Announcements

• HW #1 due Friday (9/1)
• Office hours addendum:
  – Meetings outside of scheduled hours possible
  – E-mail to setup

Chapter 2: Converters in Equilibrium
Buck Converter Review

**Pulse Width Modulation (PWM)**

- $T_s = \text{switching period}$
- $f_s = \frac{1}{T_s} = \text{switching frequency}$
- $D = \text{Duty Cycle}$
- $0 < D < 1$

- $D' = 1 - D$
- $M = \frac{V_o}{V_g} = \text{conversion ratio}$

**Average value of $v_o(t)$:**

$$\left< v_o(t) \right> = \left< v_o \right> = \frac{1}{T_s} \int_0^{T_s} v_o(t) \, dt$$

$$\left< v_o \right> = \frac{1}{T_s} \left[ T_s D V_g \right] = D V_g$$

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**Three Basic DC-DC PWM Converters**

- **Buck**
  - Step-down

- **Boost**
  - Step-up

- **Buck-boost**
  - Step up or down
  - Inverting
Chapter 2: Goals

- Develop techniques for easily determining output voltage of an arbitrary converter circuit
- Derive the principles of *inductor volt-second balance* and *capacitor charge (amp-second) balance*
- Introduce the key *small ripple approximation*
- Develop simple methods for selecting filter element values
- Illustrate via examples

Buck Output Voltage Ripple

Actual output voltage waveform, buck converter

Buck converter containing practical low-pass filter

*Actual output voltage waveform*

\[ v(t) = V + v_{ripple}(t) \]
The Small Ripple Approximation

In a well-designed converter, the output voltage ripple is small. Hence, the waveforms can be easily determined by ignoring the ripple:

\[ |v_{\text{ripple}}| \ll V \]

\[ v(t) \approx V \]

In any large, filter passive, SRA may apply

\[ v_c(t) \approx V_c \]

\[ i_L(t) \approx I_L \]

Buck Switching Intervals: Inductor Current
Subinterval 1

\[ v_c(t) = L \frac{di_L(t)}{dt} = V_g - V(t) \]

Apply SRA on \( V(t) \)

\[ L \frac{d^2i_L(t)}{dt^2} = V_g - V \]

\[ \frac{di_L(t)}{dt} = \frac{V_g - V}{L} \]

Subinterval 2

\[ v_c(t) = L \frac{di_L(t)}{dt} = -V(t) \]

Apply SRA

\[ L \frac{d^2i_L(t)}{dt^2} = -V \]

\[ \frac{di_L(t)}{dt} = -\frac{V}{L} \]
Current Waveform

\[ v_L(t) \]

\[ i_L(t) \]

Current waveform

\[ v_L(t) = V \]

\[ i_L(t) = 0 \]

Transient vs. Steady-State Operation

\[ V_g - v(t) \]

\[ \frac{V_g - v(t)}{L} = \frac{v(t)}{L} \]

\[ i_L(nT_s) = i_L((n+1)T_s) \]

\[ t = 0 \]

\[ t = \tau \]

Fundamentals of Power Electronics
Chapter 2: Principles of steady-state converter analysis
Volt-Second Balance

In steady-state:
\[ i_c(nT_s) = i_c((n+1)T_s) \]

Amount \( i_c \) goes up in 1:
\[ 2\Delta i_c = \frac{V_g - V}{L} DT_s \]

Amount \( i_c \) goes down in 2:
\[ -2\Delta i_c = \frac{V}{L} D'T_s \]

Steady-state:
\[ \frac{V_g - V}{k} DX = \frac{V}{k} D'T_s \Rightarrow V_g D = V(x + D') \]

Fundamentals of Power Electronics  Chapter 2: Principles of steady-state converter analysis