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Simple Synchronous Buck Converter Design - MCP1612

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INTRODUCTION

The density of portable electronic equipment requires the design engineer to pay particular attention to a number of important design parameters. For the power conversion circuitry, two of these parameters are the efficiency and the total circuitry footprint. Keeping the efficiency high extends battery life and controls the temperature rise of the equipment. Limiting the circuitry footprint helps minimize the size of the Printed Circuit Board (PCB) and, ultimately, the total cost of the device.

The MCP1612 is an ideal choice for such a design. Since both the switching and synchronous MOSFETs are internal and switching is 1.4 MHz, the inductor, input and output capacitor size is minimized. The output voltage is set by using a simple resistor divider, with a high-bandwidth loop being accomplished by a series resistor capacitor to ground. Efficiencies of 90% and a typical shutdown current of 0.01 µA help to extend battery life.

This Application Note contains all of the information needed to design a synchronous buck converter using the MCP1612. It also contains a real-world design example with measured laboratory data.

POWER COMPONENT DESIGN

The design of the power components for the MCP1612 is made easier because the switching and synchronous MOSFETs are internal. The output filter inductor and capacitor are the only two power components that need to be selected.

Buck Inductor

The inductance and current-carrying capability of the buck inductor or output filter inductor is very easy and straightforward to calculate. The size of the inductor is selected such that a certain ripple current is achieved. As will be shown later, the amount of allowable ripple current determines the amount of output ripple voltage present at the converter load.

Solving the standard inductor equation for inductor ripple current (ΔI_L) yields:

$$\Delta I_L = \frac{V_L}{L} \times \Delta T$$

Where:

V_L = voltage across the inductor ($V_{IN} - V_{OUT}$)
L = value of inductance
ΔT = on-time of switching MOSFET

When operating in Continuous Conduction mode (meaning the inductor current never goes to zero), the on-time (ΔT) of the P-channel MOSFET is determined by multiplying the duty cycle by the switching period. Using the output voltage (V_{OUT}) to input voltage (V_{IN}) relationship, the duty cycle yields:

$$DutyCycle = \frac{V_{OUT}}{V_{IN}}$$

Therefore, it follows that ΔT is:

$$\Delta T = DutyCycle \times \frac{1}{F_{SW}}$$

Where:

F_{SW} = switching frequency

Most inductor manufacturers specify the peak current that an inductor can support before the inductance drops by a given percentage. ΔI_L should be re-evaluated if the inductance drops by a large percentage because of its peak current. The peak inductor current is calculated by:

