Buck Converter Design Example

Welcome to the Buck Converter Design Example Web seminar.
This presentation will cover the design of a buck converter using the design tool powerCAD, Texas Instruments' design tool.

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Session Agenda

- Calculate the required inductor
- Calculate the output capacitor requirements
- Select the input capacitor
- Select the diode
- Select the MOSFET
- Calculate the converter efficiency
- Create a Synchronous Buck Converter

This is the agenda for this session.
The first step is to calculate the inductor we will calculate the required inductor and the output capacitor requirements.
We will then select the input capacitor, the diode, and MOSFET.
We will then calculate the converter efficiency, and we will create a synchronous buck converter.
We will start the presentation by setting up the design requirements for our example design.

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Buck Converter Design Example Assumptions

V_{IN} = 12 V
V_{OUT} = 5 V nom.
I_{OUT} = 3 A nom.
V_{RIPPLE} = 0.5 V
f_{SW} = 500 kHz
V_{OUT} Ripple = 1% of V_{OUT} (0.05 V)
I_{OUT} Ripple = 30% (typically 30%)

For this example we assume a 12 V input voltage and we want to create a 5 V output with a 3 A load.
The switching frequency is assumed to be 500 kHz.
The output ripple will be limited to 1% of the output voltage.

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Buck Converter Design Example

Here is the schematic of the buck converter for which we will select components.
The input voltage is 12 V, the output voltage is 5 V, the output current is 3 A, the output ripple voltage is 0.5 V, the output ripple current is 30%, and the switching frequency is 500 kHz.

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Buck Converter Calculate Inductance

For an inductor: $I = L \cdot \frac{dI}{dt}$

Rearrange and solve for L:

$L = V \cdot \frac{dt}{dI}$ or $L = V \cdot \frac{1}{f_{SW}} \cdot \frac{1}{\text{Ripple}}$

Example:

$L = 5\ V \cdot \frac{1}{500\ kHz} \cdot \frac{100\%}{30\%}$ = 33.333 µH

L = 33.333 µH

Starting with the basic equation for current through an inductor:
$I = L \cdot \frac{dI}{dt}$
We can rearrange the terms to solve for L:
$L = V \cdot \frac{dt}{dI}$
For the design example, the calculation, based on value, is 5 V
The time is the inverse of the switching frequency and the current is the ripple current
This equation can be rewritten as:
$L = V \cdot \frac{1}{f_{SW}} \cdot \frac{1}{\text{Ripple}}$
For the design example, the calculation, based on value, is 33.333 µH
Note that the ripple information is user-dependent and may be based on the ripple current or the ripple voltage.

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Buck Converter Calculate Output Capacitance

For a capacitor:

$I = C \cdot \frac{dV}{dt}$ or $C = I \cdot \frac{1}{f_{SW}} \cdot \frac{1}{V_{RIPPLE}}$

Solve Ripple Voltage for V_{RIPPLE}:

$V_{RIPPLE} = \frac{I}{C} \cdot \frac{1}{f_{SW}}$

Example:

$V_{RIPPLE} = \frac{3\ A}{100\ \mu F} \cdot \frac{1}{500\ kHz}$ = 60.000 mV

V_{RIPPLE} = 60.000 mV

The output ripple voltage for the buck converter depends on the output capacitance, the output current, and the switching frequency. The output capacitance is the only component in the equation that is not fixed. The output current is the load current, which is fixed. The switching frequency is also fixed. The output ripple voltage is a function of the output capacitance. The equation shows that as the output capacitance increases, the output ripple voltage decreases. The equation shows that as the output capacitance decreases, the output ripple voltage increases.
The equation shows that as the output current increases, the output ripple voltage increases. The equation shows that as the switching frequency increases, the output ripple voltage decreases.
The equation can be rewritten to solve for the output capacitance.
The equation shows that the output capacitance is a function of the output current, the output ripple voltage, and the switching frequency.
The equation shows that as the output ripple voltage increases, the output capacitance decreases. The equation shows that as the output ripple voltage decreases, the output capacitance increases.

