

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

A-level PHYSICS

Paper 3

Section B Electronics

Thursday 29 June 2017

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.

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.
- 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	



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

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**DO NOT WRITE ON THIS PAGE
ANSWER IN THE SPACES PROVIDED**



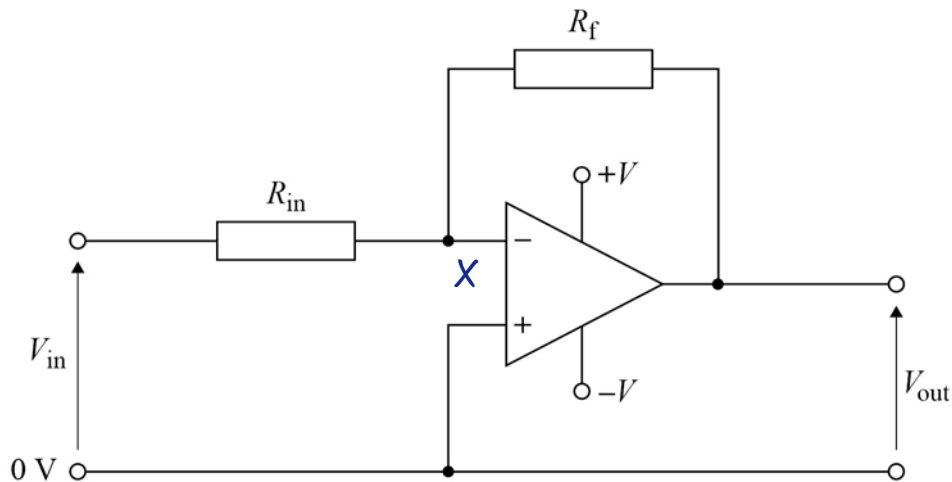
Section B

Answer **all** questions in this section.

0 1

Figure 1 shows an operational amplifier used as an inverting amplifier.

Figure 1



0 1 . 1

Label Figure 1 with an X to show the point which is a virtual earth.

[1 mark]

0 1 . 2

Name the input pin shown by a (+) on the operational amplifier.

[1 mark]

The non-inverting input

0 1 . 3

Derive the expression for the inverting amplifier gain $\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$

[2 marks]

Open-loop gain is very high, so $V_- \approx V_+ = 0$ V:

the inverting input is a virtual earth ($V_X = 0$).

No current enters the op-amp, so $I_{in} = I_f = I$

$$I = (V_{in} - V_X) / R_{in} = (V_X - V_{out}) / R_f$$

$$\text{With } V_X = 0: I = V_{in} / R_{in} = -V_{out} / R_f$$

$$\text{So } V_{out} / V_{in} = -R_f / R_{in}$$

Question 1 continues on the next page

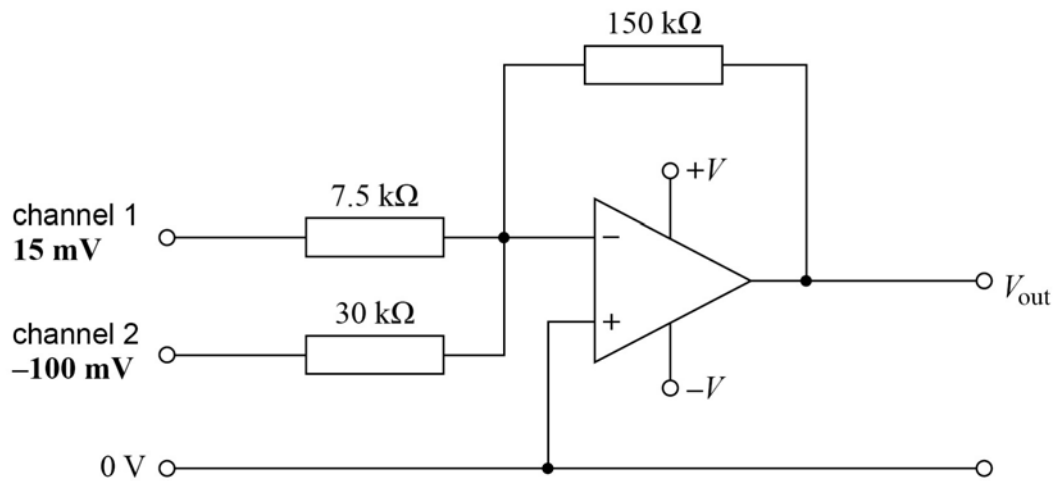
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0 1 . 4

Figure 2 shows the inverting amplifier modified to make a summing amplifier that is to form part of a two-channel audio mixer.

