Electrotechnology

22TTB211

Semester 2 2023 In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **2 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

Answer all three questions.

A formula sheet is provided at the end of the paper.

Please submit all answers on this paper.

You can make calculations on additional paper, but they will not usually be marked.

Your Seat and ID number

Please write your seat and ID number in the boxes provided. Then fill in the appropriate circles to mark your ID number for the scanner, using one digit per column.
You will also need to write your ID number at the top of each page.

Form-filling

The multiple-choice part of this test will be marked by machine.

Use a pencil to fill in the circles like this ○ → 
Do NOT tick  , do NOT dash  , do NOT cross  the circles.
Use an eraser to rectify mistakes, don't scribble them out.
Do NOT use a biro – you will not be able to erase the mark.

Indicate your answers by filling in the appropriate circles, but also write your answer on the line before the circle. This will act as a human-readable double-check in case of smudges, bad erasures or other problems. For example, if your answer is B, the right way to fill in is:

__	Ⓐ	15%	__	Ⓒ	85%
B		23%	__	Ⓓ	none of the above

Start by writing your seat and ID number, and filling in the ID grid, one digit per column:

Seat number: _____

Student ID:

↓	↓	↓	↓	↓	↓	↓
Ⓐ	0	0	0	0	0	0
Ⓑ	1	1	1	1	1	1
Ⓕ	2	2	2	2	2	2
	3	3	3	3	3	3
	4	4	4	4	4	4
	5	5	5	5	5	5
	6	6	6	6	6	6
	7	7	7	7	7	7
	8	8	8	8	8	8
	9	9	9	9	9	9

Now mark off your ID, one digit per column:

Test instructions

Answer questions **Q1, Q2 and Q3**.

Please submit all answers on this paper.
You can make calculations on additional paper, but they will not usually be marked.

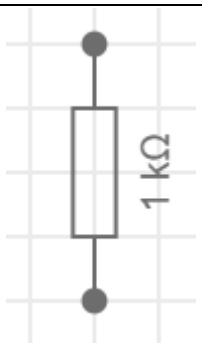
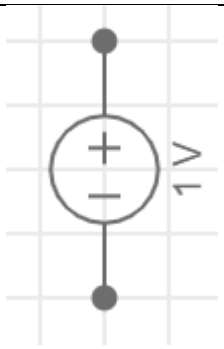
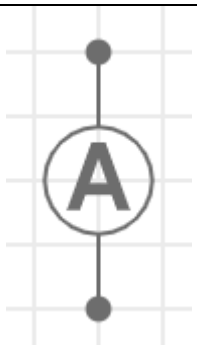
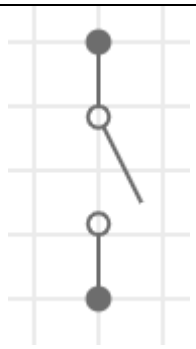
Only University-approved calculators are permitted, formulae sheets are included

1. **Electric Circuits (this question is mandatory):**

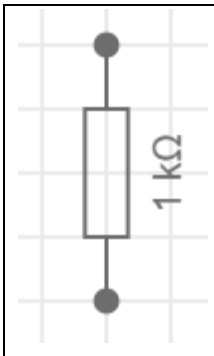
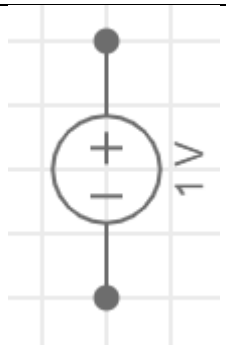
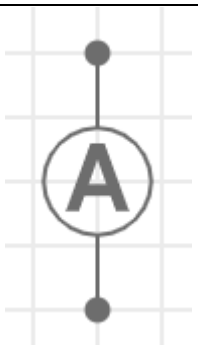
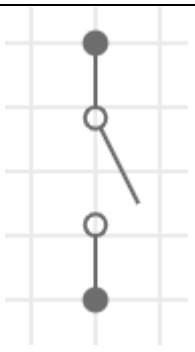
   For each question, mark the correct answer. Only one option is correct unless stated

otherwise. For a two-part question, both parts need to be correct to receive credit.
All circuit elements are assumed to be ideal unless stated otherwise. [20 marks]

a) Consider the following four circuit elements. Pick the correct name for each element.
[4 marks: 1 for each correct element name]

				
Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ Ⓕ Ⓖ Ⓗ	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ Ⓕ Ⓖ Ⓗ	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ Ⓕ Ⓖ Ⓗ	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ Ⓕ Ⓖ Ⓗ	Voltage Source Current Source Closed Switch Open Switch Volt-Meter Amp-Meter Ground Resistor

