Power Semiconductors Homework Problems

Summer 2005
Problem 1

(a) Sketch the symbol and the vertical structure of the IGBT. Briefly state the advantages of the IGBT over the MOSFET for low frequency operation.

[5 *marks*]

(b) The IRFPS40N60K power MOSFET (see attached specification sheets on pages 7 to 10) from International Rectifier operates in a boost converter with a dc link voltage V_d = 480 V, and load current I_o = 20 A. The MOSFET is driven by a gate drive IC outputting a square-wave voltage v_{GG}, of amplitude 0 V to +10 V, in series with an external gate resistance R_G = 4.3 Ω. Assume the diode has a 1V forward drop and no reverse recovery.

Useful formula: RC discharge time $t = -RC \ln\left[\dfrac{v_c - (-V_{GG})}{V_{ci} - (-V_{GG})}\right]$

(i) Determine the following parameters from the data sheet at a junction temperature of 100°C: maximum threshold voltage, minimum forward transconductance, gate-source capacitance, gate-drain capacitance, maximum on-state resistance, maximum gate voltage at the 20 A load current, and maximum conduction drop across MOSFET at 20 A.

(ii) Sketch $v_{GG}(t)$, $v_{GS}(t)$, $v_{DS}(t)$, and $i_D(t)$ during turn-off of the MOSFET. Note the approximate voltage levels on waveforms.

(iii) Calculate the following (a) turn-off delay time t_{doff}, (b) voltage rise time t_{vr}, and (c) current fall time t_{fv} at a junction temperature of 100°C. Sketch the basic switching circuit under analysis in each case.

(iv) Calculate the turn-off energy loss.

[Ans. 5 V, 21 S, 7895 pF, 75 pF, 0.26 Ω, 6V, 5.2 V, 17.5 ns, 31 ns, 6.2 ns, 0.18 mJ]

[15 *marks*]

Summer 2004
Problem 2

(a) Briefly explain reverse recovery in power diodes and sketch the effects of reverse recovery on the turn-on waveforms of the complementary IGBT or MOSFET.

[6 *marks*]

(b) The IRFP460 power MOSFET (see attached specification sheets on pages 6 and 7) from International Rectifier operates in a boost converter switching at 20 kHz with a dc link voltage V_d = 300 V, and load current I_o = 13 A. The MOSFET is driven by a gate drive IC outputting a square wave voltage v_{GG}, of amplitude –5 V to +15 V, in series with an external gate resistance R_G = 25 Ω. Assume the diode has a 1V forward drop and no reverse recovery.

Useful formulae: RC discharge time $t = -RC \ln\left[\dfrac{v_c - (-V_{GG})}{V_{ci} - (-V_{GG})}\right]$

(v) Determine the following parameters from the data sheet at a junction temperature of 80°C: maximum threshold voltage, minimum forward transconductance, gate-source capacitance, gate-drain capacitance, and on-state resistance.

(vi) Sketch $v_{GG}(t)$, $v_{GS}(t)$, $v_{DS}(t)$, and $i_D(t)$ during turn-off of the MOSFET.

(vii) Calculate the following (a) turn-off delay time t_{doff}, (b) voltage rise time t_{vr}, and (c) current fall time t_{fv} at a junction temperature of 80°C. Sketch the switching circuit under analysis in each case.

[Ans. 4 V, 13 S, 3850 pF, 350 pF, 0.43 Ω, 72.8 ns, 258 ns, 11 ns]

[14 *marks*]

Summer 2003
Problem 3

An enhancement-mode n-channel vertically diffused power MOSFET operates in a step-up converter switching at 20 kHz, with a dc link voltage V_d = 400 V, and load current I_o = 20 A. The device characteristics are as follows: threshold voltage $V_{GS(th)}$ = 4 V, drain current I_D = 20 A at gate voltage V_{GS} = 6 V, gate-source capacitance C_{gs} = 4000 pF, gate-drain capacitance C_{gd} = 400 pF, and on-state resistance $R_{DS(on)}$ = 0.25 Ω. The MOSFET is driven by an ideal voltage-source square wave v_{GG}, of amplitude 0 V to 15 V, in series with an external gate resistance R_G = 25 Ω. Assume the diode has a 1 V forward drop and no reverse recovery.

(i) Sketch $v_{GG}(t)$, $v_{GS}(t)$, $v_{DS}(t)$, and $i_D(t)$ during turn-on of the MOSFET.

(ii) Calculate the following times: (a) turn-on delay time $t_{d(on)}$, (b) current rise time t_{ir}, and (c) voltage fall time t_{fv}. For each of the time durations investigated, sketch the equivalent circuit.

[Ans. 34 ns, 22 ns, 440 ns]

Summer 2002

Problem 4

The IRFP460 power MOSFET from International Rectifier operates in a boost converter switching at 20 kHz with a dc link voltage V_d = 400 V, and load current I_o = 20 A. The MOSFET is driven by a voltage-source square wave v_{GG}, of amplitude 0 V to 15 V, in series with an external gate resistance R_G = 25 Ω. Assume the boost diode has a 1V forward drop and no reverse recovery.