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Buck Converter Select Output Capacitor

Ripple current of 30%

$I_{RIPPLE} = 0.3 \cdot I_{OUT}$ = 0.9 A

Rearrange:

$C = I \cdot \frac{1}{f_{SW}} \cdot \frac{1}{V_{RIPPLE}}$ = 30 µF

Example:

$C = 0.9\ A \cdot \frac{1}{500\ kHz} \cdot \frac{1}{0.05\ V}$ = 30 µF

C_{OUT} = 30 µF (1 x 30 µF)

Capacitor: 30 µF x 1 = 30 µF

Ripple current of 30%
$I_{RIPPLE} = 0.3 \cdot I_{OUT}$
I_{RIPPLE} = 0.9 A
Rearrange:
$C = I \cdot \frac{1}{f_{SW}} \cdot \frac{1}{V_{RIPPLE}}$
C = 30 µF
Example:
$C = 0.9\ A \cdot \frac{1}{500\ kHz} \cdot \frac{1}{0.05\ V}$
C = 30 µF
C_{OUT} = 30 µF (1 x 30 µF)
Capacitor: 30 µF x 1 = 30 µF

Now, we can calculate the required capacitance based on the output ripple voltage. The output ripple voltage is a function of the output current, the switching frequency, and the output capacitance. The output current is the load current, which is fixed. The switching frequency is also fixed. The output ripple voltage is a function of the output capacitance. The equation shows that as the output capacitance increases, the output ripple voltage decreases. The equation shows that as the output capacitance decreases, the output ripple voltage increases. The equation shows that as the output current increases, the output ripple voltage increases. The equation shows that as the switching frequency increases, the output ripple voltage decreases.
In addition, capacitor with the rated DC bias or capacitance of 1.00 µF is selected to meet the required capacitance of 30.000 µF.
The output ripple current is assumed to be 30% of the output current, or 0.9 A.
The calculated capacitance is the output capacitance.
C_{OUT} = 30.000 µF (1.00 µF)

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Output Capacitor Parasitic

- The **ESR** dominates voltage ripple and the ripple current rms.
- The **ESL** dominates the high frequency impedance. Becomes significant at high frequencies.
- Since **ESR** is approximately 5 times the **ESL**, the **ESR** parameter is usually dominant.

Capacitor Equivalent Circuit

Capacitor ESR and ESL are parasitic and minimize how well a capacitor can function at high frequencies.
Capacitor ESR is the equivalent series resistance and causes the capacitor to heat up and reduce the capacitor's lifetime. The ESR causes the capacitor to dissipate power and heat up. The ESR causes the capacitor to have a voltage ripple. The ESR causes the capacitor to have a current ripple. The ESR causes the capacitor to have a voltage ripple. The ESR causes the capacitor to have a current ripple.
Capacitor ESL is the equivalent series inductance. High ESL is a function of the capacitor's physical size and the capacitor's internal construction. The ESL causes the capacitor to have a voltage ripple. The ESL causes the capacitor to have a current ripple. The ESL causes the capacitor to have a voltage ripple. The ESL causes the capacitor to have a current ripple.
The equivalent series resistance is the dominant parasitic. The equivalent series inductance is usually dominant at high frequencies.
The equivalent series resistance is usually 5 times the equivalent series inductance.

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Buck Converter Select Input Capacitor

- Controls input Ripple Current
- Ripple current of 1 A is assumed
- Select a capacitor with a ripple current rating of 1.25 A or greater
- Calculate Capacitance:

$C = I \cdot \frac{1}{f_{SW}} \cdot \frac{1}{V_{RIPPLE}}$ = 0.833 µF

- Select a capacitor with capacitance greater than 0.833 µF and Capacitance requirements.

Input Capacitor Ripple Current

The input capacitor ripple current is a function of the switching frequency, the input capacitance, and the input voltage. The input capacitor ripple current is a function of the switching frequency, the input capacitance, and the input voltage. The input capacitor ripple current is a function of the switching frequency, the input capacitance, and the input voltage. The input capacitor ripple current is a function of the switching frequency, the input capacitance, and the input voltage.