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)

$T_s \Rightarrow$ switching period

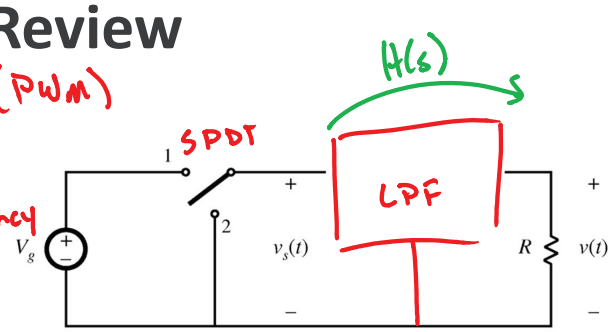
$f_s = \frac{1}{T_s} \Rightarrow$ switching frequency

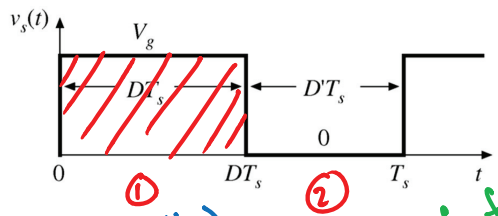
$D \Rightarrow$ Duty Cycle

$0 \le D \le 1$

$D' = 1 - D$

$M = \frac{V}{V_g} \Rightarrow$ conversion ratio

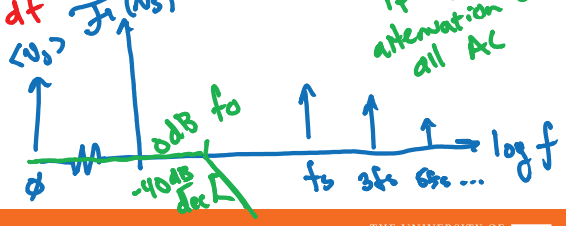




Average value of $v_s(t)$:

$$\langle v_s(t)\rangle\Big|_{T_s} = \langle v_s\rangle = \frac{1}{T_s}\int_0^{T_s} v_s(t)\,dt$$