Figure 2



Calculate the voltage gain produced by channel 1.

[1 mark]

$$\text{Gain} = -R_f / R_{in1} = -150 \text{ k}\Omega / 7.5 \text{ k}\Omega$$

voltage gain (channel 1) = -20

0 1 . 5

The mixer is tested using the input signals to channels 1 and 2 with the amplitudes shown in **Figure 2**.

Calculate the amplitude of the output voltage V_{out} produced in the test.

[2 marks]

$$\begin{aligned} V_{out} &= -R_f (V_1 / R_1 + V_2 / R_2) \\ &= -150 \text{ k}\Omega \times (15 \text{ mV} / 7.5 \text{ k}\Omega + (-100 \text{ mV}) / 30 \text{ k}\Omega) \\ &= -((+0.30 \text{ V}) + (-0.50 \text{ V})) = +0.20 \text{ V} \end{aligned}$$

V_{out} = +0.20 V



0	1	.	6
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Describe how the function of the audio mixer could be improved by changing the two input resistors from fixed values to variable values.

[1 mark]

With variable resistors the gain of each channel can easily be changed, so the relative levels of the two channels can be set, giving the required balance between the two signals.

8

Turn over for the next question

Turn over ►



0 2

A die, where dots on the faces of a cube indicate the numbers 1 to 6, is shown in **Figure 3** and is used in many games.

Figure 3



A student makes an electronic version of this by feeding pulses from a pulse generator into a 4-bit binary counter.

The circuit uses the first three outputs of the counter A (least significant bit), B and C.

By feeding the outputs from the counter through logic gates, the seven LEDs shown in **Figure 4** can be made to display the numbers 1 to 6 in sequence.

Figure 4

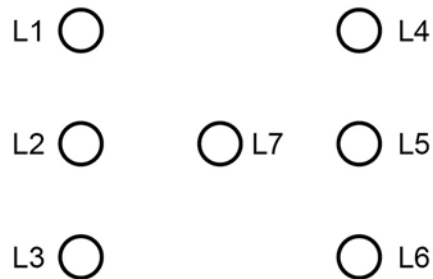
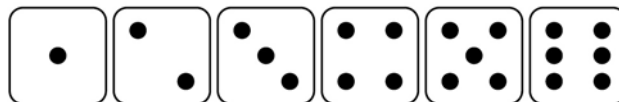


Figure 5 shows the sequence of numbers.

Figure 5



The black dots show which LEDs are lit for each of the numbers 1 to 6.



The partially completed truth table in **Table 1** shows which of the LEDs (L1 to L6) are ON (logic 1) and which are OFF (logic 0) during the counting sequence.

Table 1

Number shown on die	Logic inputs			Logic outputs						
	C	B	A	L1	L2	L3	L4	L5	L6	L7
1	0	0	0	0	0	0	0	0	0	1
2	0	0	1	1	0	0	0	0	1	0
3	0	1	0	1	0	0	0	0	1	1
4	0	1	1	1	0	1	1	0	1	0
5	1	0	0	1	0	1	1	0	1	1
6	1	0	1	1	1	1	1	1	1	0
Reset 6 → 1										

0 2 . 1

Complete **Table 1** to show the logic outputs for the lamps L1 and L6.

[2 marks]

0 2 . 2

Deduce the **simplest** Boolean expression that can be used to show how output L7 can be controlled by the logic inputs.

