Key Concepts for EE 452 Midterm

- Use correct units in all problems [V, A, W, J, s]
- Names of power semiconductor devices & their defining characteristics
- Ripple equations:

$$v_L \approx L \frac{2\Delta i_L}{\Delta t} \quad , \quad i_c \approx C \frac{2\Delta V_c}{\Delta t}$$ ← Evaluate in one ckt configuration.

- Volt-second & Charge balance equations:

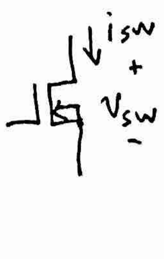
$$\langle v_L \rangle = 0 = D\,(v_L \text{ for configuration } 1) + D'(v_L \text{ for configuration } 2)$$

$$\langle i_c \rangle = 0 = D\,(i_c \text{ ---- '' }) + D'(i_c \text{ ---- '' })$$

- Using balance equations, know how to obtain the following:

Know how to compute with loss mechanisms included (R_{on}, R_L, V_f)
- → Voltage conversion ratio $M = \frac{V}{V_g}$
- → Efficiency $\eta = \frac{P_{out}}{P_{in}}$
- → Steady state inductor currents & cap voltages
  - ↳ Apply to pick suitable devices

- Given device waveforms, compute switching energy & power loss

for a device 

$$E_{loss} = \underbrace{\int_{\tau = t_0}^{\tau = t_{final}} v_{sw}(\tau)\, i_{sw}(\tau)\, d\tau}_{\text{area under curve}}$$

$$P_{sw\,loss} = F_{sw} E_{loss}$$

→ Know how η is impacted by $P_{sw\,loss}$ & F_{sw}.

EE 452 – Power Electronics Design, Autumn 2021

Midterm – Cover Page

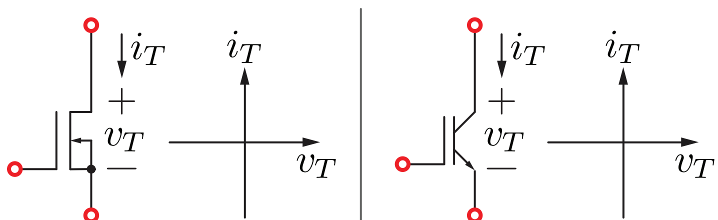
Friday November 5th 2021

Name: ______________________________

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 (excluding the body diode).

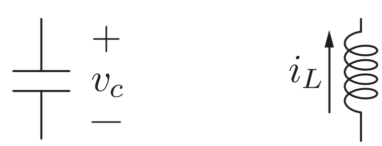


(a) MOSFET (b) IGBT

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).



$i_c = C\frac{dv_c}{dt}$ $v_L = L\frac{di_L}{dt}$

(a) (b)

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

Problem 2: Steady-state converter analysis. [60 Points Total]
Consider the converter below where the inductor has winding resistance R_L. All other components are ideal. Use the small-signal approximation for all analysis below.

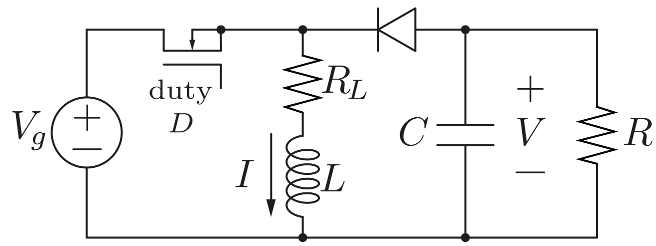


Figure 3: Converter for Problem 2.

(a) [**5 Points**] What is the name of the converter in Figure 3?

(b) [**5 Points**] Derive the Volt-second balance equation.

(c) [**5 Points**] Derive the charge balance equation.

(d) [**10 Points**] Solve for the inductor current I in terms of V, R, D, and $D' = 1 - D$.

(e) **[10 Points]** Compute the conversion ratio $M := V/V_g$ in terms of R_L, R, D, and $D' = 1 - D$.

(f) **[10 Points]** Compute the efficiency η in terms of R_L, R, D, and $D' = 1 - D$.

(g) **[15 Points]** Use your result from parts (d)–(e) and the numerical values below. Compute the critical switching frequency, f_s, such that the inductor current dc component and ripple component are the same (i.e., $I = \Delta i$).

- $D = 0.5, \quad R = 10\,\Omega, \quad R_L = 0.1\,\Omega, \quad L = 100\,\mu\text{H}$

Problem 3: Switching loss analysis [30 Points Total]
Consider the switch transition waveforms for an IGBT. The waveforms and device quantities are shown in Figure 4.

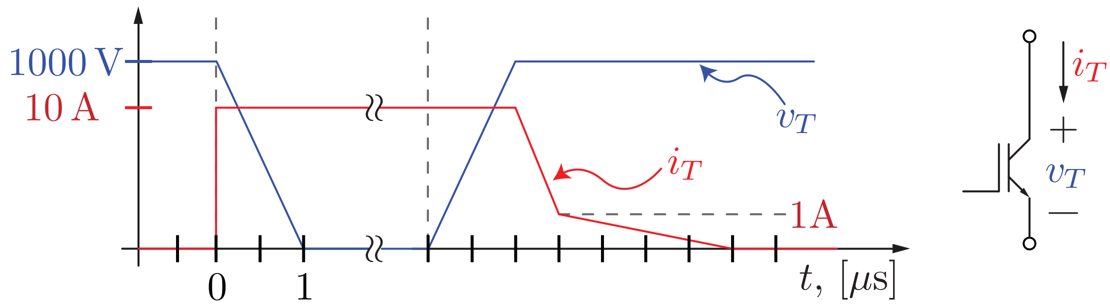


Figure 4: IGBT waveforms for Problem 3.

(a) **[10 Points]** Draw the waveform of the power dissipated in the IGBT. Use the blank plot provided below.

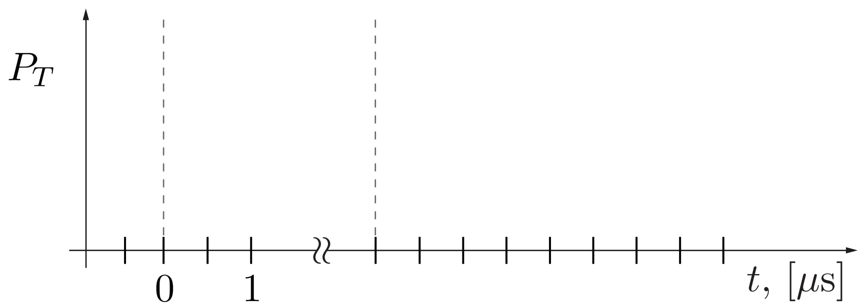


Figure 5: Plot for Problem 3(a).

(b) **[10 Points]** Compute the total energy dissipated during both switch transitions.

(c) **[10 Points]** Neglecting all other sources of loss and assuming an input power of $P_{\text{in}} = 50\,\text{kW}$, compute the maximum switching frequency such that $\eta \geq 0.98$.