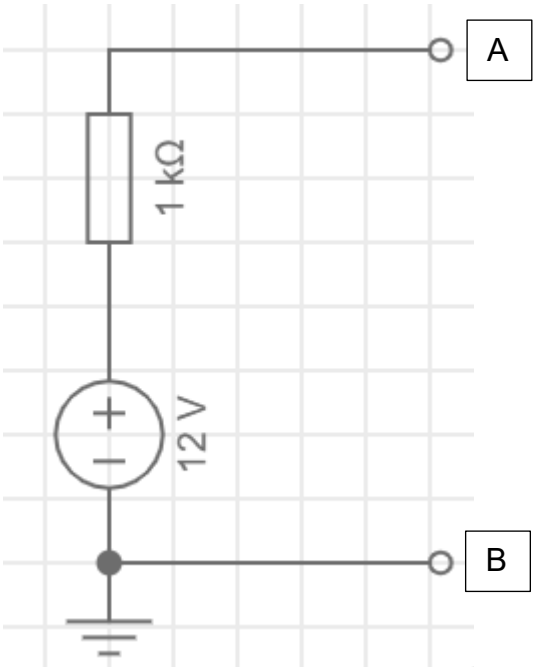
b) For the same four elements, assume they are used as part of a circuit. Can the voltage across the element be positive, zero, or negative (negative pole at the top)? Several correct answers may apply to each element.
[4 marks: 1 for each correct combination for an element]

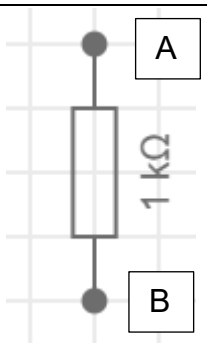
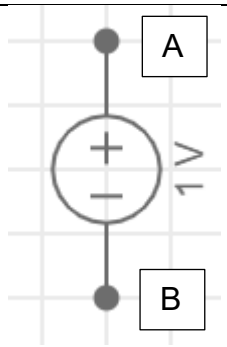
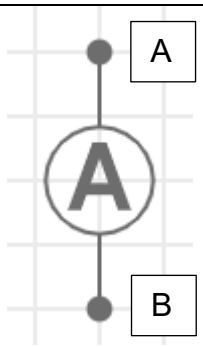
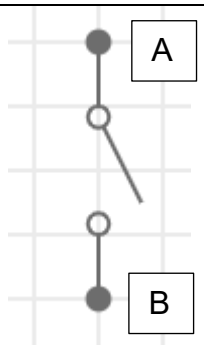
				

Ⓐ Ⓑ Ⓒ	Ⓐ Ⓑ Ⓒ	Ⓐ Ⓑ Ⓒ	Ⓐ Ⓑ Ⓒ	Positive Zero Negative

c) Considering the same four elements, what happens when you connect them in turn to the following real supply? Assume that terminal A is connected to terminal A and terminal B to terminal B, to form a closed circuit. State what voltage results across the element.

[4 marks: 1 for each correct combination for an element]



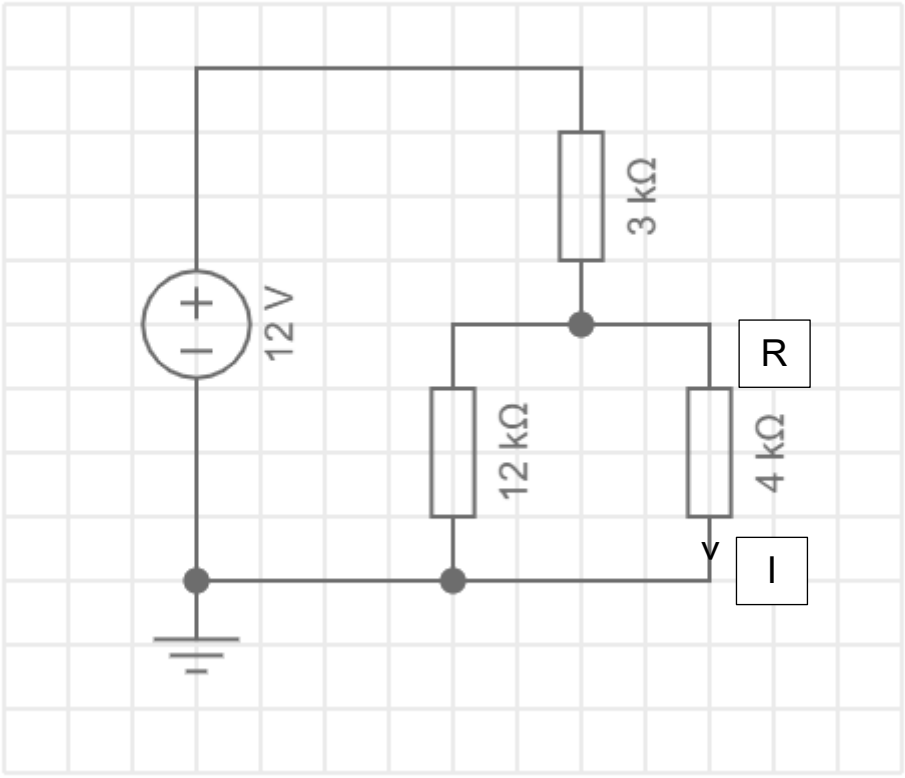
				
Ⓐ Ⓑ Ⓒ Ⓓ	Ⓐ Ⓑ Ⓒ Ⓓ	Ⓐ Ⓑ Ⓒ Ⓓ	Ⓐ Ⓑ Ⓒ Ⓓ	0V 1V 2V 4V

Student ID:							

