EE155/255 F16 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.

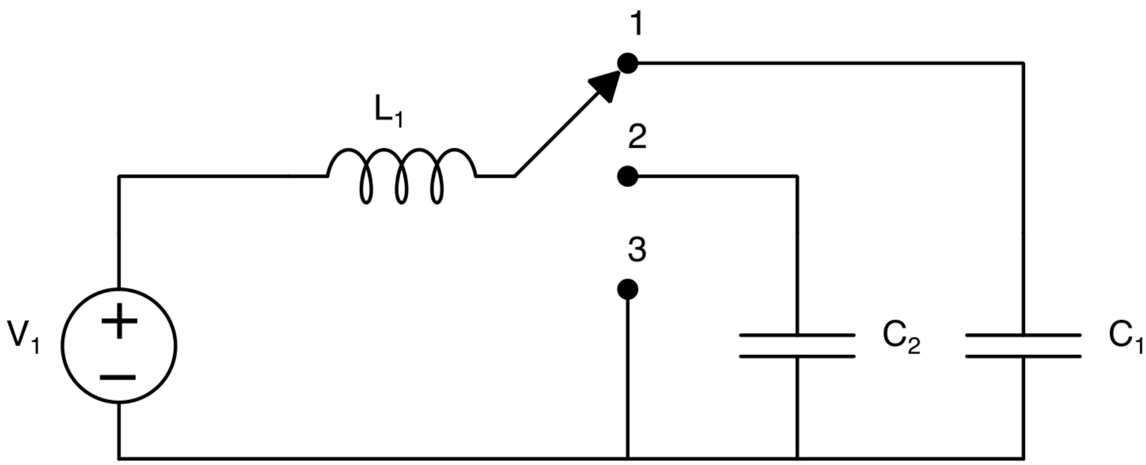
Signature:____

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 8 pages.

1		**15**
2		**20**
3		**10**
4		**20**
5		**20**
6		**20**
7		**15**
Total		**120**

Problem 1: Periodic Steady State Analysis [15 Points]



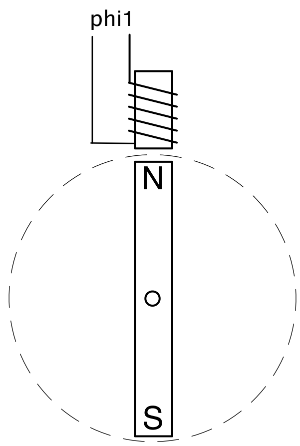
Consider the converter shown in the drawing above. The three-position switch operates with a cycle time of t_c = 10μs, has a duty factor in position 1 of D_1, a duty factor in position 2 of D_2, and a duty factor in position 3 of D_3. $D_1+D_2+D_3 = 1$. The inductor is 1μH and both capacitors are 100μF. Source V_1 is 1V. And in steady state, the voltage across C_2 is 2V.

(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 the duty factors.

(b) [10 Points, 5 Points Each] Write expressions for the change in inductor current ΔI and the change in capacitor C_1 voltage ΔV over one cycle of the switch when not in the periodic steady state.

(c) [5 points] What is the natural frequency of the response on capacitor C_1 to a transient in duty factor.

Problem 2: Motors [20 Points – 5 points each]



Suppose you have a single-phase brushless permanent magnet motor (as shown above). The rotor is shown in the $\theta=0$ position. You may neglect the inductance in the motor windings.

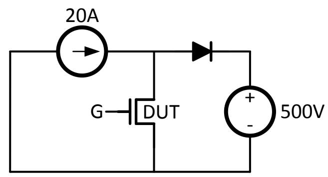
(a) When the motor has an angular velocity of $\omega=2$ rad/s you observe a sine wave with amplitude 1V (RMS) and frequency of 2 rad/s across the single open-circuit winding. If you increase the angular velocity to $\omega = 4$ rad/s, what voltage waveform will you see across the winding? (Express voltage as a function of time, t).

(b) You apply a torque of 2 N-m to the shaft of the motor rotating at 10 rad/s in the direction of rotation. What resistance must be applied across the winding to keep the motor at a steady speed?

