

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	
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3	
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5	
TOTAL	



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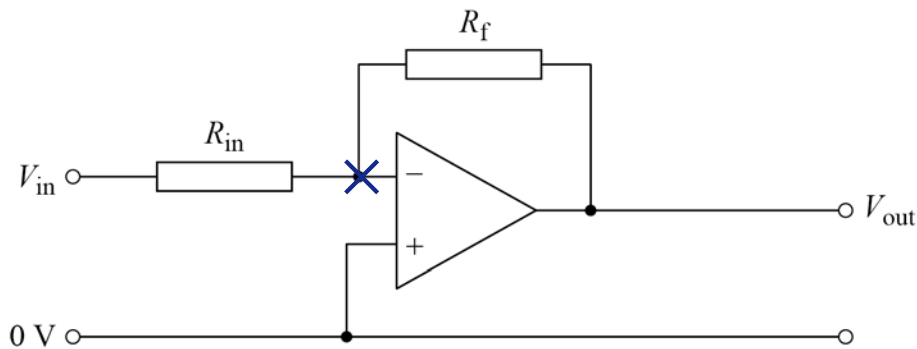
Section B

Answer **all** questions in this section.

0 1

Figure 1 shows a circuit containing an ideal operational amplifier. A signal V_{in} is applied to one of the amplifier inputs.

Figure 1



0 1. 1

Draw an **X** on the circuit in **Figure 1** to indicate a virtual earth point.

[1 mark]

0 1. 2

Show that the closed loop voltage gain for the amplifier in **Figure 1** is given by:

$$\frac{R_f}{R_{in}} = - \frac{V_{out}}{V_{in}}$$

State any assumptions made in your answer.

[2 marks]

$V_+ = 0 \text{ V}$ and open-loop gain is very large, so $V_- \approx 0 \text{ V}$ (virtual earth).

Current through R_{in} : $I = (V_{in} - 0) / R_{in} = V_{in} / R_{in}$

Current through R_f : $I = (0 - V_{out}) / R_f = -V_{out} / R_f$

No current enters the op amp (infinite input impedance), so the same current I flows through R_{in} and R_f : $V_{in} / R_{in} = -V_{out} / R_f$

rearranging: $R_f / R_{in} = -V_{out} / V_{in}$ (V_{out} inverted)

assumptions ideal op amp: infinite input impedance (I in $R_{in} = I$ in R_f)

and inverting input is a virtual earth at 0 V (infinite open-loop gain)

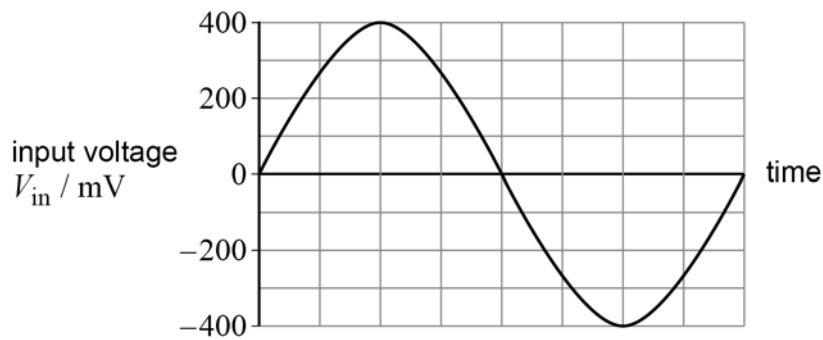
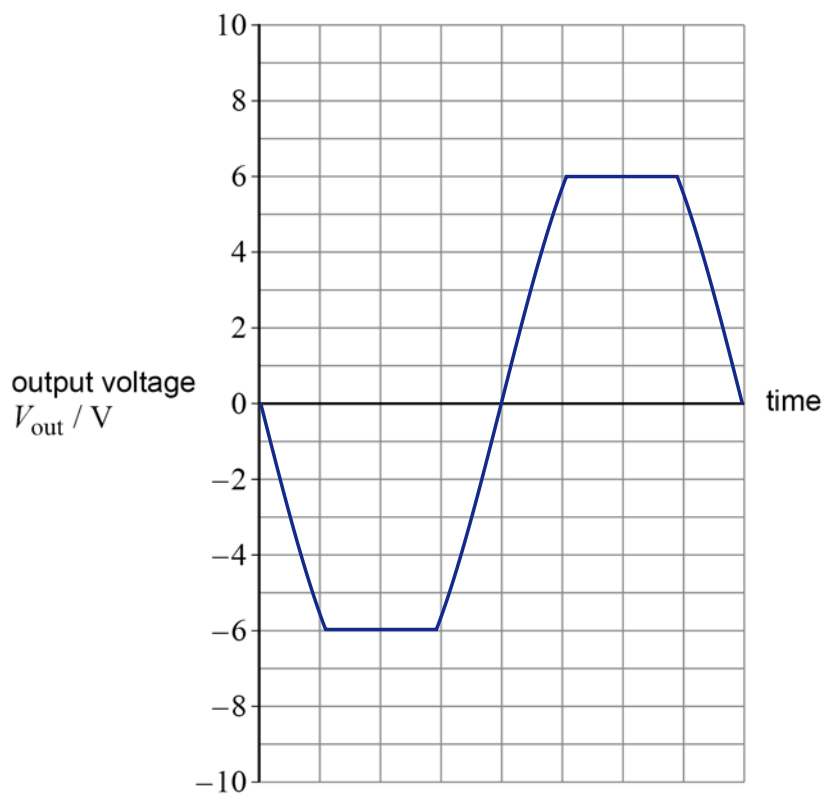
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0 1 3

