EE4001 Power Electronics, Drives, Energy Co Summer '08

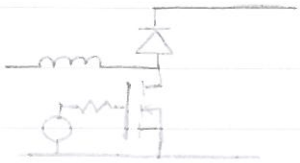
6 a) $V_d = 480V$

$I_o = 20A$

$V_{GG} = 0 \rightarrow 10V$

$R_G = 4.3\Omega$

$V_F = 1V$



i) $V_{GS(th)}$ Max $= 5V$

g_{FS} Min $= 21S$

$C_{GS} = C_{iss} - C_{rss} = 7895pF$

$C_{GD} = C_{rss} = 75pF$

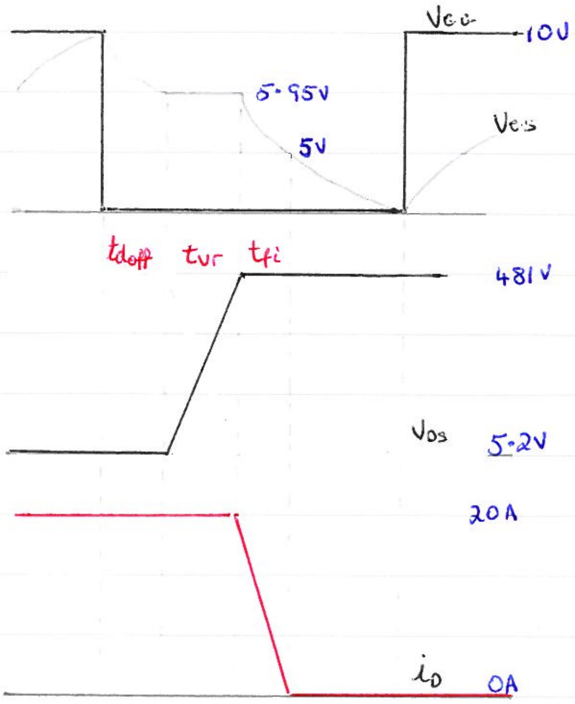
$R_{DS(on)}$ @ 100°C $= 0.26\Omega$

V_{GS} @ $I_D = 20A$ $= V_{G(th)MAX} + \frac{I_D}{g_{FS\,min}}$

$V_{GS\,MAX} = 5.95V$

$V_{DS\,MAX} = I_D R_{DS(on)} = 5.2V$

ii)



iv) Turn-off Energy Loss

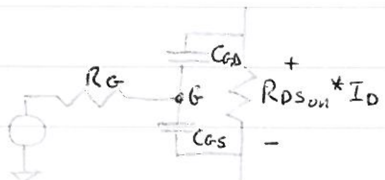
$E_{off} = \frac{1}{2}(V_D + V_F) I_o (t_{vr} + t_{fi})$

$= 153\mu J$

iii) $t_{doff} = -R_G[C_{GS} + C_{GD}] \ln\left[\frac{V_{GS\,I_D}}{V_{GG}}\right]$

Discharge from $15V \rightarrow 5.95V$

$t_{doff} = 17.8ns$

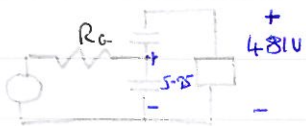


$t_{vr} = \frac{C_{dg}\Delta V_{ds}}{i_{Rg}} \Rightarrow i_{Rg} = \frac{V_{GS\,I_D}}{R_G}$

$t_{vr} = 25.79ns$

Initial

$V_{dg} = 0.75V$



Final

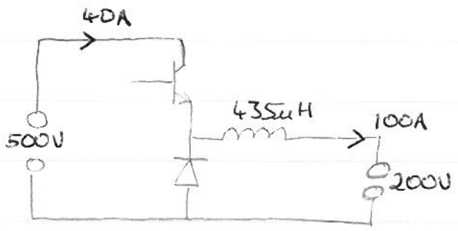
$V_{dg} = -475.05$

$t_{fi} = -R_G[C_{GS} + C_{GD}] \ln\left[\frac{5}{5.95}\right]$

$= 5.96ns$

EE4001 Power Electronics, Drives, Energy Conversion Summer '08

6 b)



$f_{sw} = 10\,kHz$ $\Delta i_{p-p} = 27{\cdot}6A$

$I_{LMAX} = 114A$

$I_{LMIN} = 86A$

$I_{Qrms} = 63{\cdot}\ A$ $I_{Drms} = 77A$

$I_{QAVG} = 40A$ $I_{DAVG} = 60A$

IGBT turn-on @ I_{LMIN}, turn-off @ I_{LMAX}

$$P_{QCOND} = V_{CEon} I_{QAVG} + R_{CE} I_{Qrms}^2$$
$$= 65W$$

$$P_{Q(Turn-on)} = f_{sw} E_{on}(86A) \frac{500}{600}$$
$$= (10)(12)(\tfrac{5}{6})$$
$$= 100W$$

$$P_{Q(Turn-off)} = f_{sw} E_{off}(114A) \frac{500}{600}$$
$$= 10(17)(\tfrac{5}{6})$$
$$= 142W$$

$$P_{D(off)} = f_{sw} E_{rr}(86A) \frac{500}{600}$$
$$= 10(12)\tfrac{5}{6}$$
$$= 100W$$

