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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

Tuesday 17 June 2025

Morning

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.

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.

For Examiner's Use

Question	Mark
1	
2	
3	
4	
5	
TOTAL	



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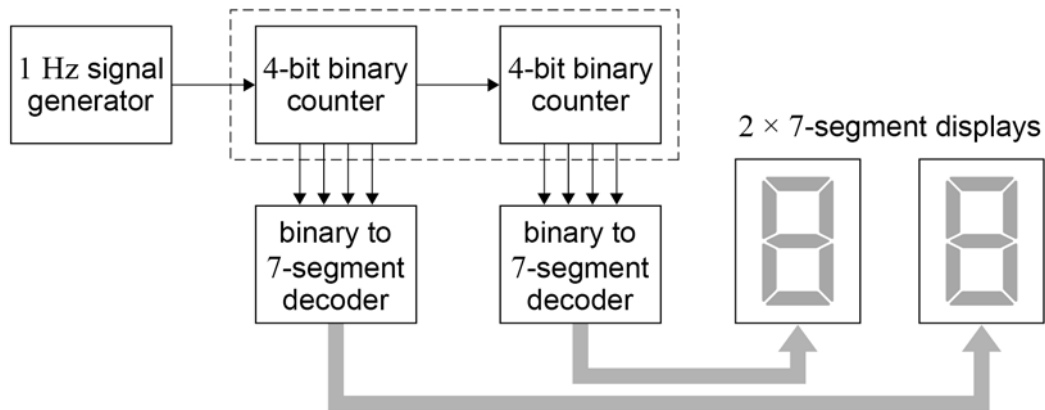
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Section B

Answer **all** questions in this section.

0 1 . 1 **Figure 1** shows a system diagram for a timer designed by a student.

