ECEN 4797/5797

Introduction to Power Electronics

Lecture #5

Wednesday, September 2, 2009

Steady State Converter Analysis:

Conduction Losses & Equivalent Circuit Modeling

(Cont. Chapter 3)

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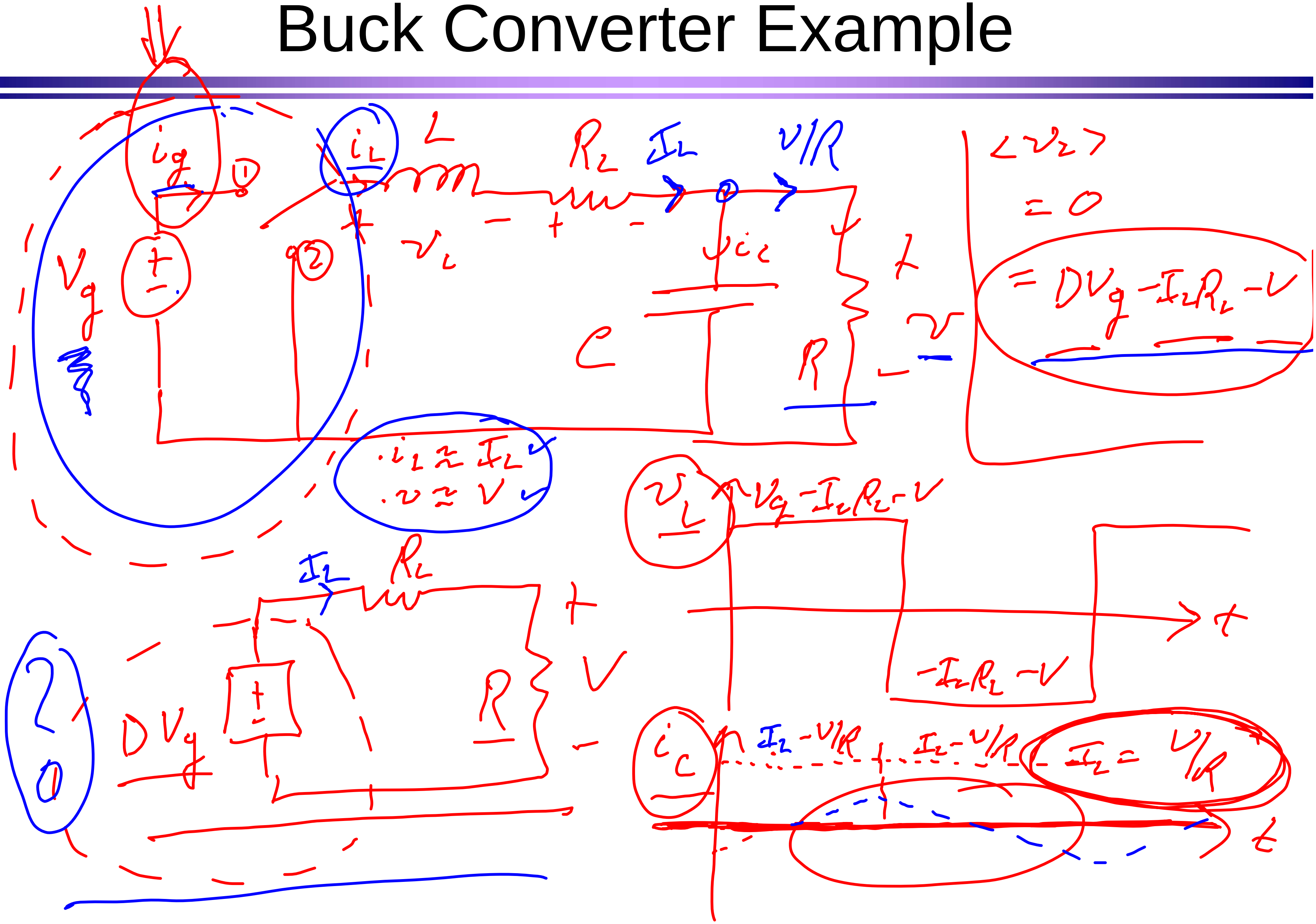
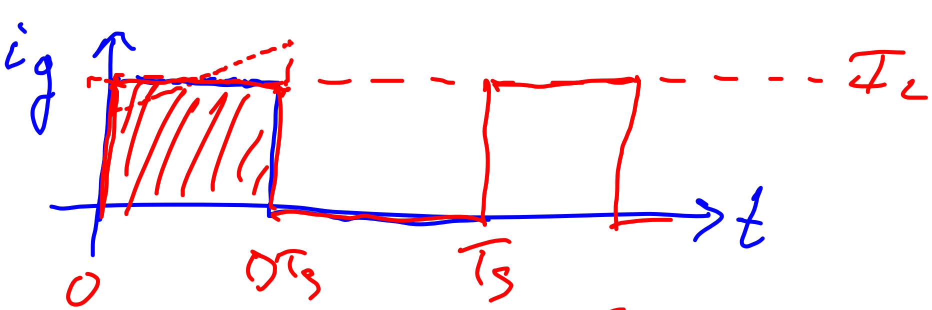
Buck Converter Example

