Application Report

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Calculating Efficiency

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PMP-DC/DC Controllers

ABSTRACT

This application report provides a step-by-step procedure for calculating buck converter efficiency and power dissipation at operating points not provided by the data sheet.

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1 Introduction

Texas Instruments has a large portfolio of DC/DC converters which operate over a wide range of input and output voltages. However, the data sheet provides efficiency curves only at certain operating conditions. The same device may be used at different output voltages, and the user may need to know the efficiency or power dissipation at those output voltages. This application report explains how to calculate the dissipated power at any output voltage and thereby plot the efficiency of the converter at any output voltage. This provides a quick and easy method to obtain the power supply's efficiency without the need to make laboratory measurements.

The three main causes of power dissipation in a DC/DC converter are:

- Inductor conduction losses
- MOSFET conduction losses
- MOSFET switching losses

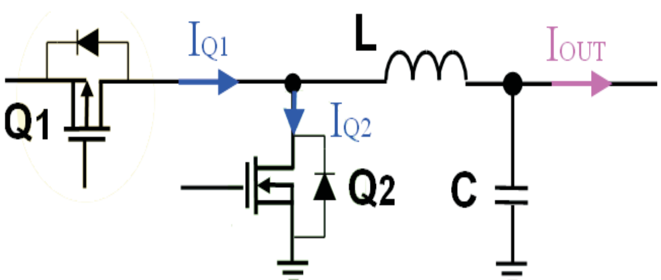

Figure 1. Basic Topology of Buck Converter

2 Power Dissipated in the Inductor

Figure 2 shows the current through the inductor in a typical DC/DC converter.

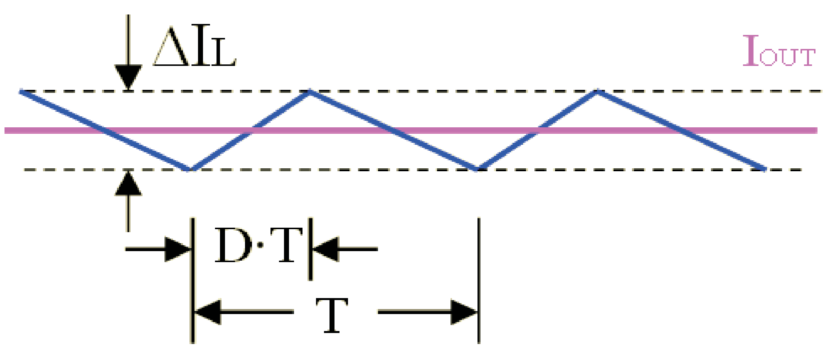

Figure 2. Inductor Current

The inductor conduction loss is given by:

$$P_L = I^2_{RMS\_L} \times R_{DCR} \tag{1}$$

Where R_{DCR} is the DC-Resistance of the inductor.

The rms inductor current is given by:

$$I^2_{RMS\_L} = I^2_O + \frac{\Delta I^2}{12} \tag{2}$$

Where ΔI = ripple current

Typically ΔI is about 30% of the output current. Therefore, the inductor current can be calculated to be:

$$I_{RMS\_L} = I_O \times 1.00375 \tag{3}$$

Because the ripple current contributes only 0.375% of I_{RMS_L}, it can be neglected. The power dissipated in the inductor now can be calculated as:

$$P_L = I_O^2 \times R_{DCR} \quad (4)$$

3 Power Dissipated in the MOSFETs

Figure 3 shows the current through the high-side MOSFET:

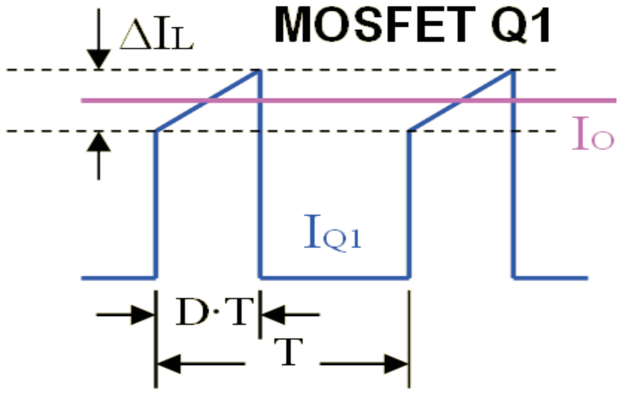

Figure 3. Buck Converter High-Side MOSFET Current

The power dissipated in the high-side MOSFET is given by:

$$P_{Q1} = I_{RMS\_Q1}^2 \times R_{DSON1} \quad (5)$$

Where R_{DSON1} is the on-time drain-to-source resistance of the high-side MOSFET.