[1 mark]

$$L7 = NOT A$$

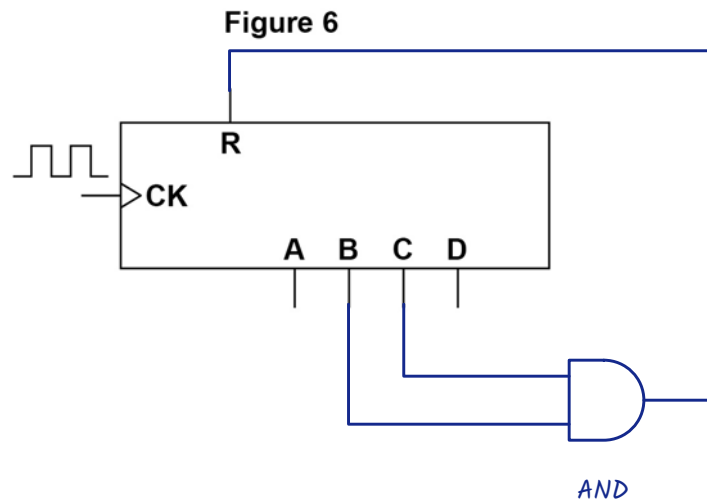
Question 2 continues on the next page

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0 2 . 3

Figure 6 shows some of the input and output pins of the 4-bit binary counter.



The data sheet for the counter indicates that the counter resets when the reset pin **R** is taken from logic 0 to logic 1.

Draw on **Figure 6** the logic gate needed and the connections required from the outputs to the reset pin **R** on the counter so that the counter cycles as required.

[2 marks]



0 2 . 4

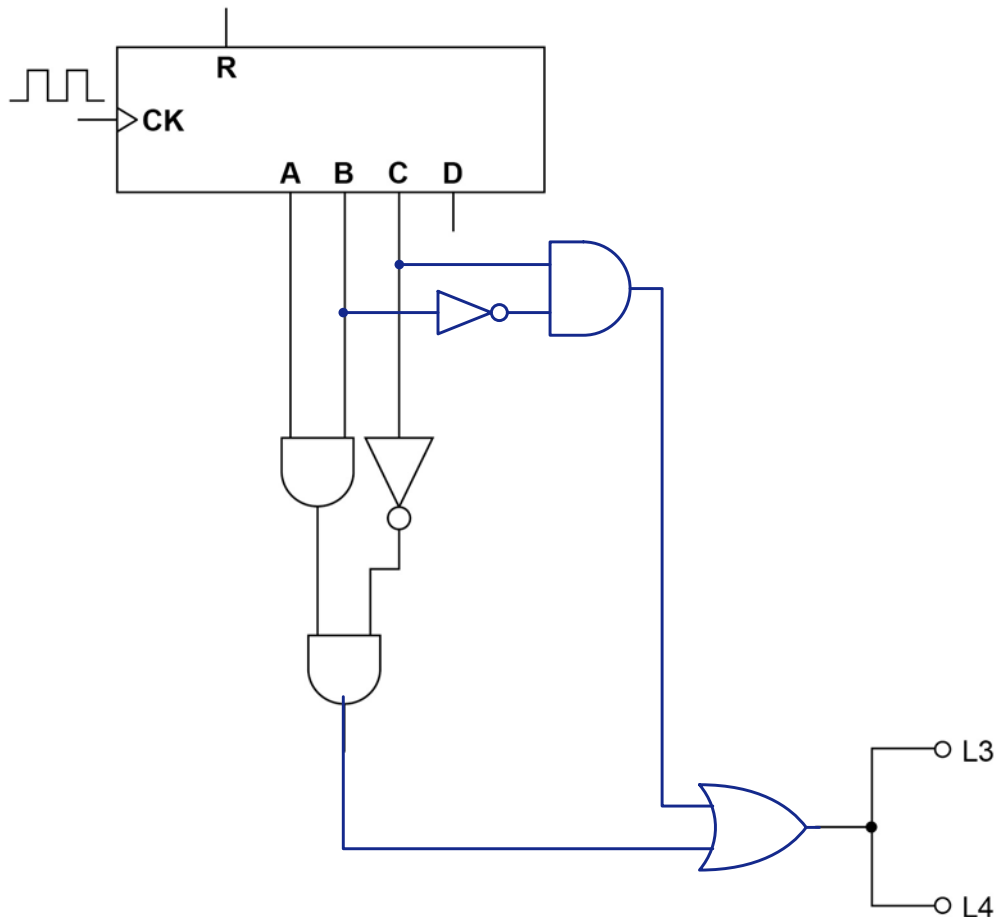
The output of both L3 and L4 can be written as $(A \cdot B \cdot \bar{C}) + (\bar{B} \cdot C)$

Figure 7 shows part of a logic circuit needed to represent this Boolean expression.