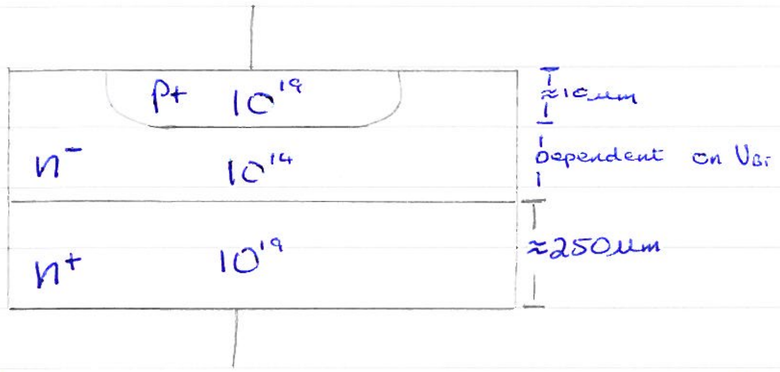
$$P_{D(COND)} = V_F I_{DAVG} + R_F I_{Drms}^2$$
$$= (0{\cdot}8 \times 60) + (5{\cdot}3m \times 77^2)$$
$$= 79{\cdot}4W$$

$P_{Q(COND)} = 65W$ $P_{Q(SW)} = 242W$

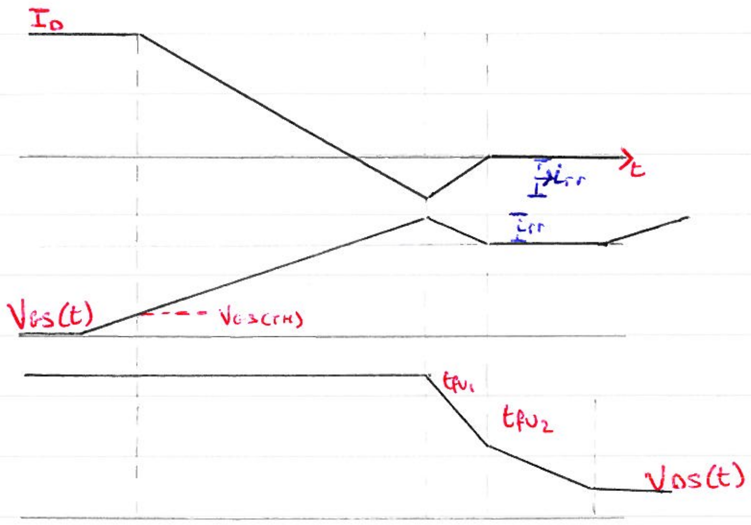
$P_{D(COND)} = 79{\cdot}4W$ $P_{D(rr)} = 100W$

EE4001 Power Electronics, Drives, Energy Conv. Summer '07

6 c)



The n^- drift region absorbs the depletion layer of the reverse-biased p-n junction. Its width determines the breakdown voltage.



b)

$f_{sw} = 20kHz$

$V_d = 300V$

$I_o = 13A$

$V_G \Rightarrow -5 \rightarrow 15V$

$R_G = 25\Omega$

$V_f = 1V$

$V_{TH\ MAX} = 4V$

$g_{fs\ MIN} = 13S$

$C_{GS} = C_{iss} - C_{oss} = 1850pF$

$C_{GD} = C_{rss} = 350pF$

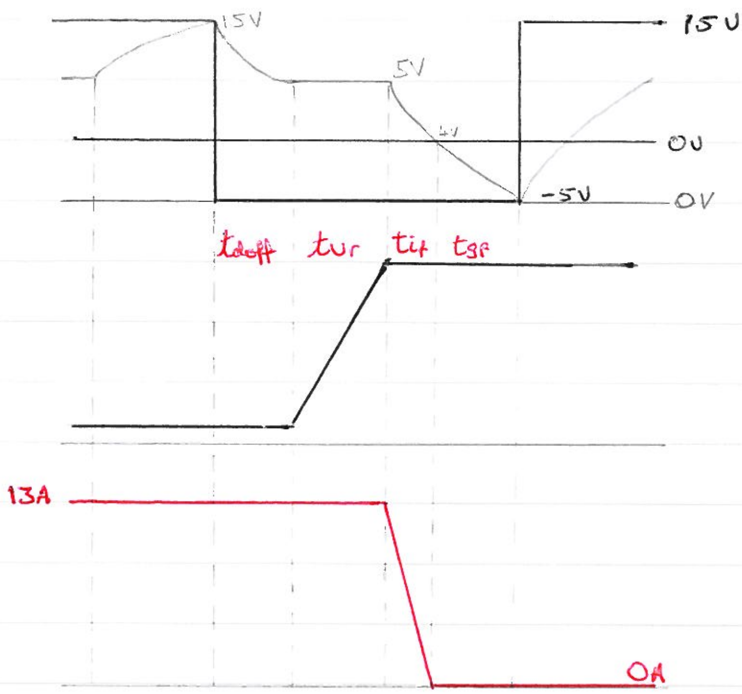
$R_{DS(on)}$ @ $80°C$ $= 1.6 \times 0.27 = 432m\Omega$