$$I_{L(PEAK)} = I_{OUT(MAX)} + \left(\frac{1}{2} \times \Delta I_L\right)$$

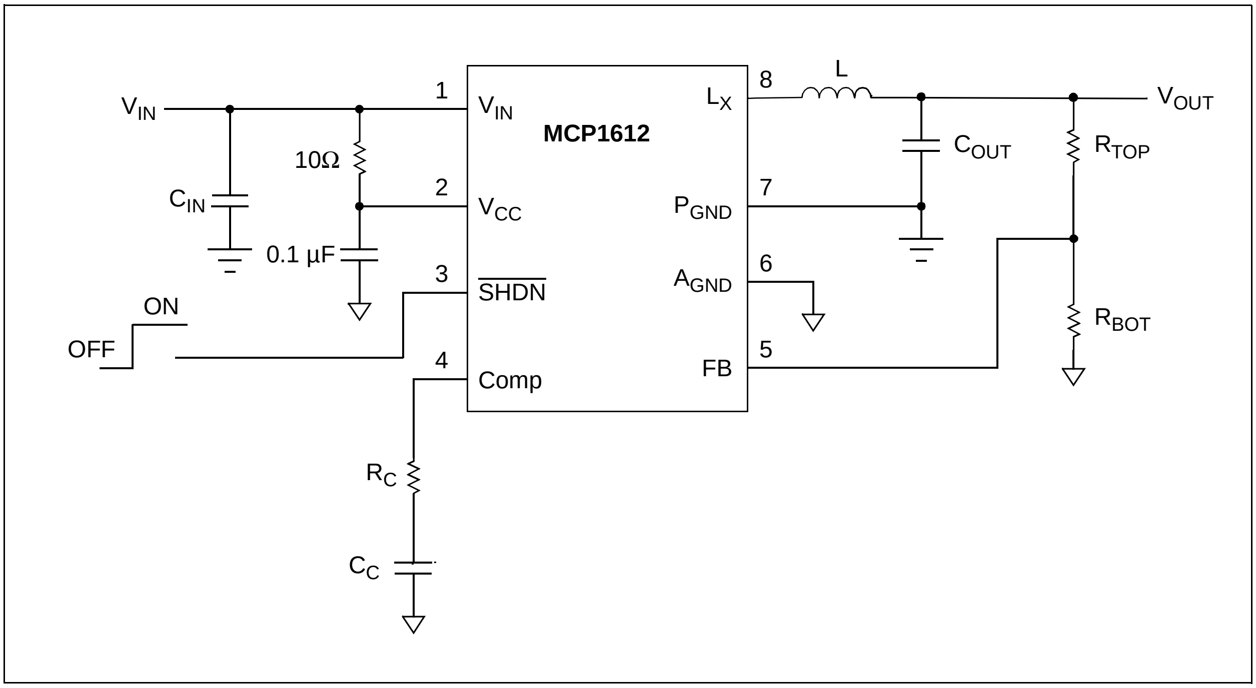

FIGURE 1: *Typical Application Schematic.*

Output Capacitor

The MCP1612 is designed to allow the use of ceramic, tantalum or aluminum electrolytic capacitors as output filter capacitors. The output capacitor is chosen to meet the output ripple specification and to provide storage for load transients. The value of the capacitance is not the only parameter of the capacitor that determines ripple voltage. All capacitors have an Equivalent Series Resistance (ESR) that contributes to the ripple voltage. Ceramic capacitors have the lowest ESR, but increase in cost with higher capacitance values. Aluminum electrolytic and tantalum capacitors are relatively inexpensive in higher capacitance values, but they also have a much higher ESR.

Solving the standard capacitor equation for the output ripple voltage (ΔV_C) yields:

$$\Delta V_C = \frac{I_C \times \Delta T}{C_{OUT}}$$

Where:

I_C = peak-to-peak ripple current
ΔT = on-time of P-channel MOSFET
ΔV_C = output ripple voltage

As previously stated, the capacitor ESR also contributes to the output ripple voltage. This ripple voltage ($V_{ESRRIPPLE}$) is defined as:

$$V_{ESRRIPPLE} = I_C \times ESR$$

SETTING OUTPUT VOLTAGE

The output voltage of the MCP1612 is easily set by the use of an external resistor divider network. The divided-down output voltage is internally compared to a 0.8V reference. The output voltage can be set to any voltage between 0.8V and V_{IN}.

A resistor value of 200 kΩ or lower is recommended for R_{BOT}, the lower end of the resistor divider. If a higher-value resistor is used, the circuit will become more susceptible to noise at the feedback pin. The top resistor (R_{TOP}) of the resistor divider is easily calculated by using the following equation:

$$R_{TOP} = R_{BOT} \times \left(\frac{V_{OUT}}{V_{FB}} - 1\right)$$

Where:

V_{OUT} = desired output voltage
V_{FB} = MCP1612 internal reference voltage
R_{TOP} = top resistor value
R_{BOT} = bottom resistor value

INPUT AND V_{CC} FILTER

Input Capacitor

The input current in a buck topology is pulled from the source and input capacitor in pulses. The size of the input capacitor determines the amount of peak current that is pulled from the source. The input capacitor also reduces the amount of voltage ripple present at the input to the converter.

The value of the input capacitor can be calculated the same way as the output capacitor. A capacitance value is chosen and the corresponding ripple voltage is calculated. For most applications, a 10 µF ceramic capacitor connected between the V_{IN} and P_{GND} pins of the MCP1612 is recommended to filter the current pulses. A lower-value capacitor can be used in applications that have a low source impedance. Ceramic or aluminum electrolytic capacitors can be used, but the capacitor ripple current rating should not be exceeded.

V_{CC} Filter

The V_{CC} pin provides bias for the internal analog circuitry. It is important that this voltage stay free of line transients and, therefore, it is recommended that a separate filter be used for this voltage. Placing a 10Ω resistor between V_{IN} and AV_{CC} and a 0.1 µF capacitor between V_{CC} and A_{GND} is sufficient to filter any high-frequency line transients on V_{IN} caused by the MCP1612 switching.

