[ENG17]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BENG (HONS) ELECTRICAL & ELECTRONIC ENGINEERING

SEMESTER ONE EXAMINATION 2018/2019

INTERMEDIATE ELECTRICAL PRINCIPLES & ENABLING POWER ELECTRONICS

MODULE NO: EEE5013

Date: Monday 14th January 2019 **Time: 10:00 – 12:30**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions.

Answer ANY FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

Electronic calculators may be used provided that data and program storage memory is cleared prior to the examination.

CANDIDATES REQUIRE: **Formula Sheet (attached).**

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Intermediate electrical principles & enabling power electronics
Module no. EEE5013

Q1.

(a) Determine the input voltage (V_{in1}) from a cascaded operational amplifier circuit as shown in Fig.Q1(a).

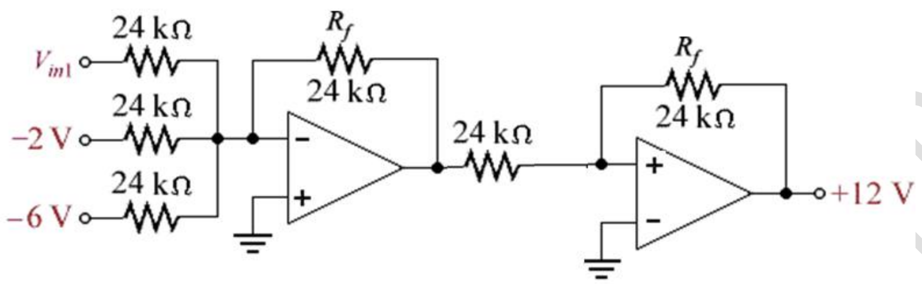

Fig.Q1 (a): A cascaded operational amplifier circuit.

[5 marks]

(b)

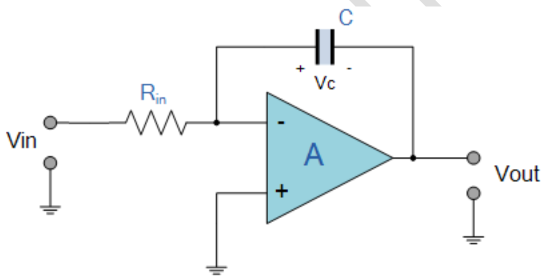

Fig.Q1 (b) An Operational amplifier integrator Circuit

A summing inverting negative feedback operation circuit, as shown in Fig. Q1 (b) with V_{in} , resistors R_{in} and capacitor C, and an output of V_{out}.

i) Derive the formula for the output of the circuit in Fig.Q1(b) in term of R_{in}, C and V_{in}.

[10 marks]

ii) If a 0 to -1 volts repetitive input signal is applied to the integrator circuit, draw the output signal over time for four period time cycle.

[5 marks]

Question 1 continues over the page….
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Question 1 continued….

(c) Fig.Q1(c) shows the voltage gain against the frequency of an op-amp. Determine the cutoff frequency of an op-amp having a unit gain frequency f_1 = 50 MHz and voltage differential gain G_d = 25**V**/μ**V.**

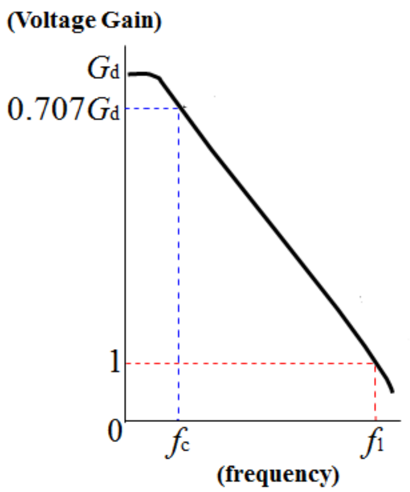

Fig.Q1 (c) An Operational amplifier's gain verse frequency

[5 marks]

Total 25 marks

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Q2.

(a) A half-wave rectifier circuit is composed from an AC source with RMS voltage of 120 V and a frequency of 60 Hz, a diode, an inductor of 10 mH, and a load resistor of 5 ohms. Calculate and plot the current i along with v_S.

