Final Exam

EECE 493 - 101 December 4, 2008 Instructor: Nathan Ozog

Name:

Student Number:

Read all of the following information before starting the exam:

- The duration of this exam is **3 hours**.
- Anyone caught copying or allowing someone to copy from them will be ejected from the exam.
- Circle or otherwise indicate your final answers.
- This exam contains 3 Main Questions with supplemental material provided in the back of the exam which may be removed.
- Assumptions presented in class shall be employed where appropriate.
- Good luck!

Question	Points	Score
1	30	
2	50	
3	20	
Total:	100	

(10)

(5)

The circuit shown in Figure 1 operates in two switched topologies:

Topology 1: $0 < t \le DT$

• Q1 is **ON**

Topology 2: $DT < t \leq T$

• Q1 is **OFF**



Figure 1: DC-DC Galvanically Isolated Converter Circuit

The converter shown in Figure 1 has the following loss elements:

- Primary Winding Resistance R_p
- Secondary Winding Resistance \mathbf{R}_s
- MOSFET Resistance R_{on}
- Diode Forward Voltage Drop V_D

1. We would like to analyze the DC operation of the circuit in Figure 1.

- (a) Derive the steady-state equivalent circuit model for this circuit. (10)
- (b) Derive the analytic expression for converter efficiency η .
- (c) Determine the maximum blocking voltage across the MOSFET
- (d) Derive an expression for the output voltage ripple of this circuit in terms of Δi_{lm} . (5)

2. The circuit shown in Figure 2 operates in two switched topologies:

Topology 1: $0 < t \le d(t)T$ • Q1 is ON Topology 2: $d(t)T < t \le T$

• Q1 is \mathbf{OFF}



Figure 2: DC-DC Converter Circuit with PWM Feedback Control

The parameters of this circuit are:

Parameter	Value
V_g	20 V
V	100 V
f_{sw}	200 kHz
R	5Ω
L	$1 \mu H$
С	$400\mu H$

Table 1: Circuit Parameters

(2)

(5)

- (a) We would like to determine the DC operating characteristic of the circuit in Figure 2.
 - i. Determine the steady state duty cycle, D, of this circuit.
 - ii. confirm analytically that the converter operates in continuous current mode (CCM). (3)
- (b) We would like to find a set of transfer functions describing how small perturbations (15) in the load current, $i_{load}(t)$, input voltage, $v_g(t)$ and duty cycle, d(t) affect the output voltage v(t). Using either an AC small signal equivalent circuit or an averaged state-space model derive the following transfer functions:
 - i. $Z_{out}(s)$
 - ii. $G_{vg}(s)$
 - iii. $G_{vd}(s)$

Notes:

- If you are using the AC small signal **equivalent circuit**, draw and label your complete model and show the assumptions you use to derive each transfer functions using separately drawn circuits.
- If you are using the averaged **state space** model, clearly define $\mathbf{x}(t)$ and $\mathbf{u}(t)$. $\mathbf{y}(t)$ is not a necessary parameter.

• The equation for the inverse of a 2x2 matrix is
$$\begin{pmatrix} a & b \\ c & d \end{pmatrix}^{-1} = \frac{1}{ad-bc} \begin{pmatrix} d & -b \\ -c & a \end{pmatrix}$$

- (c) We would like to control our circuit using the feedback loop shown in Figure 2. As Figure 2 shows, it is assumed that the reference voltage is $V_{ref} = 5$ V and that $v_c = 0$ at the DC operating point.
 - i. Choose r_1 , r_2 and r_3 of the voltage sensor circuit and express its transfer function, (3) H(s).
 - ii. Plot the PWM saw-tooth function labeling V_{max} , V_{min} ; redraw the comparator (2) circuit with the '+' and '-' ports at the appropriate places; and express the transfer function G_{pwm} of this device.
 - iii. The form of the uncompensated 'loop gain' $T_u(s)$ is

$$T_u(s) = H(s)G_{vd}(s)G_{pwm}(s) = T_u(0)\frac{1 - \frac{s}{\omega_z}}{1 + \frac{s}{Q\omega_0} + \frac{s^2}{\omega_0^2}}$$

Give the values of ω_z and ω_0 (in rads/s), as well as Q and $T_u(0)$ (in decibels).

iv. Figures at the back of the exam booklet contain 6 bode plots graphed together for (5) comparison, and individually. Identify the plot that corresponds to the uncompensated loop gain, $T_u(s)$, you derived.

(4)

(d) We would like to design a compensator to reject disturbances up to a frequency of $\sim 1.6 \text{kHz} (10 \text{krad/s})$, meaning we would like to set our frequency rejection bandwidth at $\sim 16 \text{kHz} (100 \text{krads/s})$. The compensators we have at our disposal are shown in Figure 3.



Figure 3: PI and PD Compensators

- i. Discuss how you would like to change the frequency characteristic of $T_u(s)$ to (4) achieve appropriate gain, bandwidth and stability margin.
- ii. Choose either the PI or the PD controller and discuss why your choice is appropriate (4) to compensate $T_u(s)$.
- iii. If you chose:
 - the PD compensator, state your specification for the pole, zero placement and steady state gain.
 - the PI compensator, state your specification for the zero placement and infinite gain.
- iv. Calculate the resistor and capacitor values necessary to achieve your specification. (3)

- 3. General knowledge questions: choose 5 of the 8 following questions to answer. If you answer (20) more than 5, only the first 5 will be graded.
 - (a) An IGBT can be constructed from a BJT and a MOSFET. Draw this using symbols. State one advantage of using an IGBT instead of a BJT and one advantage of using an IGBT instead of a MOSFET.
 - (b) An Silicon Controlled Thyristor (SCR) can be constructed from two BJT's. Draw this using symbols. What is the reason that an SCR cannot be turned off via its gate?
 - (c) If current control is implemented on buck, boost or buck-boost converter using a constant reference current, i_c , and without any added ramp, prove that it becomes unstable for $D > \frac{1}{2}$.
 - (d) State the advantage of using current mode control instead of PWM control.
 - (e) Explain the purpose of having AC transformers in between power supplies and the power grid, and why it is advantageous to place these transformers after the rectification stage (inside the DC-DC converter) instead of before it (in the 60Hz AC portion).
 - (f) A forward converter is shown in Figure 4. For this converter determine the maximum steady state duty cycle, D, that it can be operated at.
 - (g) Briefly explain the reason is high efficiency desirable in power converters.
 - (h) Explain the advantage of operating a DC-DC converter in Discontinuous Current Mode (DCM).



Figure 4: Forward Converter