

Please write clearly in block capitals.

Centre number

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Candidate number

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Surname

StemUp Model Solution

Forename(s)

Candidate signature

I declare this is my own work.

A-level PHYSICS

Paper 3

Section B Electronics

Materials

For this paper you must have:

- a pencil and a ruler
- a scientific calculator
- a Data and Formulae Booklet
- a protractor.

Instructions

- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- Do **all** rough work in this book. Cross through any work you do not want to be marked.
- Show **all** your working.

Information

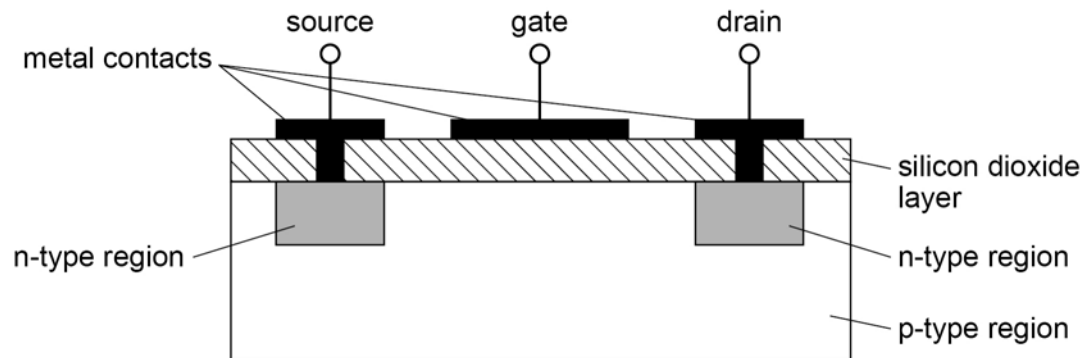
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 35.
- You are expected to use a scientific calculator where appropriate.
- A Data and Formulae Booklet is provided as a loose insert.

Time allowed: The total time for both sections of this paper is 2 hours. You are advised to spend approximately 50 minutes on this section.

For Examiner's Use	
Question	Mark
1	
2	
3	
4	
5	
TOTAL	



J U N 2 1 7 4 0 8 3 B E 0 1

Section BAnswer **all** questions in this section.**0 1****Figure 1** shows a simplified structure of an N-channel enhancement mode MOSFET.**Figure 1****0 1 . 1**

State the name of the part shown in this MOSFET structure that causes the input resistance to be very large.

[1 mark]

The silicon dioxide layer (insulator between gate and channel).

0 1 . 2

Which terminal of the MOSFET is connected directly to 0 V when it is used as a simple switch?