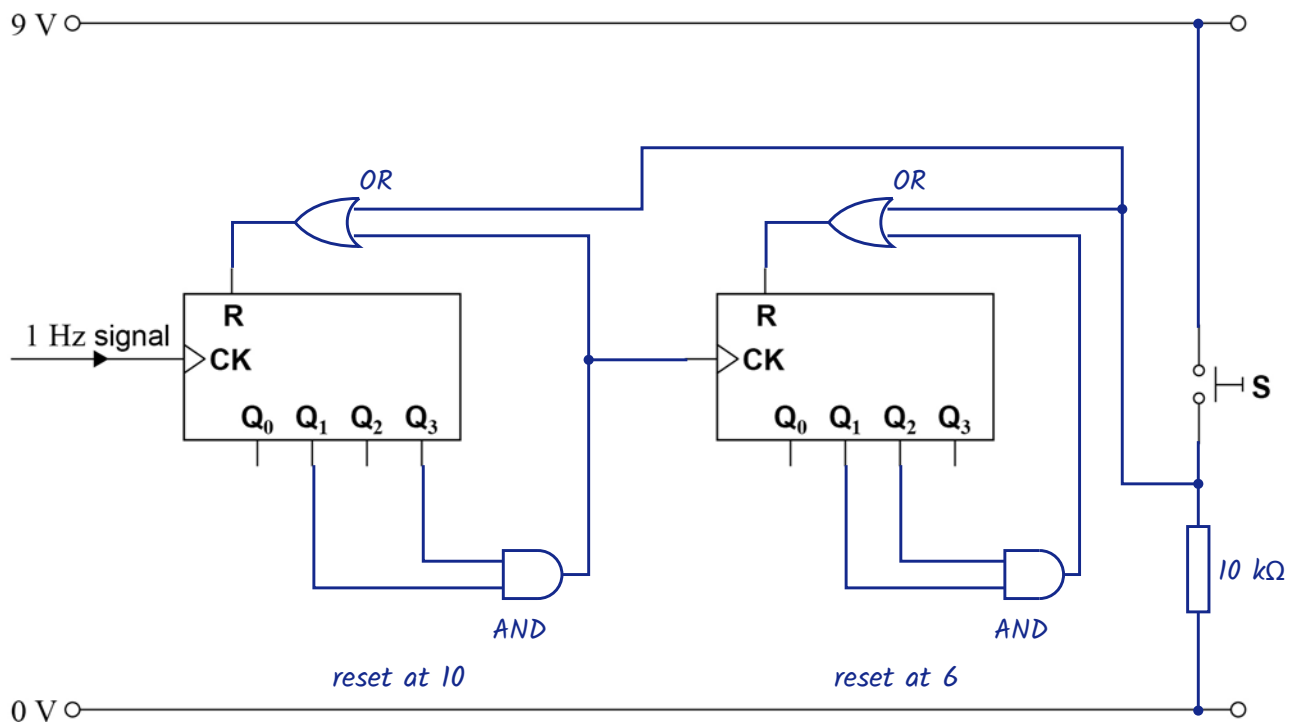
Figure 1

The system displays the numbers from 00 to 59 before resetting.
The timer is designed to count in time intervals of 1 s.

Part of **Figure 1** is enclosed within dashed lines.

Figure 2 shows an incomplete circuit diagram for this part of the system.

Figure 2 also includes a switch **S** that is used to manually reset both counters.

Figure 2

Each counter in **Figure 2** advances by 1 when **CK** receives the rising edge of a pulse. When **R** on a counter receives a logic 1, that counter resets.

Complete the circuit diagram in **Figure 2** by adding:

- logic gates to select the reset code for each counter
- a link to show how the second counter is triggered from the first counter
- a resistor with switch **S** to form the manual reset
- logic gates for each of the counters to provide the reset conditions at **R**.

[5 marks]

0 1 . 2

Another student designs a logic system to combine judgements from three people. When at least two of the three people input logic 1, the system provides an output of logic 1. Otherwise, the output is logic 0.

The three people are represented by inputs **X**, **Y** and **Z**.

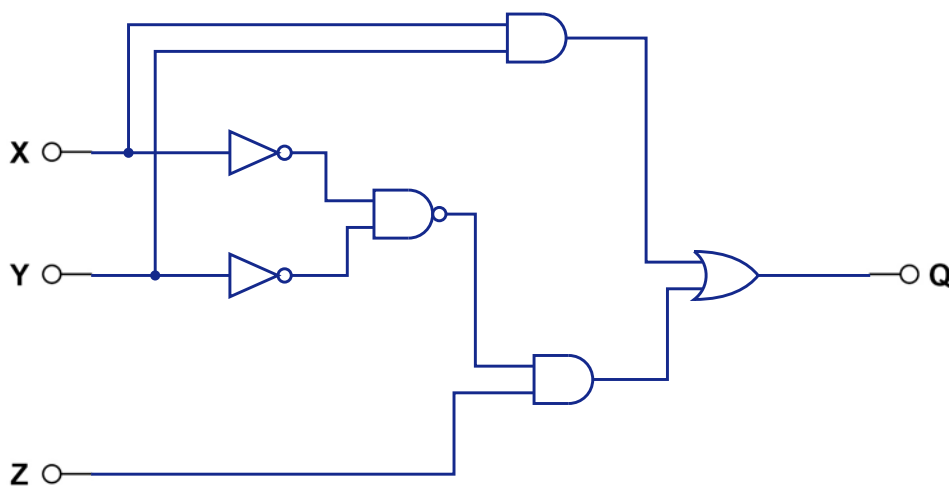
The output **Q** from this logic system is given by the Boolean expression:

$$Q = (X \cdot Y) + Z \cdot (\overline{X} \cdot \overline{Y})$$

Complete **Figure 3** to show the combinational logic diagram for this expression. Use only the logic gates indicated in the expression. Do not transform the expression.

[2 marks]

Figure 3



Question 1 continues on the next page

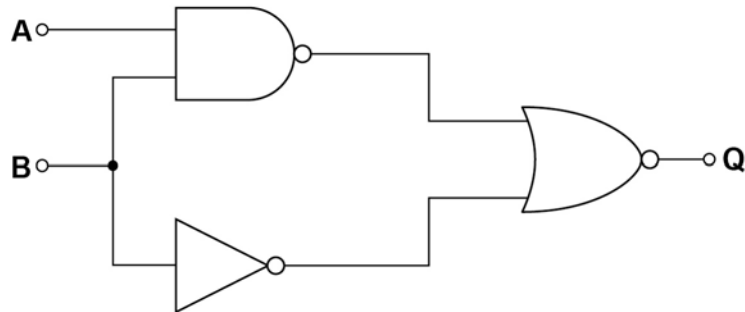
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0 1 . 3 A single logic gate can sometimes be used to replace a more complex logic system.

