EE155/255 F15 Midterm

Name: (please print)_______________________________

In recognition of and in the spirit of the Stanford University Honor Code, I certify that I will neither give nor receive unpermitted aid on this exam.

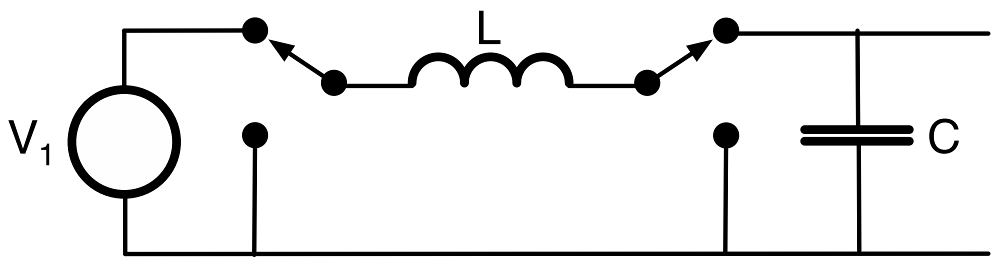
Signature:____

You may not, collaborate in any manner on this exam. This exam is open notes limited to one 8.5 x 11 inch sheet of notes. You have 120 minutes to complete the exam. Please do all of your work on the exam itself. Attach any additional pages as necessary.

Before starting, please check to make sure that you have all 10 pages.

1		**15**
2		**15**
3		**15**
4		**20**
5		**15**
6		**20**
7 (extra credit)		**15**
Total		**115**

Problem 1: Periodic Steady State Analysis [15 Points]

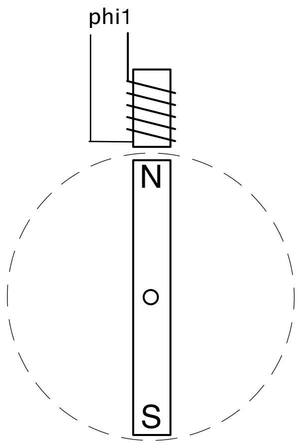


Consider the converter shown in the drawing above. The left switch operates with a cycle time of t_{cl} = 20μs and a duty factor of D_l. The right switch operates with a cycle time of t_{cr} = 10μs and a duty factor of D_r. The duty factors reflect the amount of time each switch spends in its upper position. The inductor and capacitor have values of 100μH and 100μF respectively. Source V_1 is 100V.

(a) [5 Points] If the converter is in periodic steady state, what is the voltage across the capacitor C_1? Give your answer in terms of D_l and D_r.

(b) [10 Points, 5 Points Each] Write expressions for the change in inductor current ΔI and the change in capacitor voltage ΔV over one cycle of the left switch when not in the periodic steady state.

Problem 2: Motors [15 Points – 5 points each]



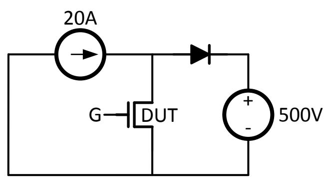
Suppose you have a single-phase brushless permanent magnet motor (as shown above) with motor constant K_M = 1 Vs/rad. The winding of the single phase has resistance R=5Ω. The rotor is shown in the θ=0 position. You may neglect the inductance in the motor windings.

(a) If the rotor has angular velocity $\omega = d\theta/ dt$, what is the voltage seen across the winding of the single phase if it is left open?

(b) Write an expression for the current as a function of rotor position θ that should be provided to the single phase to give an average torque of 1N-m – averaged over a cycle.