Tick (✓) **one** box.**[1 mark]**

drain

☐

gate

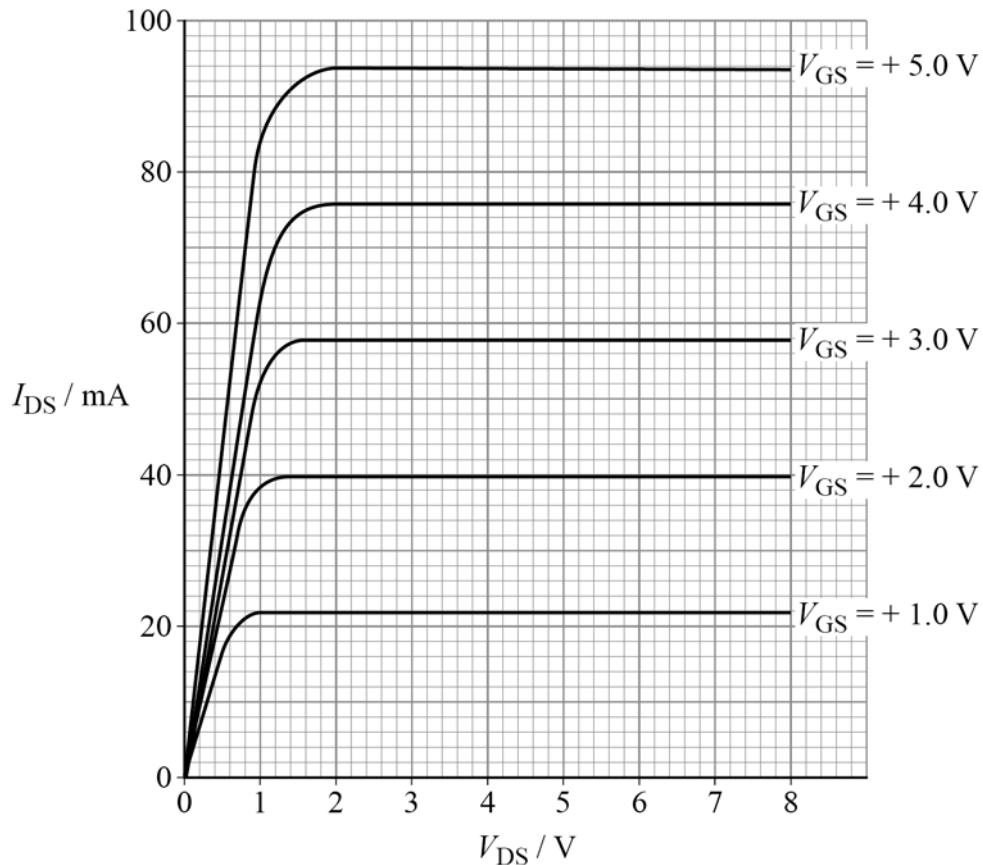
☐

source

☒

Figure 2 shows how the drain–source current I_{DS} of the MOSFET varies with drain–source voltage V_{DS} for a range of gate–source voltages V_{GS} .

Figure 2



The MOSFET is used as a simple switch in a filament lamp circuit.
The circuit uses power rails of 12 V and 0 V.
The resistance of the lamp is $154 \, \Omega$ when operating at its full power of 0.65 W.

0 1 3

Deduce the minimum value of V_{GS} needed for the lamp to operate at full power.

[2 marks]

For the lamp: $P = I^2 R$ so $I = \sqrt{P/R} = \sqrt{0.65 / 154}$

$I = 0.065 \, \text{A} = 65 \, \text{mA}$ (this is I_{DS})

p.d. across lamp = $IR = 0.065 \times 154 = 10 \, \text{V}$

so $V_{DS} = 12 - 10 = 2 \, \text{V}$ (on the flat part of the curves)

From Figure 2, $I_{DS} = 65 \, \text{mA}$ lies between the 3.0 V and 4.0 V curves, giving $V_{GS} \approx 3.4 \, \text{V}$

$V_{GS} = \underline{\quad 3.4 \quad} \, \text{V}$

Question 1 continues on the next page

Turn over ►



0 1 . 4

Figure 3 shows an individual MOSFET. The drain–source leakage current I_{DSS} for this MOSFET is about 10 nA.

Figure 4 shows a microchip where millions of MOSFETs are combined to enable complex processes to be carried out on one chip.

Figure 3

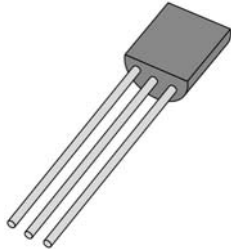
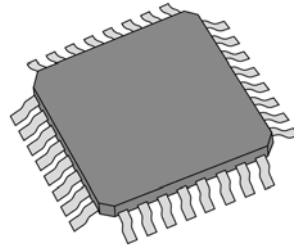


Figure 4



A mobile phone has a central processing unit (CPU) which uses a microchip similar to the one in **Figure 4**.

Table 1 shows the technical specification for the mobile phone.

Table 1

Number of transistors in the CPU	8.5×10^9
Battery capacity	3110 mA h
Phone time available on stand-by from one full charge	≈ 12 hours

A fully charged battery with a capacity of 1 A h allows 3600 C of charge to flow through it before it is fully discharged.



The I_{DSS} value for each MOSFET used in the mobile phone CPU must be different from that measured in the individual MOSFET shown in **Figure 3**.

Discuss, using the data provided, the reason for this difference.