Ⓔ Ⓕ Ⓖ Ⓗ	Ⓔ Ⓕ Ⓖ Ⓗ	Ⓔ Ⓕ Ⓖ Ⓗ	Ⓔ Ⓕ Ⓖ Ⓗ	6V 8V 10V 12V

d) Considering the following circuit, what is the marked current I flowing through the marked resistor R? Round to two significant digits.

[4 marks: 2 for correct digits, 1 for the magnitude, 1 for the unit]



First digit	Decimal point	Second digit	Magnitude	Unit
⓪ 0		⓪ 0		Ⓐ A
① 1		① 1	Ⓐ $< 10^{-3}$ (less than 0.001)	Ⓑ V
② 2		② 2	Ⓑ $\cdot 10^{-3}$ (0.001 to 0.009)	Ⓒ C
③ 3		③ 3	Ⓒ $\cdot 10^{-2}$ (0.01 to 0.09)	Ⓓ W
④ 4		④ 4	Ⓓ $\cdot 10^{-1}$ (0.1 to 0.9)	Ⓔ Ω

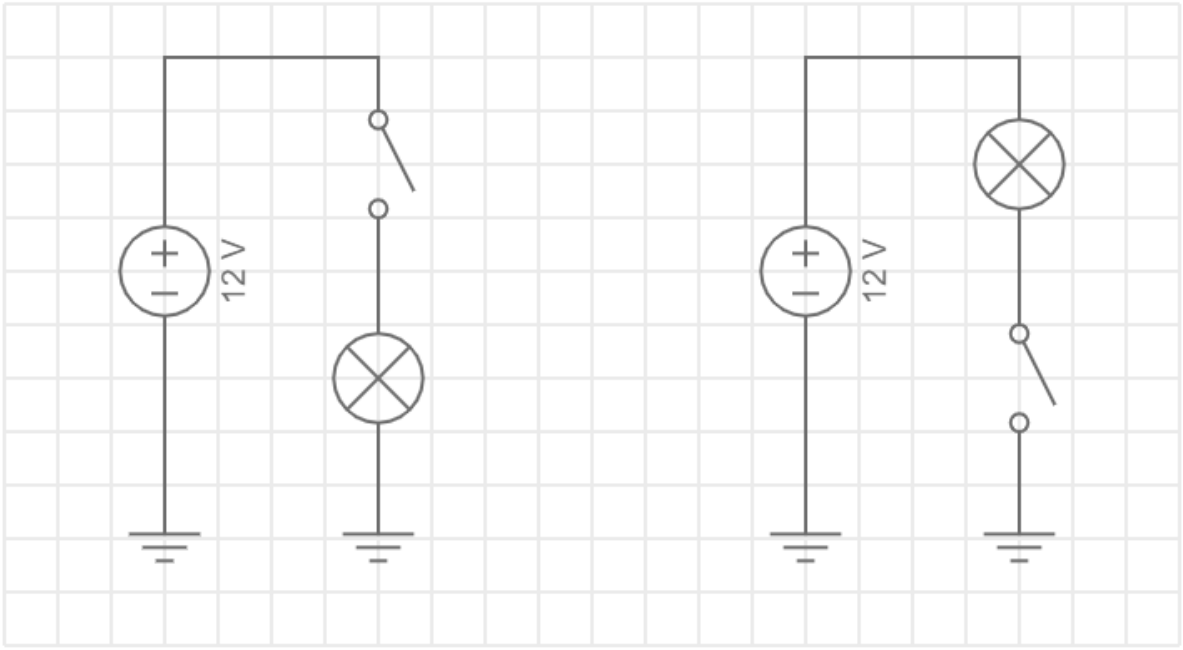
⑤ 5	⑤ 5	Ⓔ $\cdot 10^0$ (1 to 9)	Ⓕ F
⑥ 6	⑥ 6	Ⓕ $\cdot 10^1$ (10 to 99)	Ⓖ s
⑦ 7	⑦ 7	Ⓖ $\cdot 10^2$ (100 to 999)	Ⓗ H
⑧ 8	⑧ 8	Ⓗ $\cdot 10^3$ (1000 to 9999)	Ⓘ 1
⑨ 9	⑨ 9	Ⓘ $> 10^3$ (10000 or more)	Ⓙ J

Now write your answer here: _____

Example: A value of 152 Ω is expressed as $1.5 \cdot 10^2$ Ω, and marked 1 5 G E.

e) Consider the following two circuits in a vehicle that has a grounded chassis or metal frame. Which statements apply to the comparison? More than one may apply.