[15 marks]

(b) A single-phase full-bridge inverter is operated from a 48 V battery and is supplying power to a pure resistive load of 10 ohms. Determine:

i) The fundamental output voltage and the first five harmonics. **[5 marks]**
ii) Output RMS power and output fundamental power **[2 marks]**
iii) Transistor switch ratings **[3 marks]**

Total 25 marks

Q3.

(a) A simple DC chopper is operating at a frequency of 2 kHz from a 96 V DC source to supply a load resistance of 8 ohms. The load time constant is 6 millisecond. if the average load voltage is 57.6 V, find:

i) T_{ON} period of the chopper **[3 marks]**
ii) The average load current **[4 marks]**
iii) The magnitude of the ripple current and its RMS value **[8 marks]**

(b) Prove that :

i) the line-to-line voltage of a balanced 3-phase voltages leads its corresponding phase voltage by 30^o **[5 marks]**

ii) the line-to-line current of a balanced 3-phase currents lags its corresponding phase current by 30^o. **[5 marks]**

(Hint: You may use the circuit and phasor diagrams to support your mathematical derivations for both branches i and ii.)

Total 25 marks

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Q4.

(a) Explain the power factor correction of a constant voltage inductive load. What is its importance in relation to reactive power utilisation and the supply current ? You may use a circuit diagram and the power triangle to answer this question.

[9 Marks]

(b) For the circuit shown in Fig. Q4(b) .

i) Calculate the voltage at node A and node B. You may use KCL in your answer.

[10 marks]

ii) Draw the voltage and current phasor diagrams. Take V_B as a reference phasor.

[6 marks]

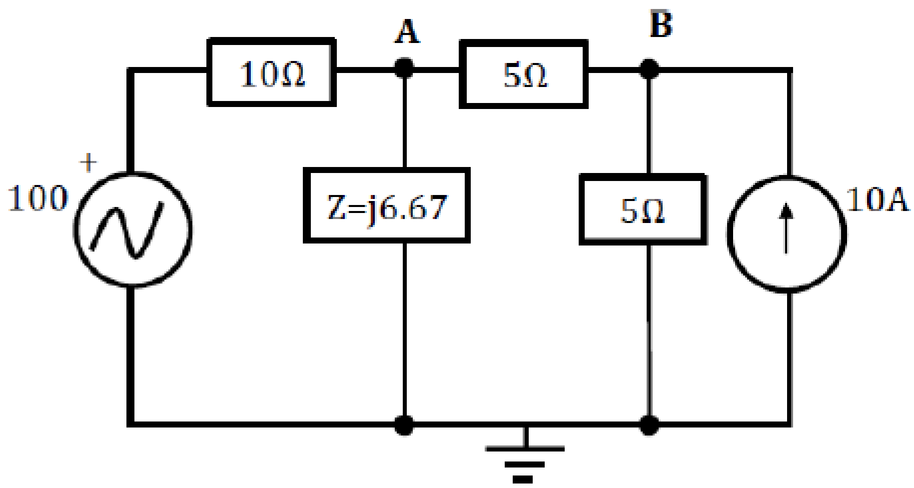

Fig.Q4 (b)

Total 25 marks

Q5.

(a) A MOSFET Device (MTP14N06A) has load current of 5 A (rms), find its respective junction temperature at steady state. Given that $R_{\theta ca}$ = 5 ^{o}C/W, $R_{DS\ (on)}$ = 0.2 Ω, $R_{\theta jc}$ = 4.3 ^{o}C/W and $P_{D(max)}$= 70 W.

(8 marks)

(b) An MOSFET IRF440 is required to operate at 30% duty cycle at the switching frequency of 10 kHz. Given the max. junction temperature $T_{j(max)}$= 80 ^{o}C, and the case temperature $T_{c(case)}$=40^{o}C with ambient temperature $T_{A(ambient)}$=30^{o}C, R_{cs}= 0.02 ^{o}C/W , find

(i) The transient impedance Z **(5 marks)**

(ii) The Peak Power and the maximum current **(6 marks)**

(iii) The required heat sink **(6 marks)**

Total 25 marks

Q6.

