How to Calculate a Buck Converter's Inductance

Introduction

In the buck circuit, the inductor design is a key element that is closely related to system efficiency, the output voltage ripple (ΔV_{OUT}), and loop stability. This article discusses how to calculate the inductance of a buck converter using the MPQ2314 as well as key parameters including the rising current of the inductor temperature, saturation current DC resistance, operating frequency, and magnetic loss.

Working Principles of Buck Topology

The working state of the upper tube (Q1) is divided into two processes: inductor charging mode and inductor discharging mode (see Figure 1). Q1 is turned on in inductor charging mode, where the inductor current (I_L) rises, the inductor stores energy, and the output capacitor charges. Q1 is turned off in inductor discharging mode, where I_L drops and the inductor releases energy.

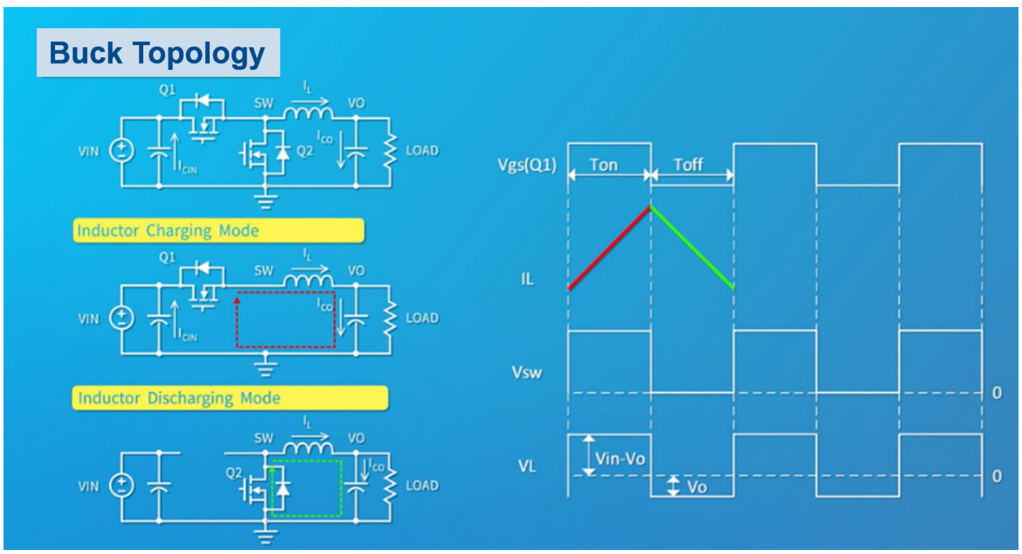

Figure 1: Inductor Charging Mode and Inductor Discharging Mode

The inductance (L) can be calculated based on the relationship between the voltage and current across the inductor. This relationship can be calculated with Equation (1):

$$V = L \times dI / dt \tag{1}$$

Where the voltage across the inductor is V_{IN} - V_{OUT}, dI is the peak-to-peak I_L (ΔI_L) (typically 10% to 60% of the maximum output current, I_{OUT}), and dt is Q1's turn-on time, calculated with Equation (2):

$$dt = D \times t_{SW} \tag{2}$$

With Equation (1), the state of the inductor's energy storage when Q1 is turned on can be analyzed.

Figure 2 shows how to calculate for duty cycle, inductor current variation, and inductance.

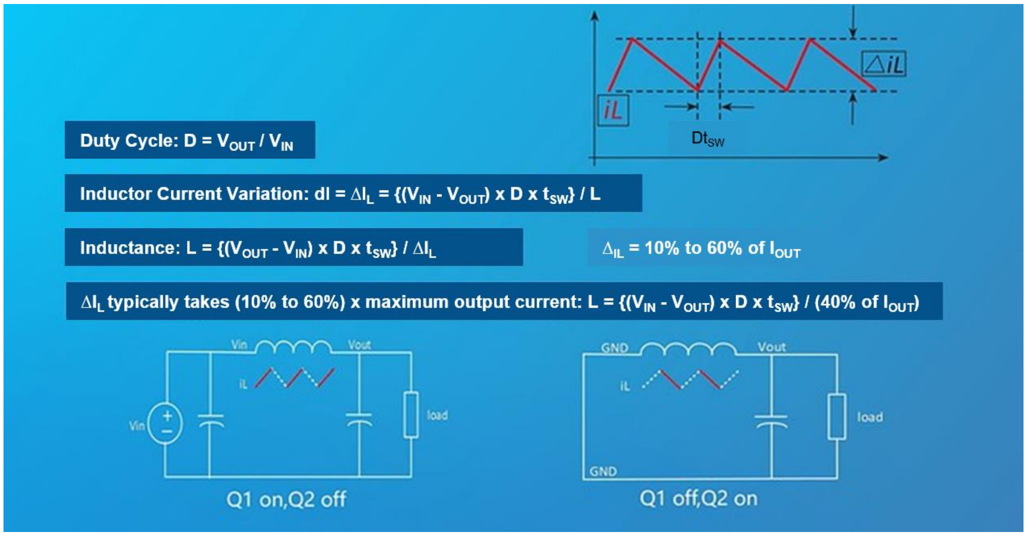

Figure 2: Calculating Duty Cycle, Inductor Current Variation, and Inductance

To balance ΔV_{OUT} and efficiency when designing the inductor, the system typically enters continuous conduction mode (CCM) at full loads and discontinuous conduction mode (DCM) at light loads. In CCM, ΔV_{OUT} is lower due to the inductor's small ripple current. In DCM, the IC typically enters the frequency reduction mode, reducing the operating frequency and thereby improving light-load efficiency.

