Switching Regulator IC Series

Calculation of Power Loss (Synchronous)

No.AEK59-D1-0065-2

This application note describes how to obtain the power loss required to calculate the temperature of a semiconductor device. Temperature control is important to ensuring product reliability.

Figure 1 is a circuit diagram of a synchronous rectification type DC/DC converter. Figure 2 shows a switching node voltage waveform and an inductor current waveform, where power loss is generated.

IC power loss comes mainly in the form of the five factors listed below.

1. Conduction loss caused by MOSFET on-resistance P_{ON-L}, P_{ON-H}
2. MOSFET switching loss P_{SW-H}
3. Dead time loss P_D
4. MOSFET gate charge loss P_G
5. Operating loss caused by IC control circuit P_{IC}

Conduction Loss

Conduction loss is calculated between Section A and Section B of the waveform in Fig. 2. In Section A, the high-side MOSFET is ON and the low-side MOSFET is OFF. Therefore, conduction loss can be calculated from the output current, on-resistance and on-duty cycle. In Section B, the high-side MOSFET is OFF and the low-side MOSFET is ON. Therefore, conduction loss can be calculated from the output current, on-resistance and off-duty cycle.
Conduction losses P_{ON-H} and P_{ON-L} can be calculated using the following formulas.

High-side MOSFET

$$P_{ON-H} = I_O^2 \times R_{ON-H} \times \frac{V_O}{V_{IN}} \quad [W] \qquad (1)$$

Low-side MOSFET

$$P_{ON-L} = I_O^2 \times R_{ON-L} \times \left(1 - \frac{V_O}{V_{IN}}\right) \quad [W] \qquad (2)$$

I_O: Output current $[A]$
R_{ON-H}: High − side MOSFET on − resistance $[\Omega]$
R_{ON-L}: Low − side MOSFET on − resistance $[\Omega]$
V_{IN}: Input voltage $[V]$
V_O: Output voltage $[V]$

Switching Loss

Switching loss is calculated between Section C and Section D of the waveform in Fig. 2. When the high-side MOSFET and the low-side MOSFET alternately turn ON/OFF, switching-loss is generated during the transition to ON. Since the formula that calculates the areas of the two triangles is similar to the formula that calculates the power loss during the rise and fall transition, the calculation of switching-loss can be approximated using a simple figure calculation.
Switching loss P_{SW-H} can be calculated using the following formula.

High-side MOSFET

$$P_{SW-H} = \frac{1}{2} \times V_{IN} \times I_O \times (t_r + t_f) \times f_{SW} \quad [W] \qquad (3)$$

V_{IN}: Input voltage $[V]$
I_O: Output current $[A]$
t_r: High − side MOSFET rise time $[sec]$
t_f: High − side MOSFET fall time $[sec]$
f_{SW}: Switching frequency $[Hz]$

The low-side MOSFET turns ON at the gate voltage while the body-diode is powered. Then, by turning OFF the FET at the gate voltage, the load current continues running in the same direction through the body-diode. Thus, the drain voltage remains low. Accordingly, switching-loss P_{SWL} becomes minimal.

Dead Time Loss

When both the high-side MOSFET and low-side MOSFET turn ON simultaneously, a short-circuit occurs between VIN and GND, and a very large current spike is generated. To prevent this, the dead time is set to turn OFF both MOSFETs, although the inductor current continuously flows. During the dead time, this inductor current flows to the low-side MOSFET body-diode. Dead time loss P_D is calculated between section E and section F of the waveform in Fig. 2, using the following formula.

$$P_D = V_D \times I_O \times (t_{Dr} + t_{Df}) \times f_{SW} \quad [W] \qquad (4)$$

V_D: Low − side MOSFET Body − diode forward voltage $[V]$
I_O: Output current $[A]$
t_{Dr}: Dead time at rising $[sec]$
t_{Df}: Dead time at falling $[sec]$
f_{SW}: Switching frequency $[Hz]$

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Gate Charge Loss

Gate charge loss is a power loss ascribed to MOSFET gate charging. It depends on the gate electric charge (or the gate capacity) of the high-side MOSFET and low-side MOSFET. Gate charge loss is calculated using the following formula.

$$P_G = (Q_{g-H} + Q_{g-L}) \times V_{gs} \times f_{SW} \quad [W] \qquad (5)$$

or

$$P_G = (C_{g-H} + C_{g-L}) \times {V_{gs}}^2 \times f_{SW} \quad [W] \qquad (6)$$