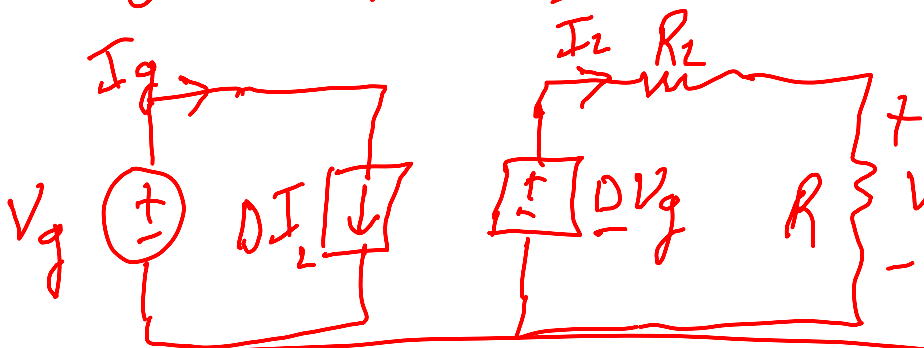


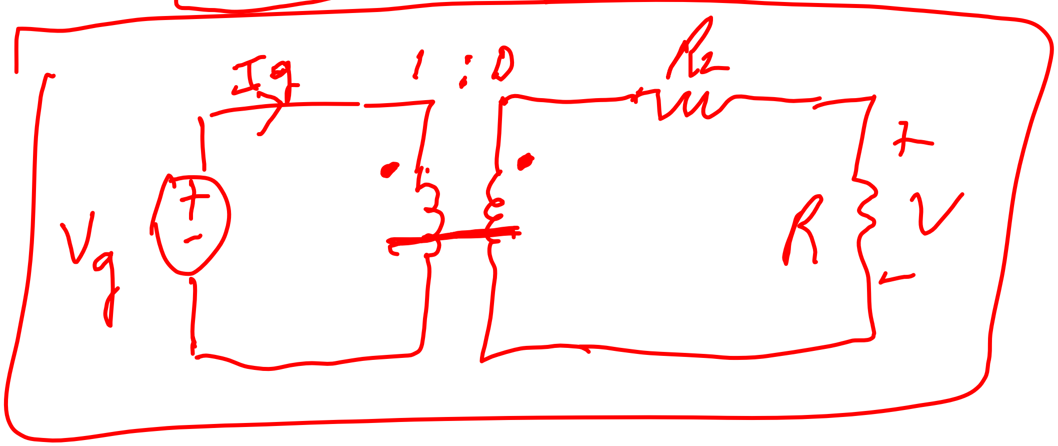
Input Port Modeling



$$\langle i_g \rangle = \frac{1}{T_s}\int_0^{T_s} i_g(t)\,dt$$

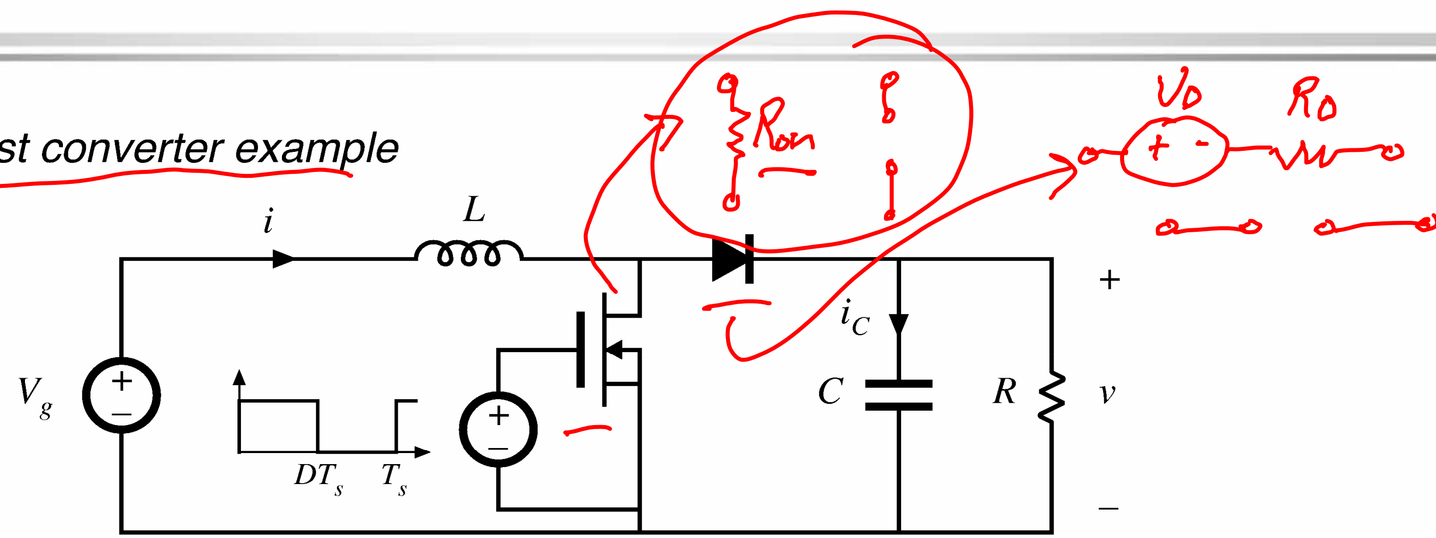
