First Semester Examination
2022/2023 Academic Session

February 2023

EEK361 – POWER ELECTRONICS
(ELEKTRONIK KUASA)

Duration: 3 hours
(Masa: 3 jam)

Please check that this examination paper consists of **TWELVE (12)** pages of printed material including appendix before you begin the examination.

*[Sila pastikan bahawa kertas peperiksaan ini mengandungi **DUA BELAS (12)** muka surat yang bercetak termasuk lampiran sebelum anda memulakan peperiksaan ini.]*

Instructions: This question paper consists of **FOUR (4)** questions. Answer **ALL** questions. All questions carry the same marks.

[***Arahan:*** *Kertas soalan ini mengandungi **EMPAT (4)** soalan. Jawab **SEMUA** soalan. Semua soalan membawa jumlah markah yang sama.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah digunapakai.]

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1. (a) A diode is a specialized electronic component with two electrodes called the anode and the cathode. The most common function of a diode is to allow an electric current to pass in one direction while blocking it in the opposite direction:

Diod adalah komponen elektronik khusus dengan dua elektrod yang dipanggil anod dan katod. Fungsi yang paling umum diod adalah untuk membolehkan arus elektrik mengalir dalam satu arah sambil menyekatnya dari arah yang bertentangan:

(i) Draw the structure, symbol and *I-V* characteristics of a diode.

Lukiskan struktur, simbol dan ciri-ciri I-V diod.

(30 marks/*markah*)

(ii) The reverse recovery time of diode is $t_{rr} = 5\mu s$ and the fall rate of a diode current is $di/dt = 40A/\mu s$. Determine the reverse current, I_{rr} and storage charge Q_{rr} for abrupt recovery.

Masa pemulihan balik diode adalah $t_{rr} = 5\mu s$ *dan kejatuhan kadar arus diod adalah* $di/dt = 40A/\mu s$. *Tentukan arus pemulihan terbalik* I_{rr} *dan caj penyimpanan terbalik* Q_{rr} *untuk pemulihan yang mendadak.*

(20 marks/*markah*)

(b) Power diodes have high current and high voltage ratings compared to ordinary signal diodes:

Diod kuasa mempunyai nilai kadaran arus dan voltan yang tinggi berbanding dengan diod isyarat biasa:

(i) List two differences between power diode and signal diode and list two types of power diodes commonly used in converter circuits.
Senaraikan dua perbezaan antara diod kuasa dan diod isyarat dan senaraikan dua jenis diod kuasa yang biasa digunakan dalam litar penukar.

(20 marks/*markah*)

(ii) Two diodes are connected in series as in Figure 1.1 to share a total voltage of $V_D = 5kV$. The reverse leakage current of the diode is $I_{s1} = 30mA$ and $I_{s2} = 35mA$. Find the diode blocking voltage if the voltage sharing resistor are equal $R_1 = R_2 = 100k\Omega$.

Dua diod disambung secara siri seperti dalam Rajah 1.1 berkongsi voltan keseluruhan $V_D = 5kV$. Arus kebocoran balik diod adalah $I_{s1} = 30mA$ dan $I_{s2} = 35mA$. Cari voltan sekatan diod jika voltan perintang perkongsian adalah sama $R_1 = R_2 = 100k\Omega$.

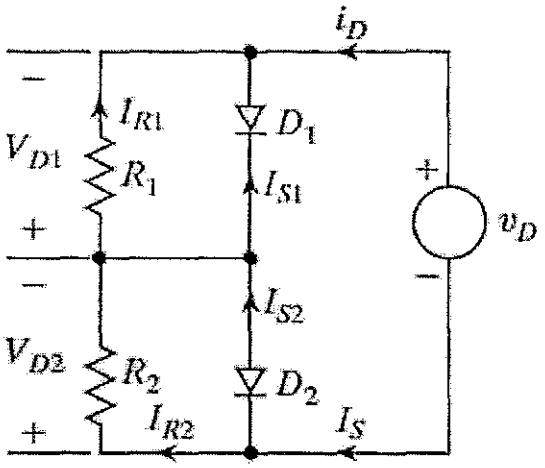

Figure 1.1
Rajah 1.1

(30 marks/*markah*)

2. (a) Explain and draw circuit components showing the thyristor protection.

Terangkan dan lukis komponen litar perlindungan terhadap thyristor.

(20 marks/*markah*)

(b) Power BJT are still widely used despite the dominance of MOSFET and IGBT in power electronics switches.