(a) Enumerate the basic grounding system then explain what is meant by equipment grounding. **(10 marks)**

(b) A rectangular plank floats in water. The base of the plank has a width of 25 cm, and a length of 120 cm. The thickness of the plank is 4 cm, of which a uniform 3.0 cm is below water level.

i) Calculate the pressure at the bottom of the plank, and thus the total upwards force from the water. **(4 marks)**

ii) What is the weight of the plank, and what is its mass? **(4 marks)**

iii) What is the density of the plank? **(2 marks)**

iv) If the plank later reaches sea-water, which has a density of 1027kg/m^3, how much <u>higher</u> will it float in the sea water? **(5 marks)**

Total 25 marks

END OF QUESTIONS

Formula sheets over the page….

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Formula sheet

These equations are given to save short-term memorisation of details of derived equations and are given without any explanation or definition of symbols; the student is expected to know the meanings and usage.

Converters:

$$\%\mathrm{THD}_i = 100 \times \frac{I_{\mathrm{dis}}}{I_{s1}} = 100 \times \frac{\sqrt{I_s^2 - I_{s1}^2}}{I_{s1}} = 100 \times \sqrt{\sum_{h \neq 1} \left(\frac{I_{sh}}{I_{s1}}\right)^2}$$

$$\mathrm{PF} = \frac{V_s I_{s1} \cos \phi_1}{V_s I_s} = \frac{I_{s1}}{I_s} \cos \phi_1$$

$$\mathrm{DPF} = \cos \phi_1$$

$$\mathrm{PF} = \frac{I_{s1}}{I_s} \mathrm{DPF}$$

$$\mathrm{PF} = \frac{1}{\sqrt{1 + \mathrm{THD}_i^2}} \mathrm{DPF}$$

$$A_u = \sqrt{2} V_s (1 - \cos u) = \omega L_s I_d$$

$$\cos u = 1 - \frac{\omega L_s I_d}{\sqrt{2} V_s}$$

$$V_d = 0.45 V_s - \frac{\text{area } A_u}{2\pi} = 0.45 V_s - \frac{\omega L_s}{2\pi} I_d$$

$$V_d = 1.35\, V_{LL} \cos\alpha - 3 \frac{\omega L_s}{\pi} I_d$$

$$\cos(\alpha + u) = \cos \alpha - 2 \frac{\omega L_s}{\sqrt{2} V_{LL}} I_d$$

$$\gamma = 180 - (\alpha + u)$$

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$$V_L = \left[\frac{1}{T}\int_0^T v_L^2(t)dt\right]^{1/2}$$

$$V_{dc} = \frac{1}{T}\int_0^T v_L(t)\,dt$$

$$\text{TUF} = \frac{P_{dc}}{V_s I_s} = \frac{V_{dc} I_{dc}}{V_s I_s}$$

$$\text{RF} = \frac{V_{ac}}{V_{dc}}$$

$$\sigma = \frac{P_{dc}}{P_L} = \frac{V_{dc} I_{dc}}{V_L I_L}$$

$$\text{FF} = \frac{V_L}{V_{dc}} \quad \text{or} \quad \frac{I_L}{I_{dc}}$$

$$V_{d\alpha} = \frac{1}{2\pi}\int_\alpha^\pi V_{max}\sin(\omega t)d(\omega t) = \frac{V_{max}}{2\pi}(1+\cos\alpha)$$

$V_{ph} = \frac{V}{\sqrt{3}}$, $I_{ph} = I$ *for star connection*, $V_{ph} = V$, $I_{ph} = \frac{I}{\sqrt{3}}$ *for delta connection*

$S = \sqrt{3}VI \;\; V.A$, $P = \sqrt{3}VIcos\theta \;\; W.$, $Q = \sqrt{3}VIsin\theta \;\; V.A.r$