Figure 2A shows the input signal V_{in} that is applied to the circuit in **Figure 1**.

Figure 2A**Figure 2B**

The circuit in **Figure 1** has a closed loop gain of -20 and has power-supply voltages of ± 6.0 V.

Draw, on **Figure 2B**, the output waveform from the operational amplifier circuit over the same time interval as that shown on **Figure 2A**.

[2 marks]

gain -20 : peak -20×0.4 V = ∓ 8 V, clipped at ± 6 V



0 1 . 4

A student converts the circuit in **Figure 1** into one that will add two input signals V_1 and V_2 .

The new circuit produces an output voltage V_{out} so that:

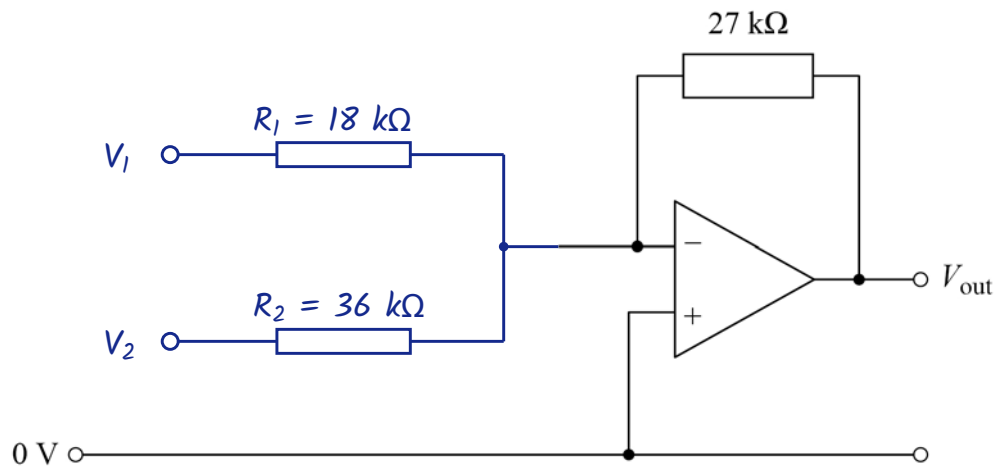
$$V_{\text{out}} = -(1.5V_1 + 0.75V_2)$$

The circuit is to include a $27 \text{ k}\Omega$ feedback resistor.

Complete **Figure 3** to show the circuit that the student constructs.
Annotate your circuit with the values of any additional components.