Figure 4 shows a logic system with inputs **A** and **B** and output **Q**.

Figure 4



Which single logic gate could replace this combinational logic system?

Tick (✓) **one** box.

[1 mark]

OR

☐

NOR

☐

EOR

☐

AND

☒

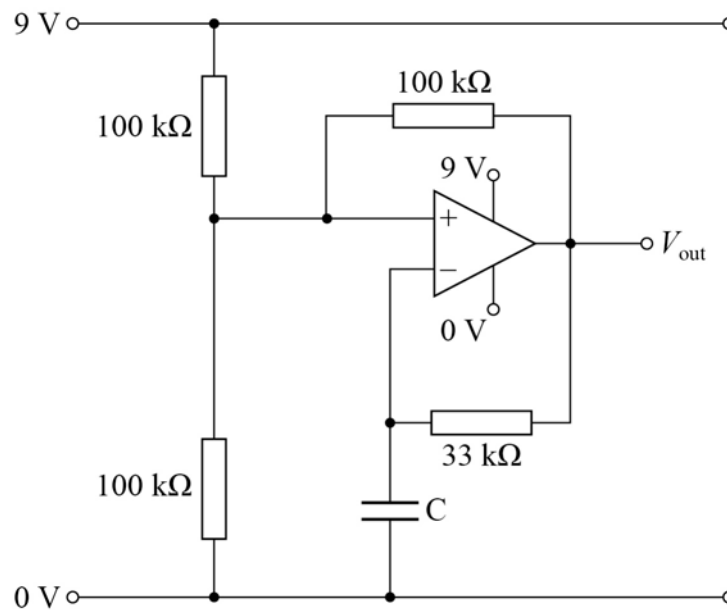
NAND

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0 2

Figure 5 shows an operational amplifier circuit designed to function as an oscillator. The circuit produces square waves.

Figure 5



Assume that the operational amplifier is ideal and that it is operating as a comparator in this application.

0 2 . 1

Explain the combined role of the 33 kΩ resistor and C in this circuit.

[1 mark]

The 33 kΩ resistor and C determine the charging / discharging rate of C (time constant RC), and so the oscillation frequency.

0 2 . 2

State the function of the potential divider formed by the three 100 kΩ resistors.

[1 mark]

They set the reference voltage at the non-inverting (+) input of the op amp (3.0 V or 6.0 V, depending on V_{out}).

Question 2 continues on the next page

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0 2 . 3

Deduce the voltage V_+ at the non-inverting input of the operational amplifier when:

- the output voltage V_{out} is 0.0 V
- the output voltage V_{out} is 9.0 V.

[3 marks] *$V_{\text{out}} = 0.0 \text{ V}$: feedback $100 \text{ k}\Omega$ is in parallel with the lower $100 \text{ k}\Omega$*

$R_{\text{parallel}} = (100 \times 100) / (100 + 100) = 50 \text{ k}\Omega$

$V_+ = 9.0 \times 50 / (100 + 50) = 3.0 \text{ V}$

 $V_{\text{out}} = 9.0 \text{ V}$: feedback $100 \text{ k}\Omega$ is in parallel with the upper $100 \text{ k}\Omega$

$R_{\text{parallel}} = 50 \text{ k}\Omega$ (between 9 V and V_+)

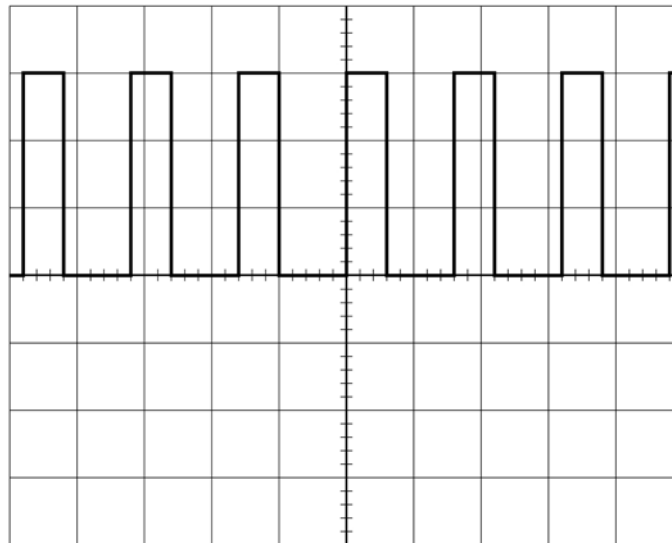
$V_+ = 9.0 \times 100 / (50 + 100) = 6.0 \text{ V}$