[3 marks]

Stand-by current if each MOSFET leaked 10 nA:

$$I = 8.5 \times 10^9 \times 10 \times 10^{-9} = 85 \text{ A}$$

$$\text{Battery charge: } Q = 3.110 \text{ A h} \times 3600 \text{ C} = 1.12 \times 10^4 \text{ C}$$

$$\text{Time to discharge: } t = Q / I = 1.12 \times 10^4 / 85 = 132 \text{ s}$$

t ≈ 2.2 minutes, which is much less than 12 hours.

Current available for 12 h stand-by:

$$I = 1.12 \times 10^4 / (12 \times 3600) = 0.26 \text{ A}$$

$$I_{DSS} \text{ per MOSFET} = 0.26 / 8.5 \times 10^9 \approx 3 \times 10^{-11} \text{ A} = 0.03 \text{ nA}$$

*With 10 nA per MOSFET the battery would be flat in about 2 minutes,
not 12 hours, so the leakage current of each CPU MOSFET must be
much smaller, about 0.03 nA or less (over 300 times smaller), because
the CPU transistors are far smaller.*

7

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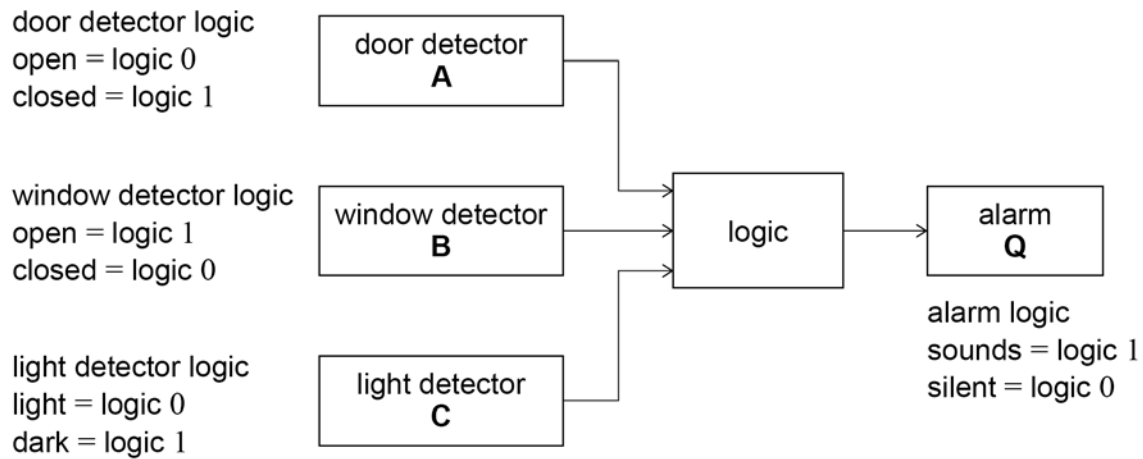
0 2

A burglar-alarm system in a house sounds an alarm during the hours of darkness when **one** of the following conditions is met:

- the door is opened
- the window is opened
- both the door and the window are opened.

Figure 5 shows the main burglar-alarm subsystems and the logic status for the inputs and output.

Figure 5



0 2 . 1 Table 2 is a partially completed truth table for the logic subsystem.

Table 2

Inputs			Output
C	B	A	Q
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	1
1	0	1	0
1	1	0	1
1	1	1	1

Complete **Table 2**.

[1 mark]

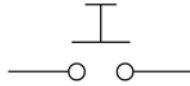
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Figure 6 shows the symbol of the push-to-make switch used in the door detector. When the door is closed, the switch button is pushed down onto the contacts. It automatically releases when the door opens.

Figure 6



0 2 . 2

Complete **Figure 7** to show how this switch, together with a $10\text{ k}\Omega$ resistor, can be connected to create the door detector circuit in **Figure 5**.

Label the output of the circuit with an X.