(c) Driving the winding with a DC current source with current I_0 and the rotor "locked" in a stationary position, you observe a torque of 1 N-m with the rotor at $\theta=30$ degrees. What torque do you expect with the same current and the rotor at $\theta=90$ degrees?

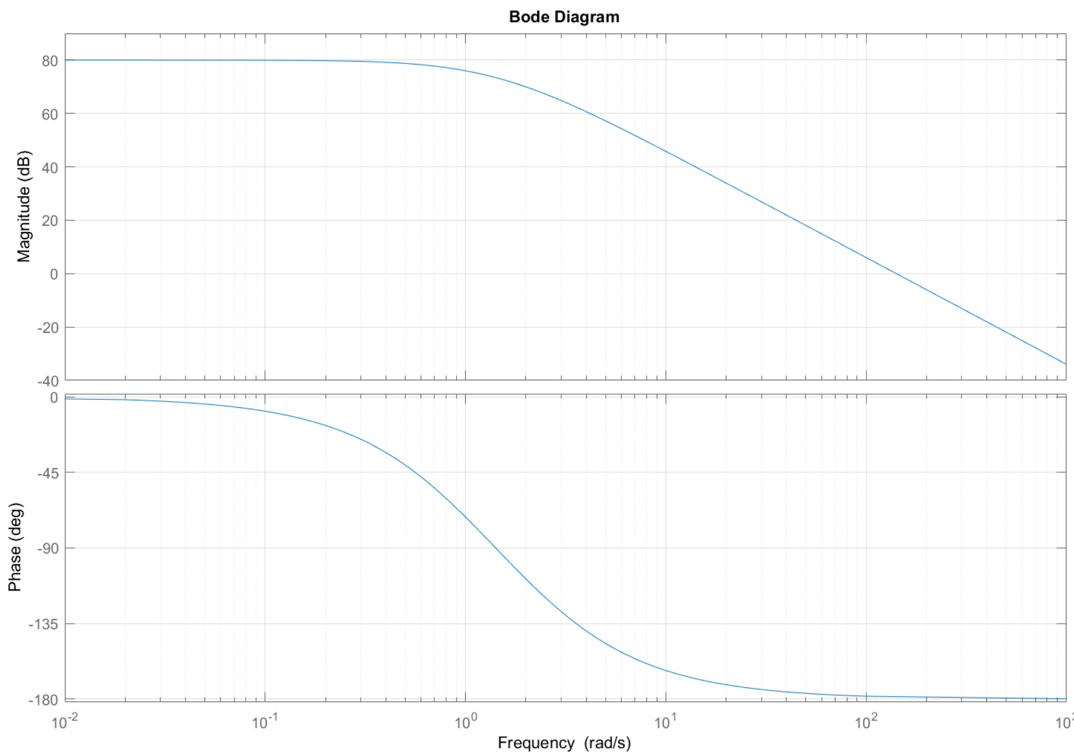
(d) What torque do you expect at $\theta=90$ degrees and a current of $2I_0$?

Problem 3: FET Losses [10 points, 5 points each]



Consider the boost converter shown above operating in the periodic steady state with a 100kHz switching frequency f_{cy}. Suppose the MOSFET has a Ron of 100mΩ 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 a linear 100pF capacitor and that duty factor D=0.5. Assume the diode has zero forward voltage drop and no reverse recovery charge (i.e., it switches off instantly). 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 with the open-loop frequency response as shown in the Bode plot above. The DC gain is 10^4, there is one pole at -1 rad/s, and one pole at -2 rad/s. 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] Add a PD controller to the system leaving the DC gain unchanged (i.e., P=1). What is the smallest derivative gain you can add that will give a phase margin of at least 60 degrees? (An approximate answer (within a factor of 2) is OK. You need not be exact.)

(d) [5 Points] What is the frequency of the zero you added in part (c)?

