EE6314E SWITCHED MODE POWER CONVERSION – Winter 2023-24
ASSIGNMENT – 1
Submission Date : 20th Feb 2024

Device Data :

MOSFET IRF 540 100V/23A @ 100 deg C Case Temperature, r_s = 44 mΩ, C_{gd1} = 450 pF, C_{gd2} = 125pF, C_{gs1} = 2400pF, C_{gs2} = 1800pF, C_{ds1} = 1100pF, C_{ds2} = 500pF.

SchottkyDiodes :

MBR 1045 45V/10A, V_γ = 0.2 V, r_d = 32 mΩ

MBR 1060 60V/10A, V_γ = 0.2 V, r_d = 60 mΩ

MBR 10100 100V/10A, V_γ = 0.2 V, r_d = 60 mΩ

MBR 1645 45V/16A, V_γ = 0.2 V, r_d = 30 mΩ

Ultrafast Diodes:

MUR 820 200V/8A, V_γ = 0.5 V, r_d = 40 mΩ

MUR 1520 200V/15A, V_γ = 0.5 V, r_d = 40 mΩ

1. Both non-isolated Buck converters and non-isolated Boost converters employ an inductor L and a bulk capacitor C in their design. (a) Distinguish clearly between the roles of L and C in the two types of converters. (b) Explain how the size of L and C get affected in the two types of converters when the switching frequency is increased with current ripple and voltage ripple specifications kept constant.
2. A Buck Converter has V_{in} = 24V, d = 0.5, f_s = 100kHz, C=100µF, CxESR = 30µs. The steady-state current in the inductor was a periodic raised triangular waveform varying between 2.5A and 3.5 A. Load is a resistance R. All components are ideal. Find (i) L (ii) R (iii) V_0 and % p-p ripple in output voltage.
3. A 120V input / 24V Output non-isolated Buck Converter is operating with a fixed duty ratio of 0.2. The switching frequency is 40 kHz and the filter inductor has 0.48 mH inductance. Derive and plot the variation of Output DC Voltage level against output current variation in the range 0 to 5A. Assume ideal operation for all components.
4. A Boost Converter has V_{in} = 24V, d = 0.5, f_s = 100kHz, C=100µF, CxESR = 30µs. The steady-state current in the inductor was a periodic raised triangular waveform varying between 2.5A and 3.5 A. Load is a resistance R. All components are ideal. Find (i) L (ii) R (iii) V_0 and % p-p ripple in output voltage.
5. An Ideal Buck Converter runs from 120V DC Supply at a duty ratio of 0.4 at 50kHz and uses L = 576 µH and C = 10µF (Poly propelene non-polarised capacitor). (a) ***Find*** the output voltage, peak to peak ripple in inductor current and peak to peak ripple in output voltage if the output load is drawing a current of 5A DC. (b) ***Plot*** switch current, switch voltage, diode current, diode voltage, inductor voltage, inductor current, capacitor current and output voltage with d = 0.4 and I_o = 5A and mark all salient values and time intervals. (c) ***Find*** output voltage (after deriving the expression for it) if load current is reduced to 0.2A while duty ratio is maintained at 0.4.
6. Find L & C for a Buck Converter in CCM design. V_{in} = 40 to 56V, V_0 = 24V, I_0 =0.4A to 4A, Maximum p-p ripple in V_0< 50mV, Maximum p-p ripple in inductor current < 1 A, Switching frequency = 40kHz, r_cC product = 50µs.
7. Assume that you are using IRF540 and MBR10100 in the above design. Find V_0 accounting for r_l, r_c ,r_s , r_d, V_γ with V_{in} = 48V, d = 0.5 and I_0 = 4A. Take r_l = 30mΩ.

