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# MC13783 Buck and Boost Inductor Sizing

by: **Power Management Application Team**

## 1 Introduction

The purpose of this application note is to provide a method of choosing the size of the inductors for the optimized switching regulators versus the current consumption of the application. This will allow to optimize the size and the cost of these components.

The recommendations for external components used for a reference or application design implemented with the MC13783 are outlined in the application note *External Component Recommendations for the MC13783 Reference Design* (document number: AN3295).

## 2 Buck Converter

The buck converter architecture used for the MC13783 is a simple PWM voltage mode control topology using a clock, which is 32 times the crystal oscillator clock of 1.024 MHz. Pulse skip mode is supported and would occur at a current level determined by the external L,C components and the input and output levels.

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## 2.1 Current Limit

The current limit value not only is temperature-and process-dependent, but it is also related to the slope of the current flowing through the power switch (this includes notion of delay). The current limit tolerance is 800-1000 mA for single connection and is 1300-1500 mA for parallel connection.

## 2.2 Theoretical Inductor Sizing

For a buck topology switching power supply as shown in Figure 1, the external components selection is driven by input, output voltage levels, load requirements, switching frequency and desired amount of voltage output ripple (ripple current).

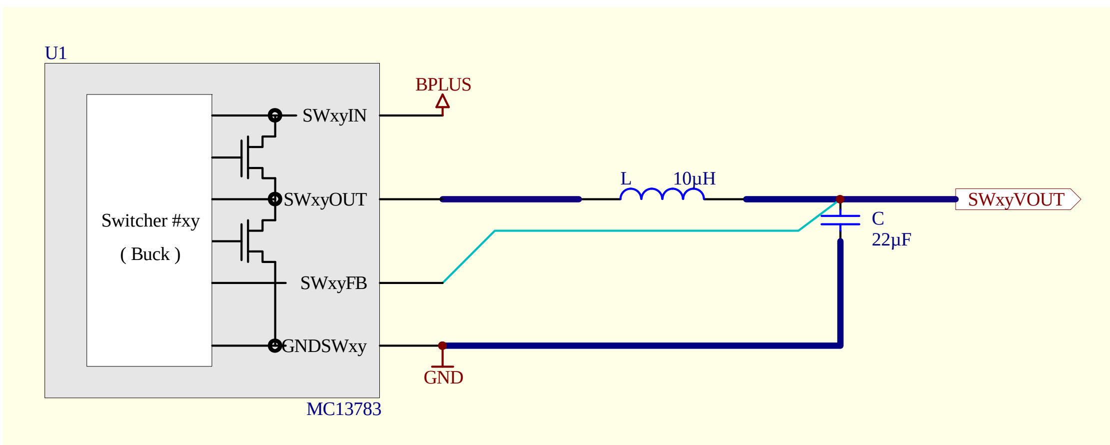


**Figure 1. MC13783 Buck Converter Topology for Single Connection**

The operating frequency and inductor selection are inter-related in that higher operating frequencies allow the use of a smaller inductor value. However, operating at a higher frequency generally results in lower efficiency because of increased internal gate charge losses.

For a given switching frequency, the highest inductor current ripple occurs at maximum input voltage and maximum output voltage. The following equations are presented for L sizing.

$$\Delta IL_{max} = \frac{1}{fs \cdot L} \cdot Vout_{max} \cdot \left(1 - \frac{Vout_{max}}{Vin_{max}}\right)$$

***Eqn. 1***

However, the inductor current ripple is directly proportional to the amount of voltage output ripple. All DC current of the inductor is provided to the load and the remaining AC current is going through the output capacitor.

$$IL_{ac} = IC_{ac}$$

***Eqn. 2***

In most cases when ESR is large enough, the maximum output voltage ripple is given by Equation 3:

$$\Delta Vout = ESR \cdot \Delta IL$$

***Eqn. 3***

Accepting the larger values of inductor current ripple allows the use of lower inductance, but results in higher output voltage ripple and greater core and power device conduction losses.

$$L = \frac{1}{fs \cdot \Delta IL_{max}} \cdot Vout_{max} \cdot \left(1 - \frac{Vout_{max}}{Vin_{max}}\right)$$

