Switching Regulator IC Series

Phase Compensation Design for Current Mode Buck Converter

This application note explains the method used by ROHM for designing the phase compensation for current mode buck converters.

1. Phase compensation for current mode buck converters

ROHM current mode buck converters employ 2-poles and 1-zero system. In this system, the phase compensation is configured by connecting resistor R_{ITH} and capacitor C_{ITH} in series with the output of the error amplifier . Rea represents the output resistance of the error amplifier, Vref is the reference voltage, and V_{FB} is the feedback reference voltage (Figure 1).

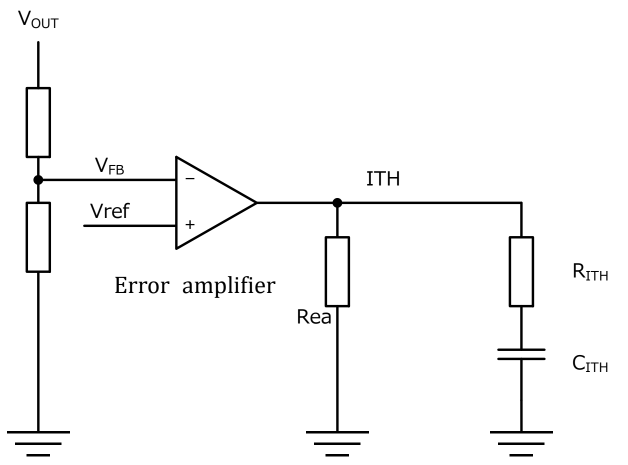

Figure 1. Phase compensation circuit diagram

2. Settings for phase compensation parts

Figure 2 shows the Bode plot for Fig. 1. The phase is delayed by 90° at a pole and advanced 90° at the zero. However, in the actual circuits, other poles that cause a phase delay to occur and the phase margin will be smaller than 90°.

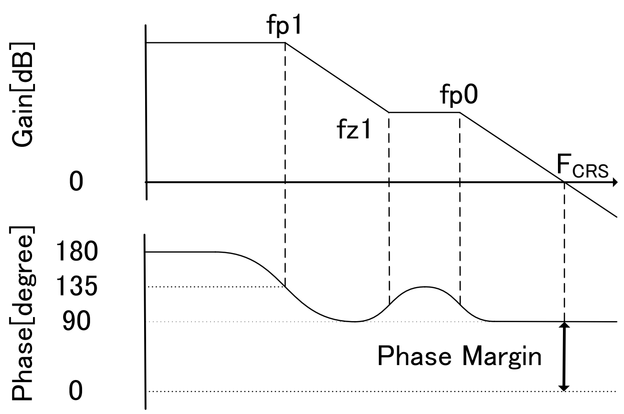

Figure 2. Bode plot

First, determine the frequencies of pole (fp1) and zero (fz1) that are formed in Figure 1.

$$fp1 = \frac{1}{2\pi \cdot Rea \cdot C_{ITH}} \quad [Hz] \tag{1}$$

$$fz1 = \frac{1}{2\pi \cdot R_{ITH} \cdot C_{ITH}} \quad [Hz] \tag{2}$$

In addition, there is a pole (fp0) due to output capacitance C_{OUT} and output load resistance R_{OUT}. fp0 is calculated using Equation (3).

$$fp0 = \frac{1}{2\pi \cdot R_{OUT} \cdot C_{OUT}} \quad [Hz] \tag{3}$$

Rea: Output resistance of the error amplifier[Ω]
R_{ITH}: Resistance for phase compensation[Ω]
C_{ITH}: Capacitance for phase compensation[F]
R_{OUT}: Output load resistance[Ω]
C_{OUT}: Output capacitance[F]

R_{OUT} is determined using maximum output current I_{OUTmax} for each IC. Ohm's law gives the relation $R_{OUT} = V_{OUT}/I_{OUTmax}$ (V_{OUT}: output voltage).

Next, R_{ITH} is represented as Equation (4).

$$R_{ITH} = \frac{2\pi \cdot F_{CRS} \cdot V_{OUT} \cdot C_{OUT}}{G_{MA} \cdot V_{FB} \cdot G_{MP}} \quad [\Omega] \tag{4}$$

F_{CRS}: Crossover frequency[Hz]
V_{OUT}: Output voltage[V]
C_{OUT}: Output capacitance[F]
G_{MA}: Transconductance of the error amplifier[A/V]
G_{MP}: Current sense gain[A/V]
V_{FB}: Feedback reference voltage[V]

In addition, matching zero (fz1) to dominant pole (fp0) can yield an appropriate compensation. Equation (5) is obtained from fp0 = fz1.

$$C_{ITH} = \frac{R_{OUT} \cdot C_{OUT}}{R_{ITH}} \tag{5}$$

R_{OUT}: Output load resistance[Ω]
C_{OUT}: Output capacitance[F]
R_{ITH}: Resistance for phase compensation[Ω]

3. Introduction of actual example

Recently, ceramic capacitors are often used for C_{OUT}. However, the DC bias characteristics and AC voltage characteristics must be considered for the ceramic capacitors. When the DC bias is 1.8 V and the AC voltage is 30 mV, it can be confirmed that the capacitance of 22 μF is reduced to the actual capacitance of ~16.5 μF (Figures 3 and 4).

