# EE 452 – Power Electronics, Fall
## Midterm – Cover Page

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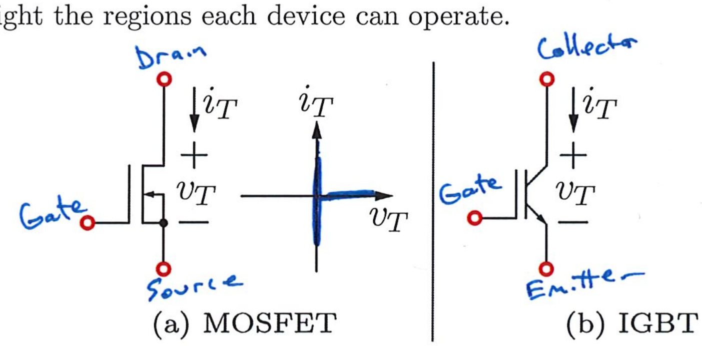
**Instructions.** Show all your work and clearly indicate your final answer for each problem. When you are done, staple this cover sheet to your work.

**Problem 1: Devices and component polarities [10 Points Total]**

(a) **[6 Points]** Write down the names for each of the red terminals in Figure 1, and highlight the regions each device can operate.



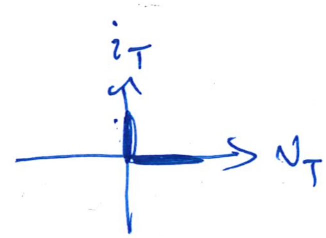




Figure 1: (a) MOSFET, and (b) IGBT.

(b) **[2 Points]** Label the capacitor current, $i_c$, along with its direction in Figure 2(a).

(c) **[2 Points]** Label the inductor voltage, $v_L$, along with its +/− terminals in Figure 2(b).

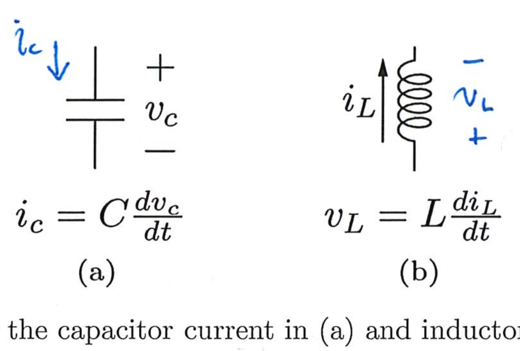



Figure 2: Draw the capacitor current in (a) and inductor voltage in (b).

## Problem #2

(a) $\boxed{\text{Buck Boost}}$ a

(b) Volt sec balance

$$\langle v_L \rangle = 0 = (V_g - IR_L)D + (V - IR_L)D'$$

$$= \boxed{-IR_L + DV_g + D'V = 0} \quad \text{b} \qquad (1)$$

(c) Charge Balance

$$\langle i_c \rangle = 0 = \left(-\frac{V}{R}\right)D + \left(-I - \frac{V}{R}\right)D'$$

$$= \boxed{-D'I - \frac{V}{R} = 0} \quad \text{c} \qquad (2)$$

(d) Solve for $I$.

Use (2) to get

$$\boxed{I = -\frac{V}{RD'}} \quad \text{d} \qquad (3)$$

(e) Compute $M = \frac{V}{V_g}$

(3) → (1) gives

$$0 = \frac{VR_L}{D'R} + DV_g + D'V = V\left(\frac{R_L}{D'R} + D'\right) + DV_g = 0$$

$$\rightarrow \quad M = \frac{V}{V_g} = \boxed{\frac{-D}{\frac{R_L}{RD'} + D'}} = \boxed{\frac{-DD'}{\frac{R_L}{R} + D'^2} = M} \quad \text{e} \qquad (4)$$

Sanity check

$$\lim_{R_L \to 0} M = \frac{-DD'}{D'^2} = \frac{-D}{D'} = \frac{-D}{1-D}$$ ← regular buck boost!

(F). Compute $\eta$

$$P_{out} = \frac{V^2}{R} \quad \& \quad P_{in} = V_g \underbrace{(D I)}_{\text{avg input current}} = \frac{-V V_g D}{R D'}$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{V^{\cancel{2}}}{\cancel{R}} \left( \frac{-\cancel{R} D'}{\cancel{V} V_g D} \right) = \frac{-V D'}{V_g D} \qquad (5)$$

* (4) -> (5)

$$= \frac{D'}{\cancel{D}} \frac{\cancel{D} D'}{\frac{R_L}{R} + D'^2} = \boxed{\frac{D'^2}{\frac{R_L}{R} + D'^2} = \eta} \quad \boxed{F}$$

(g) Compute $f_s$ s.t. $\Delta i = I$

- look @ ripple w/ MOSFET on -> $v_L = L \frac{\Delta i}{\Delta t}$

$$\underbrace{V_g - I R_L}_{v_L} = V_g - \underbrace{\left(\frac{-V}{R D'}\right)}_{I} R_L$$

