Application Note

Switching Regulator IC Series

Method for Determining Constants of Peripheral Parts of Buck DC/DC Converter

This application note explains the procedures for determining the constants of peripheral parts of a buck DC/DC converter.

Contents

You can calculate the constants of peripheral parts by following the contents of this document. However, contact us before you use a setting other than the recommended constant that is shown in the application example described in the data sheet.

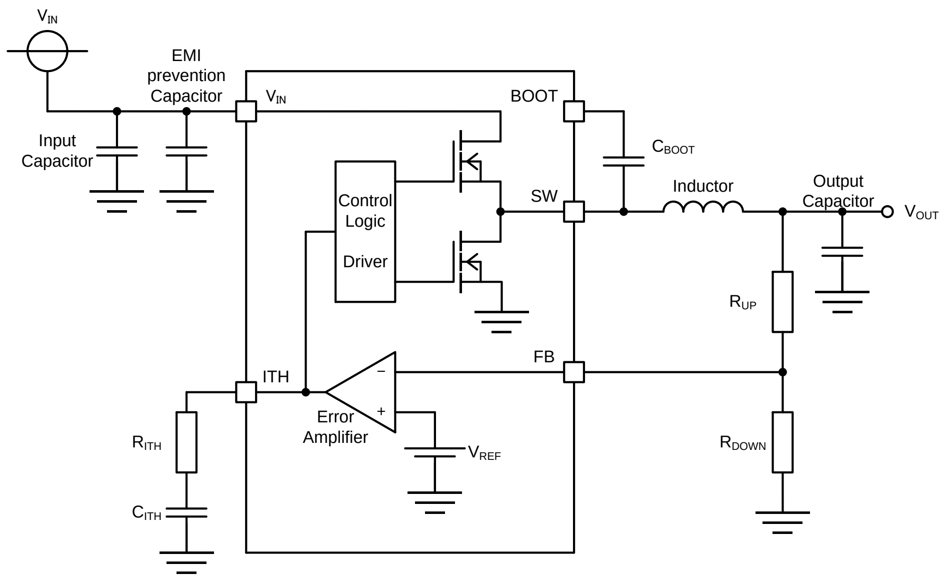

Figure 1. Circuit diagram of buck DC/DC converter

1. Significance of correctly determining the constants for a buck DC/DC converter

Compared with an LDO, a buck DC/DC converter typically has more parts that are externally connected. Therefore, determining the constants of parts is more complicated compared with the case for an LDO. It is important to correctly select the parts.

We will show the design procedures in the next chapter.

2. Procedures for determining the constants

2.1. Determination of the input capacitor

The input capacitor is connected between the input and the ground for stabilizing the input voltage and as an EMI countermeasure. Although ceramic capacitors are increasingly used for the input capacitors, it is necessary to consider the DC bias characteristic, i.e., decrease in the actual capacitance by the input voltage. For more details, contact the manufacturer of each capacitor.

The capacitors listed in the data sheet are selected ones whose actual capacitance is sufficiently secured. When you use a capacitor with the same capacitance but with a low profile or smaller size, the actual capacitance may not be sufficiently secured due to the DC bias characteristic. If the model number is listed in the data sheet, check the DC bias characteristic and ensure that the actual capacitance is greater than that of the listed capacitor.

For example, if a capacitor listed in the data sheet with a nominal value of 10 μF and the 3216 size is connected for an input voltage of 5 V, the actual capacitance is 9.6 μF based on Figure 2. The actual capacitance of a capacitor with the same nominal value and the 1608 size decreases to 3.1 μF. In this case, the stable operation of the IC may be impaired because the actual capacitance of the capacitor with the 1608 size is significantly lower than that of the capacitor described in the data sheet.