Peranti BJT kuasa masih lagi digunakan secara meluas walaupun MOSFET dan IGBT telah mendominasi bagi peranti suis elektronik kuasa.

(i) Discuss why NPN BJTs are widely used than PNP for switching application.

Bincangkan mengapa BJT jenis NPN digunakan dengan meluas daripada jenis PNP untuk aplikasi suis.

(30 marks/*markah*)

(ii) What is the difference between MOSFET and IGBT, and for high speed switching application which device is more suitable? Explain.

Apakah perbezaan antara peranti MOSFET dan IGBT, dan bagi aplikasi suis berkelajuan tinggi, peranti manakah yang lebih sesuai? Terangkan.

(20 marks/*markah*)

(c) Two power MOSFETs are connected in parallel as shown in Figure 2.1 and carry the total current $I_T = 20A$. The drain-to-source voltage of MOSFET, M_1 is $V_{DS1} = 2.5V$ and that of MOSFET, M_2 is $V_{DS2} = 3V$. Calculate the drain current of each MOSFET and differences in current sharing if the current sharing series resistance for R_{S1} and R_{S2} are 0.3Ω and 0.2Ω, respectively.

Dua MOSFET kuasa disambungkan secara selari seperti di Rajah 2.1 dan membawa jumlah arus $I_T = 20A$. Voltan saliran-sumber MOSFET, M_1 adalah $V_{DS1} = 2.5V$ dan MOSFET, M_2 adalah $V_{DS2} = 3V$. Hitungkan arus saliran untuk setiap MOSFET dan perbezaan perkongsian arus jika perkongsian perintang sesiri R_{S1} dan R_{S2} adalah masing-masing 0.3Ω and 0.2Ω.

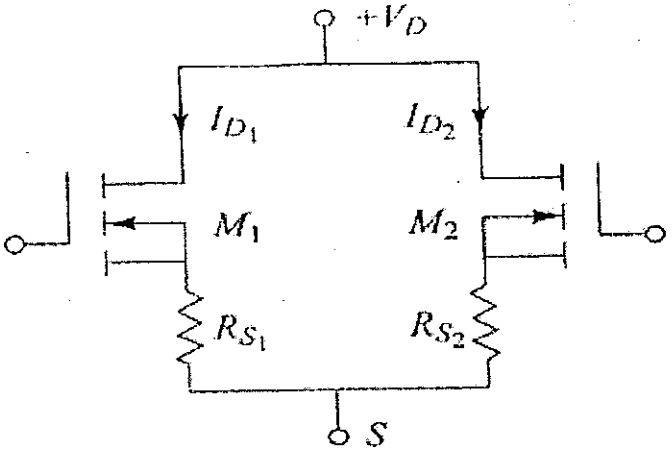

Figure 2.1
Rajah 2.1

(30 marks/*markah*)

3. (a) A single-phase full-wave controlled rectifier is operated from a 240 V, 60 Hz supply and connected to a 25 Ω resistive load. Given that the output power (P_{dc}) of the rectifier is 30% of the maximum possible output power, answer the following:

Satu penukar gelombang-penuh satu-fasa dikendalikan daripada bekalan 240 V, 60 Hz dan disambung ke satu beban rintangan 25 Ω. Diberikan bahawa kuasa keluaran (P_{dc}) penerus tersebut ialah 30% daripada kuasa keluaran maksimum yang mungkin, jawab yang berikut:

(i) Draw the schematic diagram of the rectifier circuit

Lukiskan gambarajah skematik untuk litar penerus tersebut.

(6 marks/*markah*)

(ii) Sketch the waveforms of the input voltage and current, and output voltage and current.

Lakarkan bentuk gelombang untuk voltan dan arus masukan, dan voltan dan arus keluaran.

(8 marks/*markah*)

(iii) Derive an equation for the average output voltage in terms of the firing angle, α.

Terbitkan satu persamaan untuk voltan keluaran purata dalam sebutan sudut pacuan, α.

(10 marks/*markah*)

(iv) Derive an equation for the rms output voltage in terms of the firing angle, α.

Terbitkan satu persamaan untuk voltan keluaran rms dalam sebutan sudut pacuan, α.

(12 marks/*markah*)

(v) Calculate the firing angle of the thyristors.

Kirakan sudut pacuan thyristor.

(12 marks/*markah*)

(vi) Calculate the rectification efficiency.

Kirakan kecekapan penerusan.