***Eqn. 4***

All conduction losses are proportional to the RMS inductor current as shown in Equation 5:

$$Conduction_{LOSSES} \sim IL_{rms}^2 = IL^2 + \frac{\Delta IL^2}{12}$$

***Eqn. 5***

Most of the time the inductor will be selected to reach the required output voltage ripple, especially when the DC-DC converter will directly supply the IC without the "filtering" of the low drop out linear regulators. Its value will result from the following equation:

$$L = \frac{ESR}{fs \cdot \Delta Vout_{max}} \cdot Vout_{max} \cdot \left(1 - \frac{Vout_{max}}{Vin_{max}}\right)$$

***Eqn. 6***

Physical size of the inductor is roughly proportional to its peak energy storage as shown in Equation 7.

$$E = \frac{1}{2} \cdot L \cdot Ipeak^2$$

$$IL_{peak} = IL_{dc} + \frac{\Delta IL}{2}$$

$$IL_{peakmax} = IL_{dcmax} + \frac{1}{fs \cdot L} \cdot Vout_{max} \cdot \left(1 - \frac{Vout_{max}}{Vin_{max}}\right)$$

***Eqn. 7***

The $Ilpeak_{max}$ is the maximum inductor peak current in steady state operation. During transient (especially at power-up), the peak current can be higher since the power device can be turned on during $Ton_{max}$ for more than one cycle. In this case, the peak current will be limited by the current limit function.

## 2.3 Numerical Application Example

A numerical application example of the MC13783 is if a switcher is used with a 750 mA max. DC load, a 1.6 V max. output voltage, and 4.2 V maximum input voltage, then:

L = 10 μH

Fs = 1.024 MHz

$Ilpeak_{max}$ = 750 mA + 96 mA = 846 mA

# 3 Boost Converter

The boost converter architecture used for the MC13783 is a simple PWM current mode control topology using a clock which is 32 times the crystal oscillator clock (1.024 MHz). Pulse skip mode is supported and would occur at a current level determined by the external L,C components and the input and output levels.

## 3.1 Theoretical Inductor Sizing

For a boost topology switching power supply as shown in Figure 2, the external components selection is driven by input, output voltages levels, load requirements, switching frequency, and desired amount of voltage output ripple (ripple current).

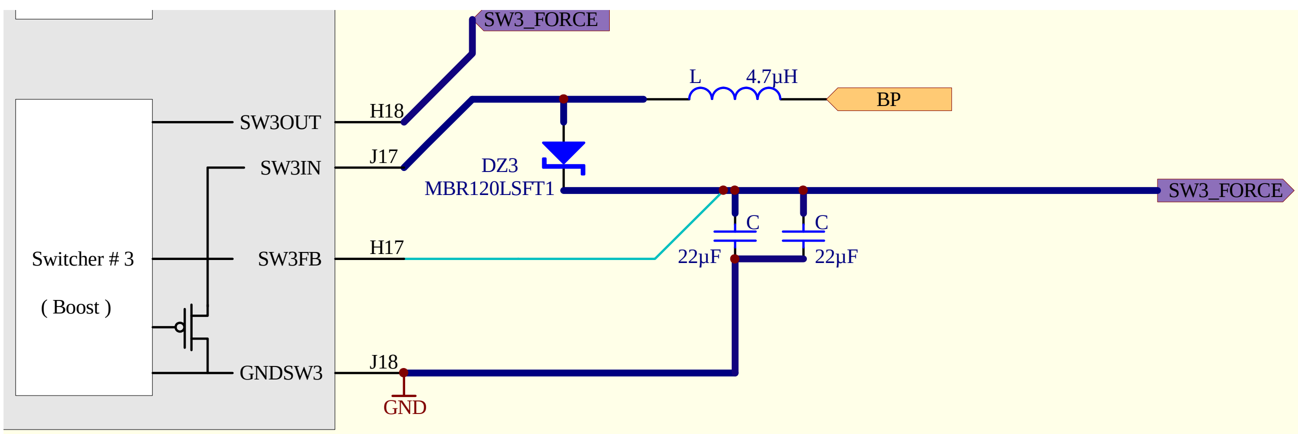


Figure 2. MC13783 Boost Converter Topology

The operating frequency and inductor selection are inter-related in that higher operating frequencies allow the use of smaller inductor value. However, operating at a higher frequency generally results in lower efficiency because of increased internal gate charge losses. For a given switching frequency, the highest inductor current ripple occurs at maximum output voltage and for Vin = Vout/2.