Substituting for I_{RMS_Q1}:

$$P_{Q1} = \frac{V_O}{V_{IN}} \times \left(I_O^2 + \frac{\Delta I^2}{12} \right) \times R_{DSON1} \quad (6)$$

Figure 4 shows the current through the low-side MOSFET:

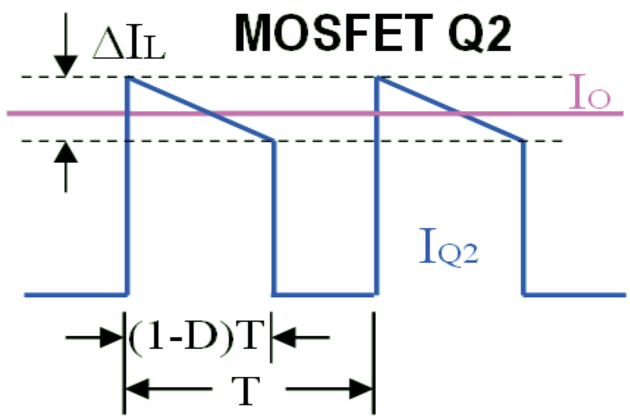

Figure 4. Buck Converter Low-Side MOSFET Current

The power dissipated in the low-side MOSFET is given by:

$$P_{Q2} = I_{RMS\_Q2}^2 \times R_{DSON2} \quad (7)$$

Where R_{DSON2} is the on time drain-to-source resistance of the low-side MOSFET.

Substituting for I_{RMS_Q2} :

$$P_{Q2} = \left(1 - \frac{V_O}{V_{IN}}\right) \times \left(I_O^2 + \frac{\Delta I^2}{12}\right) \times R_{DSON2} \quad (8)$$

The total power dissipated in both MOSFET's is given by:

$$P_{FET} = P_{Q1} + P_{Q2} \quad (9)$$

Substituting for P_{Q1} and P_{Q2}

$$P_{FET} = \left(I_O^2 + \frac{\Delta I^2}{12}\right) \times \left[\frac{V_O}{V_{IN}} \times (R_{DSON1} - R_{DSON2}) + R_{DSON2}\right]$$

$$\text{Where } \Delta I = \frac{(V_{IN} - V_O) \times V_O}{L \times f \times V_{IN}} \quad (10)$$

Where:

- L = Inductance (H)
- f = Frequency (Hz)
- V_{IN} = Input voltage (V)
- V_O = Output voltage (V)

For typical buck power supply designs, the inductor's ripple current, ΔI, is less than 30% of the total output current, so the contribution of $\Delta I^2/12$ to Equation 10 is negligible and can be dropped to get:

$$P_{FET} = I_O^2 \times \left[\frac{V_O}{V_{IN}} \times (R_{DSON1} - R_{DSON2}) + R_{DSON2}\right] \quad (11)$$

Note that when $R_{DSON1} = R_{DSON2}$, the power dissipated in the MOSFETs is independent of the output voltage. From Equation 11, the MOSFET conduction losses at any output voltage can be calculated. The other losses such as switching losses and inductor conduction losses are independent of output voltage and remain constant with changes in output voltage. Hence, P_D now can be computed as:

$$P_D = P_L + P_{FET} + \text{Other\_losses} \quad (12)$$

The other losses include the MOSFET switching losses, quiescent current losses etc. If both the total power supply losses and power supply output power are known, the overall efficiency at any output voltage can be calculated with.

$$\eta = \frac{P_O}{P_O + P_D} \quad (13)$$

EXAMPLE

The following example shows how to calculate a power supply's efficiency at any output voltage if the power supply's efficiency is known at any other output voltage. This method of computing efficiency follows.

Assume the TPS54620 is used with Vin = 12 V and V_O = 3.3 V at 4 A. The data sheet does not provide an efficiency graph with these conditions. However, the data sheet does provide an efficiency graph with Vin = 12 V and V_O = 5 V at 4 A. The 5-V efficiency data can be used to calculate the 3.3-V efficiency. The 5-V at 4-A efficiency is 93.78%.