$Q_C = \sqrt{3}VI_C \;\; V.A.r$, $X_C = \frac{V}{\sqrt{3}I_C} \;\; \Omega$

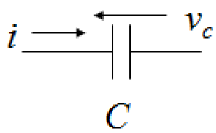
<u>Operational amplifiers</u>

Non-Inverting amplifier: $\frac{V_o}{V_i} = 1 + \frac{R_f}{R_a}$

Inverting amplifier: $\frac{V_o}{V_{in}} = \frac{-R_f}{R_a}$

$$V_o = -R_f\left(\frac{V_a}{R_a} + \frac{V_b}{R_b} + \frac{V_c}{R_c}\right) = -R_f \sum_{j=a}^{c} \frac{V_j}{R_j}$$

Gain-Bandwidth Product: $f_1 = G_d f_c$



$$v_c = \frac{1}{C}\int i\,dt \qquad i = C\,\frac{dv}{dt}$$

Integrator:

$$V_o = \frac{-1}{RC}\int V_{in}\,\mathrm{dt}$$

Differentiator:

$$v_o = -RC\,\frac{dv_{in}}{dt}$$

Thermal analysis formula

$$\theta_{JATotal} = \theta_{JC} + \theta_{CA} = \frac{T_J - T_A}{P}$$

$$\theta_{JATotal} = \theta_{JC} + \theta_{CS} + \theta_{SA} = \frac{T_J - T_A}{P}$$

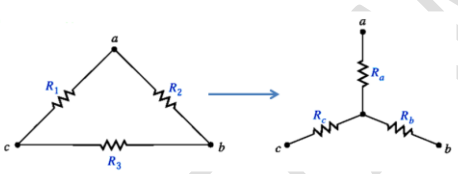
$$\Theta cs = \frac{(\rho)(t)}{A}$$

$$Z_{\theta\ (j-C)} = r(t_p) \times R_{\theta\ (j-C)}$$

$$P_{peak} = \frac{T_{j(\max)} - T_C}{Z(t_p, \delta)} \quad where\ \ \delta = dutycycle$$

$$P_{ave} = \delta \times P_{peak}$$

Three-phase systems

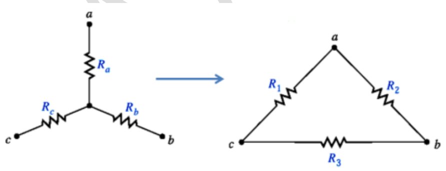


Delta to Star conversion:

$$R_a = \frac{R_1 R_2}{R_1 + R_2 + R_3}$$

$$R_b = \frac{R_2 R_3}{R_1 + R_2 + R_3}$$

$$R_c = \frac{R_3 R_1}{R_1 + R_2 + R_3}$$



$$R_1 = \frac{R_a R_b + R_b R_c + R_c R_a}{R_b}$$

$$R_2 = \frac{R_a R_b + R_b R_c + R_c R_a}{R_c}$$

$$R_3 = \frac{R_a R_b + R_b R_c + R_c R_a}{R_a}$$

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Star to Delta conversion:

Gravity:

9.81 m/s

Thermal resistance of the interface material:

$$\theta_{cs} = \frac{(\rho)(t)}{A}$$

Output voltage of a differentiator circuit:

$$v_0 = -R_2 C_1 \frac{dv_I}{dt}$$

Compressibility relationship:

$$K = -V \frac{d\,P}{d\,V}$$

General manometer:

$$\Delta P = |\ \Delta\rho\ g\ \Delta h\ |$$

Venturi meter:

$$v_{\text{in}} = C_D \sqrt{\frac{2\,\Delta P}{\rho_f\left[\left(\frac{d_{\text{large}}}{d_{\text{small}}}\right)^4 - 1\right]}}$$

Force on a submerged wall:

$$F = \frac{\rho g a h^2}{2}$$

Drag coefficient:

$$C_{Drag} = \frac{F_D}{\frac{1}{2}\rho v^2 A}$$

Flow through a small hole:

$$Q = C_D \sqrt{\frac{2\,\Delta P}{\rho}}\ A$$

Flow through a rectangular slit:

$$Q = \frac{2}{3} C_D\ W \sqrt{2g}\left[(Ho + L)^{\frac{3}{2}} - Ho^{\frac{3}{2}}\right]$$