Consider an inductor's specifications. L is measured at a certain operating frequency (typically 100kHz). L decreases as the frequency increases.

I_R is the rising current of the inductor temperature, and I_{SAT} is the saturation current. Typically, I_R is slightly below I_{SAT}. The selected I_R should exceed the peak current (I_{PK}) at full load, and also consider that the inductor cannot enter saturation during overcurrent or short-circuit conditions. Thus, I_R should exceed the current-limit protection threshold defined by the DC/DC converter.

Figure 3 shows the parameters of the MPL-AY1050-100.

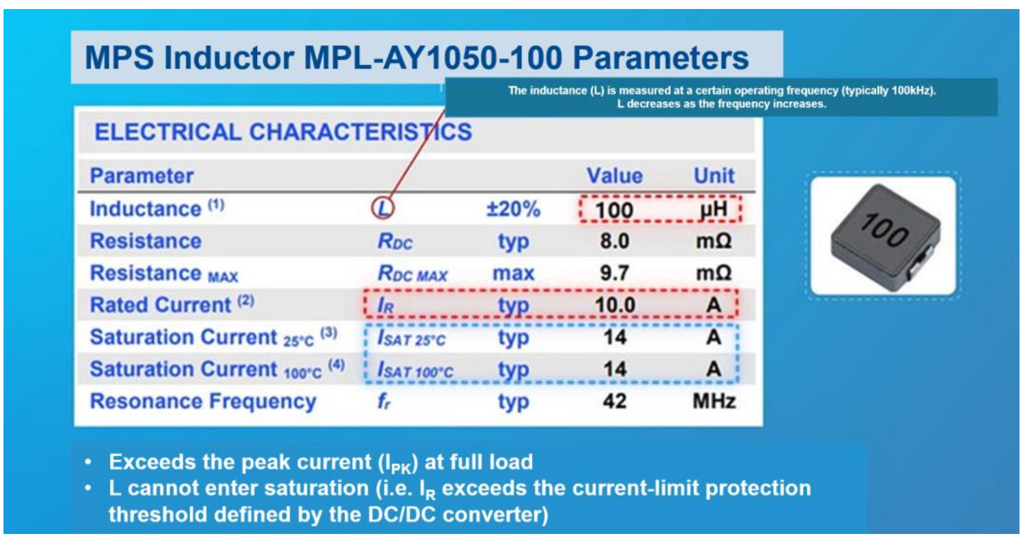

Figure 3: MPL-AY1050-100 Parameters

For the purposes of this article, we selected the MPQ2314 as the DC/DC converter, which defines the over-current protection (OCP) threshold in its specifications (typically 4A). At a full load of 2A, the inductor's I_{PK} is 2.58A, and the OCP threshold is 3.36A due to the upper and lower limit distribution of the OCP threshold. Select the inductor's I_R to exceed 4A with a margin greater than 20%.

Figure 4 shows the MPQ2314's waveforms at full load as well as OCP peak current.