$$\langle i_g \rangle = D I_2$$





3.5. Example: inclusion of semiconductor conduction losses in the boost converter model

Boost converter example



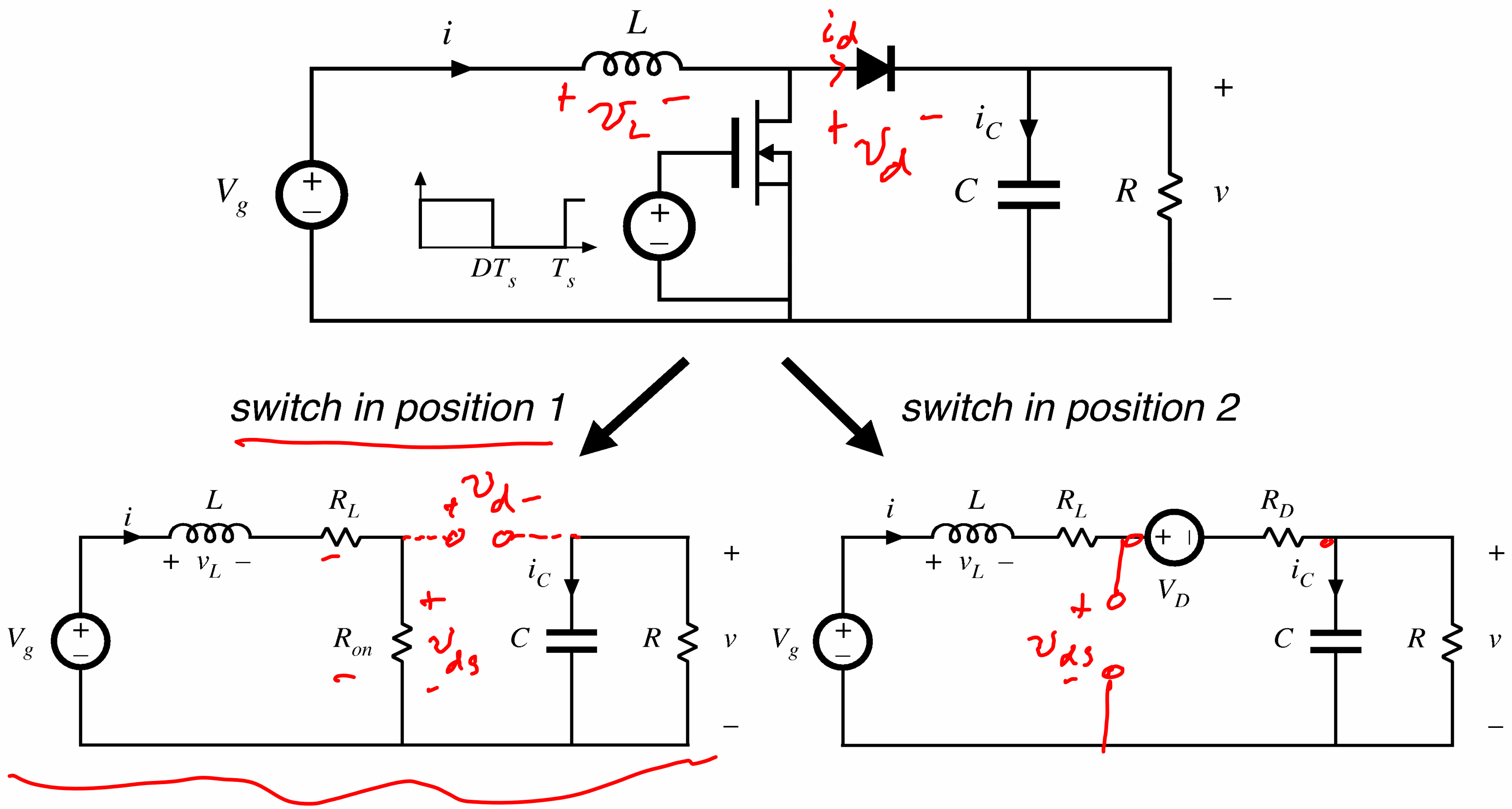
Models of on-state semiconductor devices:

MOSFET: on-resistance R_{on}

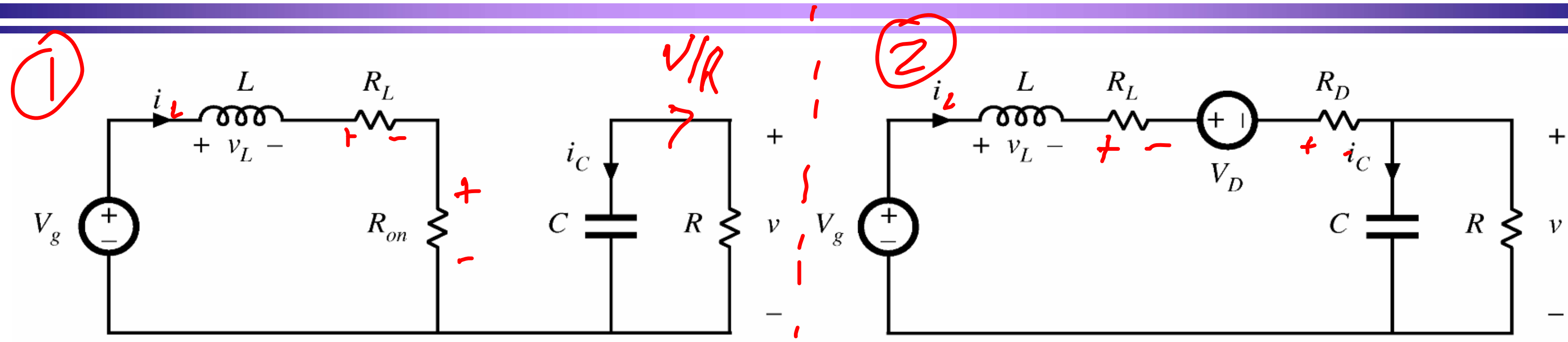
Diode: constant forward voltage V_D plus on-resistance R_D

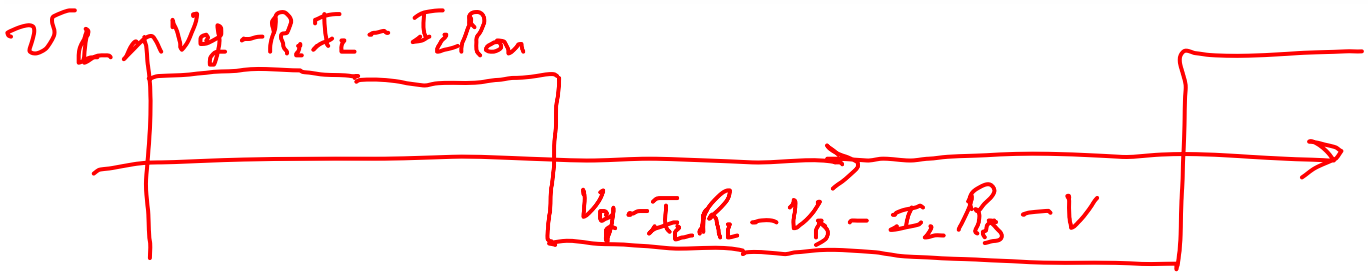
Insert these models into subinterval circuits