[2 marks]

Figure 7

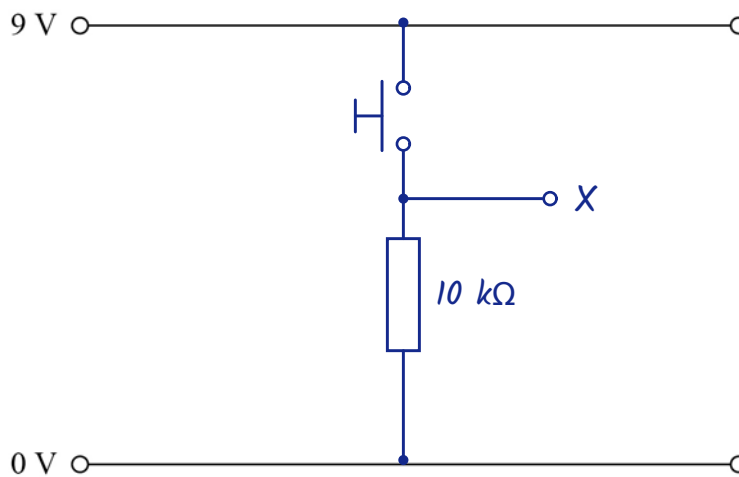
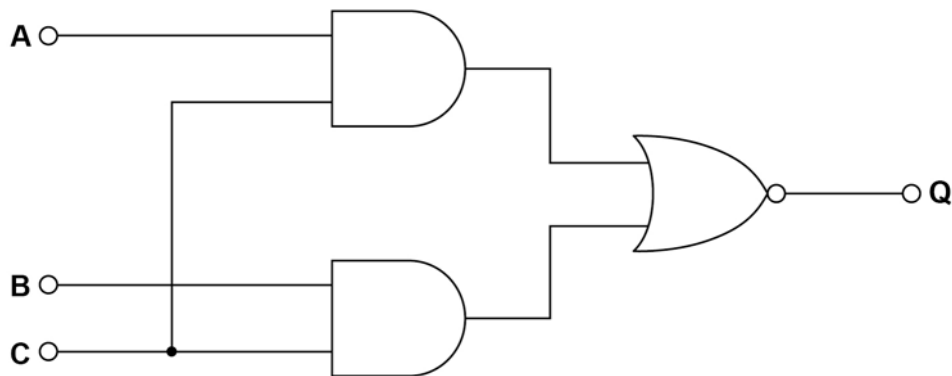


Figure 8 shows a logic circuit for a different alarm system.

Figure 8



0 2 . 3

Write the Boolean algebra expression for **Q** in terms of inputs **A**, **B** and **C**.
In your answer use only AND and NOR operators.

[2 marks]

AND gate outputs: $A \cdot C$ and $B \cdot C$, then NOR them:

$$Q = \overline{(A \cdot C) + (B \cdot C)}$$

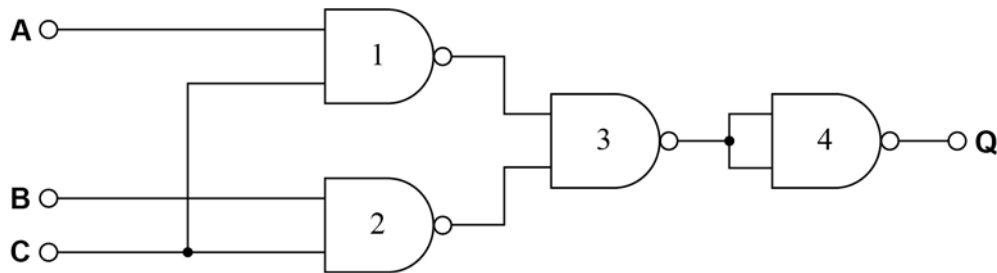
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0 2 . 4

Figure 9 shows a logic circuit that has the same function as the circuit in **Figure 8**. Only one type of gate is used in the circuit in **Figure 9**.

Figure 9

State the logic function performed by gate 4.

[1 mark]

Inverter (NOT gate): a NAND gate with its inputs joined.

0 2 . 5

Microchips containing two-input logic gates are mass-produced. Each microchip contains four identical logic gates.

A manufacturer of the logic circuit used in the burglar alarm chooses to make the circuit in **Figure 9** rather than that in **Figure 8**.

Suggest why.