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Tank draining:

$$h^{\frac{1}{2}} = h_0^{\frac{1}{2}} - \frac{C_D a\sqrt{2g}}{2A} t$$

Flow over a rectangular weir:

$$Q = \frac{2}{3} C_D W \sqrt{2g}\ H^{\frac{3}{2}}$$

Flow over a V-notch weir:

$$Q = \frac{8}{15} C_D \tan\left(\theta/_2\right)(2g)^{\frac{1}{2}}\ H^{\frac{5}{2}}$$

Poisseuille's Law:

$$Q = -\frac{\pi}{128\mu}\frac{dP}{dx} D^4$$

Darcy's Law:

$$\Delta P = \frac{2 f L \rho \overline{u}^2}{D}$$

Summary of phase and line voltages/currents for balanced three-phase systems.[1]

Connection	Phase voltages/currents	Line voltages/currents
Y-Y	$\mathbf{V}_{an} = V_p\angle 0°$ $\mathbf{V}_{bn} = V_p\angle -120°$ $\mathbf{V}_{cn} = V_p\angle +120°$ Same as line currents	$\mathbf{V}_{ab} = \sqrt{3}V_p\angle 30°$ $\mathbf{V}_{bc} = \mathbf{V}_{ab}\angle -120°$ $\mathbf{V}_{ca} = \mathbf{V}_{ab}\angle +120°$ $\mathbf{I}_a = \mathbf{V}_{an}/\mathbf{Z}_Y$ $\mathbf{I}_b = \mathbf{I}_a\angle -120°$ $\mathbf{I}_c = \mathbf{I}_a\angle +120°$
Y-Δ	$\mathbf{V}_{an} = V_p\angle 0°$ $\mathbf{V}_{bn} = V_p\angle -120°$ $\mathbf{V}_{cn} = V_p\angle +120°$ $\mathbf{I}_{AB} = \mathbf{V}_{AB}/\mathbf{Z}_\Delta$ $\mathbf{I}_{BC} = \mathbf{V}_{BC}/\mathbf{Z}_\Delta$ $\mathbf{I}_{CA} = \mathbf{V}_{CA}/\mathbf{Z}_\Delta$	$\mathbf{V}_{ab} = \mathbf{V}_{AB} = \sqrt{3}V_p\angle 30°$ $\mathbf{V}_{bc} = \mathbf{V}_{BC} = \mathbf{V}_{ab}\angle -120°$ $\mathbf{V}_{ca} = \mathbf{V}_{CA} = \mathbf{V}_{ab}\angle +120°$ $\mathbf{I}_a = \mathbf{I}_{AB}\sqrt{3}\angle -30°$ $\mathbf{I}_b = \mathbf{I}_a\angle -120°$ $\mathbf{I}_c = \mathbf{I}_a\angle +120°$
Δ-Δ	$\mathbf{V}_{ab} = V_p\angle 0°$ $\mathbf{V}_{bc} = V_p\angle -120°$ $\mathbf{V}_{ca} = V_p\angle +120°$ $\mathbf{I}_{AB} = \mathbf{V}_{ab}/\mathbf{Z}_\Delta$ $\mathbf{I}_{BC} = \mathbf{V}_{bc}/\mathbf{Z}_\Delta$ $\mathbf{I}_{CA} = \mathbf{V}_{ca}/\mathbf{Z}_\Delta$	Same as phase voltages $\mathbf{I}_a = \mathbf{I}_{AB}\sqrt{3}\angle -30°$ $\mathbf{I}_b = \mathbf{I}_a\angle -120°$ $\mathbf{I}_c = \mathbf{I}_a\angle +120°$
Δ-Y	$\mathbf{V}_{ab} = V_p\angle 0°$ $\mathbf{V}_{bc} = V_p\angle -120°$ $\mathbf{V}_{ca} = V_p\angle +120°$ Same as line currents	Same as phase voltages $\mathbf{I}_a = \frac{V_p\angle -30°}{\sqrt{3}\mathbf{Z}_Y}$ $\mathbf{I}_b = \mathbf{I}_a\angle -120°$ $\mathbf{I}_c = \mathbf{I}_a\angle +120°$