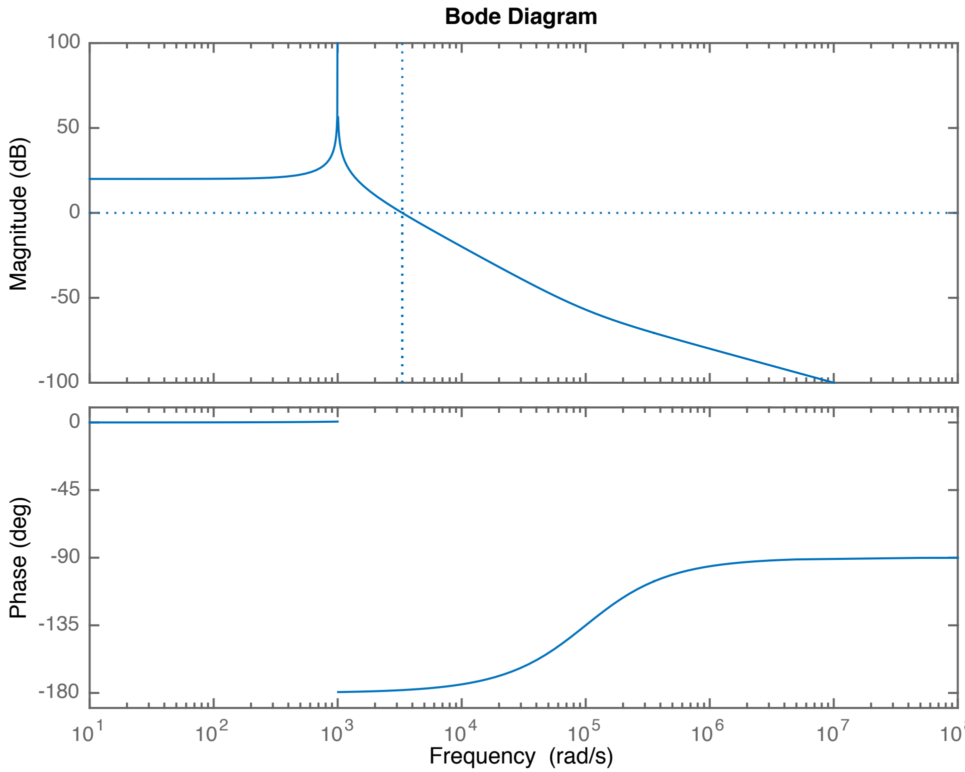
(c) Write an expression for the voltage as a function of rotor position θ that should be applied across the single phase to generate the current of part (b).

Problem 3: FET Losses [15 points]



Consider the boost converter shown above operating in the periodic steady state with a 100kHz switching frequency f_{cy}. Suppose the MOSFET has an Ron of 50mΩ and switches with a linear current ramp of 1A/ns for both turn-on and turn-off. Assume that the capacitance on the drain of the MOSFET is negligible and that duty factor D=0.5. Assume the diode has zero forward voltage drop but does have a reverse recovery charge of Q_{RR}=200nC. Assume that the inductor and capacitor are ideal and that ripple current is negligible. Compute the switching loss and conduction loss of this converter. You may ignore turn-off losses.

Problem 4: Feedback Control [20 Points]



You have a plant plus controller with the open-loop frequency response as shown in the Bode plot above. Suppose you close a feedback loop around this system. Answer the following questions about the resulting system:

(a) [5 Points] Is the system adequately damped, i.e., will any ringing after an abrupt transition die out in at most a cycle or two? (yes/no)

(b) [5 Points] At what frequency in (rad/s) will any ringing occur?

(c) [5 Points] How many poles and zeros does this system have? At what frequency in (rad/s) are the poles and zeros of this system?

(d) [5 Points] Which of the following will increase the phase margin, and hence the damping of the sytem (circle all that will):

i) Increase the DC gain by 4 (12dB).
ii) Decrease the DC gain by 4 (12dB).
iii) Move the first zero up (higher frequency) by 10.
iv) Move the first zero down (lower frequency) by 10.

Problem 5: Transformer Design [15 Points, 5Points Each]

The relevant properties for a Ferroxcube E20/10/5 core are shown in the table below. In the 3C96 material this core has a μ_r=1530 and **A_L=1.4μH/turns²**. The window area is A_W=100mm², and the length of the average turn is L_{turn} = 38mm. Recall the permeability of free space $\mu_0 = 4\pi \times 10^{-7}$.