[1 mark]

It uses one chip of 4 NAND gates, not two chips (AND and NOR), so the board is smaller and cheaper and only one type of chip is stocked.

7



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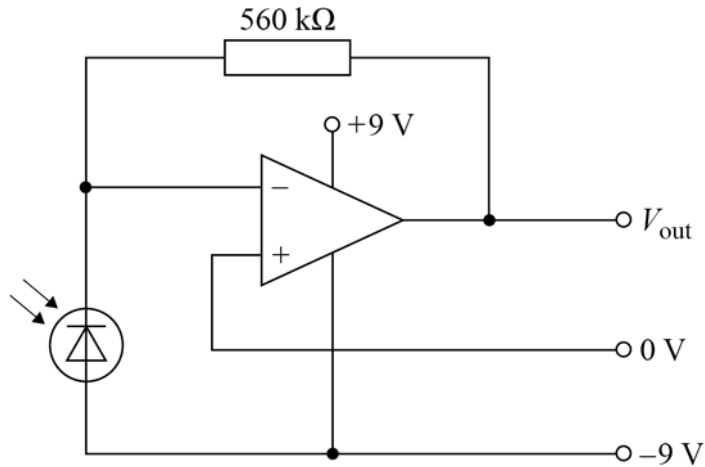
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0 3

Figure 10 shows the circuit for an infrared detector using a photodiode and an operational amplifier. In this application the operational amplifier uses a feedback resistor to give a voltage signal when the current in the photodiode changes.

Figure 10

0 3 . 1

State the mode in which the photodiode is being used in **Figure 10**.

[1 mark]

Photoconductive mode (the photodiode is reverse biased).

0 3 . 2

In the circuit shown in **Figure 10**, there is a current in the photodiode even when there is no light incident on it. This current is called the dark current.

In an optical communication system, the dark current needs to be very small in comparison to the photodiode current.

Explain why.

[1 mark]

Dark current is noise, so it must be small to keep the signal-to-noise ratio high and give a large signal difference between light and dark.



The responsivity R_λ of a silicon photodiode is a measure of its sensitivity to light at a given wavelength λ .

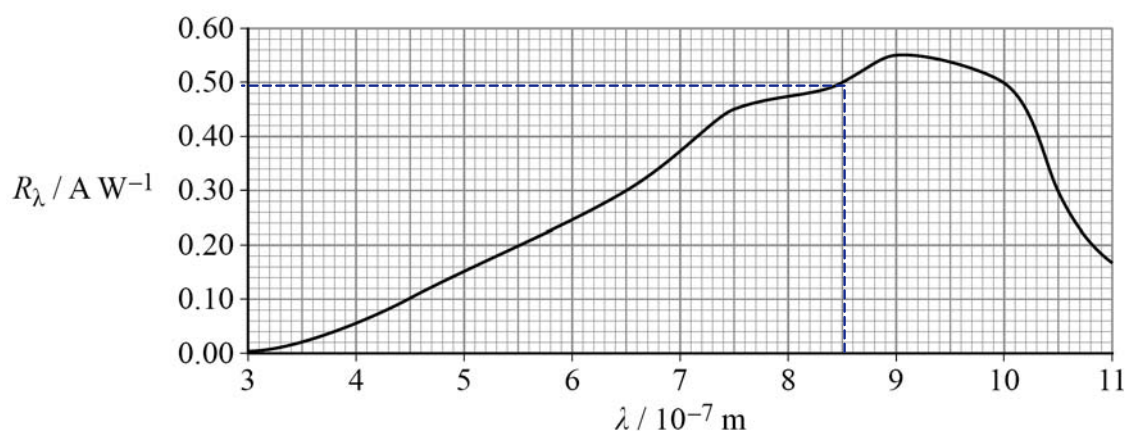
R_λ is defined as:

$$R_\lambda = \frac{I_p}{P}$$

where I_p is the current in the photodiode and P is the incident light power at the given wavelength.

Figure 11 shows the spectral response graph for this photodiode.

Figure 11



0 3 . 3

Monochromatic radiation of wavelength 850 nm and power 4.0 μW is incident on the photodiode in Figure 10.