when V_{out} is 0.0 V, $V_+ =$ 3.0 Vwhen V_{out} is 9.0 V, $V_+ =$ 6.0 V

0 2 . 4

Figure 6 shows the output from a different oscillator displayed on an oscilloscope screen.

Figure 6



The time-base is $10 \mu\text{s}$ per division.

Deduce the pulse rate frequency, in kHz, and the duty cycle for this signal.

[2 marks]

$$t_H = 0.6 \text{ div} \times 10 \mu\text{s} = 6 \mu\text{s}, \quad t_L = 1.0 \text{ div} \times 10 \mu\text{s} = 10 \mu\text{s}$$

$$\text{period } T = t_H + t_L = 6 + 10 = 16 \mu\text{s}$$

$$\text{PRF} = 1 / T = 1 / (16 \times 10^{-6}) = 6.25 \times 10^4 \text{ Hz} = 62.5 \text{ kHz}$$

$$\text{duty cycle} = t_H / (t_H + t_L) \times 100\% = 6 / 16 \times 100\% = 37.5\%$$

pulse rate frequency = 62.5 kHz

duty cycle = 37.5 %

7

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0 3 . 1

A photodiode can be used in either photovoltaic mode or photoconductive mode.

State **one** advantage of using a photodiode in photoconductive mode.

[1 mark]

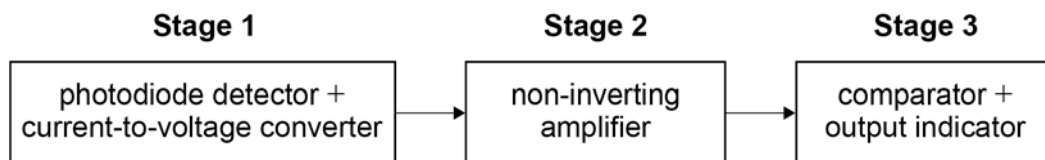
It has a shorter response time (it responds faster to changes in light intensity) than photovoltaic mode.

A light-intensity monitor uses a photodiode in reverse bias. The photodiode responds to the irradiance of light incident on it.

Irradiance is a measure of the power of the light incident on unit surface area and is measured in W m^{-2} .

Figure 7 shows the three stages that make up the light-intensity monitor.

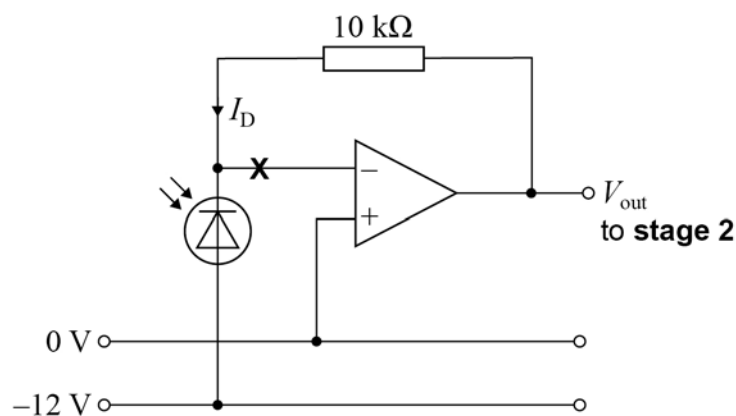
Figure 7



Each stage uses an operational amplifier. The power rails to the operational amplifiers are 0 V and +12 V; these are not shown in **Figures 8, 9 or 10**.

Figure 8 shows the circuit for **stage 1**.

Figure 8



When the photodiode detects light within its sensitive range, there is a reverse photocurrent I_D in the circuit. This current depends on the irradiance of the light. The output voltage V_{out} of the circuit is proportional to I_D . Point **X** is a virtual earth.

0 3 . 2 Explain what is meant by a virtual earth.