[3 marks]

Figure 3



For an inverting summer: $V_{\text{out}} = -R_f (V_1/R_1 + V_2/R_2)$

$R_f / R_1 = 1.5$ so $R_1 = 27 \text{ k}\Omega / 1.5 = 18 \text{ k}\Omega$ (input V_1)

$R_f / R_2 = 0.75$ so $R_2 = 27 \text{ k}\Omega / 0.75 = 36 \text{ k}\Omega$ (input V_2)

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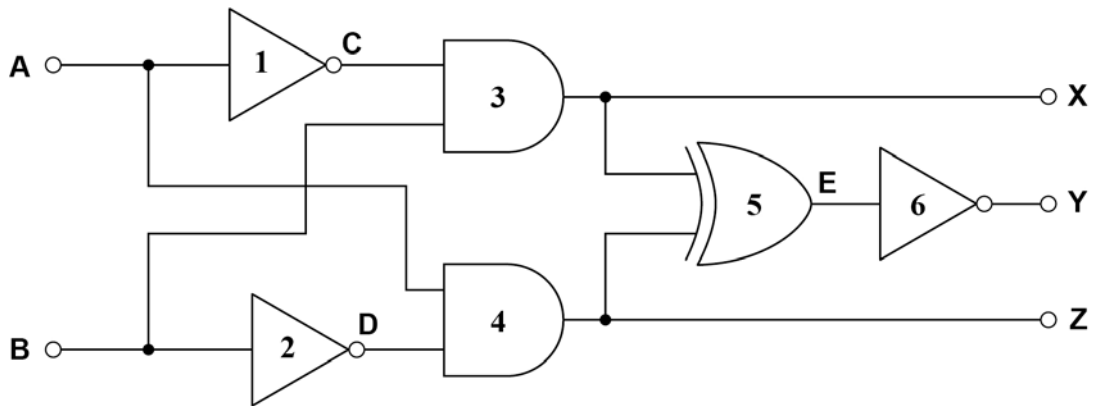
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0 2

Figure 4 shows a logic system made of logic gates labelled 1 to 6. The logic system has inputs **A** and **B** and outputs **X**, **Y** and **Z**.

Figure 4



0 2

1

Write the simplest Boolean algebra expression for output **X** in terms of inputs **A** and **B**.

[2 marks]

$$C = \bar{A} \text{ so } X = C \cdot B = \bar{A} \cdot B$$

$$X = \bar{A} \cdot B$$

0 2

2

State the name of logic gate **5** in **Figure 4**.

[1 mark]

EOR (exclusive OR) gate

0 2

3

Complete **Table 1**, the truth table for this logic system.

[2 marks]

Table 1

B	A	C	D	E	X	Y	Z
0	0	1	1	0	0	1	0
0	1	0	1	1	0	0	1
1	0	1	0	1	1	0	0
1	1	0	0	0	0	1	0



0 2 . 4

Suggest a single logic gate that can replace the combination of gates 5 and 6 in this system.

[1 mark]

NOR gate

0 2 . 5

The logic system in **Figure 4** is designed to indicate which of inputs **A** and **B** has the larger binary value, or whether the values are the same. Each decision is indicated by one of the outputs **X**, **Y** or **Z** becoming a logic 1

Which row identifies the outputs **X**, **Y** and **Z**?

Tick (✓) **one** box.

[1 mark]

X	Y	Z	
A = B	A < B	A > B	☐
A < B	A = B	A > B	☒
A < B	A > B	A = B	☐
A > B	A = B	A < B	☐

7

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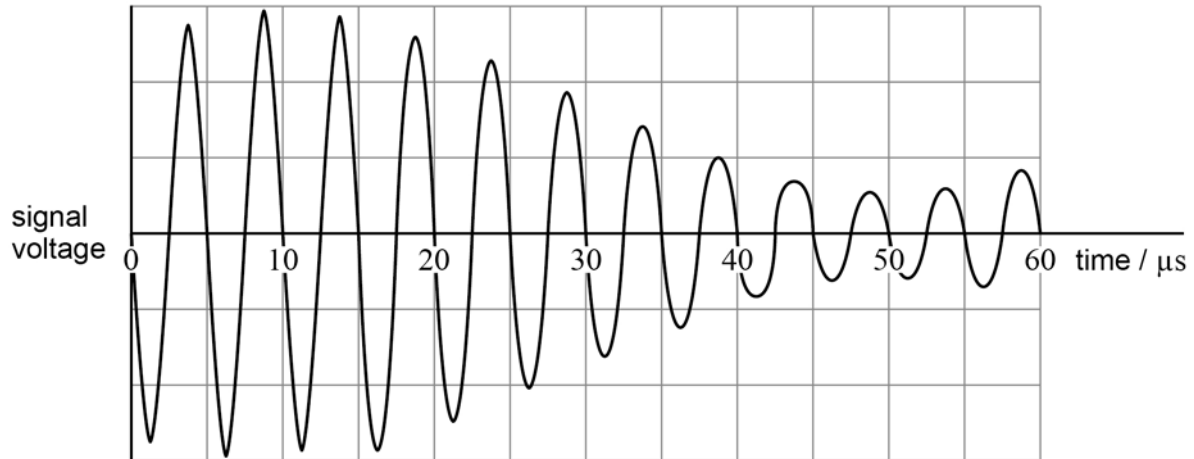