Calculate the output voltage of the detector circuit.

[3 marks]

From Figure 11 at $\lambda = 850 \text{ nm}$, $R_\lambda = 0.50 \text{ A W}^{-1}$

$$I_p = R_\lambda \times P = 0.50 \times 4.0 \times 10^{-6} = 2.0 \times 10^{-6} \text{ A} = 2.0 \mu\text{A}$$

$$V_{out} = I_p \times R = 2.0 \times 10^{-6} \times 560 \times 10^3$$

$$V_{out} = 1.12 \text{ V}$$

output voltage = 1.12 V

Question 3 continues on the next page

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0 3 . 4

The output from the detector circuit in **Figure 10** needs to be amplified by a factor of +4

Complete **Figure 12** to show the amplifier circuit required.

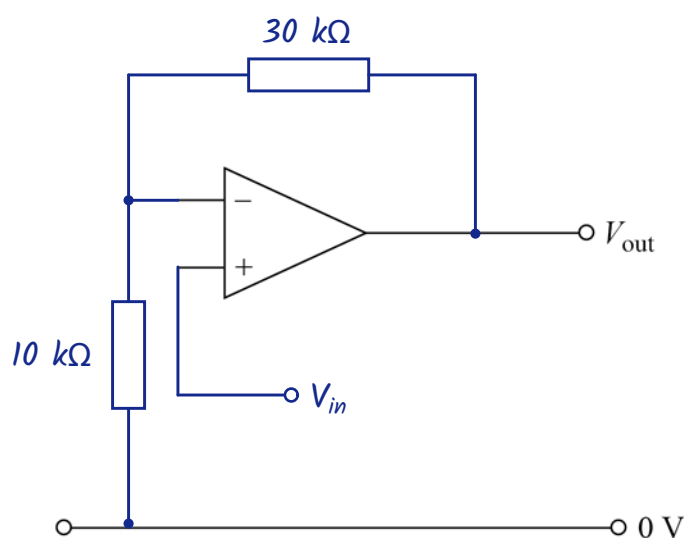
In your completed circuit you should:

- label the input point as V_{in}
- label your diagram with the values of resistance for any resistors used in your circuit. Any resistance values must lie within the range 1 k Ω to 100 k Ω .

Do **not** show the power supplies to the operational amplifier.

[3 marks]

Figure 12



non-inverting amplifier: gain = $1 + R_f/R_i = 1 + 30/10 = +4$



0 4

A Johnson decade counter uses a Johnson counter together with decoding logic. This arrangement produces a single logic 1 at a series of outputs Q_0 – Q_9 in a continuous sequence.

0 4 . 1

Describe **one** functional difference and **one** functional similarity between how a Johnson decade counter and a BCD counter output their counts.

[2 marks]

functional difference A BCD counter outputs the count as a 4-bit binary code across Q_0 to Q_3 ,

whereas a Johnson decade counter outputs a single logic 1 on one output at a time, moving sequentially from Q_0 to Q_9 .

functional similarity Both count from 0 to 9 (ten states)
and both recycle (reset to the start) on the 10th clock pulse.

Question 4 continues on the next page

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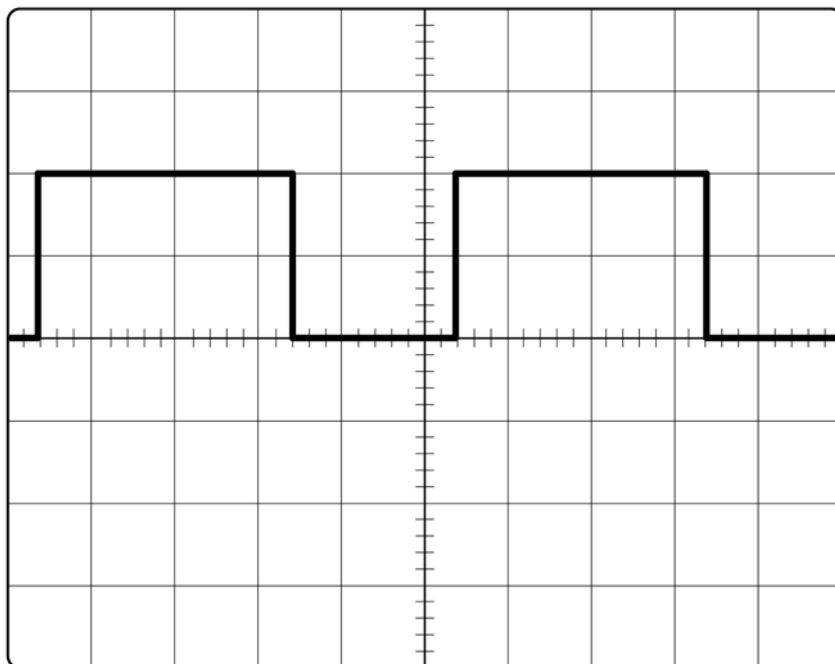