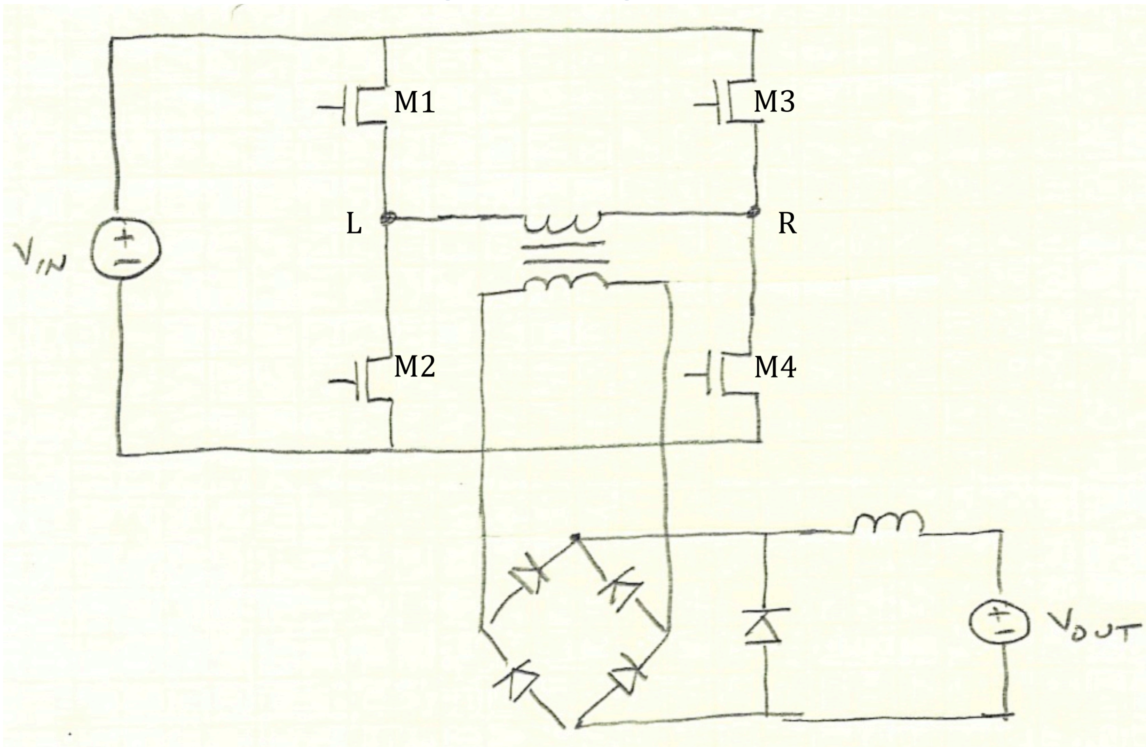
SYMBOL	PARAMETER	VALUE	UNIT
$\Sigma(I/A)$	core factor (C1)	1.37	mm^{-1}
V_e	effective volume	1340	mm^3
l_e	effective length	42.8	mm
A_e	effective area	31.2	mm^2
A_{min}	minimum area	25.2	mm^2
m	mass of core half	≈ 4.0	g

(a) Suppose you build a transformer by winding a 10-turn primary and a 20-turn secondary on this core. What is the primary-referenced magnetizing inductance of this transformer? (Hint: use A_L).

(b) Starting from zero magnetizing current, how many Volt-Seconds can the primary of the transformer of part (a) tolerate before the B-field in its core reaches 0.5T?

(c) For the core to handle 10^{-4} Volt-Seconds, how many turns would the primary need to have?

Problem 6: Soft Switching Full-Bridge [20 Points]



Consider the full-bridge converter shown in the figure above. The input supply is 400V. The output inductor is 100μH and the leakage inductance is 1μH. The total capacitance on each switching node is 1nF. The converter has a 10μs cycle time. The transformer is a 4:1 step-down and the duty cycle is adjusted so the steady state voltage across the output capacitor is 50V. Each of the transistors M1 to M4 includes a body diode (not shown).

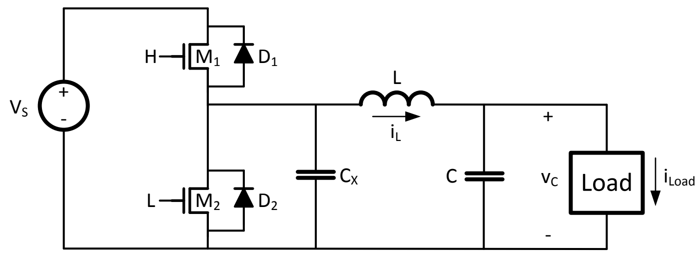
(a) [5 Points] Initially switches M1 and M4 are on and the current in the output inductor is 20A. Just after switch M1 turns off, what component determines the current in the primary winding of the transformer, and what is this current? (Hint: draw the equivalent circuit with the transformer eliminated and the secondary components referenced to the primary.)

(b) [5 Points] Given the current from (a) how long does it take node L to fall to ground? (You may assume the output inductor current does not change during this period).

(c) [5 Points] After node L falls to ground, switch M2 turns on. Some time later switch M4 turns off. At this point, what component determines the current in the primary? Approximately how much is this current? (You may assume that the current in the output inductor is a constant 20A and that there was negligible loss while the current was circulating through M2 and M4.)

(d) [5 Points] At a different, lower output current, operating point, suppose the primary current is 3A when M4 turns off. Is there enough energy in the leakage inductance to drive node R to 400V? If not, how much additional shim inductance should be added so that R does reach 400V at this operating point?

Problem 7: [Extra Credit] Soft Switching [15 Points, 5Points Each]



Consider the quasi-square-wave (QSW) buck converter shown above where V_S=100V, V_C=40V, and i_L=10A. Suppose L=10uH and the total capacitance on the switching node – including C_X is 100nF. (Hint: It is OK to use linear approximations to the waveforms of the converter.)

(a) When the low switch (M2) is on, what should i_L be before M2 turns off?

(b) If the average output current is 10A, what should i_L be when M1 turns off?

(c) What will the switching frequency of this converter be with a 10A load?