$$\langle v_s\rangle = \frac{1}{T_s}\left[T_s D V_g\right] = D V_g$$

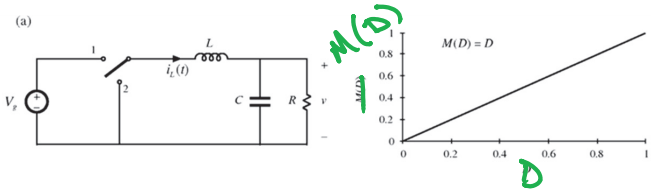


If $f_0 \ll f_s$ attenuation of all AC

Three Basic DC-DC PWM Converters

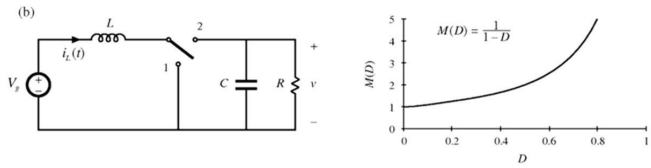
Buck

step-down



Boost

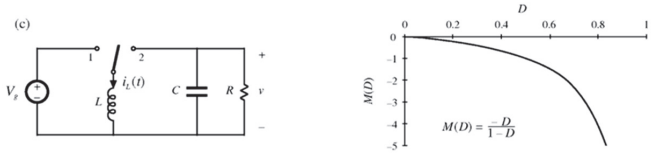
step-up



Buck-boost

steps up or down

& inverting



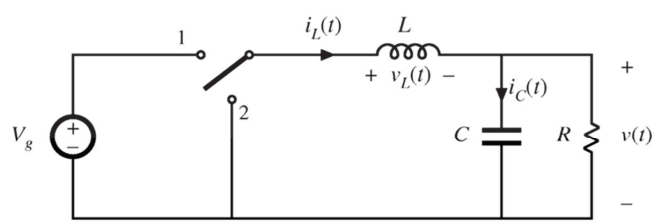
Chapter 2: Goals

- 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

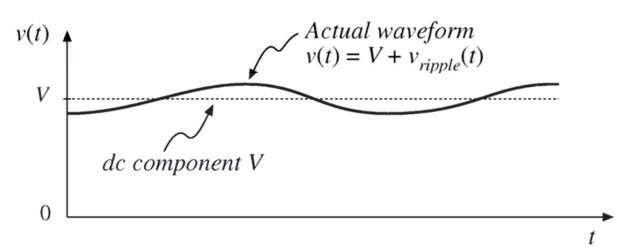
Actual output voltage waveform, buck converter

Buck converter containing practical low-pass filter



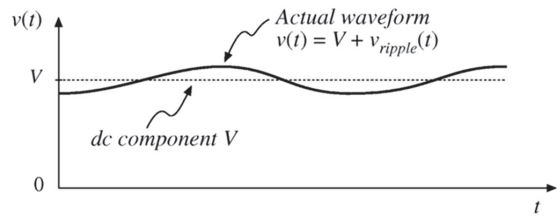
Actual output voltage waveform

$v(t) = V + v_{ripple}(t)$



The Small Ripple Approximation

$$v(t) = V + v_{ripple}(t)$$



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

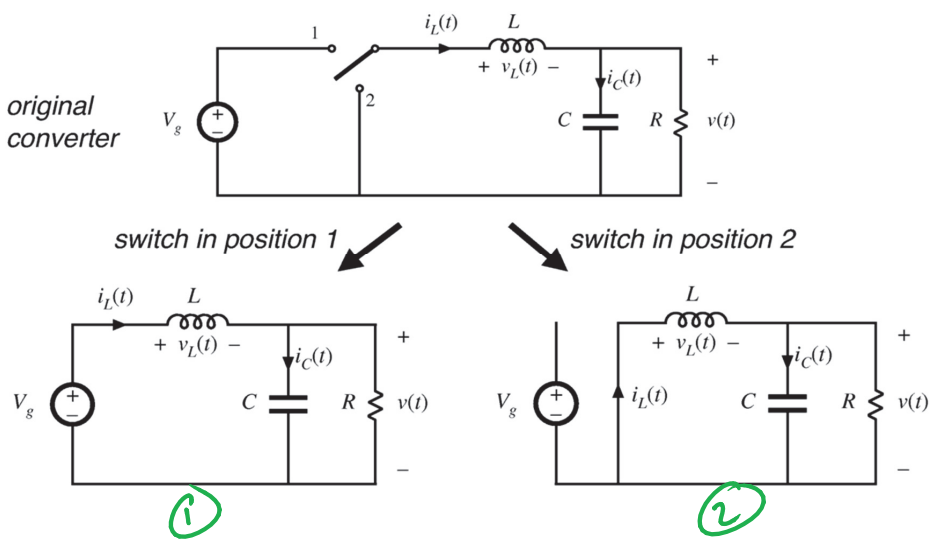
$$\left\| v_{ripple} \right\| \ll V$$

$$v(t) \approx V$$

In any large, filter passive, SRA may apply

$v_c(t) \approx V_c$ $\quad$ $i_L(t) \approx I_L$

Buck Switching Intervals: Inductor Current



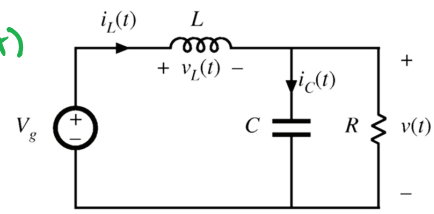
Subinterval 1

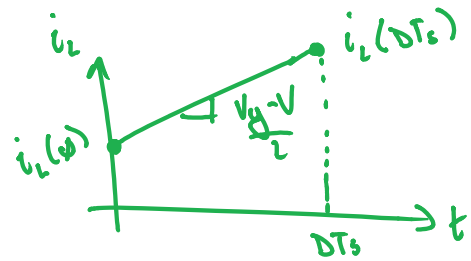
$$v_L(t) = L\frac{di_L(t)}{dt} = V_g - v(t)$$