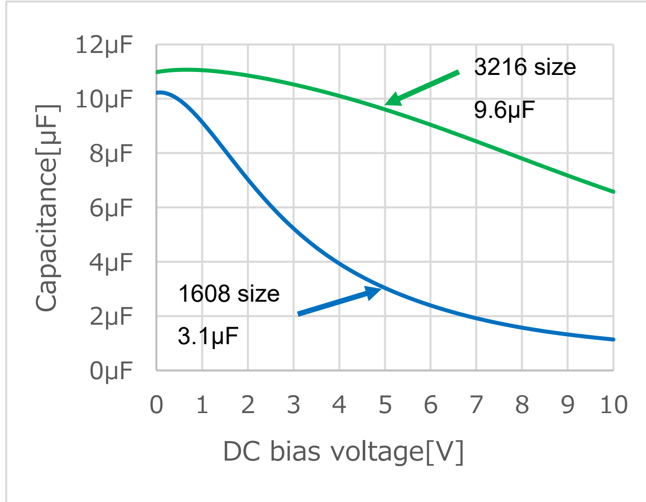

Figure 2. Example of DC bias characteristic of ceramic capacitor

In addition, it is recommended to connect a capacitor of approximately 0.1 μF adjacent to the IC for an EMI countermeasure.

If more detailed information is necessary, see the following application notes:

- Capacitor Calculation for Buck converter IC
- The Important Points of Multi-layer Ceramic Capacitor Used in Buck Converter circuit

2.2. Determination of the output capacitor

The output capacitor is connected between the output and the ground for smoothing (reduction in the output ripple). As described in 2.1, it is also necessary to check the actual capacitance from the model number listed in the data sheet, and select a ceramic capacitor to be used as an output capacitor that has an equivalent actual capacitance. If the capacitance values differ, a gap is produced in the phase compensation described in 2.5 and the stable operation of the IC may be impaired.

As with the input capacitor, see the following application notes for more detailed information:

- Capacitor Calculation for Buck converter IC
- The Important Points of Multi-layer Ceramic Capacitor Used in Buck Converter circuit

2.3. Determination of output voltage setting resistors

The output voltage setting resistors are connected between the FB terminal and the output as well as between the FB terminal and the ground (referred to as R_{UP} and R_{DOWN}, respectively). The FB terminal is connected with the input of the error amplifier inside the IC. The other input of the error amplifier is connected with the reference voltage source. Because the inputs of the error amplifier are imaginary short-circuited, the FB voltage is matched to the reference voltage (referred to as V_{REF}).

The output voltage V_{OUT} can be calculated from the setting resistances and the reference voltage as follows.

$$V_{OUT} = \frac{(R_{UP}+R_{DOWN})}{R_{DOWN}} \cdot V_{REF} \ \ [V] \qquad (1)$$

As shown in Equation (1), it is impossible to decrease V_{OUT} to V_{REF} or lower using the setting resistors. In addition, V_{OUT} of a buck converter cannot exceed V_{IN}. Since the output voltage range or the resistance value range may be specified, refer to the data sheet.

For an example of the resistance value, see the following application note:

- Resistor Value Table to set Output Voltage of Buck Converter IC

2.4. Determination of the inductor

The inductor must be selected after considering the direct current superimposition characteristic. When the maximum output current of the IC is I_L and the ripple current is ΔI_L, the saturation current of the inductor should satisfy Equation (2).

$$\text{Saturation current of the inductor} > I_L + \frac{\Delta I_L}{2} \ \ [A] \qquad (2)$$

The ripple current ΔI_L can be calculated using Equation (3).

$$\Delta I_L = \frac{V_{OUT} \cdot (V_{IN} - V_{OUT})}{V_{IN} \cdot f_{OSC} \cdot L} \ \ [A] \qquad (3)$$

V_{IN}: Input voltage [V]
V_{OUT}: Output voltage [V]
f_{OSC}: Switching frequency [Hz]
L: Inductance value [H]

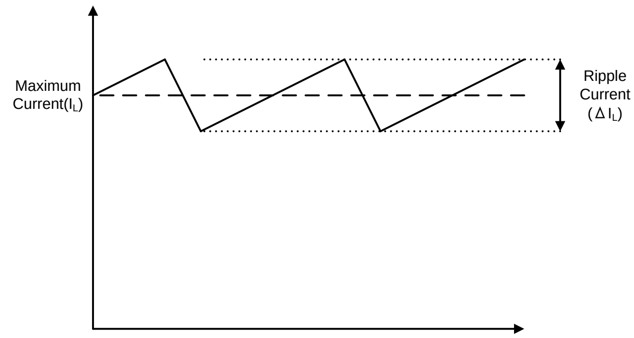

Figure 3. Current waveform of the inductor

Note that the inductance value tends to decrease with application of current even within the region below the saturation current. Therefore, allow a sufficient margin in the setting.