COMPENSATION COMPONENTS

The MCP1612 is a peak current mode buck controller and, therefore, it does not exhibit the second-order effects associated with the L-C output filter as with a voltage mode controller. Since a transconductance error amplifier is used, a simple resistor and capacitor connected from the output of the amplifier to ground is all that is needed to provide a stable, high-bandwidth control loop.

Table 1 shows values for R_C and C_C for standard circuit parameters. The values provide a stable control loop over the entire MCP1612 input voltage, output voltage and output current range.

TABLE 1: GENERAL CIRCUIT PARAMETERS

L	C_{OUT}	R_C	C_C
3.3 µH	10.0 µF	22 kΩ	1000 pF
2.2 µH	4.7 µF	12 kΩ	1000 pF

JUNCTION TEMPERATURE RISE

The MCP1612 is packaged in both an 8-pin MSOP and a thermally-enhanced, 8-pin DFN. The junction temperature rise above ambient of the MCP1612 is determined by multiplying the internal power dissipation by the thermal resistance of the package as shown:

$$T_{RISE} = P_{INT} \times \theta_{JA}$$

Where:

P_{INT} = MCP1612 internal power dissipation

θ_{JA} = package thermal resistance

It is important to note that the package thermal resistance is specified for an assumed PCB layout consisting of four layers with 1 oz. copper on the internal layers, 2 oz. copper on the external layers and exposed vias connecting the layers. The thermal resistance will be higher for a PCB that is constructed with less layers, less copper weight or fewer vias.

It can be assumed that the difference between the input power (P_{IN}) and the output power (P_{OUT}) is the power lost in the MCP1612 (P_{INT}) and in the buck inductor, P_{IND}. Neglecting the small amount of core loss, the power lost in the buck inductor is defined by the following equation:

$$P_{IND} = I_{I(PEAK)}^{2} \times R_{IND}$$

Where:

R_{IND} = inductor winding resistance

PORTABLE/LOAD-SHED APPLICATIONS

The switching frequency, efficiency, package size and extremely low shutdown current make the MCP1612 perfectly suited for portable applications or load-shed applications. Couple the 1.4 MHz switching frequency that allows the use of small inductors, and filter capacitors with the 8-pin MSOP or the space-saving 8-pin DFN package and a 1A buck converter that fits into the most space constrained designs is achievable.

When the MCP1612 is disabled by grounding the shutdown pin ($\overline{SHDN}$), the current draw is only 0.01 µA, typical. If the load cannot be shed, the quiescent current (I_Q (I_{OUT} = 0 mA)) is only 5 mA, typical. Both of these low-current draw modes, along with the high efficiency, extend battery life.

PRACTICAL DESIGN EXAMPLE

A buck converter with the following design parameters will be designed using the MCP1612. A schematic of the circuit appears in Figure 1.

$$V_{IN} = 2.7V – 4.5V$$

$$V_{OUT} = 1.8V$$

$$V_{OUT\_RIPPLE} < 15\ mV$$

$$I_{OUT} = 0 – 1A$$

The switching frequency (F_{SW}) of the MCP1612 is 1.4 MHz. The worst-case inductor ripple current is when V_{IN} is at its maximum. The inductor and output capacitor must be sized for this worst-case condition. Therefore:

$$\text{Duty Cycle} = 1.8/4.5 = 0.400$$

$$\Delta T = 0.40 * 1/1.4\ MHz = 286\ ns$$

Select L = 3.3 µH:

$$\Delta I_L = ((4.5\text{-}1.8)/3.3\ \mu H) * 286\ ns = 234\ mA$$

$$I_{L(PEAK)} = 1 + (1/2 * 234\ mA) = 1.12A$$

The 3.3 µH inductor yields an acceptable ripple current of about 20% at maximum I_{OUT}. The inductor must be able to withstand a peak current of 1.12A.

Using an output capacitor (C_{OUT}) of 10 µF yields an approximate output ripple voltage of:

$$\Delta V_C = (234\ mA * 286\ ns)/10\ \mu F = 6.68\ mV$$

$$V_{ESRRIPPLE} = 234\ mA * 10\ m\Omega = 2.34\ mV$$

$$\Delta V_{OUT} = 6.68\ mV + 2.34\ mV = 9.02\ mV$$

Since the output voltage is compared to the 0.8V internal reference voltage, a resistor divider needs to be designed. Selecting R_{BOT} = 200 kΩ, the top resistor (R_{TOP}) is:

$$R_{TOP} = 200\ k\Omega * (1.8/0.8 – 1) = 250\ k\Omega$$

The input capacitor (C_{IN}) is selected to be 10 µF. This provides adequate filtering on the input.