Apply SRA on $v(t)$

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

$$\frac{di_L}{dt} = \frac{V_g - V}{L}$$





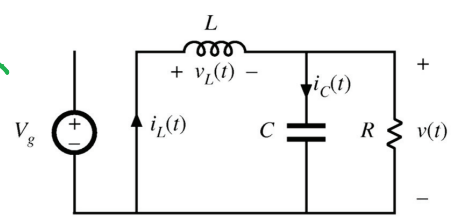
Subinterval 2

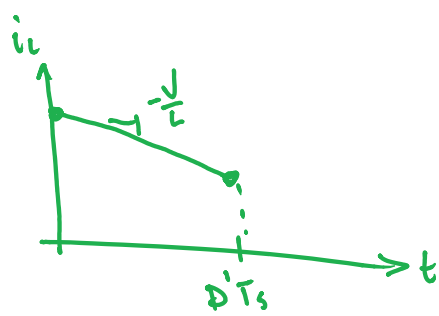
$$v_L(t) = L\frac{di_L}{dt} = -v(t)$$

Apply SRA

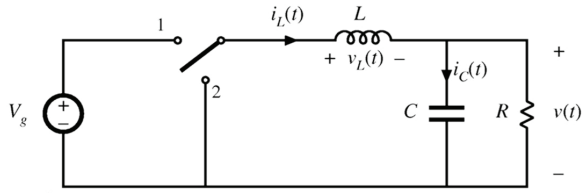
$$L\frac{di_L}{dt} = -V$$

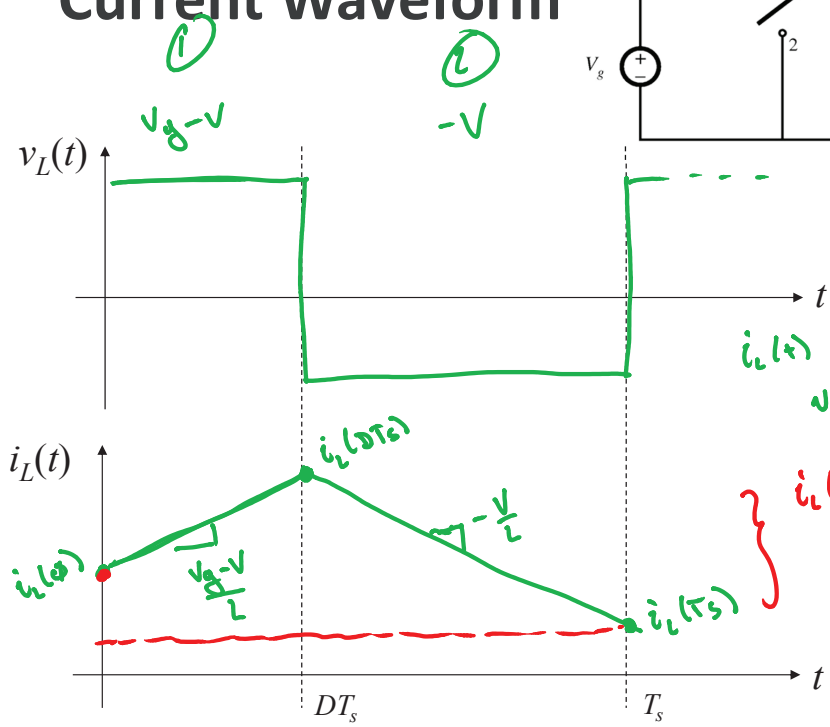
$$\frac{di_L}{dt} = -\frac{V}{L}$$





Current Waveform





$i_L(t)$ must be continuous

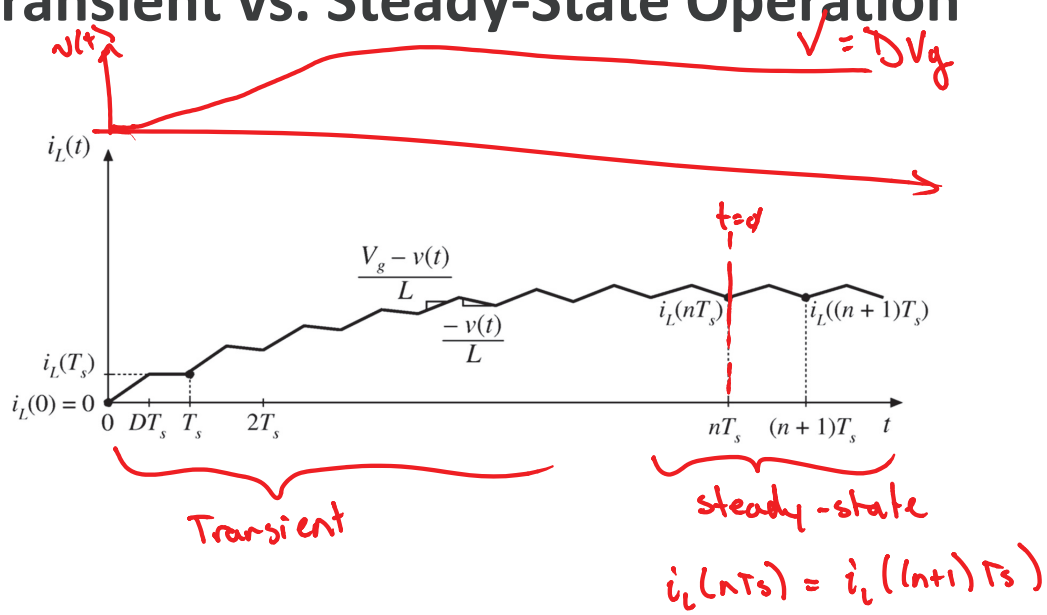
$v_L = L \frac{di_L}{dt}$

$i_L(0) \neq i_L(T_s)$