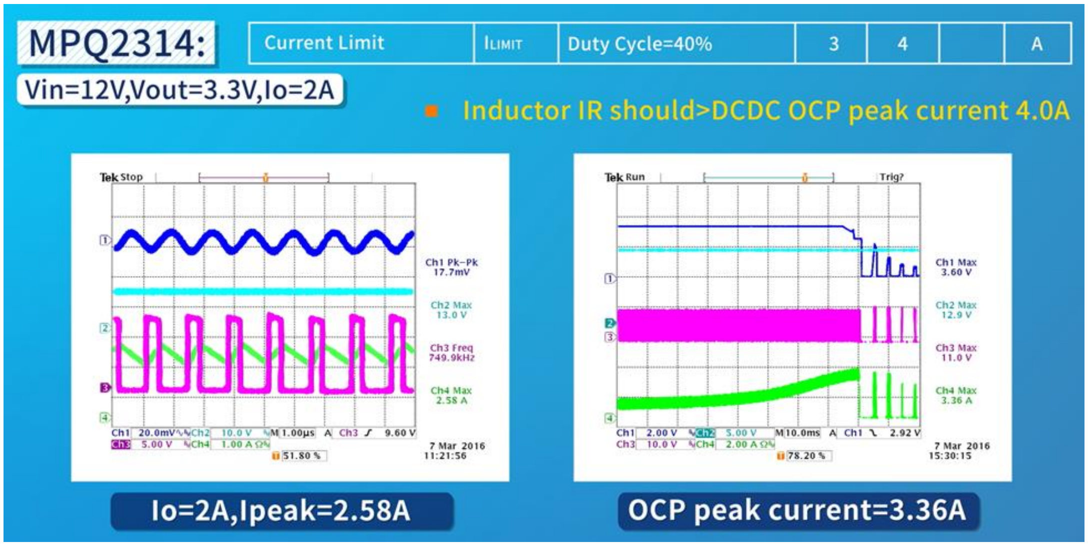

Figure 4: MPQ2314 Waveforms at Full Load and OCP Peak Current

The DC resistance (R_{DS}, also called DCR) is directly related to the inductor's conduction loss. When selecting the inductor, a smaller R_{DS} results in improved efficiency and temperature rise. Copper loss accounts for the majority of inductance loss, and magnetic loss is related to the operating frequency and the magnetic core characteristics. A higher frequency leads to greater magnetic loss.

Increasing the inductance can reduce the inductor's ripple current, which reduces ΔV_{OUT}. However, when the inductance of this magnetic core increases, R_{DS} increases while the saturation and temperature rise currents decrease. Therefore, it is necessary to consider this tradeoff before increasing the inductance (see Figure 5).

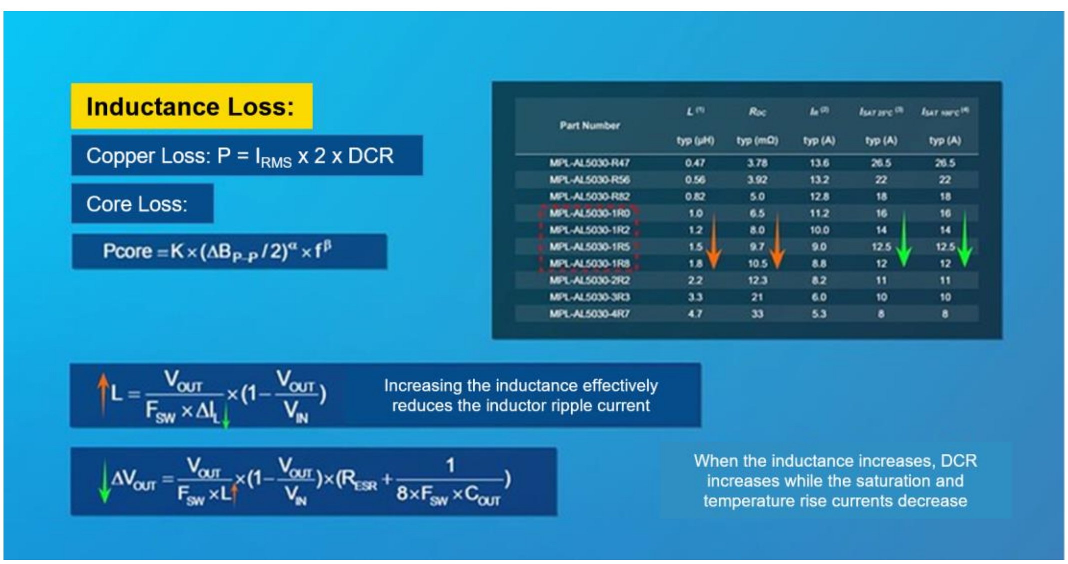

Figure 5: Calculating Inductance Loss

When selecting an inductor, approach the theoretical calculation value as close as possible, and calculate the inductor's I_{PK} to confirm its saturation and temperature rise currents. It is recommended to use a package with magnetic shielding, as it generates less noise and better EMC performance. Figure 6 shows a calculation example for selecting the inductance.

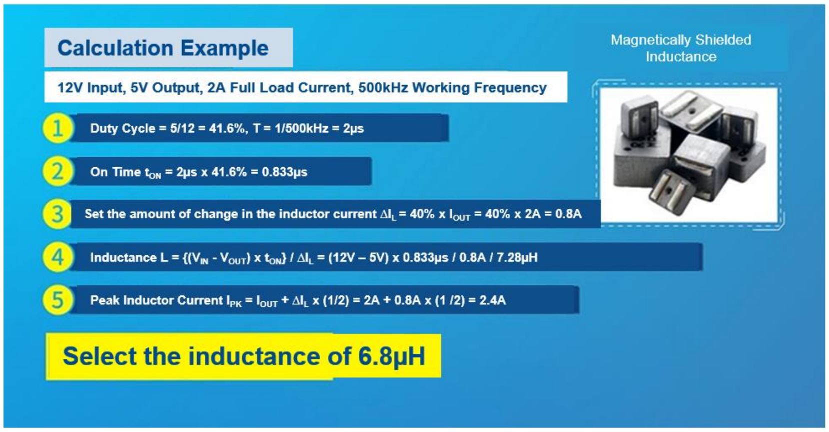

Figure 6: Calculation Example for Selecting the Inductance

Conclusion

This article laid out the steps for calculating the inductance required for a buck converter, which includes calculating for duty cycle, turn-on time, ΔI_L, L, and I_{PK}. By determining the correct inductance, system efficiency, ΔV_{OUT}, and loop stability can also be optimized.

For more details, explore MPS's online inductor selection tool, which allows the user to easily obtain the desired inductance and add the appropriate inductor model.