Boost converter example: circuits during subintervals 1 and 2

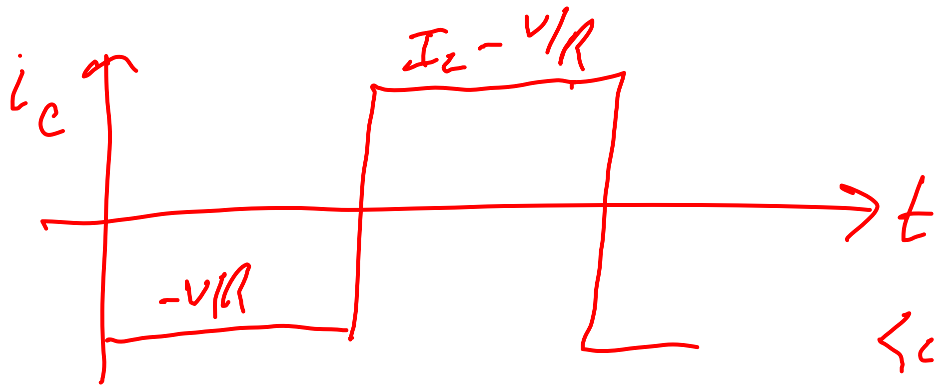


Average inductor current & capacitor voltage





- $i_L \approx I_L$
- $v \approx V$



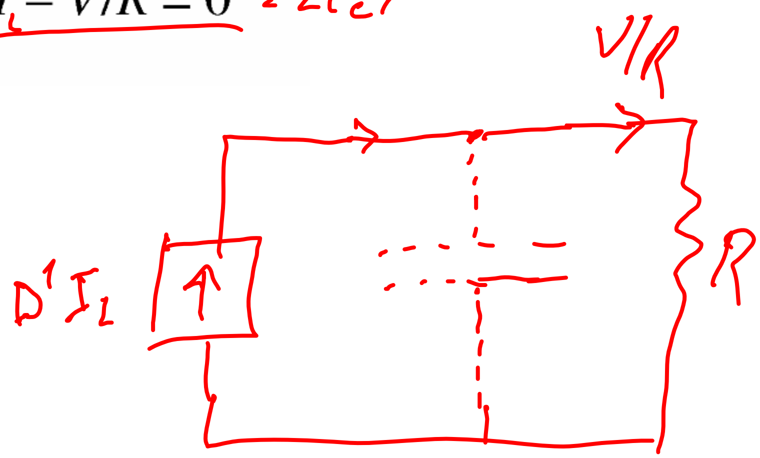
$$\langle v_L \rangle = V_g - I_L R_L - I_L D R_{on} - D' V_D - I_L D' R_D - D' V = 0$$