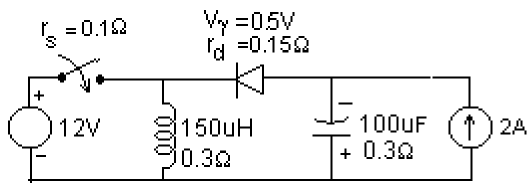
8. For the condition in Problem-7, find switching power loss in MOSFET, conduction power loss in MOSFET, Diode Power loss assuming that gate source produces straight-edged waveforms and R_g = 22Ω. Note that Schottky diodes do not have any reverse recovery process.
9. If the above converter is delivering 3A at 24V output with input voltage at 40V, find the duty ratio at which it should run (i) with all resistances and V_γ ignored and (ii) with all resistances and V_γ included.
10. Design a Boost Converter in CCM design. V_{in} = 10.5 to 12.5V, V_0 = 24V, I_0 = 1A to 3A, Maximum p-p ripple in V_0< 200mV, Maximum p-p ripple in inductor current < 1 A, Switching frequency = 40kHz, r_cC product = 30µs.
11. Assume that you are using IRF 540 and MUR 820 in the design in Problem-10 and that r_l = 50 mΩ. Prepare plots for V_o versus duty ratio variation in the range d = 0.5 to d= 0.8 with (i) V_{in} = 10.5V, I_0 = 1A (ii) V_{in} = 10.5V, I_0 = 3A (iii) V_{in} = 12.5V, I_0 = 1A and (iv) V_{in} = 12.5V, I_0 = 3A , all in the same graph, and accounting for all resistances and V_γ. Thereby, find the duty ratio variation range that is needed to maintain output voltage at 24V when V_{in} and I_0 vary in the stated ranges.
12. Assume that the converter in Problem – 11 is delivering 3A at 24 V with input at 12V. Find the (i) conduction loss in Switch and Diode (ii) Switching Losses in Switch (iii) conduction losses in inductor and (iv) conduction loss in Capacitor. It is known that stored charge in MUR820 is 20nC per Ampere of forward current.
13. A Buck Converter for 36V/5V, 10A was designed with a 60V, 25A, 40mΩ MOSFET. When this MOSFET was out of stock, it was substituted with a 300V, 75A, 20mΩ MOSFET with no other change made in the circuit board. Frequent burnout of MOSFETs on overheating was reported from units employing the new MOSFET despite the new MOSFET being a significantly over-rated one. Explain the possible reason/s for this with supporting arguments and suggest a possible solution.
14. In your capacity as a Design Engineer, you instructed your Technical Assistant to construct a 12V to 120VDC Converter to deliver a constant current source kind of load of 0.5A value. You were in a hurry and did not tell her which topology to use. She designed a Boost DC-DC Converter and tested it to find that she is not able to get the required 120V at the output. She varied the duty ratio in the entire range of 0 to 1 and found that the maximum output voltage she could get is about 50V with load current always adjusted to 0.5A. She wants to know what she did wrong. Explain it to her with supporting derivations and graphs.
15. A 120V input / 24V Output non-isolated Buck Converter is operating with a fixed duty ratio of 0.2. The switching frequency is 20 kHz and the filter inductor has 0.48 mH inductance. The converter is delivering a load of 0.5A at its output. Assume ideal operation for all components. Identify whether the converter is in DCM or CCM and calculate the output voltage. **Derive** the formula you use from basic principles. Also **sketch** the important waveforms in the converter.
16. A 48 V input / 12 V Output Buck Converter is delivering a 10A load at its output. It uses an inductor of value 100 µH and switches at 20 kHz. Neglect switch drop, diode drop and resistance drops. The power MOSFET used follows square law and its saturation current at V_{GS} = 7.5 V is 48A and it has a threshold voltage of 3.5 V. It is driven by a Gate-Source voltage of 12V through a 47Ω resistance. C_{iss1} = 2000pF, C_{iss2} = 1300pF, C_{rss1} = 600pF, C_{rss2} = 200pF, C_{oss1} = 1200pF and C_{oss2} = 400pF for the MOSFET. The diode used has a minority carrier storage that is proportional to forward current and has a value of 1.2µC when carrying 1 A forward current. Assume that parasitic inductances are negligible. (a) Calculate the switching delays in the voltage across the diode. (b)Find the switching power loss in the MOSFET. ***Show the relevant waveforms and calculations.***

17. A 12 V input / 48 V Output Boost Converter is delivering a 4A load at its output. It uses an inductor of value 60 µH and switches at 50 kHz. Neglect switch drop, diode drop and resistance drops. The power MOSFET used follows square law and its saturation current at V_{GS} = 7.5 V is 48A and it has a threshold voltage of 3.5 V. It is driven by a Gate-Source voltage of 12V through a 47Ω resistance. C_{iss1} = 2000pF, C_{iss2} = 1300pF, C_{rss1} = 600pF, C_{rss2} = 200pF, C_{oss1} = 1200pF and C_{oss2} = 400pF for the MOSFET. The diode used has a minority carrier storage that is proportional to forward current and has a value of 0.8 µC when carrying 1 A forward current. Assume that parasitic inductances are negligible.

(a) ***Calculate*** the total switch-on time and switch-off time of MOSFET. ***Show*** *the relevant waveforms and calculations.*

(b) ***Find*** the switching power loss in the MOSFET.

18. (a) Find the output voltage and peak-to-peak ripple in output voltage in the following converter by deriving the equations from basic principles when running at 0.5 duty ratio with 100kHz switching. The resistances of switch, diode, inductor and capacitor must be accounted.



(b) You instructed your technical assistant to set up this converter and experimentally obtain its efficiency. She came up with about 82%. You asked her to carry out suitable modifications such that full load efficiency is at least 94%. She decided to parallel three identical switches instead of one switch and drove the parallel combination using same gate drive that she used before for one switch. Then she found that efficiency went down to 75%. Explain to her what went wrong? Also, what suggestions will you offer her to improve the efficiency of the converter?

19. Ms. Zed designed a Boost Converter V_{in} = 12V, d = 0.75, f_s = 50kHz, L = 60µH, C=1000µF, CxESR = 30µs. The capacitor she had connected at the output has a voltage rating of 150V and the diode and switch she used has voltage rating of 100V. She wants to test the converter on open loop with d = 0.1. *(a)* ***Explain*** *why she ended up with a blown switch & diode when she tested the Converter on no load with d = 0.1? (b)* ***What is the*** *maximum value of resistive load she can have across the output?* ***Explain*** *your calculation.*

20. A 48V to 12V Buck Converter uses 225uH inductance with 250mΩ series resistance and 680uF capacitor with 50mΩ ESR. The load is a 3 Ω resistance. The converter has stray inductance of 120nH in switch path and 120nH in diode path. The switch used is IRF540 and diode used is MUR810. The converter is driven at a duty ratio of 0.27. (a) Design the snubbers across switch and diode assuming that you are using only RC snubbers across both using the design equations given in the class notes. (b) Simulate the converter in any pSpice platform (Simetrix is preferred) with the designed snubber component values and report all the relevant waveforms (show only three or four cycles and show zoomed versions to show details). (c) Evaluate the power dissipation in snubber resistors by simulation.