(12 marks/*markah*)

(b) Figure 3.1 shows a type of DC-DC converter circuit. Refering to this figure, answer the following questions:

Rajah 3.1 menunjukkan sejenis litar penukar AT AT. Merujuk kepada rajah ini, jawab soalan-soalan berikut:

(i) What is the type of this DC-DC converter?

Apakah jenis penukar AT-AT yang ini?

(5 marks/*markah*)

(ii) Draw the equivalent circuit during Mode 1 (when switch is on) and Mode 2 (when switch is off).

Lukiskan litar setara ketika Mod 1 (bila suis tertutup) dan Mod 2 (bila suis terbuka).

(10 marks/*markah*)

(iii) Prove that the average output voltage, $V_a = kV_s$, where V_s is the input voltage and k is the duty cycle.

Buktikan bahawa voltan keluaran purata, $V_a = kV_s$, di mana V_s ialah voltan input dan k ialah kitar tugas.

(25 marks/*markah*)

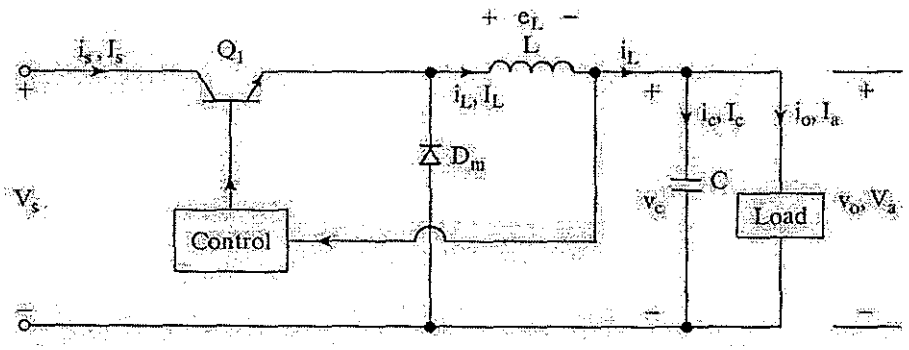

Figure 3.1
Rajah 3.1

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4. (a) Design a single-phase full-wave AC volage controller based-on phase control technique to control the power delivered to a resistive load from an AC source.

Rekabentuk satu pengawal voltan AU gelombang penuh satu fasa berdasarkan teknik kawalan fasa untuk mengawal kuasa yang dihantar ke satu beban perintang daripada satu sumber AU.

(i) Draw the circuit diagram of the AC voltage controller.

Lukis gambarajah litar untuk pegawal voltan AU tersebut.

(10 marks/*markah*)

(ii) Sketch the waveforms of the input and output voltage, and the output current.

Lakarkan bentuk gelombang untuk voltan masukan dan keluaran, dan arus keluaran.

(6 marks/*markah*)

(iii) Explain the operation of the circuit.

Terangkan operasi litar tersebut.

(15 marks/*markah*)

(iv) Derive an equation for the rms output voltage in terms of the firing angle, α.

Terbitkan satu persamaan untuk voltan keluaran rms dalam sebutan sudut pacuan, α.

(15 marks/*markah*)

(b) Explain two types of devices that can be used for over voltage protection in a power electronics circuit.

Terangkan dua jenis peranti yang boleh digunakan untuk perlindungan voltan berlebihan dalam litar elektronik kuasa.

(15 marks/*markah*)

(c) A power MOSFET is used in the design of a power electronics switching circuit. A heat sink with thermal resistance, $R_{\theta,SA}$ = 3.6 °C/W is attached to the MOSFET. Assume that the ambient temperature is 29 °C, answer the following: (Note: the data sheet of the MOSFET is given in Appendix A).

Satu MOSFET kuasa digunakan dalam rekabentuk satu litar pensuisan elektronik kuasa. Satu penenggelam haba dengan perintang haba, $R_{\theta,SA}$ = 3.6 °C/W dipasang pada MOSFET tersebut. Andaikan bahawa suhu sekitar adalah 29 °C, jawab soalan-soalan berikut: (Nota: Helaian data untuk MOSFET tersebut diberikan dalam Lampiran A).

(i) Draw the electrical analogy circuit for heat transfer from semiconductor junction of the MOSFET to ambient. Label and explain each of the components in the analogy circuit.

Lukiskan litar analogi elektrik untuk pengaliran haba dari simpang semikonduktor MOSFET ke sekitar. Label dan terangkan setiap komponen dalam litar analogi tersebut.