$$\langle i_C \rangle = D' I_L - V/R = 0$$

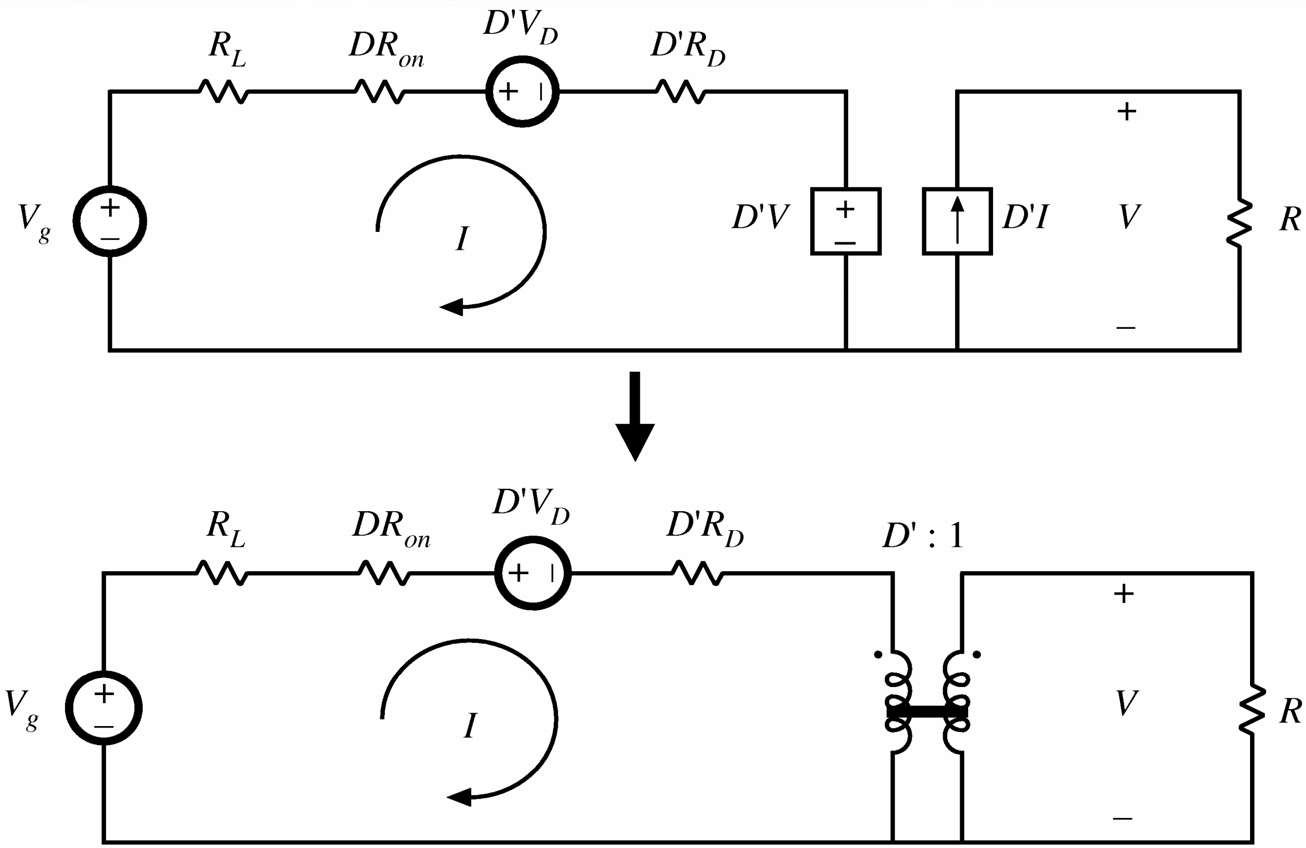
Equivalent circuit model

$$V_g - IR_L - IDR_{on} - D'V_D - ID'R_D - D'V = 0 \quad = \langle v_L \rangle$$

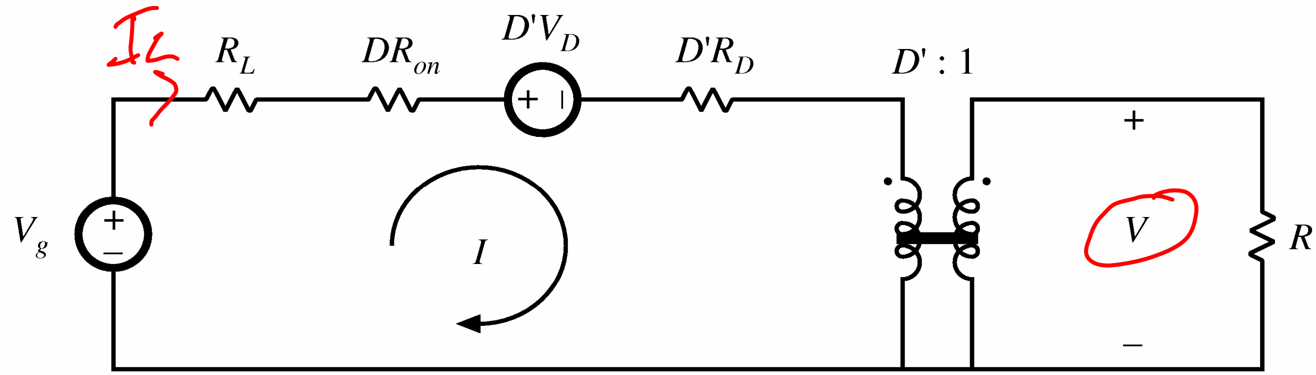
$$D'I_L - V/R = 0 \quad = \langle i_c \rangle$$



Complete equivalent circuit



Solution for output voltage

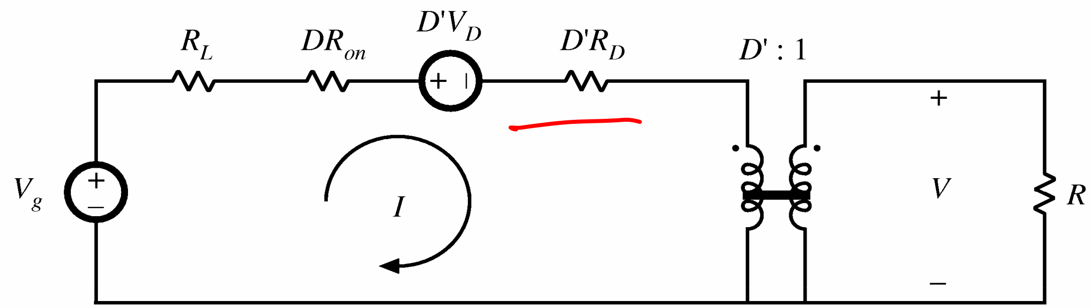


$$V = \left(\frac{1}{D'}\right)\left(V_g - D'V_D\right)\left(\frac{D'^2R}{D'^2R + R_L + DR_{on} + D'R_D}\right)$$

$$\frac{V}{V_g} = \left(\frac{1}{D'}\right)\left(1 - \frac{D'V_D}{V_g}\right)\left(\frac{1}{1 + \frac{R_L + DR_{on} + D'R_D}{D'^2R}}\right)$$