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Datasheet

PD - 90372A

International Rectifier

REPETITIVE AVALANCHE AND dv/dt RATED
HEXFET® TRANSISTORS
THRU-HOLE (TO-204AA/AE)

IRF440
500V, N-CHANNEL

Product Summary

Part Number	BVDSS	$R_{DS(on)}$	I_D
IRF440	500V	0.85Ω	8.0A

TO-3

The HEXFET® technology is the key to International Rectifier's advanced line of power MOSFET transistors. The efficient geometry and unique processing of this latest "State of the Art" design achieves: very low on-state resistance combined with high transconductance; superior reverse energy and diode recovery dv/dt capability.

The HEXFET transistors also feature all of the well established advantages of MOSFETs such as voltage control, very fast switching, ease of paralleling and temperature stability of the electrical parameters.

They are well suited for applications such as switching power supplies, motor controls, inverters, choppers, audio amplifiers and high energy pulse circuits.

Features:

- Repetitive Avalanche Ratings
- Dynamic dv/dt Rating
- Hermetically Sealed
- Simple Drive Requirements
- Ease of Paralleling

Absolute Maximum Ratings

	Parameter		Units
I_D @ V_{GS} =0V, T_C = 25°C	Continuous Drain Current	8.0	A
I_D @ V_{GS} = 0V, T_C = 100°C	Continuous Drain Current	5.0	
I_{DM}	Pulsed Drain Current ①	32	
P_D @ T_C = 25°C	Max. Power Dissipation	125	W
	Linear Derating Factor	1.0	W/°C
V_{GS}	Gate-to-Source Voltage	±20	V
E_{AS}	Single Pulse Avalanche Energy ②	700	mJ
I_{AR}	Avalanche Current ①	8.0	A
E_{AR}	Repetitive Avalanche Energy ①	-	mJ
dv/dt	Peak Diode Recovery dv/dt ③	3.5	V/ns
T_J T_{STG}	Operating Junction Storage Temperature Range	-55 to 150	°C
	Lead Temperature	300 (0.063 in. (1.6mm) from case for 10s)	
	Weight	11.5(typical)	g

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Electrical Characteristics @ Tj = 25°C (Unless Otherwise Specified)

	Parameter	Min	Typ	Max	Units	Test Conditions
BV_{DSS}	Drain-to-Source Breakdown Voltage	500	—	—	V	V_{GS} = 0V, I_D = 1.0mA
$\Delta BV_{DSS}/\Delta T_J$	Temperature Coefficient of Breakdown Voltage	—	0.78	—	V/°C	Reference to 25°C, I_D = 1.0mA
$R_{DS(on)}$	Static Drain-to-Source On-State Resistance	—	—	0.85	Ω	V_{GS} = 10V, I_D = 5.0A ④
		—	—	0.98		V_{GS} = 10V, I_D =8.0A ④
$V_{GS(th)}$	Gate Threshold Voltage	2.0	—	4.0	V	$V_{DS} = V_{GS}$, I_D =250μA
g_{fs}	Forward Transconductance	4.7	—	—	S (℧)	V_{DS} > 15V, I_{DS} = 5.0A ④
I_{DSS}	Zero Gate Voltage Drain Current	—	—	25	μA	V_{DS}=400V, V_{GS}=0V
		—	—	250		V_{DS} = 400V V_{GS} = 0V, T_J = 125°C
I_{GSS}	Gate-to-Source Leakage Forward	—	—	100	nA	V_{GS} = 20V
I_{GSS}	Gate-to-Source Leakage Reverse	—	—	-100		V_{GS} = -20V
Q_g	Total Gate Charge	27.3	—	68.5	nC	V_{GS} =10V, ID=8.0A V_{DS} = 250V
Q_{gs}	Gate-to-Source Charge	2.0	—	12.5		
Q_{gd}	Gate-to-Drain ('Miller') Charge	11	—	42		
$t_{d(on)}$	Turn-On Delay Time	—	—	21	ns	V_{DD} =250V, I_D =8.0A, R_G =9.1Ω
t_r	Rise Time	—	—	73		
$t_{d(off)}$	Turn-Off Delay Time	—	—	72		
t_f	Fall Time	—	—	51		
$L_S + L_D$	Total Inductance	—	6.1	—	nH	Measured from drain lead (6mm/0.25in. from package) to source lead (6mm/0.25in. from package)
C_{iss}	Input Capacitance	—	1300		pF	V_{GS} = 0V, V_{DS} = 25V f = 1.0MHz
C_{oss}	Output Capacitance	—	310	—		
C_{rss}	Reverse Transfer Capacitance	—	120	—		