(15 marks/*markah*)

(ii) Calculate the maximum power that can be absorbed by the MOSFET without exceeding its maximum junction temperature, T_J.

Kirakan kuasa maximum yang boleh diserap oleh MOSFET tersebut tanpa melebihi suhu simpang maksimumnya, T_J .

(12 marks/*markah*)

(iii) A small cooling fan is attached to the heat sink such that the MOSFET can absorb 40 W of power without exceeding its maximum T_J. Calculate the required thermal resistance ($R_{\theta,SA}$) of the heat sink with the fan attached.

Satu kipas penyejuk kecil telah dipasang pada penenggelam haba tersebut supaya MOSFET ini boleh menyerap kuasa 40 W tanpa melebihi T_J maksimumnya. Kirakan rintangan haba ($R_{\theta,SA}$) yang diperlukan untuk penenggelam haba dengan kipas dipasang.

(12 marks/*markah*)

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APPENDIX A

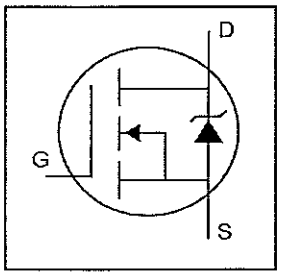
LAMPIRAN A

PD - 94006A

IRF640N
IRF640NS
IRF640NL

HEXFET® Power MOSFET

- Advanced Process Technology
- Dynamic dv/dt Rating
- 175°C Operating Temperature
- Fast Switching
- Fully Avalanche Rated
- Ease of Paralleling
- Simple Drive Requirements



V_{DSS} = 200V

$R_{DS(on)}$ = 0.15Ω

I_D = 18A

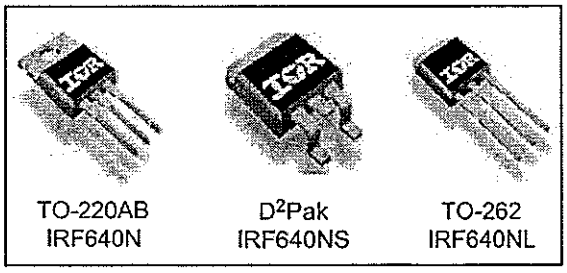
Description

Fifth Generation HEXFET® Power MOSFETs from International Rectifier utilize advanced processing techniques to achieve extremely low on-resistance per silicon area. This benefit, combined with the fast switching speed and ruggedized device design that HEXFET Power MOSFETs are well known for, provides the designer with an extremely efficient and reliable device for use in a wide variety of applications.

The TO-220 package is universally preferred for all commercial-industrial applications at power dissipation levels to approximately 50 watts. The low thermal resistance and low package cost of the TO-220 contribute to its wide acceptance throughout the industry.

The D^2Pak is a surface mount power package capable of accommodating die sizes up to HEX-4. It provides the highest power capability and the lowest possible on-resistance in any existing surface mount package. The D^2Pak is suitable for high current applications because of its low internal connection resistance and can dissipate up to 2.0W in a typical surface mount application.

The through-hole version (IRF640NL) is available for low-profile application.



TO-220AB IRF640N | D^2Pak IRF640NS | TO-262 IRF640NL

Absolute Maximum Ratings

	Parameter	Max.	Units
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ 10V	18	A
I_D @ T_C = 100°C	Continuous Drain Current, V_{GS} @ 10V	13	
I_{DM}	Pulsed Drain Current ①	72	
P_D @T_C = 25°C	Power Dissipation	150	W
	Linear Derating Factor	1.0	W/°C
V_{GS}	Gate-to-Source Voltage	± 20	V
E_{AS}	Single Pulse Avalanche Energy②	247	mJ
I_{AR}	Avalanche Current①	18	A
E_{AR}	Repetitive Avalanche Energy①	15	mJ
dv/dt	Peak Diode Recovery dv/dt ⑥	8.1	V/ns
T_J	Operating Junction and	-55 to +175	°C
T_{STG}	Storage Temperature Range		
	Soldering Temperature, for 10 seconds	300 (1.6mm from case)	

Thermal Resistance

	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	—	1.0	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface ④	0.50	—	
$R_{\theta JA}$	Junction-to-Ambient④	—	62	

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APPENDIX B

LAMPIRAN B

Question	Course Outcome (CO)	Programme Outcome (PO)
1	1	PO1
2	2	PO2
3	2	PO2
4	3	PO3