TEXAS INSTRUMENTS

Calculating Efficiency

Arvind Raj

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.

Contents

List of Figures

List of Tables

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
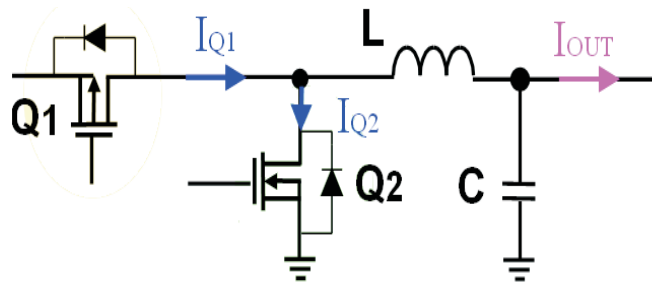- MOSFET conduction losses
- MOSFET switching losses

Figure 1. Basic Topology of Buck Converter

2 Power Dissipated in the Inductor

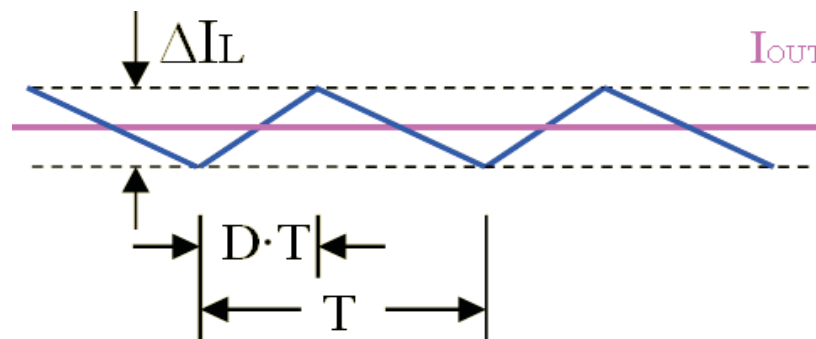Figure 2 shows the current through the inductor in a typical DC-DC converter.

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:

$$P_L = I_O^2 \times R_{DCR}$$

(4)

3 Power Dissipated in the MOSFETs

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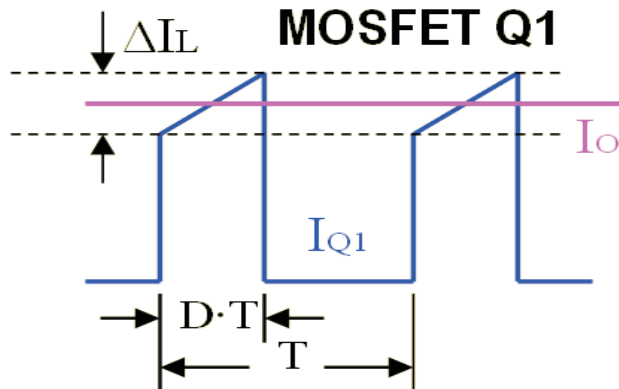

Figure 3. Buck Converter High-Side MOSFET Current

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

$$P_{Q1} = I_{RMS\_Q1}^2 \times R_{DSON1}$$

(5)

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

Substituting for I_{RMS_Q1}:

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

(6)

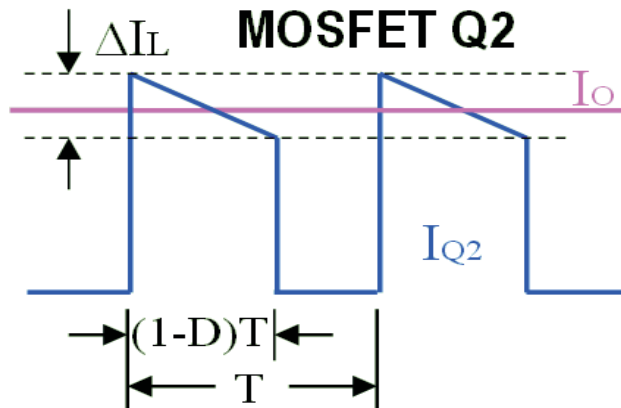Figure 4 shows the current through the low-side MOSFET:

Figure 4. Buck Converter Low-Side MOSFET Current

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

$$P_{Q2} = I_{RMS\_Q2}^2 \times R_{DSON2}$$

(7)

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

Substituting for I_{RMS_Q2} :

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

(8)

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

$$P_{FET} = P_{Q1} + P_{Q2}$$

(9)

Substituting for P_{Q1} and P_{Q2}

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

Where $\Delta I = \dfrac{(V_{IN} - V_O) \times V_O}{L \times f \times V_{IN}}$

(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 the is negligible and can be dropped to get:

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

(11)

Note that when $R_{DSON1} = R_{DSON2}$, the power dissipated in the MOSFETs is independent of the output voltage. From , 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:

$$P_D = P_L + P_{FET} + Other\_losses$$

(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.

$$\eta = \frac{P_O}{P_O + P_D}$$

(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 Vo = 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 Vo = 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.

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

(14)

2. Calculate the MOSFET total conduction loss.

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

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

(15)

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

3. Calculate the inductor conduction loss.

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

4. Calculate the other losses.

$$Other\_losses = P_D - P_{FET} - P_L = 0.81\ W \tag{17}$$

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

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

$$= 4A^2 \times \left[\frac{3.3V}{12V} \times \left(0.026\ \Omega - 0.019\ \Omega \right) + 0.019\ \Omega \right] = 334.8\ mW \tag{18}$$

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

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

7. Calculate the efficiency at Vo = 3.3 V.

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

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

4   Results

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

Table 1. TPS54620 Efficiency

Vo = 5 V		Vo = 5 V	
Io(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

A second example is where the TPS62750 is used with Vo = 2 V. The TPS62750 data sheet does not provide efficiency with Vo = 2 V, but does provide efficiency with Vo = 3.6 V. Table 2 shows measured v/s calculated efficiency for the TPS62750 in this example.

Table 2. TPS62750 Efficiency

Vo=3.6 volts		Vo=2 volts	
Io(A)	Efficiency(%)	Measured Efficiency(%)	Calculated Efficiency(%)
0.1	91.95	86.94	86.46
0.2	92.63	87.04	87.26
0.3	93.18	87.97	88.13
0.4	92.95	87.94	87.66
0.5	92.54	87.54	86.87
0.6	92.19	86.91	86.33

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.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DLP® Products	www.dlp.com	Communications and Telecom	www.ti.com/communications
DSP	dsp.ti.com	Computers and Peripherals	www.ti.com/computers
Clocks and Timers	www.ti.com/clocks	Consumer Electronics	www.ti.com/consumer-apps
Interface	interface.ti.com	Energy	www.ti.com/energy
Logic	logic.ti.com	Industrial	www.ti.com/industrial
Power Mgmt	power.ti.com	Medical	www.ti.com/medical
Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
RFID	www.ti-rfid.com	Space, Avionics & Defense	www.ti.com/space-avionics-defense
RF/IF and ZigBee® Solutions	www.ti.com/lprf	Video and Imaging	www.ti.com/video
		Wireless	www.ti.com/wireless-apps