1. Calculate the total power loss for the 5-V output.

$$P_D = V_O \times I_O \times \left(\frac{1-\eta}{\eta}\right) = 5V \times 4A \times \left(\frac{1 - 0.9378}{0.9378}\right) = 1.326 \text{ W} \quad (14)$$

2. Calculate the MOSFET total conduction loss.

$$P_{FET} = I_O^2 \times \left[\frac{V_O}{V_{IN}} \times (R_{DSON1} - R_{DSON2}) + R_{DSON2}\right]$$

$$= 4A^2 \times \left[\frac{5V}{12V} \times (0.026\,\Omega - 0.019\,\Omega) + 0.019\Omega\right] = 350.66\text{mW} \quad (15)$$

Note that R_{DSON1} and R_{DSON2} are provided in the TPS54620 data sheet.

3. Calculate the inductor conduction loss.

$$P_L = I_O^2 \times R_{DCR} = 4A^2 \times 0.104\ \Omega = 166.4\ mW \quad (16)$$

4. Calculate the other losses.

$$Other\_losses = P_D - P_{FET} - P_L = 0.81\ W \quad (17)$$

5. Calculate the MOSFET conduction loss at V_O = 3.3 V.

$$P_{FET(new)} = I_O^2 \times \left[\frac{V_{O(new)}}{V_{IN}} \times (R_{DSON1} - R_{DSON2}) + R_{DSON2}\right]$$
$$= 4A^2 \times \left[\frac{3.3V}{12V} \times (0.026\ \Omega - 0.019\ \Omega) + 0.019\ \Omega\right] = 334.8\ mW \quad (18)$$

6. Calculate the total power dissipated at V_O = 3.3 V.

$$PD(3.3V) = PL + PFET(3.3V) + Other\_losses = 0.166W + 0.334W + 0.81W = 1.31W \quad (19)$$

7. Calculate the efficiency at V_O = 3.3 V.

$$\eta = \frac{V_O \times I_O}{V_O \times I_O + P_{D(3.3V)}} = \frac{3.3\ V \times 4\ A}{3.3\ V \times 4\ A + 1.31\ W} = 90.97\% \quad (20)$$

The calculated value of 90.97% closely agrees with the measured value of 91.84%.

4 Results

Table 1 shows the efficiency measured at V_O = 5 V and different output currents on the TPS54620 synchronous buck converter. Using the measured value at V_O = 5 V, the efficiency was calculated at V_O = 3.3 V and then verified with the measured data.

Table 1. TPS54620 Efficiency

V_O = 5 V		V_O = 3.3 V	
I_O (A)	Efficiency (%)	Measured Efficiency (%)	Calculated Efficiency (%)
1	92.98	91.29	89.88
2	94.45	92.68	91.97
3	94.29	92.53	91.76
4	93.78	91.84	91.07
5	93.03	90.66	90.04
6	92.15	89.57	88.84

Table 2 shows the efficiency measured on the TPS62840 device with V_O = 1.8 V at V_{IN} = 3.6 V. The TPS62840 data sheet does not provide efficiency with V_O = 1.55 V, it is then calculated and verified with measured data.

Table 2. TPS62840 Efficiency

V_O = 1.8 V		V_O = 1.55 V	
I_O	Efficiency (%)	Measured Efficiency (%)	Calculated Efficiency (%)
10 µA	88.51	87.41	88.51
100 µA	89.26	88.22	89.26
1 mA	89.45	88.42	89.44
10 mA	90.97	90.08	90.89
100 mA	91.86	91.09	91.09
600 mA	85.5	84.28	81.64

5 Conclusion

This application report provides a quick and easy method to calculate the efficiency of a buck converter at conditions other than what is provided by the data sheet. This procedure provides accurate results and eliminates the need to build and test the power supply to get the efficiency data.

6 References

1. Texas Instruments, *TPS62840 1.8-V to 6.5-V, 750-mA, 60-nA I_Q Step-Down Converter Data Sheet*

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (February 2010) to A Revision **Page**

- Changed V_O = 5 V to V_O = 3.3 V in the header row of the *TPS54620 Efficiency* table 5
- Changed *TPS62840 Efficiency* table information. 5
- Added *References* section. 6