$V_{GS_{ID}} = V_{th} + \frac{I_{DS}}{g_{min}} = 5V$

$V_{DSmax} = R_{DSon} I_D = 5.6V$

EE4001 Power Electronics, Drives, Energy Conversion Summer '07

6. b) ii)

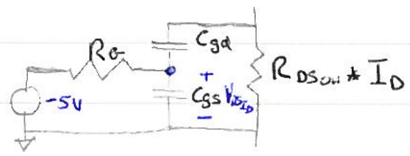


iii)

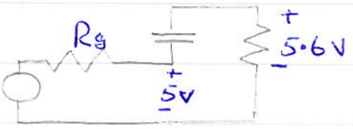
c) $t_{doff} = -R_g(C_{gs}+C_{gd})\ln\left[\frac{V_{GS_{I_0}}-(-V_{GG})}{V_{GG}-(-V_{GG})}\right]$

$= -25(4200)\ln\left[\frac{5+5}{15+5}\right]$

$= 72.8\,ns$



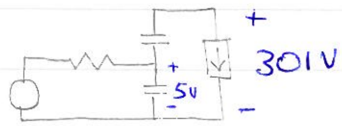
b) $t_{vr} = \frac{C_{gd}\,\Delta V_{gd}}{i_{rg}}$



$\Delta V_{gd} = V_{dg} - (V_{DS} - V_{GS_{I_0}})$

$= -296 - (-0.6)$

$= -295.4\,V$



$i_{rg} = \frac{V_{GG} - V_{GS_{I_0}}}{R_g}$

$= -0.4\,A$

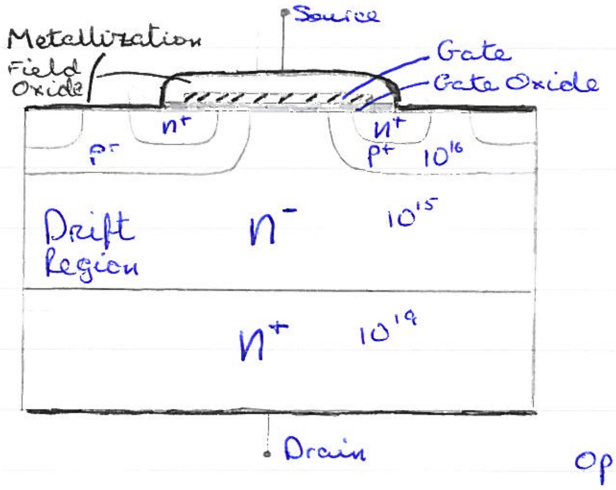
$t_{vr} = 258\,ns$

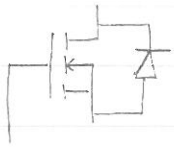
c) $t_{fi} = -R_G(C_{GS}+C_{GD})\ln\left[\frac{V_{GTH}-(-V_{GG})}{V_{GS_{I_D}}-(-V_{GG}}\right]$

$= 11\,ns$

EE4001 Power Electronics, Drives, Energy Conversion Summer '06

5 a)





The MOSFET is more suitable for low frequency operation than an IGBT as an IGBT has higher turn-on and turn-off energy losses.