$f_s = \frac{1}{T_s}$

$$= V_g + \frac{V R_L}{R D'} = \frac{L \, 2 \Delta i f_s}{D}$$

solve for $\Delta i$

$$\Delta i = \frac{D}{2 L f_s} \left( V_g + \frac{V R_L}{R D'} \right)$$

* Use (4) from part (e) -> $V = V_g M = V_g \left( \frac{-D D'}{\frac{R_L}{R} + D'^2} \right)$

$$= \frac{D}{2 L f_s} \left( V_g + \frac{R_L}{R \cancel{D'}} V_g \left( \frac{-D \cancel{D'}}{\frac{R_L}{R} + D'^2} \right) \right)$$

$$= \frac{D V_g}{2 L f_s} \left( 1 - \frac{D \frac{R_L}{R}}{\frac{R_L}{R} + D'^2} \right) = \ldots$$

. . .

$$= \frac{DV_g}{2Lf_s}\left(\frac{\frac{R_L}{R} + D'^2 - D\frac{R_L}{R}}{\frac{R_L}{R} + D'^2}\right)$$

$$= \frac{DV_g}{2Lf_s}\left(\frac{\frac{R_L}{R}\overbrace{(1-D)}^{D'} + D'^2}{\frac{R_L}{R} + D'^2}\right)$$

$$= \frac{DV_g}{2Lf_s}\left(\frac{\frac{R_L}{R}D' + D'^2}{\frac{R_L}{R} + D'^2}\right) = \Delta i \qquad (6)$$

• Now look @ $I$ & put into terms of $V_g, R, R_L, D, D'$

$$I = \frac{-V}{RD'} = \frac{-\overbrace{V_g M}^{V = V_g M}}{RD'} = \frac{V_g}{R\cancel{D'}}\left(\frac{D\cancel{D'}}{\frac{R_L}{R} + D'^2}\right)$$

$$= \frac{V_g}{R}\frac{D}{\frac{R_L}{R} + D'^2} = I \qquad (7)$$

Set (6) & (7) equal

$$\frac{\cancel{DV_g}}{2Lf_s}\frac{\frac{R_L}{R}D' + D'^2}{\cancel{\left(\frac{R_L}{R} + D'^2\right)}} = \frac{\cancel{V_g}}{R}\frac{\cancel{D}}{\cancel{\left(\frac{R_L}{R} + D'^2\right)}}$$

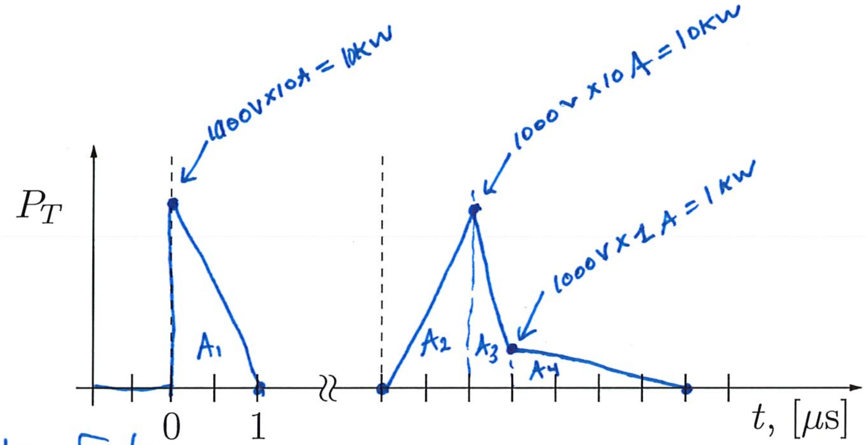
$$\Rightarrow \frac{1}{2Lf_s}\left(\frac{R_L}{R}D' + D'^2\right) = \frac{1}{R}$$

$$\rightarrow f_s = \frac{R}{2L}\left(\frac{R_L}{R}D' + D'^2\right) = \boxed{12.75\,\text{kHz} = f_s} \quad \boxed{g}$$

# Problem #3

Problem 3 Handout:

(a)




(b) Compute $E_{loss}$

$A_1 = \frac{1}{2}\times 1\,\mu s \times 10\,kW = \frac{1}{2}\times 10^{-6} \times 10\times 10^{3} = \underbrace{\frac{1}{2}}_{0.5}\times 10^{-2} = 0.005\,J = \underline{5mJ} = A_1$

$A_2 = \frac{1}{2}\times 1\,\mu s \times 10\,kW = \underline{5mJ} = A_2$

$A_3 = 0.5\,\mu s \times 1\,kW + \frac{1}{2}\times 0.5\,\mu s \times 9\,kW$

$0.5\times 10^{-6} \times 1 \times 10^{3}$

$= 0.5\times 10^{-3} + 0.25\times 10^{-6} \times 9 \times 10^{3}\ J$

$= 0.5\,mJ + \frac{9}{4}\times 10^{-3}\ J$

$= \underline{2.75\,mJ} = A_3$

$A_4 = \frac{1}{2}\times 2\,\mu s \times 1\,kW$

$= 1\times 10^{-6} \times 10^{3}\ J = 1\times 10^{-3}\ J$

$= \underline{1\,mJ = A_4}$

$E_{loss} = A_1 + A_2 + A_3 + A_4 = \boxed{13.75\,mJ = E_{loss}}$ 3b

#3 continued

(c) Compute $f_{s,max}$ s.t $\eta \geq 0.98$.

$$P_{loss} = E_{loss} f_s$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_{in} - P_{loss}}{P_{in}} = 1 - \frac{E_{loss} f_s}{P_{in}} \geq 0.98$$

$$\rightarrow f_s \leq (1 - 0.98) \frac{P_{in}}{E_{loss}} = f_{s,max}$$

$$\boxed{\cong 72.73 \text{ kHz}}$$

3c