0 3

Figure 5 shows the output signal from the tuner circuit of a radio receiver.

The radio carrier wave is amplitude modulated by a single-frequency test tone.

Figure 5



0 3. 1

Determine the frequency, in kHz, of the carrier wave.

[1 mark]

One cycle of the carrier takes $T = 5 \mu\text{s}$

$$f = 1 / T = 1 / (5 \times 10^{-6} \text{ s}) = 2.0 \times 10^5 \text{ Hz}$$

frequency of carrier wave = 200 kHz

0 3. 2

Determine the frequency, in kHz, of the test tone.

[2 marks]

Half a cycle of the test tone (envelope max to min) $\approx 42 \mu\text{s}$

$$T = 2 \times 42 \mu\text{s} = 84 \mu\text{s}$$

$$f = 1 / T = 1 / (84 \times 10^{-6} \text{ s}) = 1.19 \times 10^4 \text{ Hz}$$

frequency of test tone = 11.9 kHz



0 3 . 3

State **one** advantage of using frequency modulation (FM) rather than amplitude modulation (AM).

[1 mark]

FM is immune to noise in amplitude, since the information is stored in the frequency variation, not the amplitude.

0 3 . 4

The frequency range of the FM radio band in the UK is 88 to 108 MHz.

The FM stations are allocated centre frequencies that start at 88.100 MHz and are separated by 200 kHz.

Calculate the maximum number of stations allowed within the range.

[1 mark]

$$\begin{aligned} \text{number} &= (108 \text{ MHz} - 88 \text{ MHz}) / 200 \text{ kHz} \\ &= 20 \text{ MHz} / 0.200 \text{ MHz} = 100 \end{aligned}$$

maximum number of stations = 100

0 3 . 5

A radio station broadcasting on FM transmits a maximum audio frequency of 15 kHz and has a frequency deviation of ± 75 kHz.

Deduce whether the radio station fits the FM bandwidth allocation in the UK.

[2 marks]

$$\begin{aligned} \text{Bandwidth} &= 2(\Delta f + f_m) \\ &= 2 \times (75 \text{ kHz} + 15 \text{ kHz}) \\ &= 2 \times 90 \text{ kHz} = 180 \text{ kHz} \end{aligned}$$

The bandwidth needed is 180 kHz, which is less than the 200 kHz separation allocated to each station, so the station fits within its allocated 200 kHz band (yes, it fits).

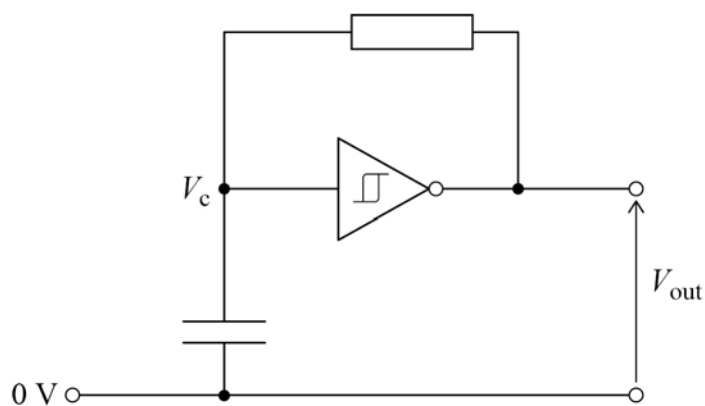
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0 4

Figure 6 shows a type of NOT gate called a Schmitt Trigger. This is connected to a capacitor of capacitance C and a resistor of resistance R to make an oscillator circuit. The circuit is used to produce continuous clock pulses.