M(D) ideal

Solution for converter efficiency



$$P_{in} = (V_g)\,(I)$$

$$P_{out} = (V)\,(D'I)$$

$$\eta = D'\,\frac{V}{V_g} = \frac{\left(1 - \dfrac{D'V_D}{V_g}\right)}{\left(1 + \dfrac{R_L + DR_{on} + D'R_D}{D'^2 R}\right)}$$

Conditions for high efficiency:

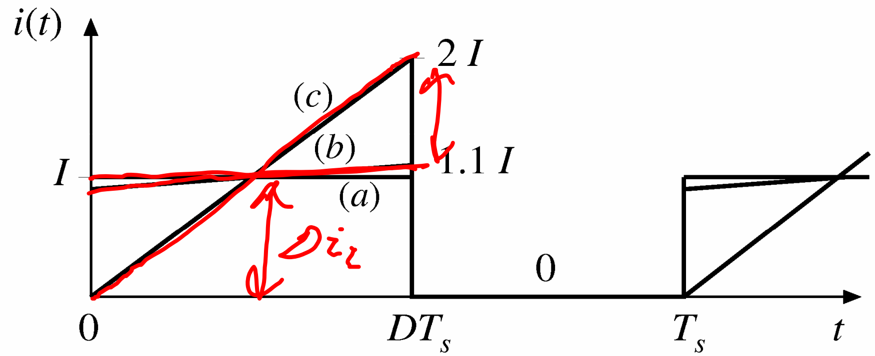
$$V_g/D' \gg V_D$$

$$D'^2 R \gg R_L + DR_{on} + D'R_D$$

Accuracy of the averaged equivalent circuit in prediction of losses

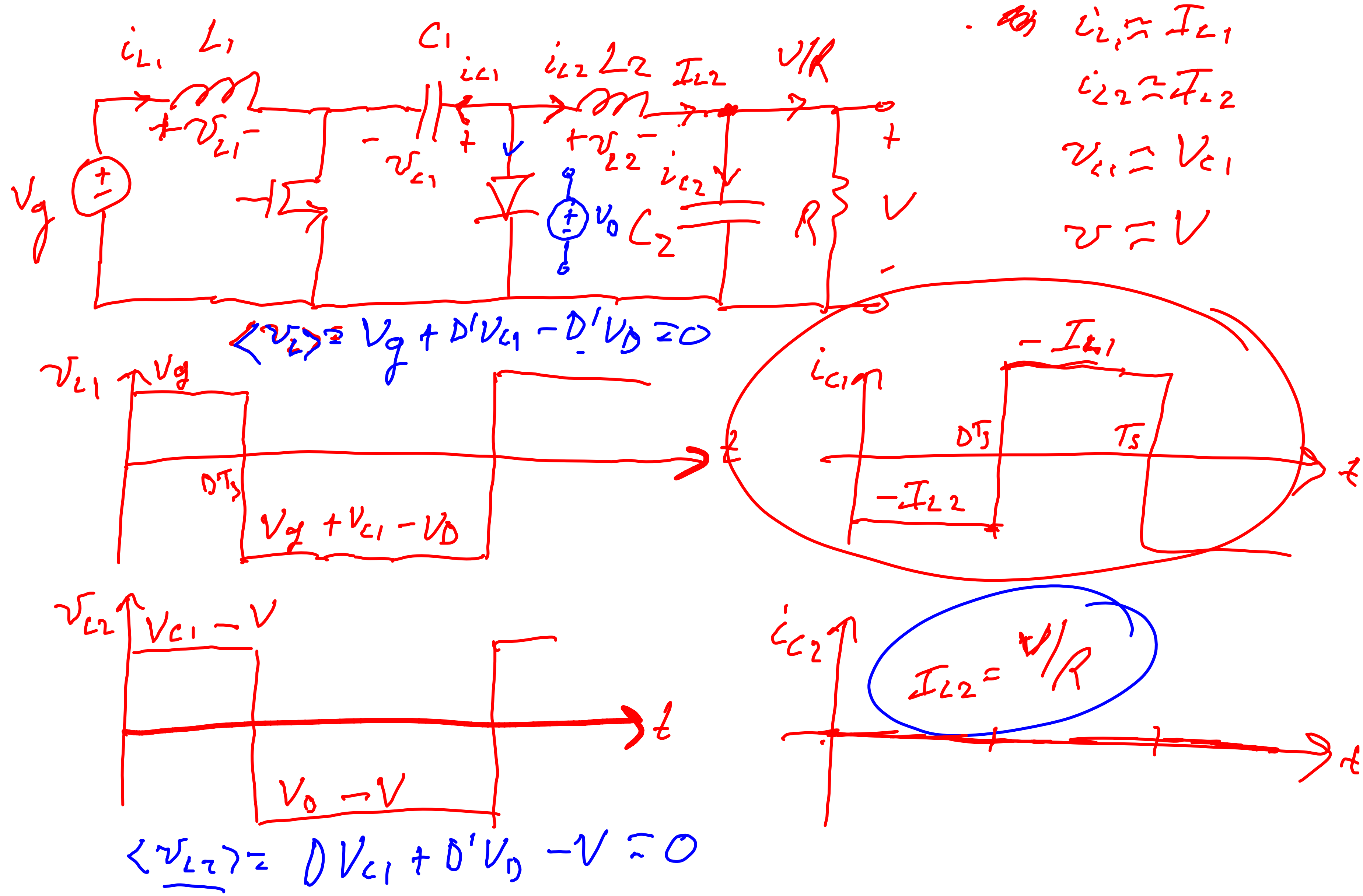
- Model uses average currents and voltages
- To correctly predict power loss in a resistor, use rms values
- Result is the same, provided ripple is small