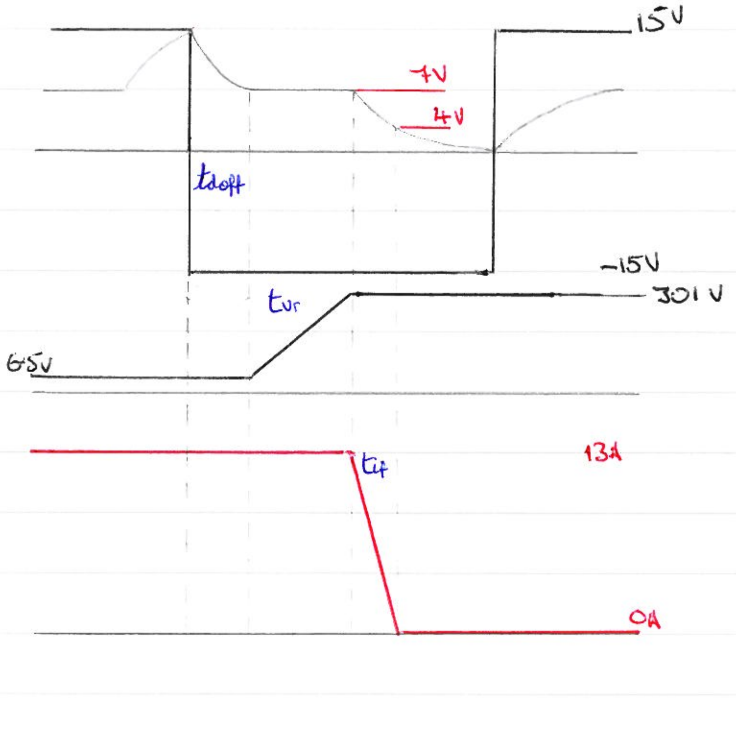
The MOSFET is more suitable at low voltage as the C-E drop of an IGBT is approximately constant across voltages, while the $R_{DS(on)}$ of a MOSFET reduces with a breakdown voltage decrease.

b) $f_{sw} = 50\,kHz$ $\quad V_{GS} = 7V$ $\quad R_{DS(on)} = 0.5\,\Omega$

$V_d = 300V$ $\quad C_{gs} = 1000pF$ $\quad V_{GG} \Rightarrow -15V \rightarrow +15V$

$I_o = 10A$ $\quad C_{gd} = 150pF$ $\quad R_G = 50\,\Omega$

$V_f = 1V$ $\quad V_{GS_{TH}} = 4V$ $\quad V_{DS} = 6.5V$

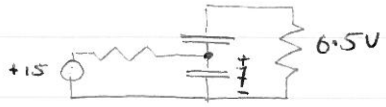


EE4001 Power Electronics, Drives, Energy Conversion Summer '06

5b) ii) $t_{don} = -R_G(C_{gs}+C_{gd})\ln\left[1-\frac{4}{15}\right]$
$= 17.8\,ns$

$t_{ir} = -R_G(C_{gs}+C_{gd})\ln\left[1-\frac{7-4}{15-4}\right]$
$= 18.3\,ns$

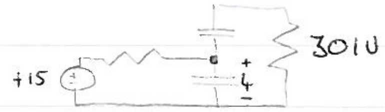
$t_{vf} = \dfrac{C_{gd}\,\Delta V_{dg}}{i_{rg}}$



$V_{dg} = 0.5V$

$\Delta V_{dg} = 297.5$

$i_{rg} = \dfrac{V_{cc}-V_{gs}}{r_g} = 0.16A$



$V_{dg} = -297V$

$t_{vf} = 278.9\,ns$

iii) $E_{on} = \frac{1}{2}(V_d+V_F)I_o(t_{ir}+t_{vf}) + \frac{1}{2}R_{DSon}I_o t_{vf}$
$= 582\,\mu J$

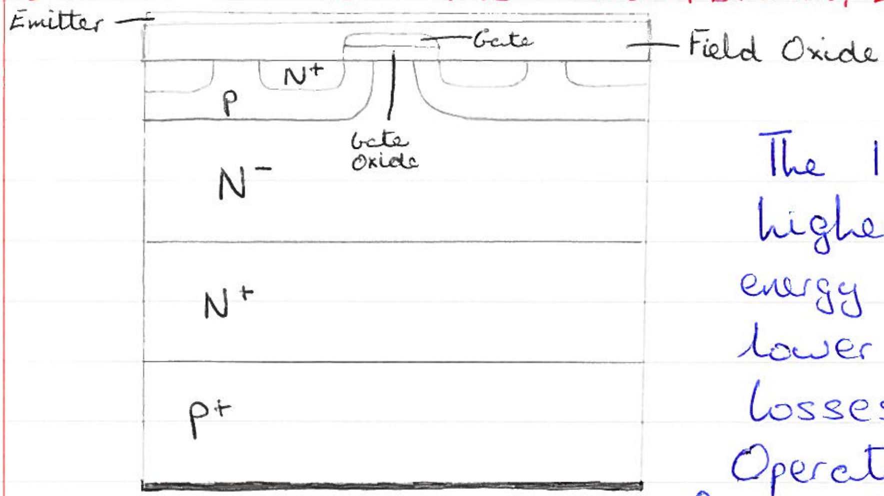
iv) $T_j = T_{HS} + (\Theta_{js} * P_{MOS})$

$P_{MOS} = 4 f_{sw} E_{on}$
$= 116.4\,W$

$T_j = T_{HS} + ([\Theta_{j\text{-}c} + \Theta_{cs}] \times P_{MOS})$
$= 70 + ([0.45+0.24]\times 116.4)$
$= 150.3\ ^\circ C$

EE4001 Power Electronics, Drives, Energy Conversion Sum. '05

5 a)