[2 marks for an all-correct answer]



__ Ⓐ Both circuits are functionally identical.

__ Ⓑ The lightbulb on the right gets more power.

__ Ⓒ The switch in the left circuit needs a higher voltage rating.

__ Ⓓ The left circuit may use less wire if the switch is close to the battery, and the light is far away (like a headlight).

__ Ⓔ The right circuit may use less wire if the switch is far from the battery, and the lamp is close to the battery (e.g. an indicator light in the cockpit for an open hatch).

f) Consider the two circuits from (e) above. Which one would you choose if the switch is in a plastic case, and the lightbulb has a metal case mounted to the vehicle frame? Give both the answer and the reason.

[2 marks for a fully correct answer]

___ Ⓐ the left circuit
___ Ⓑ the right circuit
___ Ⓒ they are both equally good

because

___ Ⓐ the light is brighter
___ Ⓑ the circuit is safer
___ Ⓒ there is no difference
___ Ⓓ the case can be used as ground

2. **AC Analysis (this question is mandatory):**

For each question, mark the correct answer. Two-part questions require both answers to be correct for marks to be awarded. Only one choice is correct unless stated otherwise.

[20 marks]

a) Consider the following four circuit elements. Select the equation that represents their behaviour, where k is a generic way of denoting the value of the components. $u(t)$ denotes the voltage across the elements, and $i(t)$ the current through it.

[4 marks: 1 per element for the correct equation]

				
Ⓐ	Ⓐ	Ⓐ	Ⓐ	$u(t) = k$
Ⓑ	Ⓑ	Ⓑ	Ⓑ	$i(t) = k$
Ⓒ	Ⓒ	Ⓒ	Ⓒ	$u(t) = \sin kt$

Ⓓ	Ⓓ	Ⓓ	Ⓓ	$i(t) = \sin kt$
Ⓔ	Ⓔ	Ⓔ	Ⓔ	$i(t) = k/u(t)$
Ⓕ	Ⓕ	Ⓕ	Ⓕ	$i(t) = k\frac{d}{dt}u(t)$
Ⓖ	Ⓖ	Ⓖ	Ⓖ	$u(t) = k\frac{d}{dt}i(t)$
Ⓗ	Ⓗ	Ⓗ	Ⓗ	$u(t) = k\, i(t)$

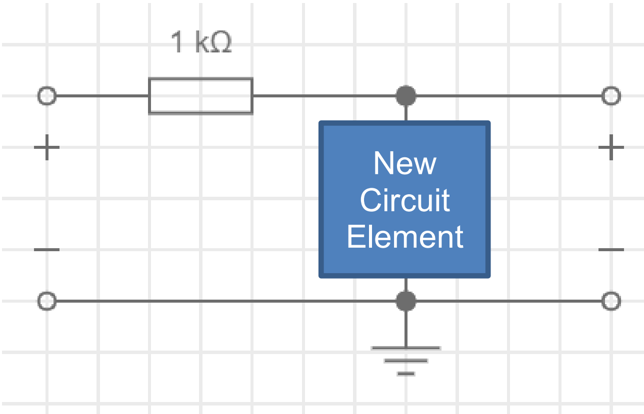
b) Considering the same four circuit elements, select the appropriate unit for the value k.

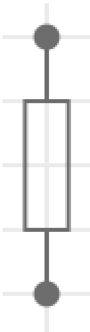
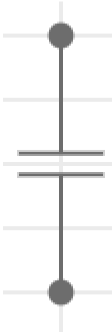
[4 marks: 1 per element for the correct unit]

				
Ⓐ	Ⓐ	Ⓐ	Ⓐ	A
Ⓑ	Ⓑ	Ⓑ	Ⓑ	V
Ⓒ	Ⓒ	Ⓒ	Ⓒ	C
Ⓓ	Ⓓ	Ⓓ	Ⓓ	W
Ⓔ	Ⓔ	Ⓔ	Ⓔ	s
Ⓕ	Ⓕ	Ⓕ	Ⓕ	F
Ⓖ	Ⓖ	Ⓖ	Ⓖ	rad/s
Ⓗ	Ⓗ	Ⓗ	Ⓗ	H
Ⓘ	Ⓘ	Ⓘ	Ⓘ	1
Ⓙ	Ⓙ	Ⓙ	Ⓙ	J
Ⓚ	Ⓚ	Ⓚ	Ⓚ	Ω

c) Consider the same four circuit elements again. If you insert them in turn into the circuit below, what kind of a circuit do you get as a result? The input is on the left, and the output on the right.