Problem 5: Transformer Design [20 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
Σ(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

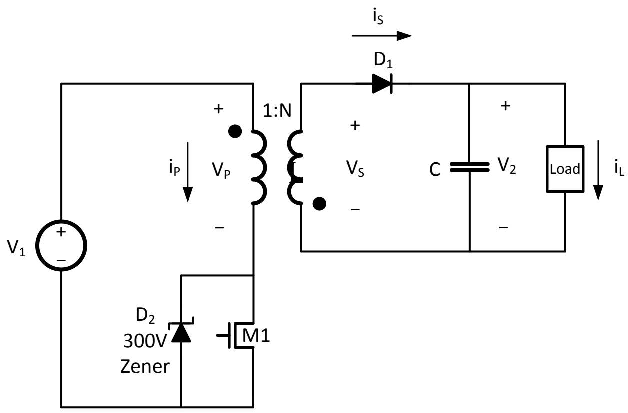
(a) Suppose you build a transformer by winding a 5-turn primary and a 40-turn secondary on this core. What is the primary-referenced magnetizing inductance of this transformer? (Hint: use A_L).

(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?

(d) For the configuration of part (a), what is the secondary-referenced magnetizing inductance of the transformer?

Problem 6: Flyback Converter [20 Points]



Consider the flyback converter shown in the figure above. The input supply is 50V. The transformer has a 1:2 turns ratio. The magnetizing inductance of the transformer is 20μH, and its primary-referenced leakage inductance is 1μH. The load current is 1A. The converter has a 10μs cycle time and operates in **discontinuous conduction mode** (i.e., the magnetizing current goes to zero before the end of each cycle).

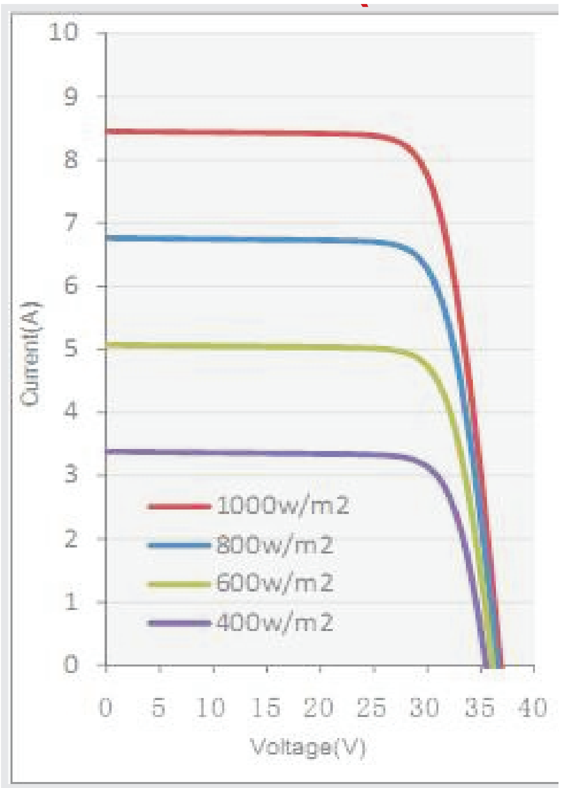
(a) [5 Points] Ignoring the leakage inductance, what duty factor is required to give an output voltage of 100V in the steady state? (Hint: the duty factor depends on the output current.)

(b) [5 Points] What is the peak magnetizing current in this configuration?

(c) [5 Points] Considering the leakage inductance, what duty factor is required to give an output voltage of 100V in the steady state?

(d) [5 Points] How much energy is lost in the Zener diode each cycle?

Problem 7: Photovoltaics [15 Points, 3 Points Each]



Suppose I have a string of 3 PV modules. The first two have I-V characteristics given by the 1000W/m^2 line on the figure above. The third follows the 400W/m^2 line. The three modules are connected with bypass diodes across each module. Answer each of the following questions about this three module configuration.

(a) What is the approximate open-circuit voltage of the 3-panel configuration?

(b) What is the approximate short-circuit current of the 3-panel configuration?

(c) At the lowest current where the 400W/m^2 panel bypasses, what are I and V?

(d) What is the approximate maximum power point MPP of the three-panel configuration?

(e) Can the maximum power point be found by gradient search (hill climbing) from both the open-circuit and short-circuit configurations? (yes or no, and explain)