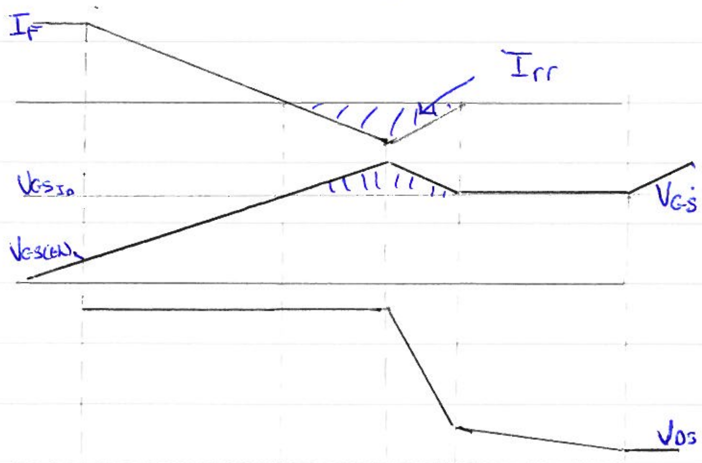
The IGBT generally has higher turn-on/turn-off energy losses but lower conduction losses than a MOSFET. Operating at low frequencies reduces the impact of switching & makes conduction the dominant loss.

b) Done, 2008

EE4001 Power Elec... Summer '04

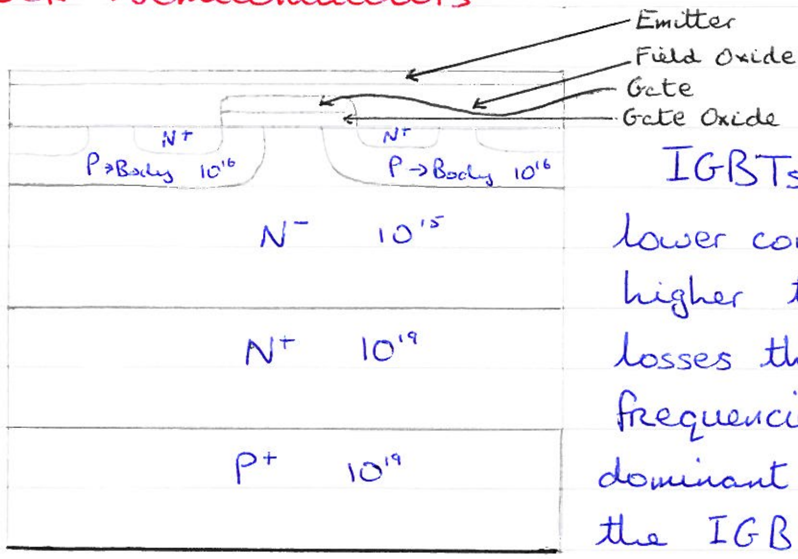
5 a) Diode current decays at a rate determined by the turn-on of the complementary IGBT/MOSFET.

- Initially, I_F drops to zero, but excess carries remain in the drift region, keeping junctions forward biased.
- This causes I_F to go negative as excess carriers are swept out.
- Negative current I_F decays to zero as the excess carriers are swept out.



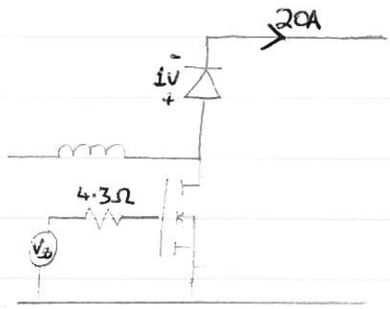
EE4001 Power Electronics, Drives, Energy Conv.
Power Semiconductors

1a)



IGBTs typically have lower conduction losses and higher turn-on/turn-off energy losses than MOSFETS. At low frequencies, conduction is the dominant source of loss, making the IGBT the better choice.

b) $V_d = 480V$
$I_o = 20A$
$V_{GG+} = 10V$
$R_G = 4.3\Omega$
$V_f = 1\ V$



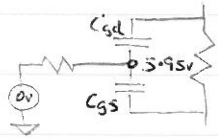
i) $V_{GS(th)}$ Max $= 5V$ $\quad$ $R_{DS(on)}$ Max @ $100°C = 0.26\Omega$

g_{fs} Min $= 21S$ $\quad$ V_{GS} @ $I_D = 20A = V_{GS(th)} + \frac{I_D}{g_{fs}}$

$C_{gs} = C_{iss} - C_{rss} = 7895pF$ $\quad$ V_{GS} @ $I_D = 20A = 5.95V$

$C_{gd} = C_{rss} = 75pF$ $\quad$ $V_{DS(on)} = I_D R_{DS(on)} = 5.2V$

iii) a) $t_{d(off)} = -R_G(C_{gs}+C_{gd})\ln\left[\frac{V_{GS I_o}}{V_{GG}}\right]$
$= 17.8ns$