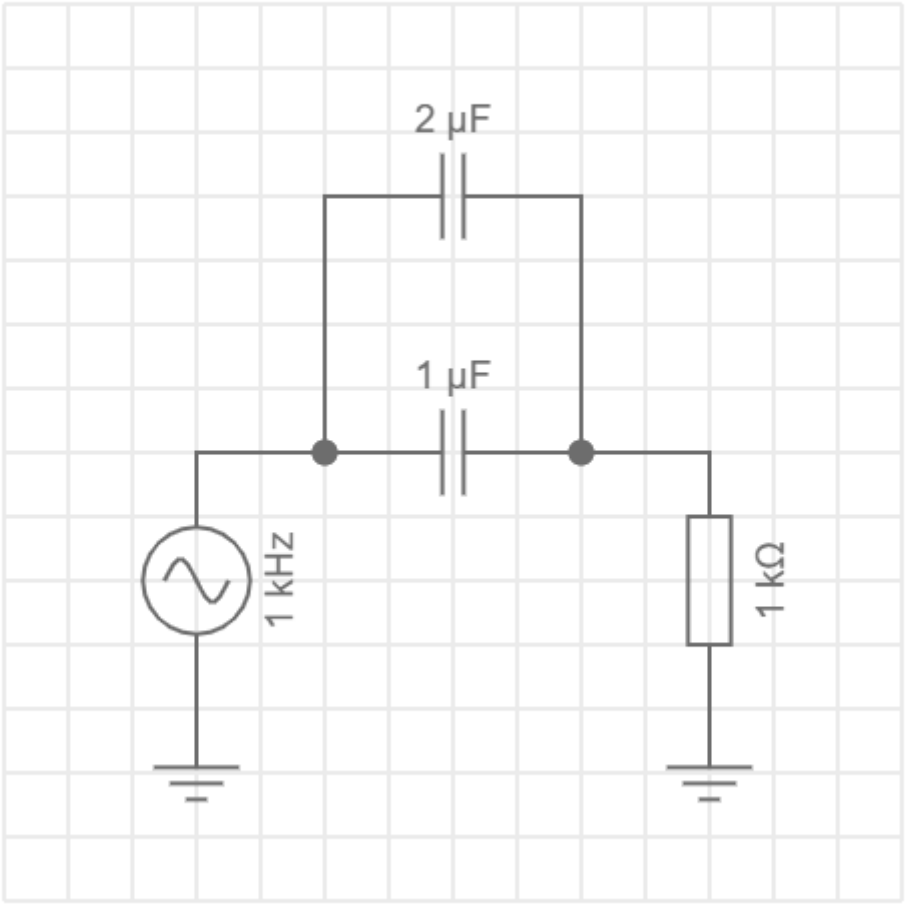
[4 marks: 1 per element for the correct unit]



				
(A)	(A)	(A)	(A)	Switched Circuit
(B)	(B)	(B)	(B)	Low Pass Filter
(C)	(C)	(C)	(C)	High Pass Filter
(D)	(D)	(D)	(D)	Resonant Filter
(E)	(E)	(E)	(E)	Band-Pass Filter
(F)	(F)	(F)	(F)	All-Pass Filter
(G)	(G)	(G)	(G)	Motor Circuit
(H)	(H)	(H)	(H)	Down Converter
(I)	(I)	(I)	(I)	Frequency Generator
(J)	(J)	(J)	(J)	Amplifier
(K)	(K)	(K)	(K)	Voltage Divider

d) Considering the following RC circuit, calculate its time constant.

[4 marks: 2 for correct digits, 1 for magnitude, 1 for the unit]