Figure 6



V_{out} switches HIGH or LOW when the input voltage V_c passes through one of two trigger voltage values.

The output voltage V_{out} switches to:

- LOW when V_c rises and reaches the upper trigger voltage V_U
- HIGH when V_c falls and reaches the lower trigger voltage V_L .

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0 4 . 1

Initially the capacitor is uncharged and V_c is at 0 V.

Explain the sequence of actions of this circuit as the output goes through one full cycle. The first two stages have been done for you.

You should refer to the RC circuit in **Figure 6** and to V_U and V_L in your answer.

[3 marks]

Stage 1: Since V_c is LOW, the output is HIGH.

Stage 2: The capacitor now charges through the resistor, making V_c rise.

Stage 3: *When V_c reaches a value of V_U , the output voltage V_{out} drops LOW.*

Stage 4: *The capacitor now discharges through the resistor R (into the LOW output), causing the value of V_c to fall.*

Stage 5: *When V_c falls and reaches a value of V_L , the output voltage V_{out} jumps HIGH again, so the capacitor charges and the cycle repeats.*

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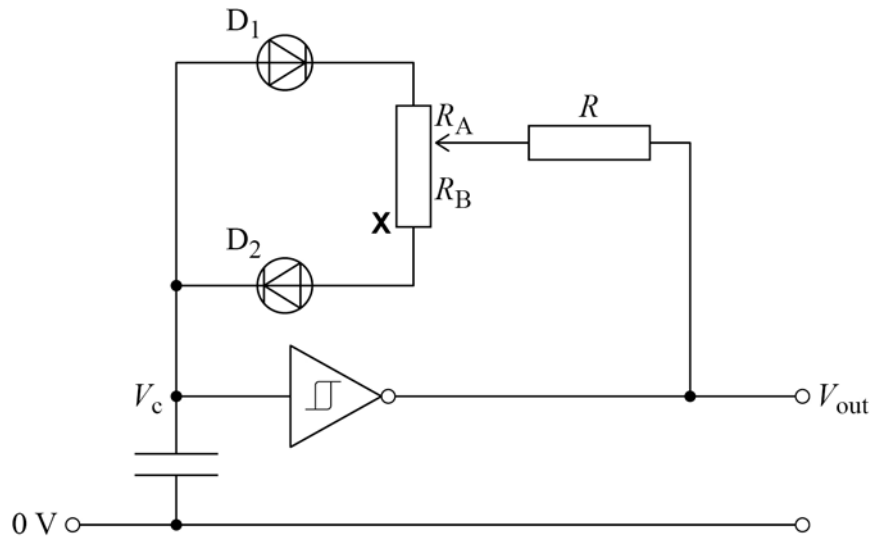


0 4 . 2

Figure 7 shows the oscillator circuit after it has been modified by the addition of:

- two diodes D_1 and D_2
- a potential divider that has a total resistance value of $(R_A + R_B)$.

Figure 7



In this particular circuit:

- the time t_H for the output signal to be HIGH is given by $t_H = 0.7C(R + R_B)$
- the time t_L for the output signal to be LOW is given by $t_L = 0.7C(R + R_A)$.



The slider of the potential divider is moved towards **X**, as shown in **Figure 7**.

State and explain the effect of this change on:

- the mark-to-space ratio ($t_H : t_L$)
- the pulse rate frequency (PRF).

[4 marks]

mark-to-space ratio *Moving the slider towards X makes R_B smaller and R_A bigger.*

So $t_H = 0.7C(R + R_B)$ is reduced and $t_L = 0.7C(R + R_A)$ is increased.

Hence the mark-to-space ratio $t_H : t_L$ is reduced (gets smaller).

PRF *$PRF = 1/T = 1/(t_H + t_L) = 1 / (0.7C(2R + R_A + R_B))$.*

The total resistance ($2R + R_A + R_B$) is constant, since $R_A + R_B$ is the fixed total of the potential divider.

So the period T is unchanged and, as a result of the constant resistance, the PRF does not change.