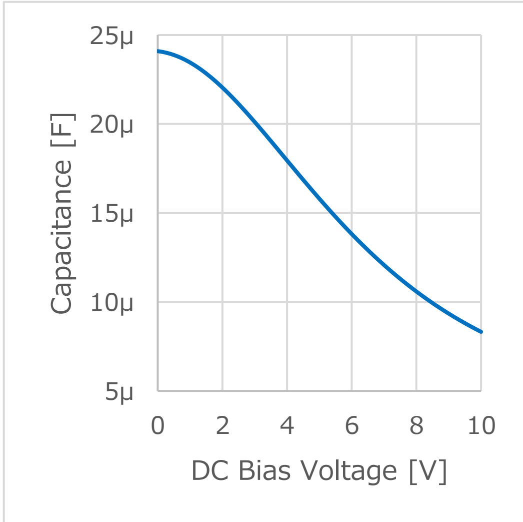

Figure 3. Example of DC bias characteristics of ceramic capacitor

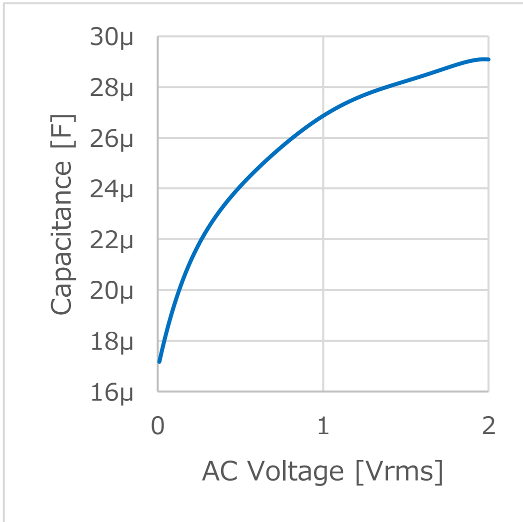

Figure 4. Example of AC voltage characteristics of ceramic capacitor

Substituting V_{OUT} = 1.8 V, R_{OUT} = 600 mΩ (I_{OUTmax} = 3 A), C_{OUT} = 33 μF (parallel connection of 2 ceramic capacitors with the above characteristics), F_{CRS} = 60 kHz, G_{MP} = 13 A/V, G_{MA} = 260 μA/V, and V_{FB} = 0.8 in Equations 4 and 5 results in the following calculations:

$$R_{ITH} = \frac{2\pi \cdot 60\text{kHz} \cdot 1.8\text{V} \cdot 33\mu\text{F}}{260\mu\text{A/V} \cdot 0.8\text{V} \cdot 13\text{A/V}}$$

$$R_{ITH} = 8.28\text{k}\Omega \cong 8.2\text{k}\Omega$$

$$C_{ITH} = \frac{600\text{m}\Omega \cdot 33\mu\text{F}}{8.28\text{k}\Omega}$$

$$C_{ITH} = 2391\text{pF} \cong 2400\text{pF}$$

The setting is achieved, as shown above. Figure 5 shows an example of the phase characteristics obtained. Since fp1 in Figure 2 is lower than 1 kHz, it does not appear in Figure 5. In addition, since fp0 = fz1, there is no change in gain or phase due to fp0 and fz1 in contrast to the phase characteristics in Figure 2.

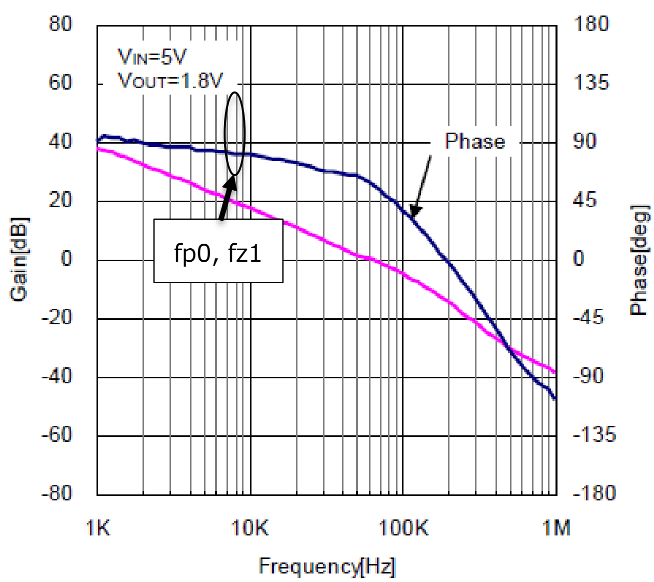

Figure 5. Example of phase characteristics

This is the method used by ROHM for setting the phase compensation constants. However, when the constant value settings are listed in the data sheet for each IC, these values should be preferred since the described settings are according to the results of various verifications.

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