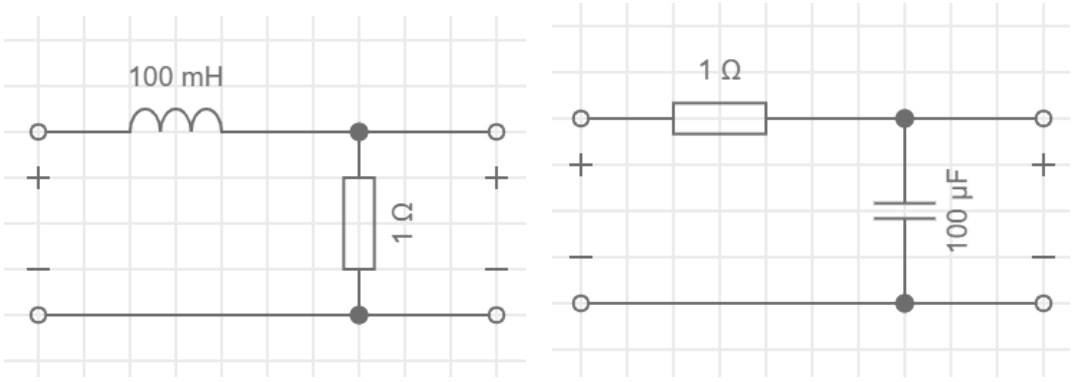


First digit	Decimal point	Second digit	Magnitude	Unit
⓪ 0		⓪ 0		Ⓐ A
① 1		① 1	Ⓐ $< 10^{-3}$ (less than 0.001)	Ⓑ V
② 2		② 2	Ⓑ $\cdot 10^{-3}$ (0.001 to 0.009)	Ⓒ C
③ 3		③ 3	Ⓒ $\cdot 10^{-2}$ (0.01 to 0.09)	Ⓓ W
④ 4		④ 4	Ⓓ $\cdot 10^{-1}$ (0.1 to 0.9)	Ⓔ Ω
⑤ 5		⑤ 5	Ⓔ $\cdot 10^{0}$ (1 to 9)	Ⓕ F
⑥ 6		⑥ 6	Ⓕ $\cdot 10^{1}$ (10 to 99)	Ⓖ s
⑦ 7		⑦ 7	Ⓖ $\cdot 10^{2}$ (100 to 999)	Ⓗ H
⑧ 8		⑧ 8	Ⓗ $\cdot 10^{3}$ (1000 to 9999)	Ⓘ 1
⑨ 9		⑨ 9	Ⓘ $> 10^{3}$ (10000 or more)	Ⓙ J

Now write your answer here: _____

e) Consider the following two filter circuits. The input is on the left, the output on the right. In a high-power application (not just a signal application), which one would be more efficient, and why?

[2 marks for an all-correct answer]



___ Ⓐ The left-hand circuit is more efficient.
___ Ⓑ Both circuits are equally efficient.
___ Ⓒ The right-hand circuit is more efficient.

because

___ Ⓐ Inductors are more efficient than capacitors.
___ Ⓑ Capacitors are more efficient than inductors.
___ Ⓒ The element closer to the source gets more power.
___ Ⓓ The element closer to the output is more important.
___ Ⓔ The load can contribute to the working of the filter.
___ Ⓕ The circuit has a longer time constant.

f) Assume that you have an audio signal with frequencies between 20 Hz and 20 kHz. It is subject to a disturbance with a frequency of 100 kHz. Which filter could you use to reduce the disturbance without affecting the signal itself? Name all that apply.

[2 marks for a fully correct answer]

___ Ⓐ a low-pass filter
___ Ⓑ a high-pass filter
___ Ⓒ a band-pass filter
___ Ⓓ a notch filter
___ Ⓔ a resonant filter

3. **DC Motors and Drives (this question is mandatory):**

For each question, mark the correct answer. Two-part questions require both answers to be correct for marks to be awarded. Only one choice is correct unless stated otherwise.

[20 marks]

a) Consider a DC motor that is connected to an ideal voltage source of 20 V. When the motor shaft is clamped, the resistance of the motor windings produces 400 W of heating power. Calculate the resistance of the motor windings.

[3 marks: 1 for 1st digit, 1 for magnitude, 1 for units]

First digit	Magnitude	Unit
① 1	Ⓐ $< 10^{-3}$ (less than 0.001)	Ⓐ V
② 2	Ⓑ 10^{-3} (0.001 to 0.009)	Ⓑ A
③ 3	Ⓒ 10^{-2} (0.01 to 0.09)	Ⓒ W
④ 4	Ⓓ 10^{-1} (0.1 to 0.9)	Ⓓ Ω
⑤ 5	Ⓔ 10^{0} (1 to 9)	Ⓔ Vs/rad
⑥ 6	Ⓕ 10^{1} (10 to 99)	Ⓕ rad/s
⑦ 7	Ⓖ 10^{2} (100 to 999)	Ⓖ Vrad/s
⑧ 8	Ⓗ 10^{3} (1000 to 9999)	Ⓗ Arad/s
⑨ 9	Ⓘ $> 10^{3}$ (10000 or more)	Ⓘ Hz

Now write your answer here: _____

b) At a certain operating point, the current flowing through the above motor connected to the same ideal source (20 V) is 5 A. Calculate the total mechanical power (including any losses) that is produced by the motor at that point. Round to 2 significant digits.

[3 marks: 1 for the digits, 1 for magnitude, 1 for units]

First digit	Decimal point	Second digit	Magnitude	Unit
⓪ 0		⓪ 0		Ⓐ A
① 1		① 1	Ⓐ $< 10^{-3}$ (less than 0.001)	Ⓑ V
② 2		② 2	Ⓑ $\cdot 10^{-3}$ (0.001 to 0.009)	Ⓒ C
③ 3		③ 3	Ⓒ $\cdot 10^{-2}$ (0.01 to 0.09)	Ⓓ W
④ 4		④ 4	Ⓓ $\cdot 10^{-1}$ (0.1 to 0.9)	Ⓔ Ω
⑤ 5		⑤ 5	Ⓔ $\cdot 10^{0}$ (1 to 9)	Ⓕ F
⑥ 6		⑥ 6	Ⓕ $\cdot 10^{1}$ (10 to 99)	Ⓖ s
⑦ 7		⑦ 7	Ⓖ $\cdot 10^{2}$ (100 to 999)	Ⓗ H
⑧ 8		⑧ 8	Ⓗ $\cdot 10^{3}$ (1000 to 9999)	Ⓘ 1
⑨ 9		⑨ 9	Ⓘ $> 10^{3}$ (10000 or more)	Ⓙ J

Now write your answer here: _____

Student ID:							

c) While operating at the same point as in (b) above, the speed of the motor is 2865 rpm. Calculate the motor constant, kt.