0 4 . 2

An astable oscillator produces a continuous train of pulses.

Figure 13 shows the display of the pulses on an oscilloscope.

Figure 13



The oscilloscope settings are:

voltage gain = 2 V / division

time-base = 50 μ s / division.

Determine the duty cycle and frequency of the signal.

[3 marks]

$$t_{on} = 3 \text{ div} \times 50 \mu\text{s/div} = 150 \mu\text{s}$$

$$t_{off} = 2 \text{ div} \times 50 \mu\text{s/div} = 100 \mu\text{s}$$

$$\text{duty cycle} = t_{on} / (t_{on} + t_{off}) \times 100 = 150 / 250 \times 100 = 60\%$$

$$\text{period } T = 5 \text{ div} \times 50 \mu\text{s/div} = 250 \mu\text{s}$$

$$f = 1 / T = 1 / 250 \times 10^{-6} = 4000 \text{ Hz} = 4 \text{ kHz}$$

duty cycle = 60% (0.6)

frequency = 4 kHz



0 4 . 3

The astable is adjusted to produce a 600 Hz test signal.

This signal is applied to the clock input of the BCD counter and to the clock input of the Johnson decade counter.

The outputs of the BCD counter are Q_0 , Q_1 , Q_2 and Q_3 where Q_0 is the least significant part of the output.

The outputs of the Johnson decade counter are Q_0 , Q_1 , $Q_2 \dots Q_9$.

Determine the frequency of the pulses available at Q_2 for each counter.

[2 marks]

BCD counter: Q_2 is logic 1 only for counts 4 to 7, so it gives one pulse for every 10 clock pulses:

$$f = 600 / 10 = 60 \text{ Hz}$$

Johnson decade counter: Q_2 is logic 1 once every 10 clock pulses (one output high at a time, cycling Q_0 to Q_9):

$$f = 600 / 10 = 60 \text{ Hz}$$

BCD counter: frequency of pulses = 60 Hz

Johnson decade counter: frequency of pulses = 60 Hz

7

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0 5

Table 3 shows some communication applications that transmit using different regions of the electromagnetic spectrum.

Table 3

Application	Spectrum region	Typical transmission frequency / MHz
national radio station	longwave	0.198
amateur radio	shortwave	28.2
satellite TV link	microwave	10 700

Explain why each transmission takes the pathway it does from the transmitter to the receiver.