7

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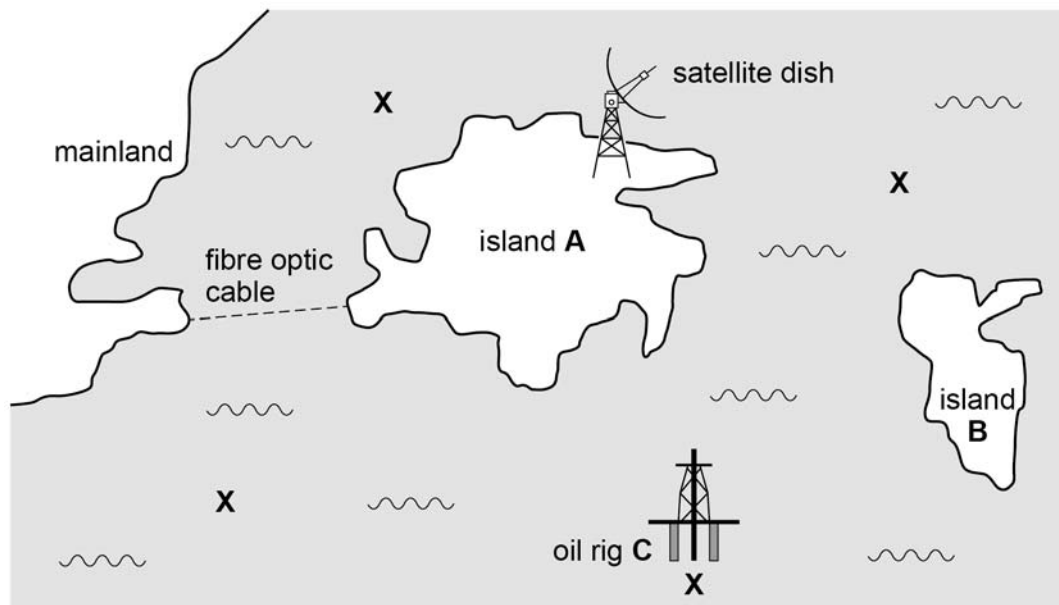
0 5

Figure 8 shows island **A**, a fully developed island off the mainland coast. The island is connected to the mainland by a fibre optic cable lying along the seabed and it also has a satellite link.

Nobody lives on island **B**, but it is due to be developed as a major holiday resort over the next 5 years.

Moveable oil rig **C** is due to explore the four sites marked 'X' for oil and gas over a 9-month period.

Figure 8



A communications company has been asked to provide solutions for island **B** which will allow the development to begin immediately and then later to support a fully developed holiday resort.

A communications solution is also required for oil rig **C** during the 9-month exploration period.

Describe appropriate solutions involving fibre optic cabling and satellite communication systems for each of the two clients, island **B** and oil rig **C**.

In your answer you should:

- outline the way each communications system operates
- suggest, with reasons, your choice of system for each solution.

[6 marks]

Fibre optic: digital data is placed on the cable by a high power IR laser diode. The light travels along the fibre by total internal reflection.

Opto/electronic repeaters (regenerators) or opto amplifiers are used along



long links. At the receiver a photodiode converts the optical data back into electrical signals.

Satellite: digital data is sent through free space as microwaves (typically 12 to 18 GHz) from a focused, directional dish (uplink). Microwaves are used because they penetrate the atmosphere. The satellite, likely in geostationary orbit, receives the data and re-transmits it at a different microwave frequency to a dish at another location (downlink).

Island B: initially use a satellite link, since mobile satellite units are quick and easy to set up and early usage is low, so the lower bandwidth and data rate are not an issue (though there is some signal delay in two-way conversations). Later, as the resort develops and usage grows, install a submarine fibre optic cable (cable ship, terminations, internal network). This needs more forward planning and expense, but gives much higher bandwidth and data rate, is more reliable, has low security issues and is immune to EM interference and noise, unlike satellite with its higher maintenance costs.

Oil rig C: use a satellite link. Fibre optic cable is not an option because the rig is mobile and moves between four sites. Satellite is a low-cost short-term solution for 9 months, and light use with limited platform requirements means the reduced bandwidth and lower data rate are not critical, despite signal delay in conversations and some reliability issues.

END OF QUESTIONS



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