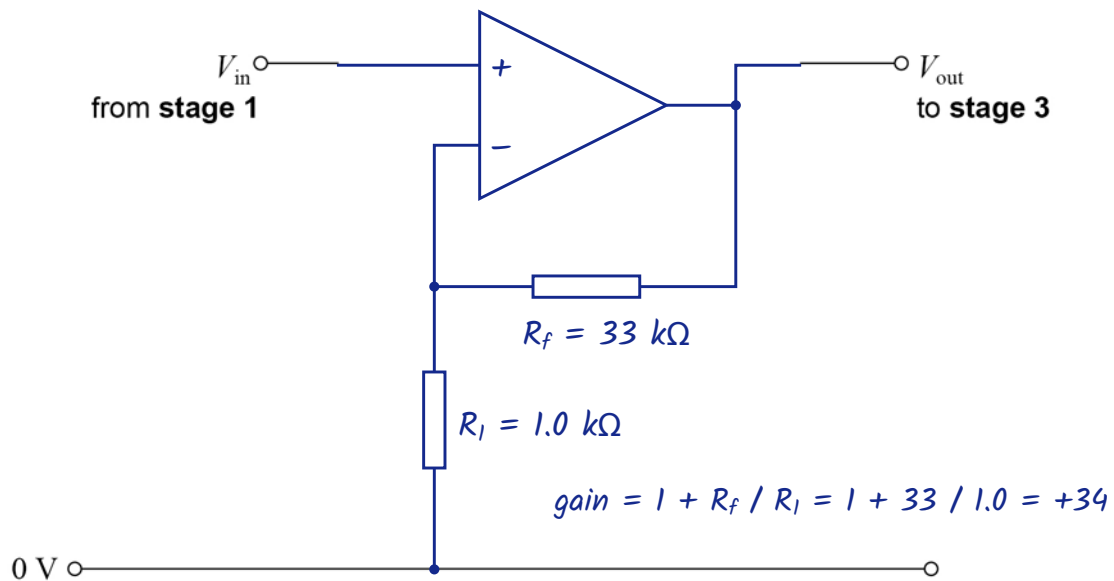
[1 mark]

A point held at 0 V (acts as if earthed) by the circuit configuration, though it has no direct physical connection to earth.

0 3 . 3 The output signal V_{out} from **stage 1** is used as the input signal V_{in} for **stage 2**.

Figure 9 is an incomplete circuit diagram of **stage 2**.

Figure 9



Complete **Figure 9** to show how an operational amplifier is configured to produce a voltage gain of +34

In your answer:

- label resistors with their values within the range 1 kΩ to 100 kΩ
- show the inverting (−) and non-inverting (+) inputs to the operational amplifier
- do **not** show the power supplies or power rails for the operational amplifier.

[2 marks]

Question 3 continues on the next page

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0 3 . 4

Stage 3 uses an operational amplifier as a comparator to determine whether the irradiance detected by the photodiode in **stage 1** exceeds a critical value.

Figure 10 shows the **stage 3** circuit diagram.