[3 marks: 1 for 1st digit, 1 for magnitude, 1 for units]

First digit	Magnitude	Unit
① 1	① $< 10^{-3}$ (less than 0.001)	Ⓐ V
② 2	② 10^{-3} (0.001 to 0.009)	Ⓑ A
③ 3	③ 10^{-2} (0.01 to 0.09)	Ⓒ W
④ 4	④ 10^{-1} (0.1 to 0.9)	Ⓓ Ω
⑤ 5	⑤ 10^{0} (1 to 9)	Ⓔ Vs/rad
⑥ 6	⑥ 10^{1} (10 to 99)	Ⓕ rad/s
⑦ 7	⑦ 10^{2} (100 to 999)	Ⓖ Vrad/s
⑧ 8	⑧ 10^{3} (1000 to 9999)	Ⓗ Arad/s
⑨ 9	⑨ $> 10^{3}$ (10000 or more)	Ⓘ Hz

Now write your answer here: _____

d) Calculate the maximum mechanical power (including any mechanical losses such as friction) that the motor is capable of generating when connected to the 20V ideal source as above.

[3 marks: 1 for 1st digit, 1 for magnitude, 1 for units]

First digit	Magnitude	Unit
① 1	① $< 10^{-3}$ (less than 0.001)	Ⓐ V
② 2	② 10^{-3} (0.001 to 0.009)	Ⓑ A
③ 3	③ 10^{-2} (0.01 to 0.09)	Ⓒ W
④ 4	④ 10^{-1} (0.1 to 0.9)	Ⓓ Ω
⑤ 5	⑤ 10^{0} (1 to 9)	Ⓔ Vs/rad
⑥ 6	⑥ 10^{1} (10 to 99)	Ⓕ rad/s
⑦ 7	⑦ 10^{2} (100 to 999)	Ⓖ Vrad/s
⑧ 8	⑧ 10^{3} (1000 to 9999)	Ⓗ Arad/s
⑨ 9	⑨ $> 10^{3}$ (10000 or more)	Ⓘ Hz

Now write your answer here: _____

e) For the same operating point of maximum mechanical power, calculate the electrical power dissipated as heat due to the flow of current through the motor windings.

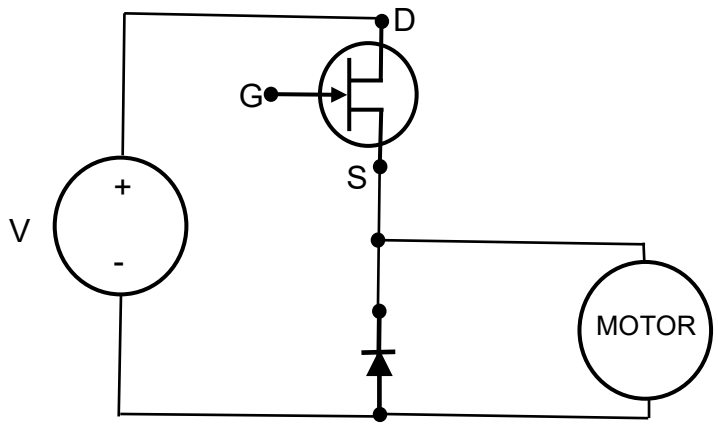
[3 marks: 1 for 1st digit, 1 for magnitude, 1 for units]

First digit	Magnitude	Unit
① 1	① $< 10^{-3}$ (less than 0.001)	Ⓐ V

② 2	② 10^{-3} (0.001 to 0.009)	Ⓑ A
③ 3	③ 10^{-2} (0.01 to 0.09)	Ⓒ W
④ 4	④ 10^{-1} (0.1 to 0.9)	Ⓓ Ω
⑤ 5	⑤ 10^{0} (1 to 9)	Ⓔ Vs/rad
⑥ 6	⑥ 10^{1} (10 to 99)	Ⓕ rad/s
⑦ 7	⑦ 10^{2} (100 to 999)	Ⓖ Vrad/s
⑧ 8	⑧ 10^{3} (1000 to 9999)	Ⓗ Arad/s
⑨ 9	⑨ $> 10^{3}$ (10000 or more)	Ⓘ Hz

Now write your answer here: _____

f) The above motor is powered by a quarter-bridge, as shown in the figure below. What type of control signal is typically fed to the gate (G) of the MOSFET transistor for effective speed regulation? Choose one answer only: [2 marks, 1 per part]



___ Ⓐ a DC signal
___ Ⓑ a sinusoidal signal
___ Ⓒ a rectangular signal
___ Ⓓ a triangular signal
___ Ⓔ noise

because (choose only one reason):

___ Ⓐ it is a DC motor the resistive loss depends on the current
___ Ⓑ a switching signal allows for efficient regulation
___ Ⓒ a frequency domain signal is required and easy to generate
___ Ⓓ the application dictates the signal
___ Ⓔ the signal needs to be synchronous to the motion

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g) Assume that the motor connected as in (f) above is running with an average current of 10 A and a duty cycle of 10%. If the voltage drop at the diode is 0.7 V, calculate approximately the average power dissipated by the diode under such operating conditions.