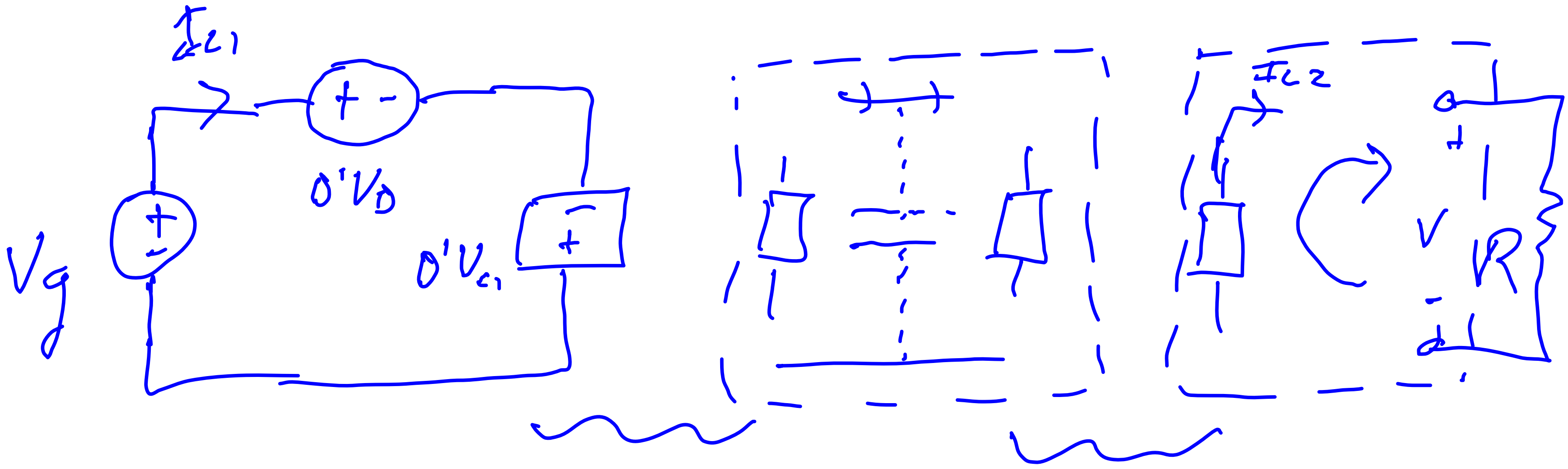
MOSFET current waveforms, for various ripple magnitudes:



Inductor current ripple	MOSFET rms current	Average power loss in R_{on}
(a) $\Delta i = 0$	$I\sqrt{D}$	$D\,I^2\,R_{on}$
(b) $\Delta i = 0.1\,I$	$(1.00167)\,I\sqrt{D}$	$(1.0033)\,D\,I^2\,R_{on}$
(c) $\Delta i = I$	$(1.155)\,I\sqrt{D}$	$(1.3333)\,D\,I^2\,R_{on}$

Ćuk Converter Example





I_{L1}
V_g
$D'V_D$
$D'V_{C1}$
I_{L2}
V
R