Figure 10

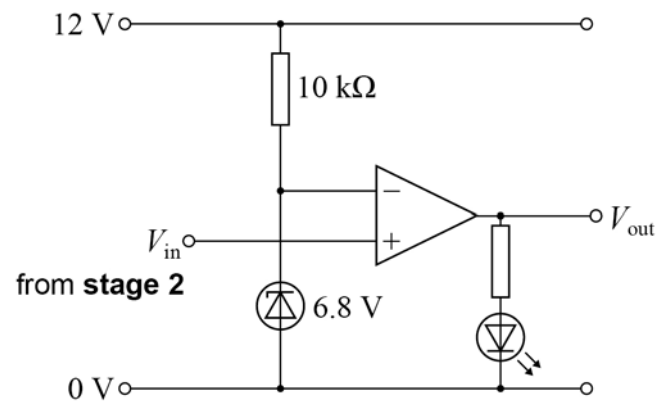
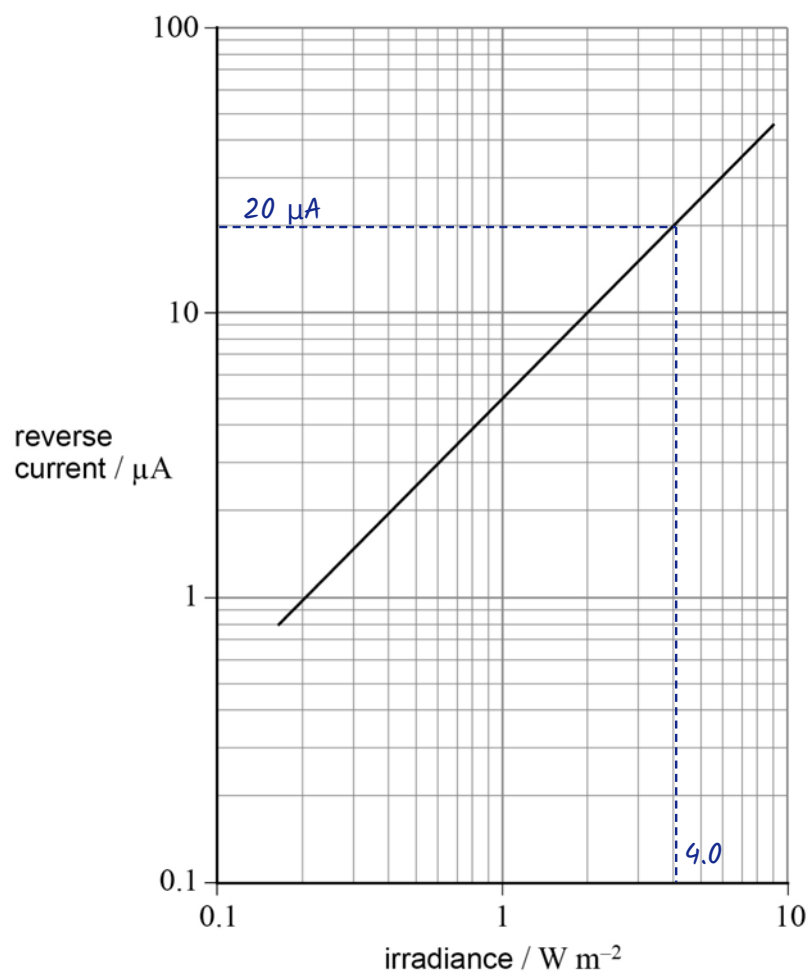


Figure 11 shows part of the data sheet for the photodiode.

Figure 11



Determine the minimum irradiance that must be detected by the photodiode in **stage 1** in order to turn on the LED in **stage 3**.

[3 marks]

LED turns on when V_{in} (+ input) exceeds $V_- = 6.8 \text{ V}$ (diode)

stage 2 gain = 34, so stage 1 output = $6.8 / 34 = 0.20 \text{ V}$

$I_D = V / R = 0.20 / (10 \times 10^3) = 2.0 \times 10^{-5} \text{ A} = 20 \text{ } \mu\text{A}$

from Figure 11, $I_D = 20 \text{ } \mu\text{A}$ gives an irradiance of 4.0 W m^{-2}

irradiance = 4.0 W m^{-2}

0 3 . 5

When the monitor is tested, the LED turns on fully.
However, the LED does not turn off fully when the irradiance falls below the critical value.

Suggest **one** reason why the LED does not turn off fully.
In your answer, refer to a limitation of real operational amplifiers.

[1 mark]

*Real op amps cannot saturate at exactly 0 V; the low output saturates
at a value $> 0 \text{ V}$, which can be enough to keep the LED partly on.*

8

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0 4 . 1

State what is meant by a carrier wave within a radio transmission system.
Go on to explain how the carrier wave is used in this system.

[2 marks]

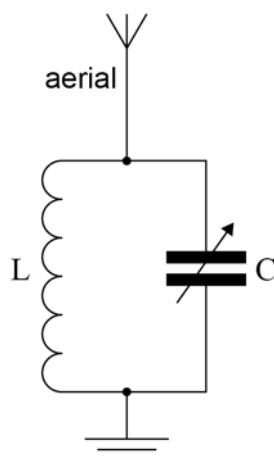
A carrier wave is a fixed-frequency radio wave assigned to a radio station, which is used to transmit the information (signal).

Some characteristic of the carrier wave, such as its amplitude (AM) or its frequency (FM), is varied (modulated) by the information signal, so the signal is carried at the station's frequency and can be recovered (demodulated) at the receiver.

