so on. With an accurate voltage reference, the circuit is more than adequate for charging sensitive Li-Ion batteries.

FIGURE 3: DUTY CYCLE vs. FREQUENCY USING FIXED ON-TIME (PF MODE)



MCU PERIPHERAL CONFIGURATION DRAWING

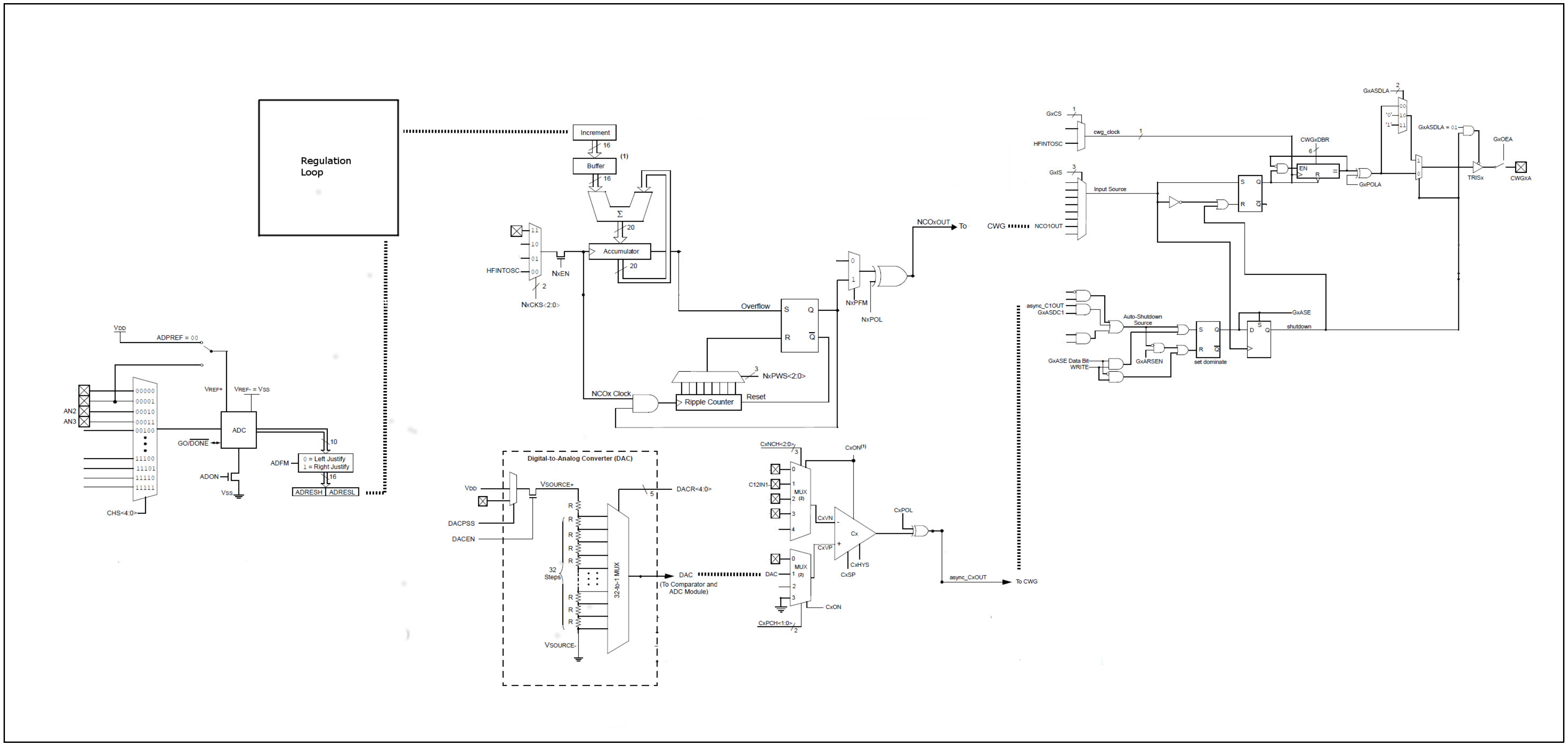
The application only needs two analog channels (one for output voltage and the other one for current sense) for the loop control algorithm. The comparator input for the overvoltage protection is configured on the same pin as the output voltage ADC input.