Source-Drain Diode Ratings and Characteristics

	Parameter	Min	Typ	Max	Units	Test Conditions
I_S	Continuous Source Current (Body Diode)	—	—	8.0	A	
I_{SM}	Pulse Source Current (Body Diode) ①	—	—	32		
V_{SD}	Diode Forward Voltage	—	—	1.5	V	T_j = 25°C, I_S = 8.0A, V_{GS} = 0V ④
t_{rr}	Reverse Recovery Time	—	—	700	nS	T_j = 25°C, I_F = 8.0A, di/dt ≤ 100A/μs V_{DD} ≤ 50V ④
Q_{RR}	Reverse Recovery Charge	—	—	8.9	μC	
t_{on}	Forward Turn-On Time	Intrinsic turn-on time is negligible. Turn-on speed is substantially controlled by $L_S + L_D$.				

Thermal Resistance

	Parameter	Min	Typ	Max	Units	Test Conditions
R_{thJC}	Junction to Case	—	—	1.0	°C/W	
R_{thJA}	Junction to Ambient	—	—	30		Typical socket mount

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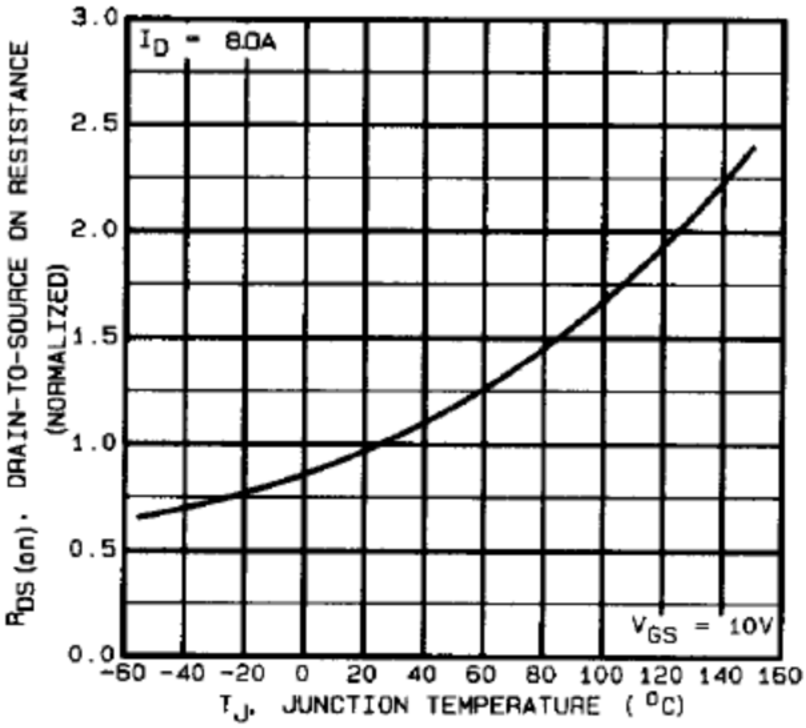

Fig. Normalized On-Resistance ($R_{DS(on)}$) verse Temperature

Table: Rectangular Pulse Duration verse Effective transient Thermal Impedance

Rectangular Pulse Duration (Seconds)	Effective Transient Thermal Impedance, $Z_{\theta jc}$ (Ω)
10 uS	0.08
20 uS	0.12
30 uS	0.18
40 uS	0.22
50 uS	0.30
60 uS	0.35

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