Complete the logic circuit in **Figure 7** by adding AND, OR and NOT gates.

[3 marks]

Figure 7



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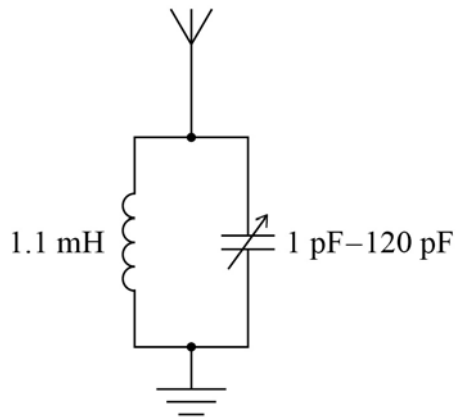
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0	3
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Figure 8 shows the first-stage filter circuit for a simple AM receiver. The circuit can be adjusted to resonate at 910 kHz so that it can receive a particular radio station.

Figure 8



0	3	.	1
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Calculate the value of the capacitance when the circuit resonates at a frequency of 910 kHz.

[2 marks]

$$f = 1 / (2\pi\sqrt{LC}) \quad \text{so} \quad C = 1 / (4\pi^2 f^2 L)$$

$$C = 1 / (4\pi^2 \times (910 \times 10^3)^2 \times 1.1 \times 10^{-3})$$

$$C = 2.78 \times 10^{-11} \text{ F}$$

capacitance = 27.8 pF

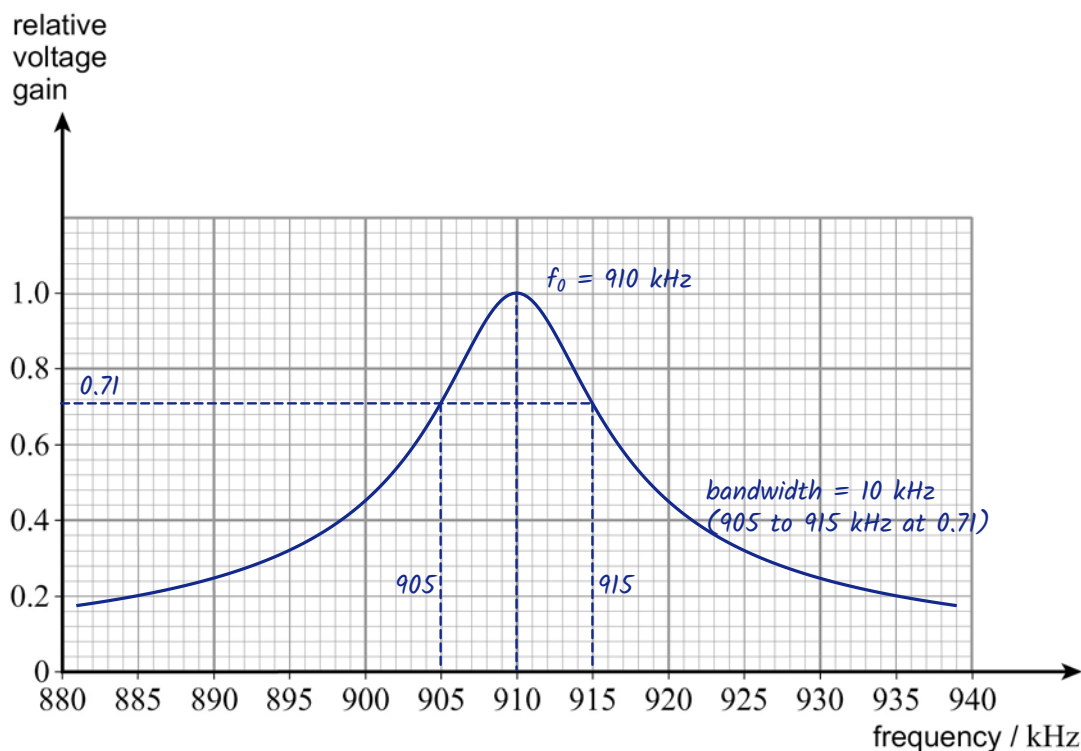


0 3 . 2

Draw on **Figure 9** an ideal response curve for the resonant circuit, labelling all relevant frequency values based upon a 10 kHz bandwidth.