Q_{g-H}: High − side MOSFET gate electric charge $[C]$
Q_{g-L}: Low − side MOSFET gate electric charge $[C]$
C_{g-H}: High − side MOSFET gate capacity $[F]$
C_{g-L}: Low − side MOSFET gate capacity $[F]$
V_{gs}: Gate drive voltage $[V]$
f_{SW}: Switching frequeny $[Hz]$

IC Operating Loss

Consumption power P_{IC} in the IC control circuit is calculated using the following formula.

$$P_{IC} = V_{IN} \times I_{CC} \quad [W] \qquad (7)$$

V_{IN}: Input voltage $[V]$
I_{CC}: IC consumption current $[A]$

Total Power Loss

IC power loss P is the total of all these values.

$$\mathrm{P} = P_{ON-H} + P_{ON-L} + P_{SW-H} + P_D + P_G + P_{IC} \quad [W] \qquad (8)$$

P_{ON-H}: Conduction loss (high − side) $[W]$
P_{ON-L}: Conduction loss (low − side) $[W]$
P_{SW-H}: Switching loss (high − side) $[W]$
P_D: Dead time loss $[W]$
P_G: Gate charge loss $[W]$
P_{IC}: IC operating loss $[W]$

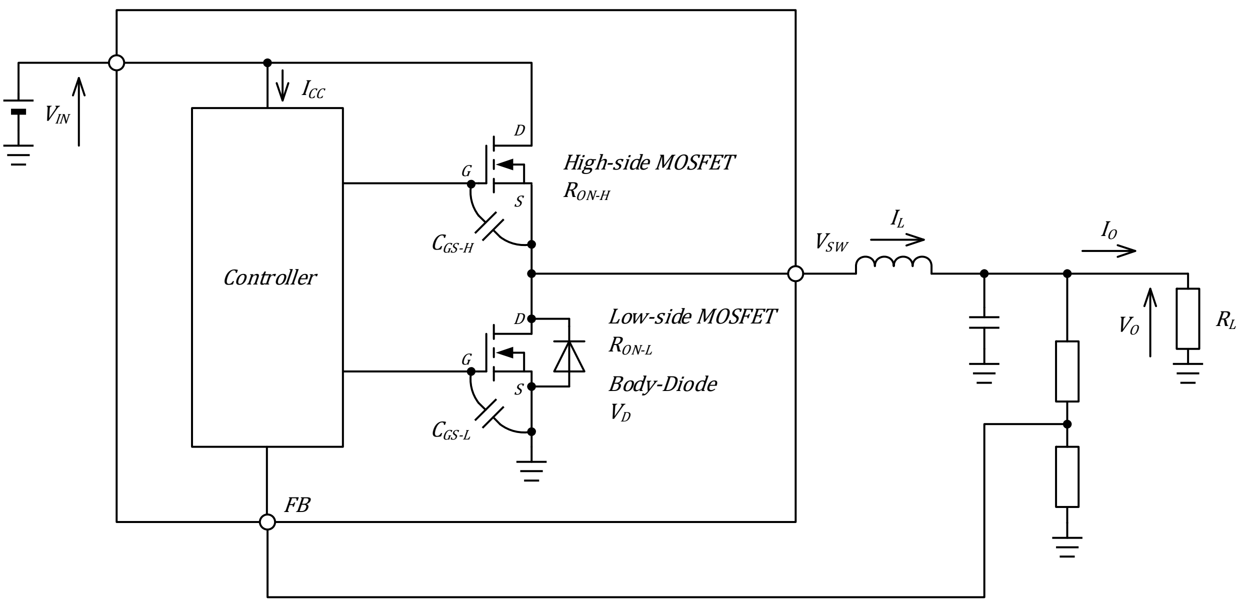

Figure 1. Synchronous Rectification Type DC/DC Converter Circuit

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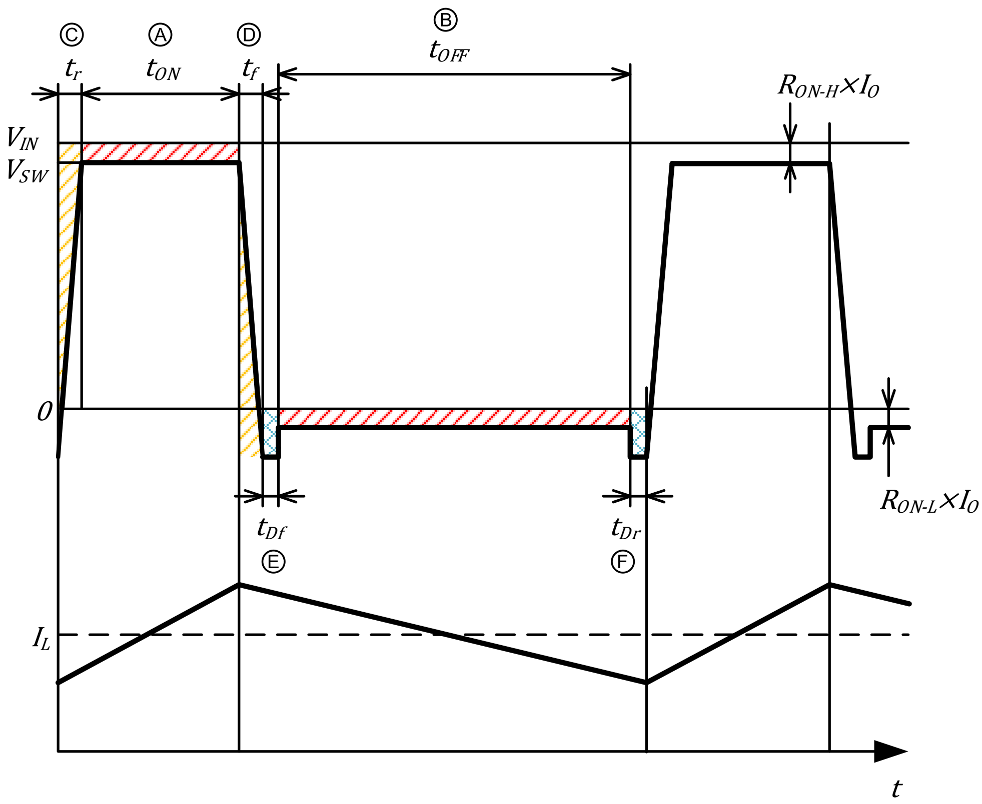

Figure 2. Switching Waveform and Loss

Calculation Example

Formula	Parameter	Result
1. Conduction loss $P_{ON-H} = {I_O}^2 \times R_{ON-H} \times \frac{V_O}{V_{IN}}$ $P_{ON-L} = {I_O}^2 \times R_{ON-L} \times \left(1 - \frac{V_O}{V_{IN}}\right)$	V_{IN}: Input voltage 12 V V_O: Output voltage 5.0 V I_O: Output current 3.0 A R_{ON-H}: High − side MOSFET on − resistance 100 $m\Omega$ R_{ON-L}: Low − side MOSFET on − resistance 70 $m\Omega$	375 mW 367.5 mW