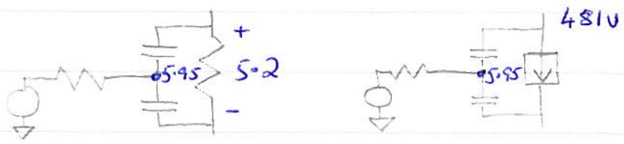


b) $t_{vr} = \frac{C_{gd}\Delta V}{i_g}$

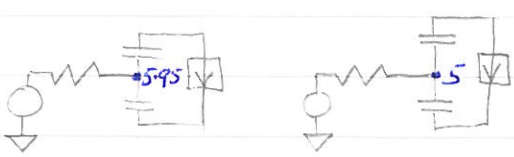
$\Delta V = -475.8$

$i_g = -\frac{5.95}{4.3} = -1.385A$

$t_{vr} = 25.8ns$

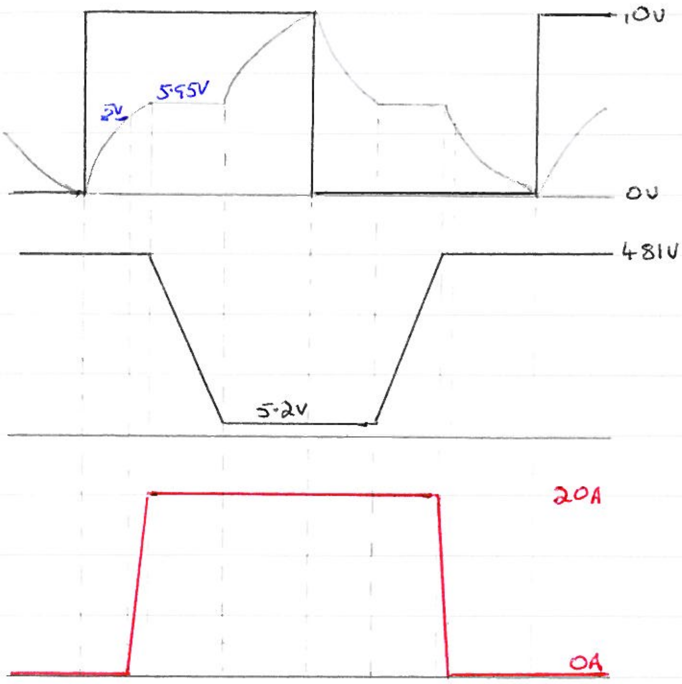


c) $t_{if} = -R_g(C_{gs}+C_{gd})\ln\left[\frac{5}{5.95}\right]$
$= 6ns$



EE4001 Power Electronics, Drives, Energy Conversion

1b ii)

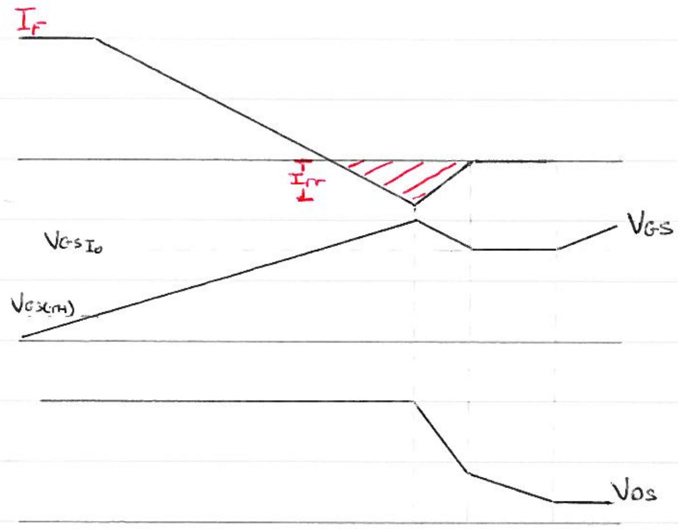


iv) $E_{off} = \frac{1}{2}(V_D + V_F) I_o (t_{vr} + t_{if})$

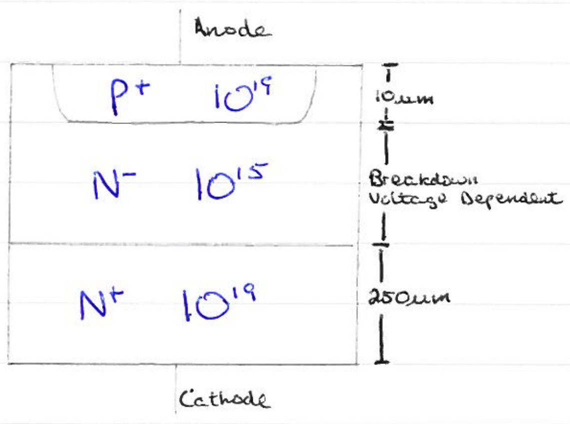
$= 153 \mu J$

2. a) The rate of decay of diode current, di/dt, is determined by the turn-on time of the complementary switch.