Figure 2 through Figure 5 show lab performance of the buck converter built with the components selected above and compensation values for R_C and C_C of 22 kΩ and 1000 pF, respectively. Unless otherwise noted, V_{IN} = 3.3V, V_{OUT} = 1.8V and I_{OUT} = 500 mA.

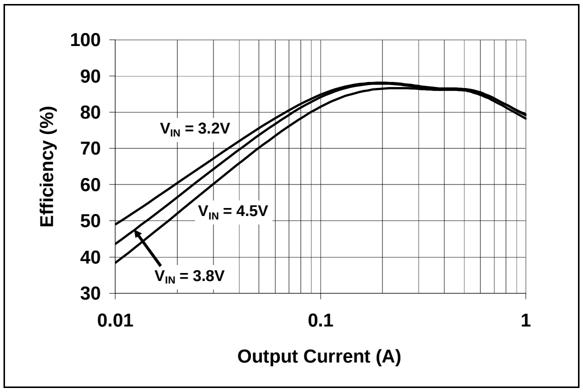

FIGURE 2: *Converter Efficiency.*

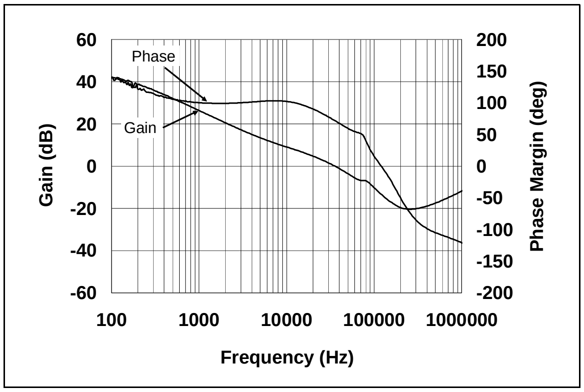

FIGURE 3: *System Bode Plot.*

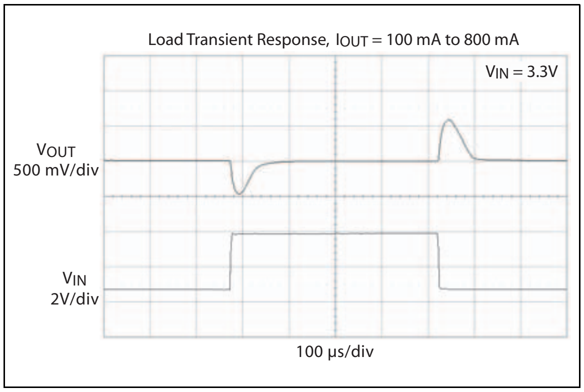

FIGURE 4: *Load Transient Response.*

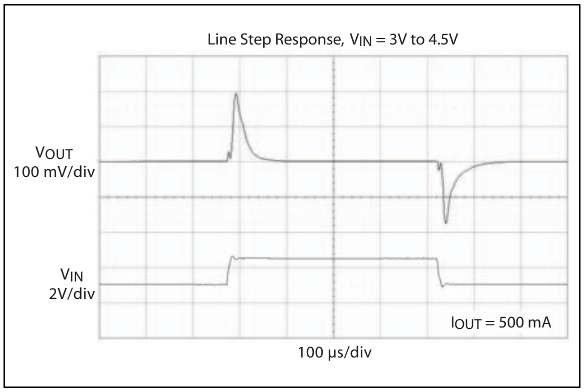

FIGURE 5: *Line Step Response.*

CONCLUSION

Designing with the MCP1612 is very simple and straightforward. The buck inductor, output filter capacitor and resistor divider network are the only components that need to be calculated.

The integrated switching and synchronous MOSFETs, as well as the 1.4 MHz switching speed, make the MCP1612 buck controller an ideal solution for a space-contained design. The output voltage is set by a simple resistor divider and a series resistor capacitor is all that is required for a high-bandwidth control loop.

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