[3 marks]

Figure 9



0 3 . 3

The Q-factor for the practical tuning circuit has a smaller value than the ideal one assumed in question 03.2.

Discuss the changes the listener might notice when tuning to this station due to the practical Q-factor being smaller.

[2 marks]

A smaller Q-factor gives a broader bandwidth, so the circuit has less selectivity.

The listener would hear crosstalk (interference) from neighbouring stations on nearby frequencies, as well as more noise (hiss).

There is also less gain at resonance (more energy loss), so the wanted signal is weaker and some signal detail is lost.

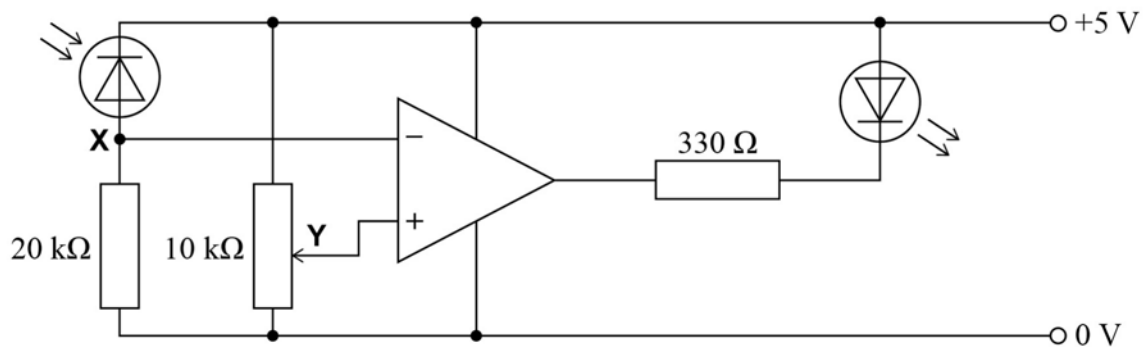
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0 4

A photodiode forms part of a light meter used for checking light levels in an office. **Figure 10** shows the circuit diagram for the light meter.

Figure 10



0 4 . 1

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

[1 mark]

Photoconductive mode (the photodiode is reverse biased)

0 4 . 2

In which mode is the operational amplifier being used in **Figure 10**?

Tick (✓) the correct box.

[1 mark]

Non-inverting amplifier

☐

Comparator

☒

Summing amplifier

☐

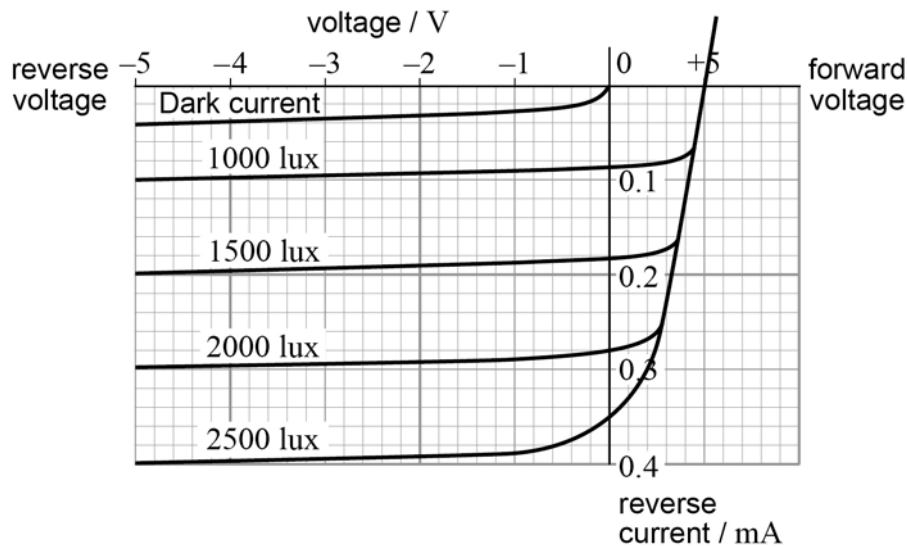
Difference amplifier

☐


0 4 . 3

Figure 11 shows an extract from a data sheet of the characteristics for a photodiode under different light levels measured in lux.