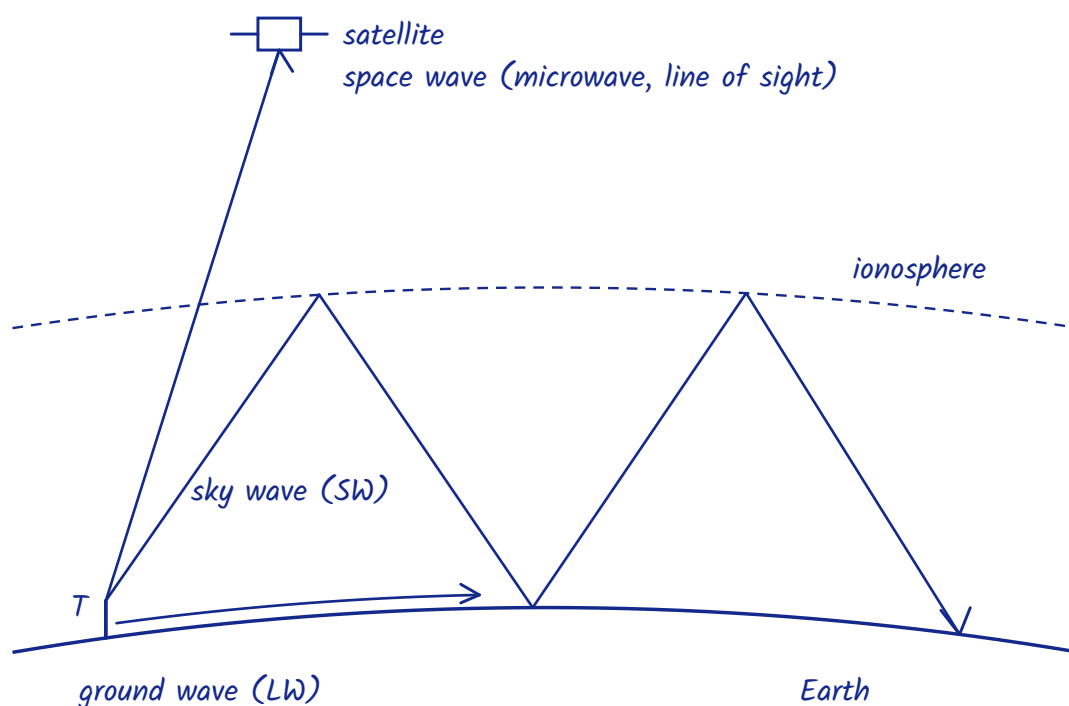
For each of the spectrum regions, you should:

- indicate a frequency range
- refer to the properties of the wave
- name the pathway and outline its properties.

You may use diagrams to help explain your answer.

[6 marks]

Space for diagrams



Longwave (national radio, 0.198 MHz): frequency range about 30 kHz to 300 kHz (LF band, broadcasts 150 kHz to 300 kHz). The pathway is the ground wave (surface wave). The wavelength is very long, $\lambda = c/f = 3.0 \times 10^8 / 1.98 \times 10^5 \approx 1500 \text{ m}$, so the waves diffract around hills, buildings and the curvature of the Earth. Interaction with the conducting surface of the Earth and refraction in the lower atmosphere (changing refractive index) bend the wave so it follows the Earth's surface beyond the horizon. Attenuation at low frequency is low, so the signal travels long distances (hundreds of km) and covers a whole country. These waves are strongly absorbed by the ionosphere, so there is little sky wave reflection.

Shortwave (amateur radio, 28.2 MHz): frequency range about 3 MHz to 30 MHz (HF band). The pathway is the sky wave. The ionosphere (layers of ionised gas) refracts these waves back towards the Earth, so they are effectively reflected, and the ground reflects them up again. These single or multiple reflections (skips) allow reception far beyond the horizon, even worldwide. Below this range the ionosphere absorbs the waves and above about 30 MHz they pass straight through it. Reception varies with the state of the ionosphere, e.g. day and night effects and the sunspot cycle.

Microwave (satellite TV link, 10 700 MHz = 10.7 GHz): frequency range about 2 GHz to 100 GHz. The pathway is the space wave (line of sight). The wavelength is only about 2.8 cm, so microwaves do not diffract around terrestrial objects and the dish needs a clear line of sight to the geostationary satellite. They pass straight through the atmosphere and the ionosphere without reflection, although there is some attenuation by the atmosphere and ionosphere (e.g. rain). Different

Turn over ►



frequencies are used for the up-link and down-link so the satellite receiver is not desensitised by its own transmitter. The up-link uses a higher frequency (about 17 to 18 GHz) than the down-link (10 to 13 GHz) because a higher frequency gives a narrower beam and the ground station can supply plenty of power to overcome attenuation, while the lower down-link frequency covers a wider target area with the limited power of the satellite. The high frequency also gives a large bandwidth to carry many TV channels of complex information.

END OF QUESTIONS



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