[3 marks: 1 for 1st digit, 1 for magnitude, 1 for units]

First digit	Magnitude	Unit
① 1	① $< 10^{-3}$ (less than 0.001)	Ⓐ V
② 2	② 10^{-3} (0.001 to 0.009)	Ⓑ A
③ 3	③ 10^{-2} (0.01 to 0.09)	Ⓒ W
④ 4	④ 10^{-1} (0.1 to 0.9)	Ⓓ Ω
⑤ 5	⑤ 10^{0} (1 to 9)	Ⓔ Vs/rad
⑥ 6	⑥ 10^{1} (10 to 99)	Ⓕ rad/s
⑦ 7	⑦ 10^{2} (100 to 999)	Ⓖ Vrad/s
⑧ 8	⑧ 10^{3} (1000 to 9999)	Ⓗ Arad/s
⑨ 9	⑨ $> 10^{3}$ (10000 or more)	Ⓘ Hz

Now write your answer here: _____

This is the end of the exam paper. Well done!

G. Mavros and T. Steffen

Kirchhoff's Voltage Law

$$\sum U_i = 0$$
$$U_{AB} = E_A - E_B$$

Kirchhoff's Current Law

$$\sum I_i = 0$$

Component behaviour

Components	Resistor R	Capacitor C	Inductor L
Behaviour (differential)	$U = RI$	$i(t) = C\frac{d}{dt}u(t)$	$u(t) = L\frac{d}{dt}i(t)$
Behaviour (integral)		$u(t) = \int \frac{1}{C}\, i(t)\, dt$	$i(t) = \int \frac{1}{L}\, u(t)\, dt$
Power $P = UI$	$P = RI^2$		
Energy $E = \int P\, dt$		$E = \frac{1}{2}CU^2$	$E = \frac{1}{2}LI^2$
Impedance	$Z = R$	$Z = \frac{1}{j\omega C}$	$Z = j\omega L$

Voltage Divider

$$\frac{U_1}{U_{in}} = \frac{R_1}{R_1 + R_2}$$
$$\frac{\underline{U_1}}{\underline{U_{in}}} = \frac{Z_1}{Z_1 + Z_2}$$

RMS Voltage for sinusoidal signals

$$u(t) = U_{peak}\sin(\omega t + \phi)$$
$$U_{RMS} = \sqrt{\frac{1}{2}}U_{Peak}$$
$$u(t) = \underline{U}\, e^{j\omega t}$$

Electric DC Motor

$$T = k_T I$$
$$k_T = n2rdB$$
$$U_{BEMF} = k_T\omega$$

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Logarithmic dB Scale:

$$A = 20\text{dB}\ \log_{10} a$$

$$a = 10^{\frac{A}{20\text{dB}}}$$

Factor	Gain		Factor	Gain
*1	0 dB		*1	0
*1.4	+3dB		*0.7 (/1.4)	-3dB
*2	+6dB		*0.5	-6dB
*4	+12dB		*0.25	-12dB
*10	+20dB		*0.1	-20dB
*100	+40dB		*0.01	-40dB

Trigonometric, Logarithmic and Exponential Functions

$$x^{a+b} = x^a x^b$$

$$\log ab = \log a + \log b$$

$$\sin\frac{\pi}{4} = \frac{1}{\sqrt{2}} = \cos\frac{\pi}{4}$$

$$\cos\alpha = \sin\left(\alpha + \frac{\pi}{2}\right)$$

$$\sin\alpha + \beta = \sin\alpha\cos\beta + \cos\alpha\sin\beta$$

$$\frac{d}{d\alpha}\sin\alpha = \cos\alpha$$

$$2\sin^2\alpha = 1 + \cos 2\alpha$$

$$\dot{x} = kx \rightarrow x = x_0 e^{kt}$$

Complex numbers

$$j^2 = -1$$

$$\frac{1}{j} = -j$$

$$|a + bj| = \sqrt{a^2 + b^2}$$

$$\frac{1}{a + bj} = \frac{a - bj}{a^2 + b^2}$$

$$e^{j\varphi} = \cos\varphi + j\sin\varphi$$

Filters

$$\tau = RC$$

$$\tau = \frac{L}{R}$$

$$\omega_{corner} = 1/\tau$$

$$\omega = 2\pi f$$