Figure 11



For a particular lighting condition, the current through the photodiode in **Figure 10** was 0.10 mA.

Estimate, using the information in **Figure 11**, the light level needed to cause this reverse current through the photodiode.

[1 mark]

light level = 1000 lux

0 4 . 4

Calculate the voltage at point **X** in the circuit shown in **Figure 10** for the light level in question **04.3**.

[1 mark]

$$V_x = IR = 0.10 \times 10^{-3} \text{ A} \times 20 \times 10^3 \Omega$$

$$V_x = 2.0 \text{ V}$$

voltage = 2.0 V

Question 4 continues on the next page

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0	4	.	5
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The $10\text{ k}\Omega$ linear potential divider shown in **Figure 10** is set to give 1.75 V at point **Y**.

Assume that the operational amplifier has ideal characteristics.

Deduce whether the output LED would be switched ON or OFF when the current through the photodiode is 0.10 mA .

[2 marks]

$V_- = V_X = 2.0\text{ V}$ and $V_+ = V_Y = 1.75\text{ V}$. The op-amp is a

comparator: since $V_- > V_+$, V_{out} is low (about 0 V).

So there is a voltage drop across the LED (and $330\text{ }\Omega$ resistor) from $+5\text{ V}$, current flows, so the LED is ON.

6



0 5

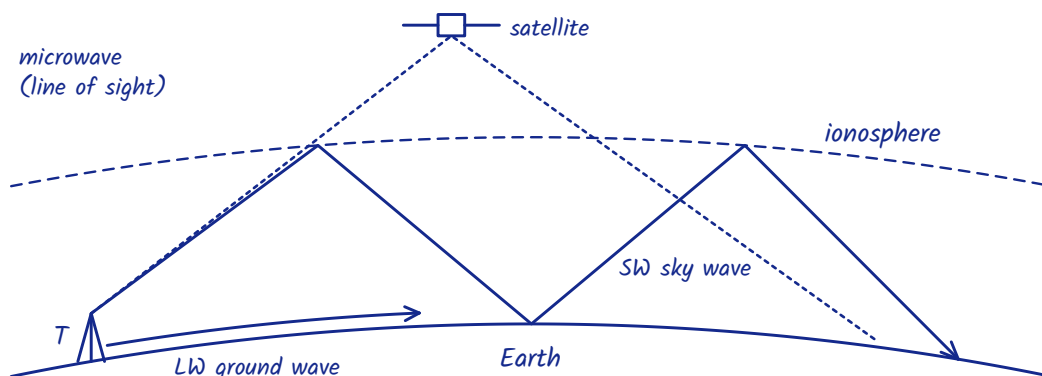
Discuss how longwave (LW), shortwave (SW) and microwave links can be used to communicate beyond the visible horizon.

For each link, you should give:

- a typical carrier frequency that is used
- an explanation of how the signals travel from the transmitter to the receiver
- a typical use.

You may use a diagram to help make clear aspects of your answer.

[6 marks]



Longwave (LW): typical carrier frequency about 150 to 300 kHz

(wavelength about 1 km to 2 km), so a very long aerial is needed. It travels as a ground (surface) wave: the long wavelength means it diffracts around the curvature of the Earth and follows the surface, so it reaches receivers beyond the visible horizon with large coverage.

Typical uses: national radio broadcasting and the national time signal.

Shortwave (SW): typical carrier frequency about 3 MHz to 30 MHz

(wavelength about 10 m to 100 m), medium-sized aerial. It travels as a sky wave: it is reflected (refracted back) by the ionosphere and can bounce between the ionosphere and the ground in several hops, so it travels thousands of km. Typical uses: international radio broadcasting, long-distance communication for ships and aircraft, and amateur radio enthusiasts.

Microwave: typical carrier frequency about 2 GHz to 100 GHz

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(wavelength about 3 mm to 150 mm), very short aerials (dishes). It travels as a direct (space) wave in straight lines and passes through the ionosphere, so it needs line of sight. To go beyond the horizon it is passed along a chain of terrestrial line-of-sight relay masts, or sent up to a satellite which retransmits it back to Earth (satellite hops). Typical uses: satellite TV, the 3G mobile telephone network and data transfer to remote locations (e.g. the Falkland Islands).

END OF QUESTIONS

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