↳ transient

i.e. not in steady state

Transient vs. Steady-State Operation



$i_L(nT_s) = i_L((n+1)T_s)$

Volt-Second Balance

In steady-state:

$i_L(nT_s) = i_L((n+1)T_s)$

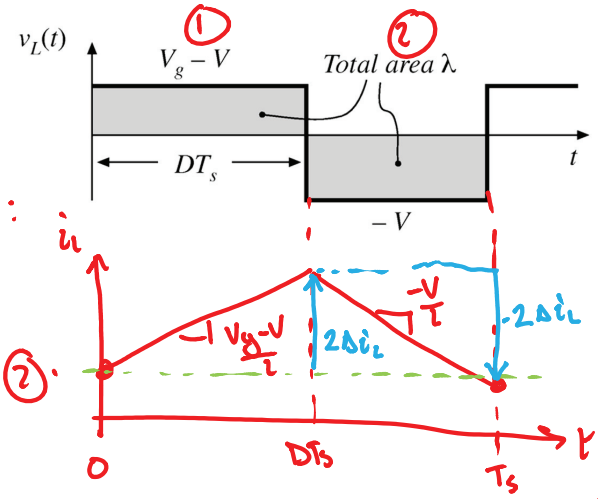
$\downarrow$

Amount i_L goes up in ①:

$2\Delta i_L = \frac{V_g - V}{L} D T_s$

Amount i_L goes down in ②:

$-2\Delta i_L = \frac{-V}{L} D' T_s$



Steady-State: $\frac{V_g - V}{\cancel{L}} D \cancel{T_s} = \frac{V}{\cancel{L}} D' \cancel{T_s} \Rightarrow V_g D = V(\cancel{D + D'})^{1}$

$V = D V_g$

$M(D) = \frac{V}{V_g} = D$