$$\Delta IL = \frac{1}{fs \cdot L} \cdot Vin \cdot \left(1 - \frac{Vin}{Vout}\right)$$

$$\Delta IL_{max} = \frac{1}{fs \cdot L} \cdot \frac{Vout_{max}}{4}$$

***Eqn. 8***

Considering the following relation in Equation 9.

$$\frac{Vout}{2} < Vin$$

***Eqn. 9***

However, the inductor current ripple is directly proportional the amount of voltage output ripple. When the power switch is closed, the current in the output capacitor is equaled to (-Iload), while when it is open as shown in Equation 10.

$$I_{C(t)} = I_{L(t)} - Iout$$

$$I_{Lac} = I_{Cac}$$

***Eqn. 10***

In most cases when ESR is large enough and when the amount of capacitance is large enough such that the ripple can be ignored due to the capacitor, the maximum output voltage ripple is given by:

a) Discontinuous Conduction Mode:

$$\Delta Vout = ESR \cdot \Delta IL$$

***Eqn. 11***

b) Continuous Conduction Mode:

$$\Delta Vout = ESR. (\Delta IL/2 + 4Iload)$$

Accepting the larger values of inductor current ripple allows the use of lower inductance, but results in higher output voltage ripple and greater core and power device conduction losses.

$$L = \frac{1}{fs \cdot \Delta IL_{max}} \cdot \frac{Vout_{max}}{4}$$

***Eqn. 12***

All conduction losses are proportional to the RMS inductor current as shown in Equation 13:

$$\text{ConductionLOSSES} \sim ILrms^2 = IL^2 + \frac{\Delta IL^2}{12}$$

***Eqn. 13***

Most of the time, the inductor will be chosen to reach the required output voltage ripple, especially when the DC-DC converter will directly supply the IC without "filtering" of the low drop out linear regulators. Its value will result from the following equation:

$$L = \frac{ESR}{fs \cdot \Delta Vout_{max}} \cdot \frac{Vout_{max}}{4}$$

***Eqn. 14***

Physical size of the inductor is roughly proportional to its peak energy storage.

$$E = \frac{1}{2} \cdot L \cdot Ipeak^2$$

$$IL_{peak} = IL_{dc} + \frac{\Delta IL}{2}$$

$$IL_{peak} = \frac{Iout_{max}}{1-D} + \frac{1}{fs \cdot L \cdot 2} \cdot Vin \cdot \left(1 - \frac{Vin}{Vout}\right)$$

$$IL_{peak} = \frac{Vout}{Vin} \cdot Iout + \frac{1}{fs \cdot L \cdot 2} \cdot Vin \cdot \left(1 - \frac{Vin}{Vout}\right)$$

$$IL_{peakmax} = \frac{Vout_{max}}{Vin_{min}} \cdot Iout_{max} + \frac{1}{fs \cdot L \cdot 2} \cdot Vin_{min} \cdot \left(1 - \frac{Vin_{min}}{Vout_{max}}\right)$$

***Eqn. 15***

The $Ilpeak_{max}$ is the maximum inductor peak current in steady state operation. During transient (especially at power-up), the peak current can be higher since the power device can be turned on during $Ton_{max}$ for more than one cycle. In this case, the peak current will be limited by the current limit function.

## 3.2 Numerical Application Example

A numerical application example of the MC13783 is if a switcher used with a 200 mA max. DC load, a 5.5 V max. output voltage, and 3.05 V minimum input voltage, then:

L = 4.7 µH

Fs = 1.024 MHz

$Ilpeak_{max}$ = 360 mA + 140 mA = 500 mA

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