- Initially, I_F drops to zero but excess carriers remain in the drift region, keeping the junction forward biased.
- I_F goes negative while the excess carriers are swept out.
- I_F returns to zero when the sweep-out is complete.



b)



The n^- drift region absorbs the depletion layer of the reverse-biased p-n junction. Its width determines breakdown voltage.

EE4001 Power Electronics, Drives, Energy Conv. Semi-C Problems

2c) $f_{sw} = 20kHz$ $\quad R_G = 25\Omega$

$V_d = 300V$ $\quad V_f = 1V$

$I_o = 13A$

$V_{GG-} = 5V$

$V_{GG+} = 15V$

i) $V_{GS(TH)}$ Max $= 4V$ $\quad R_{DS(on)}$ @ $80°C = 0.432\Omega$

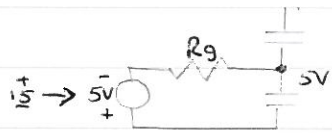
g_{fs} Min $= 13S$ $\quad V_{GS}$ @ $I_O = 13A = 5V$

$C_{gs} = 3850pF$ $\quad V_{DS(cond)} = 5.6V$

$C_{gd} = 350pF$

iii) a) $t_{d(off)} = -R_G(C_{gs}+C_{gd})\ln\left[\frac{5-(-5)}{15-(-5)}\right]$

$= 72.8ns$

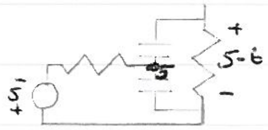


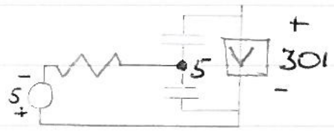
b) $t_{vr} = \frac{C_{gd}\,\Delta V_{dg}}{i_{rg}}$

$\Delta V_{dg} = +295.4$

$i_{rg} = \frac{V_{gg} - V_{gs}}{r_g} = 0.4A$

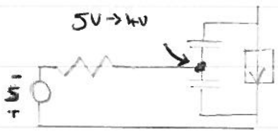
$t_{vr} = 258ns$





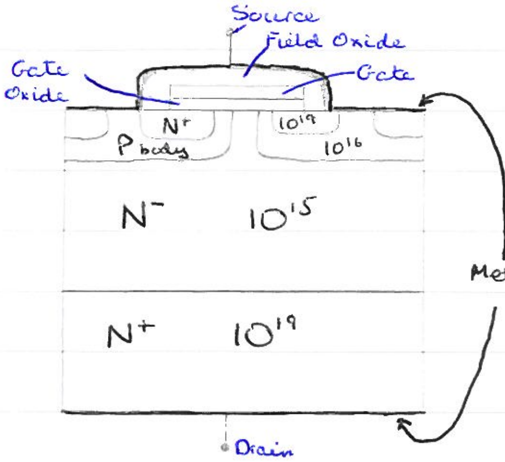
c) $t_{fv} = -R_G(C_{gs}+C_{gd})\ln\left[\frac{9}{10}\right]$

$t_{fv} = 11ns$



EE4001 Power Electronics, Drives, Energy Conv. Semi-C. Problem

6a)



MOSFETs typically have lower turn-on/turn-off energies than IGBTs, resulting in lower switching losses. Conduction losses are essentially fixed in an IGBT over a wide voltage range, while the losses in a MOSFET reduce with Voltage.

b)

$V_d = 300V$ $\quad C_{gs} = 1000pF$ $\quad V_{GG+} = 15V$

$I_o = 10A$ $\quad C_{gd} = 150pF$ $\quad R_G = 50\Omega$

$V_{GS(th)} = 4V$ $\quad R_{DS(on)} = 0.5\Omega$ $\quad V_f = 1V$

$V_{GS_{I_o}} = 7V$ $\quad V_{GG-} = -15V$

ii) a) $t_{don} = -R_g(C_{gs}+C_{gd})\ln\left[1-\frac{V_{GS(th)}}{V_{GG}}\right]$

$= 17.8ns$

b) $t_{ir} = -R_g(C_{gs}+C_{gd})\ln\left[1-\frac{7-4}{15-4}\right]$

$= 18.3ns$

c) $t_{fv} = \frac{C_{dg}\,\Delta V_{dg}}{i_{rg}}$

$\Delta V_{dg} = 296V$

$i_{rg} = \frac{V_{GG}-V_{GS}}{R_g} = 0.16A$

$t_{fv} = 277.5ns$

iii) $E_{on} = \frac{1}{2}(V_d+V_f)I_o(t_{vf}+t_{ir}) + \frac{1}{2}R_{DS(on)}I_o^2 t_{vf}$

$= 452\mu J$

iv) $T_j = T_H + (\Theta\, P_{MOS})$

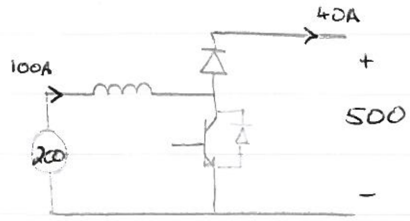
Assumed: $P_{MOS} = 4E_{on}f_{sw}$

$T_j = 70 + 45.2$

$T_j = 115.2°$

EE4001 Power Electronics, Drives, Energy Conv. Semi-C Problems

7.