If more detailed information is necessary, see the following application notes:

- Inductor Calculation for Buck Converter IC
- Considerations for Power Inductors Used for Buck Converters

2.5. Determination of the phase compensation constants

For a current mode DC/DC converter, the phase compensation resistor R_{ITH} and the phase compensation capacitor C_{ITH} are used for the phase compensation. These constants can be calculated using Equations (4) and (5).

$$R_{ITH} = \frac{2\pi \cdot V_{OUT} \cdot f_{CRS} \cdot C_{OUT}}{V_{REF} \cdot G_{MP} \cdot G_{MA}} \ \ [\Omega] \qquad (4)$$

$$C_{ITH} = \frac{C_{OUT} \cdot R_{OUT}}{R_{ITH}} \ \ [F] \qquad (5)$$

V_{OUT}: Output voltage [V]
f_{CRS}: Crossover frequency [Hz]
C_{OUT}: Output capacitance [F]
V_{REF}: Internal reference voltage [V]
G_{MP}: Current sense gain [A/V]
G_{MA}: Transconductance of the error amplifier [A/V]
R_{OUT}: Output load resistance [Ω]

Note that the constants listed in the data sheet are inspected for both the phase and gain margins, which are indexes of the loop stability. Therefore, it is recommended to avoid adhering exclusively to the equations, but use the values described in the data sheet.

If more detailed information on the phase compensation is necessary, see the following application note:

- Phase Compensation Design for Current Mode Buck Converter

2.6. Determination of the bootstrap capacitor

Since the capacitance of the bootstrap capacitor is verified for the value that enables the normal operation of the internal circuit, always use the capacitance value described in the data sheet. As with the input capacitor, check the DC bias characteristics and ensure that the actual capacitance is greater than that of the listed capacitor. When the actual capacitance is too small, the electric charges are insufficient to boost the voltage. When the actual capacitance is too large, the electric charges cannot be stored completely, blocking the normal operation. Since the electric charges are fully used for the IC operation, do not connect other loads.

For an explanation of the bootstrap operation, see the following application note:

- Bootstrap Circuit in the Buck Converter

2.7. Determination of the constant of other functions

2.7.1. Determination of the soft start time setting capacitor

Soft start time T_{SS} can be calculated using Equation (6).

$$T_{SS} = \frac{C_{SS} \cdot V_{REF}}{I_{SS}} \quad [S] \qquad (6)$$

C_{SS}: Capacitance of the capacitor to be connected with the SS terminal [F]
V_{REF}: Internal reference voltage [V]
I_{SS}: SS Terminal source current [A]

Note that the minimum soft start time for each IC is set and you cannot set T_{SS} to below the minimum. This setting is implemented because it is necessary to keep the soft start time longer than the rise time of the output voltage. See the data sheet for more details. In addition, the output load capacitance limits the minimum value of C_{SS} as shown in Equation (7).

$$C_{SS} > \frac{V_{OUT} \cdot I_{SS} \cdot (C_{Load} + C_{OUT})}{(I_{OCP} - I_{OSS} - \frac{\Delta IL}{2}) \cdot V_{REF}} \quad [F] \qquad (7)$$

V_{OUT}: Output voltage [V]
I_{SS}: SS Terminal source current [A]
C_{Load}: Total output capacitance connected with other than C_{OUT} [F]
C_{OUT}: Output capacitance [F]
I_{OCP}: Current limit value of the IC [A]
I_{OSS}: Output current during soft start [A]
ΔI_L: Ripple current [A]
V_{REF}: Internal reference voltage [V]

Contact us before you use a setting other than the recommended capacitance described in the data sheet.

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