0 4 . 2

Figure 12 shows the first stage of a radio receiver.

Figure 12



Explain the role of the LC circuit in the first stage of the receiver.

[2 marks]

The LC circuit resonates at one particular frequency, $f = 1 / (2\pi\sqrt{LC})$, set by L and C.

It acts as a filter: the signal at this frequency gives a large amplitude across LC compared with other signals from the aerial. Varying C changes the resonant frequency, selecting the station.

Question 4 continues on the next page

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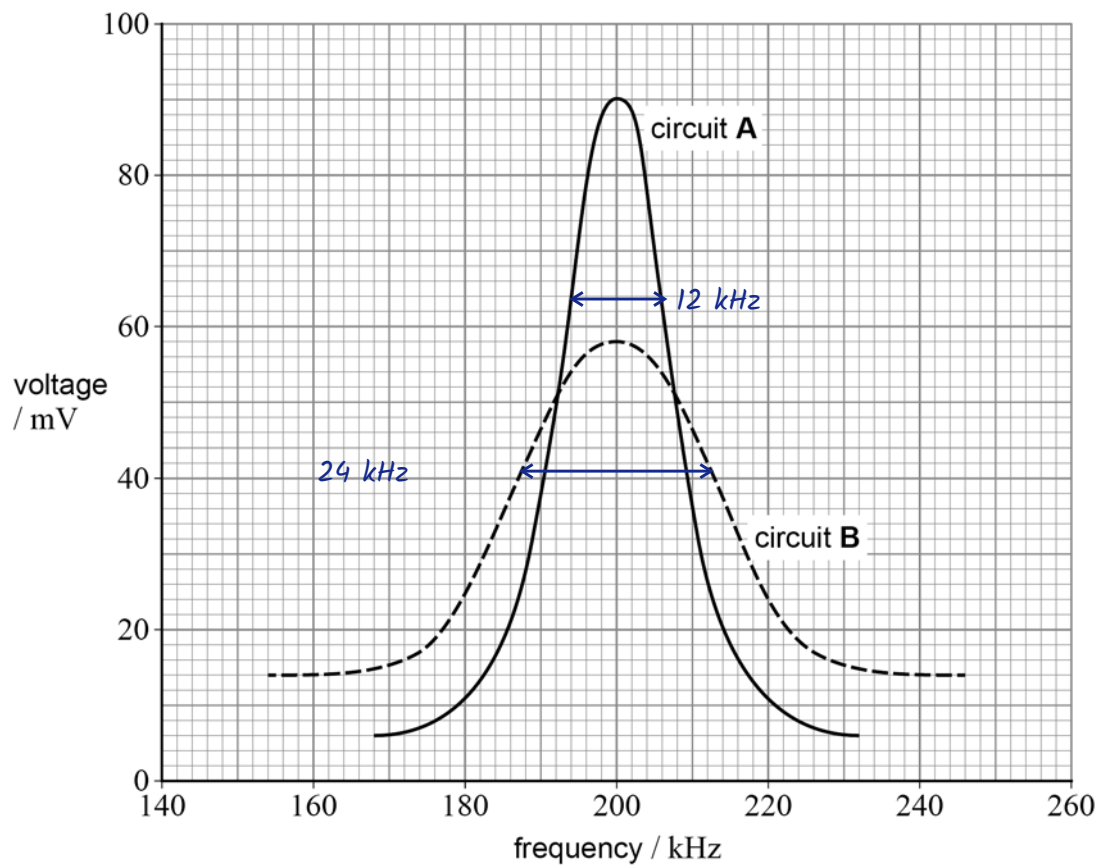


0 4 . 3

Two different LC circuits **A** and **B** are available for the first stage of a radio receiver tuned to a particular radio station. One of these circuits is to be chosen for the final design of the receiver.

Figure 13 shows the variation of voltage with frequency for both **A** and **B**.

Figure 13



The receiver is to detect an AM signal transmitted with a carrier frequency of 200 kHz over a bandwidth of 10 kHz.

Explain whether circuit **A** or circuit **B** is more appropriate for this radio receiver.

Your answer should include a discussion of:

- bandwidth
- the ability of the receiver to reject signals from other radio stations.