At the run-time, the two programming pins (PGC and PGD) can be used for other purposes, if required. The configuration of the PIC12F1501 pins for implementing the proportional control loop application is listed in the following table (see Table 2):

TABLE 2: PIC12F1501 PERIPHERAL CONFIGURATION

Pin No.	Name	Function
1	V_{DD}	Supply voltage
2	RA5	NCO channel used for providing PWM signal for the proportional control loop
3	AN3	Analog input used for reading output voltage (V_{OUT}) used in the feedback loop
4	RA3	Digital input – this input will provide start/stop functionality for the control loop algorithm
5	AN2	Analog input used for reading the current sense
6	PGC	Programming clock
7	PGD	Program data
8	V_{SS}	Ground reference

FIGURE 4: PERIPHERAL CONFIGURATION



SCOPE PLOTS OF KEY PARAMETERS

The following table (see Table 3) contains some characteristics of the charger obtained with an input of 14.3V and an output of 5V.

TABLE 3: POWER SUPPLY CHARACTERISTICS

Output Current (mA)(2)	Sw. Frequency (kHz)(3)	Efficiency (%)(1)
0	0.1-0.5	
50	11	78.0
100	22	81.3
250	56	84.6
500	108	86.4
1000	184	87.6
1200	184	88.1
1400	184	88.5
1600	184	88.8
1800	184	88.8
2000	180	88.5

Note 1: Efficiency is calculated including power loss on current shunt.

2: At 2A, the converter is running in current limiting mode.

3: PWM is fixed on-time (2 µs) with variable frequency.

FIGURE 5: OPERATING FREQUENCY vs. LOAD CURRENT

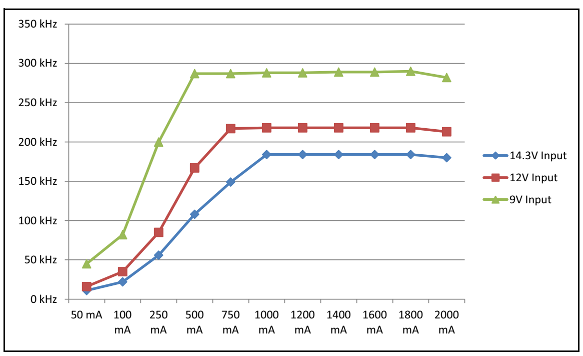


Figure 5 shows the converter operating frequency for 14.3V, 12V and 9V input at different output currents. Once the inductor current becomes continuous, the frequency/duty cycle changes very little, only to compensate for component power losses.

POWERING THE DEMONSTRATION HW

The board is powered from the input J1 connector with an input voltage between 8V and 16V.

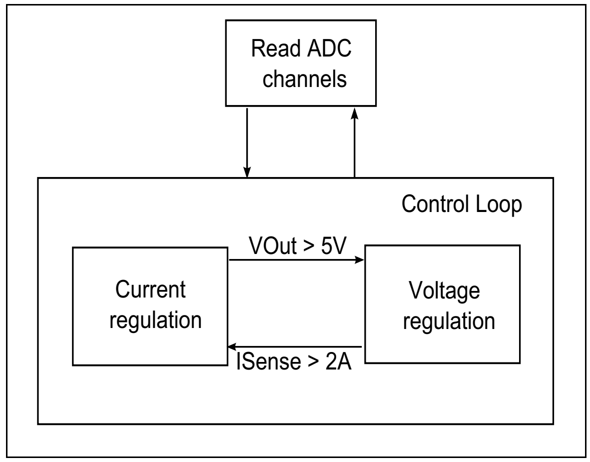
The output voltage (V_{OUT} = 5V) is obtained at J2 connector and J4 connector (USB connector).

WHERE TO FIND THE CODE AND SCHEMATICS

The code can be downloaded from www.microchip.com.