(a) Sketch $v_{GG}(t)$, $v_{GS}(t)$, $v_{DS}(t)$, and $i_D(t)$ during turn-on of the MOSFET.

(b) Determine the following parameters from the data sheet at a junction temperature of 80°C: threshold voltage, forward transconductance, gate-source capacitance, gate-drain capacitance, and on-state resistance.

(c) Calculate the following (i) turn-on delay time t_{don}, (ii) current rise time t_{ir}, (iii) voltage fall time t_{fv} and (iv) turn-on energy loss.

[Ans. 4 V, 13 S, 3850 pF, 350 pF, 0.43 Ω, 33 ns, 15 ns, 363 ns, 1.55 mJ]

Problem 5

An enhancement-mode n-channel vertically diffused power MOSFET operates in a boost converter switching at 20 kHz, with a dc link voltage V_d = 300 V, and load current I_o = 10 A. The device characteristics are as follows: threshold voltage $V_{GS(th)}$ = 4 V, drain current I_D = 10 A at gate voltage V_{GS} = 7 V, gate-source capacitance C_{gs} = 1000 pF, gate-drain capacitance C_{ds} = 150 pF, and on-state resistance $R_{DS(on)}$ = 0.5 Ω. The MOSFET is driven by an ideal voltage-source square wave v_{GG}, of amplitude 0 V to 15 V, in series with an external gate resistance R_G = 50 Ω. Assume the diode has a 1V forward drop and no reverse recovery.

(a) Sketch $v_{GG}(t)$, $v_{GS}(t)$, $v_{DS}(t)$, $i_D(t)$, $v_{diode}(t)$, and $i_{diode}(t)$ during turn-on of the MOSFET.

(b) Calculate the following (i) turn-on delay time t_{don}, (ii) current rise time t_{ir}, (iii) voltage fall time t_{fv}.

(c) Calculate the following (i) turn-off delay time t_{doff}, (ii) voltage rise time t_{vr}, (iii) current fall time t_{fv}.

(d) Calculate the turn-on and turn-off energy losses.

(e) Calculate the power dissipation in the MOSFET due to switching and conduction losses.

(f) Estimate the MOSFET junction temperature due to turn-on switching loss only, if the MOSFET is bonded to a 70 °C heatsink. The thermal impedance from the heatsink to the junction is $\theta_{J\text{-}C}$ = 0.69 °C/W.

[Ans. (i) 18 ns (ii) 18 ns (iii) 278 ns, (c)44 ns (ii) 317 ns (iii) 32 ns (d) 0.46 mJ, 0.53 mJ (e) 15.1 W (f) 100.2 °C]

Summer 2006

Problem 6

(a) Sketch the symbol and the vertical structure of the MOSFET. Briefly state the advantages of the MOSFET over the IGBT for high-frequency, low-voltage operation.

[5 *marks*]

(b) An enhancement-mode n-channel vertically diffused power MOSFET operates in a step-up converter switching at 50 kHz, with a dc link voltage V_d = 300 V, and load current I_o = 10 A. The device characteristics are as follows: threshold voltage $V_{GS(th)}$ = 4 V, drain current I_D = 10 A at gate voltage V_{GS} = 7 V, gate-source capacitance C_{gs} = 1000 pF, gate-drain capacitance C_{gd} = 150 pF, and on-state resistance $R_{DS(on)}$ = 0.5 Ω. The MOSFET is driven by a voltage-source square wave v_{GG}, of amplitude –15 V to +15 V, in series with an external gate resistance R_G = 50 Ω. Assume the diode has a 1V forward drop and neglect the reverse recovery.

Useful formulae: RC charge time $t = -RC\ln\left[1-\frac{v_c - V_{ci}}{V_{GG} - V_{ci}}\right]$ RC discharge time $t = -RC\ln\left[\frac{v_c - (-V_{GG})}{V_{ci} - (-V_{GG})}\right]$

(viii) Sketch $v_{GG}(t)$, $v_{GS}(t)$, $v_{DS}(t)$, and $i_D(t)$ during turn-off of the MOSFET. Note the approximate voltage levels on waveforms.

(ix) Calculate the following (i) turn-on delay time t_{don}, (ii) current rise time t_{ir}, (iii) voltage fall time t_{fv}.

(x) Calculate the turn-on energy losses.

(xi) Estimate the MOSFET junction temperature if the MOSFET is bonded to a 70 °C heatsink. The thermal impedance from the heatsink to the junction is $\theta_{J\text{-}C}$ = 0.5 °C/W. Assume turn-off energy loss equals the turn-on energy loss, and the conduction loss equals the combined switching loss.

[Ans. 57.7 ns, 18.3 ns, 278 ns, 0.45 mJ, 115 C]

[15 *marks*]