[2 marks]

bandwidth is measured at $0.71 \times$ peak voltage (half-power points):

A: $0.71 \times 90 = 64 \text{ mV}$, bandwidth = $205 - 193 = 12 \text{ kHz}$

B: $0.71 \times 58 = 41 \text{ mV}$, bandwidth = $211 - 187 = 24 \text{ kHz}$

both are greater than 10 kHz, so both can pass the whole AM signal

Both can accommodate the 10 kHz bandwidth, but circuit A is more appropriate. Its sharper, narrower peak (higher Q factor) makes it more selective, so it rejects signals from other stations at nearby frequencies, giving less interference.

6

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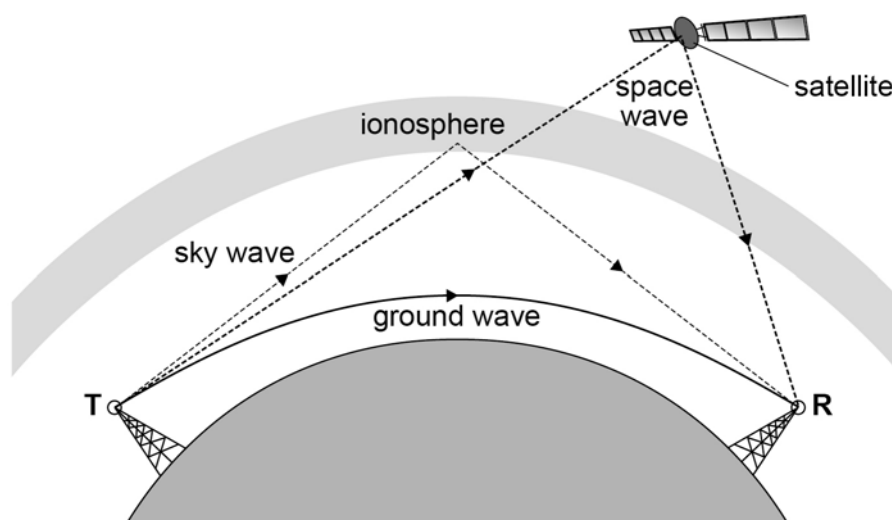
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0 5

Figure 14 shows a transmitter **T** and a receiver **R** which are not in line of sight. Three transmission pathways from **T** to **R** are shown.

Figure 14



Explain, for each of the ground wave, sky wave and space wave:

- the conditions necessary for the pathway to operate
- **one** advantage and **one** disadvantage of using that pathway.

[6 marks]

Ground (surface) wave: uses long wave (LW), about 150 kHz to 300 kHz (wavelength 1 km to 2 km), or medium wave (300 kHz to 3 MHz). The long wavelength means the waves are diffracted by the Earth's surface, so they travel along the curvature of the Earth beyond the line of sight from T to R.

Advantage: a large area of coverage for a given transmitter power, because absorption of the EM wave is less at low frequency.

Disadvantage: the signal is attenuated with distance and there may still be receivers in geographical shadows; also LW has a restricted bandwidth so it can only carry a limited amount of information.

Sky wave: uses short wave (SW), about 3 MHz to 30 MHz (wavelength 10 m to 100 m). For these frequencies the ionosphere refracts the radio



waves enough for them to be returned to Earth as if reflected, so the wave reaches R by bouncing off the ionosphere (possibly with several hops).

Advantage: very long distances are covered, and attenuation is low because of the higher frequencies (the wavelength is too short to suffer diffraction losses into the ground). Disadvantage: the ionosphere is susceptible to Sun activity, so it is unstable and signal reception fades, varying with time of day and conditions.

Space wave (satellite): uses microwaves, about 2 GHz to 100 GHz (wavelength 3 mm to 150 mm). The short wavelength penetrates the atmosphere and the ionosphere. The transmitter dish must have line of sight to the satellite (uplink), and the satellite re-transmits the signal down to the Earth station at a different frequency (downlink).

Advantage: a large bandwidth is available, so a lot of information can be carried, and one satellite can transmit to multiple receivers over a large geographical area. Disadvantage: a damp atmosphere (rain) can cause microwave attenuation, and the initial capital cost (launching the satellite and dishes) is much higher than for the other pathways.

END OF QUESTIONS



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