For a better understanding of the implemented algorithm, please see the following flowchart diagram (Figure 6):

FIGURE 6: ALGORITHM FLOWCHART



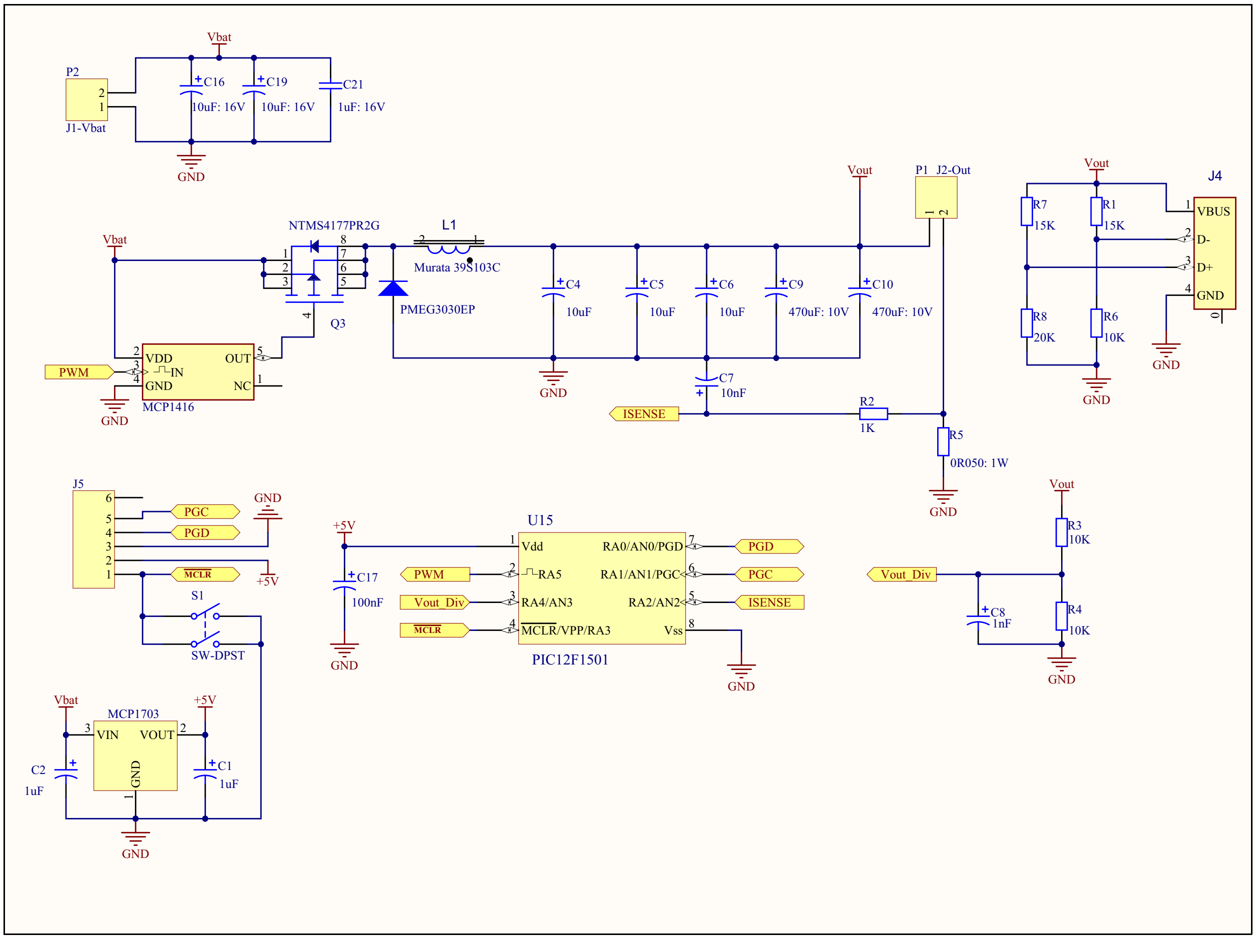
GLOSSARY

TABLE 4: ACRONYMS

PWM	Pulse-Width Modulation
ADC	Analog-to-Digital Converter
DAC	Digital-to-Analog Converter
NCO	Numerically Controlled Oscillator
PID	Proportional Integral Derivative
CWG	Complementary Waveform Generator

APPENDIX A:

FIGURE 7: SCHEMATIC



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