$I_{LMIN} = 86A$ $\quad I_{Qrms} = 77A$

$I_{LMAX} = 114A$ $\quad I_{QAVG} = 60A$

$I_{Drms} = 63.4A$

$I_{DAVG} = 40A$

Switch turn-on / Diode turn-off @ I_{Lmin}

Switch turn-off @ I_{Lmax}

i) $P_{Q(COND)} = V_{CEon} I_{QAVG} + R_{CE} I_{Qrms}^2$

$= 97W$

ii) $P_{D(COND)} = V_f I_{Davg} + r_f I_{Qrms}^2$

$= 53W$

iii) $P_{Q(on)} = f_{sw} E_{on}(86A) \frac{500}{600}$

$= 10(12)(\frac{5}{6})$

$= 100W$

iv) $P_{Q(off)} = f_{sw} E_{off}(114A) \frac{500}{600}$

$= 10(17)\frac{5}{6}$

$= 142W$

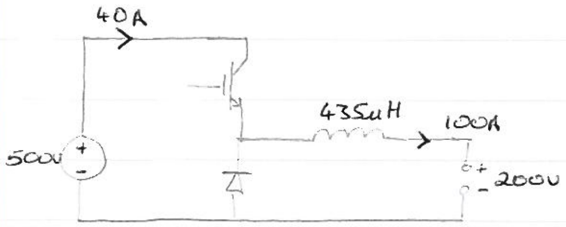
v) $P_{D(off)} = f_{sw} E_{rr}(86A) \frac{500}{600}$

$= 10(12)\frac{5}{6}$

$= 100W$

EE4001 Power Electronics, Drives, Energy Conv. Semi-C Problems

8.



$I_{Lmin} = 86A$ $\quad I_{Q rms} = 63{\cdot}4A$

$I_{Lmax} = 114A$ $\quad I_{QAVG} = 40A$

$I_{Drms} = 77A$ $\quad I_{DAVG} = 60A$

Turn-on @ I_{Lmin}, turn-off @ I_{Lmax}

i) $P_{Q(COND)} = V_{CEon} I_{QAVG} + R_{CE} I_{Qrms}^2$

$= (0{\cdot}9 \times 40) + (7{\cdot}3m \times 63{\cdot}4^2)$

$= 65W$

ii) $P_{D(COND)} = V_F I_{DAVG} + r_F I_{Drms}^2$

$= 79{\cdot}4W$

iii) $P_{Q(on)} = f_{sw} E_{on}(86A) \frac{500}{600}$

$= 100W$

iv) $P_{Q(off)} = f_{sw} E_{off}(114A) \frac{500}{600}$

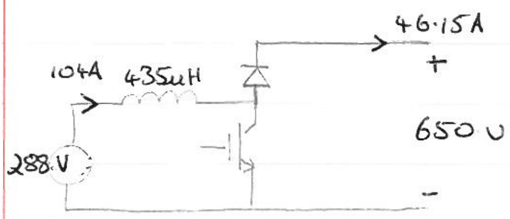
$= 146W$

v) $P_{D(off)} = f_{sw} E_{rr}(86A) \frac{500}{600}$

$= 100W$

EE4001 Power Electronics, Drives, Energy Conversion Semi-C. Probs

9.



$I_{Lmin} = 71.45A$
$I_{Lmax} = 136.95A$

$I_{Qrms} = 79\,A$ $\quad I_{Drms} = 70.5\,A$
$I_{QAVG} = 58\,A$ $\quad I_{DAVG} = 46.2\,A$

i) $P_{QCOND} = V_{CEon} I_{QAVG} + R_{CE} I_{Qrms}^2$
$= (0.9 \times 58) + (7.3m \times 79^2)$
$= 97.76W$

ii) $P_{Qon} = f_{sw} E_{on}(71.45A) \frac{650}{600}$
$= 10(10) \frac{650}{600}$
$= 108W$

iii) $P_{Qoff} = f_{sw} E_{off}(136.95A) \frac{650}{600}$
$= 10(18) \frac{650}{600}$
$= 195W$

iv) $P_{DCOND} = V_f I_{DAVG} + r_f I_{Drms}^2$
$= 63.3W$

v) $P_{Doff} = f_{sw} E_{rr}(71.45) \frac{650}{600}$
$= 10(9) \frac{650}{600}$
$= 97.5W$