2. Switching loss $P_{SW-H} = \frac{1}{2} \times V_{IN} \times I_O \times (t_r + t_f) \times f_{SW}$	f_{SW}: Switching frequency 2.0 MHz t_r: High − side MOSFET rise time 4 $nsec$ t_f: High − side MOSFET rise time 6 $nsec$	360 mW
3. Dead time loss $P_D = V_D \times I_O \times (t_{Dr} + t_{Df}) \times f_{SW}$ [W]	V_D: Low − side MOSFET body − diode forward voltage 0.5 V t_{Dr}: Dead time in rising 30 $nsec$ t_{Df}: Dead time in falling 30 $nsec$	180 mW
4. Gate charge loss $P_G = (Q_{g-H} + Q_{g-L}) \times V_{gs} \times f_{SW}$ $P_G = (C_{g-H} + C_{g-L}) \times {V_{gs}}^2 \times f_{SW}$	Q_{g-H}: High − side MOSFET gate electric charge 1 nC Q_{g-L}: Low − side MOSFET gate electric charge 1 nC C_{g-H}: High − side MOSFET gate capacity 200 pF	20 mW
5. IC operating loss $P_{IC} = V_{IN} \times I_{CC}$	C_{g-L}: Low − side MOSFET gate capacity 200 pF V_{gs}: Gate drive voltage 5.0V I_{CC}: IC consumption current 1.0 mA	12 mW
Total power loss $\mathrm{P} = P_{ON-H} + P_{ON-L} + P_{SW-H} + P_D + P_G + P_{IC}$		1.31 W

IC internal parameters such as MOSFET gate capacity and body-diode forward voltage are not open to the public in many cases. Even in such a case, it is possible to make an estimate by using the values in the above calculation example.

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