A-Level Physics

Analogue Signal Processing

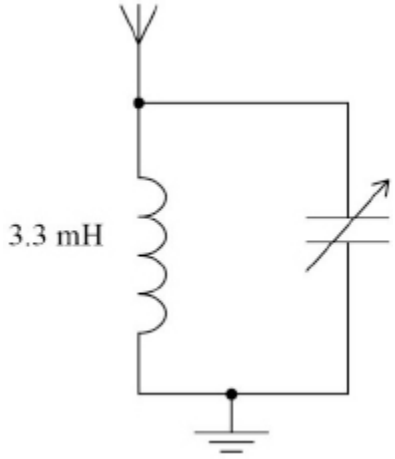
Question Paper

Time available: 59 minutes
Marks available: 57 marks

1. **Figure 1** shows the filter circuit that forms the first stage in an amplitude modulated (AM) radio receiver.

The circuit contains a 3.3 mH inductor and a variable capacitor.

Figure 1



(a) The circuit is tuned to receive a radio station transmitting at a frequency of 1053 kHz.

Calculate the value of the capacitance needed to receive this station.

capacitance = _____ pF

(1)

(b) The circuit is retuned to receive a different radio station by setting the variable capacitor to a value of 9.3 pF.

The table shows the capacitance range of four variable capacitors **W**, **X**, **Y** and **Z**.

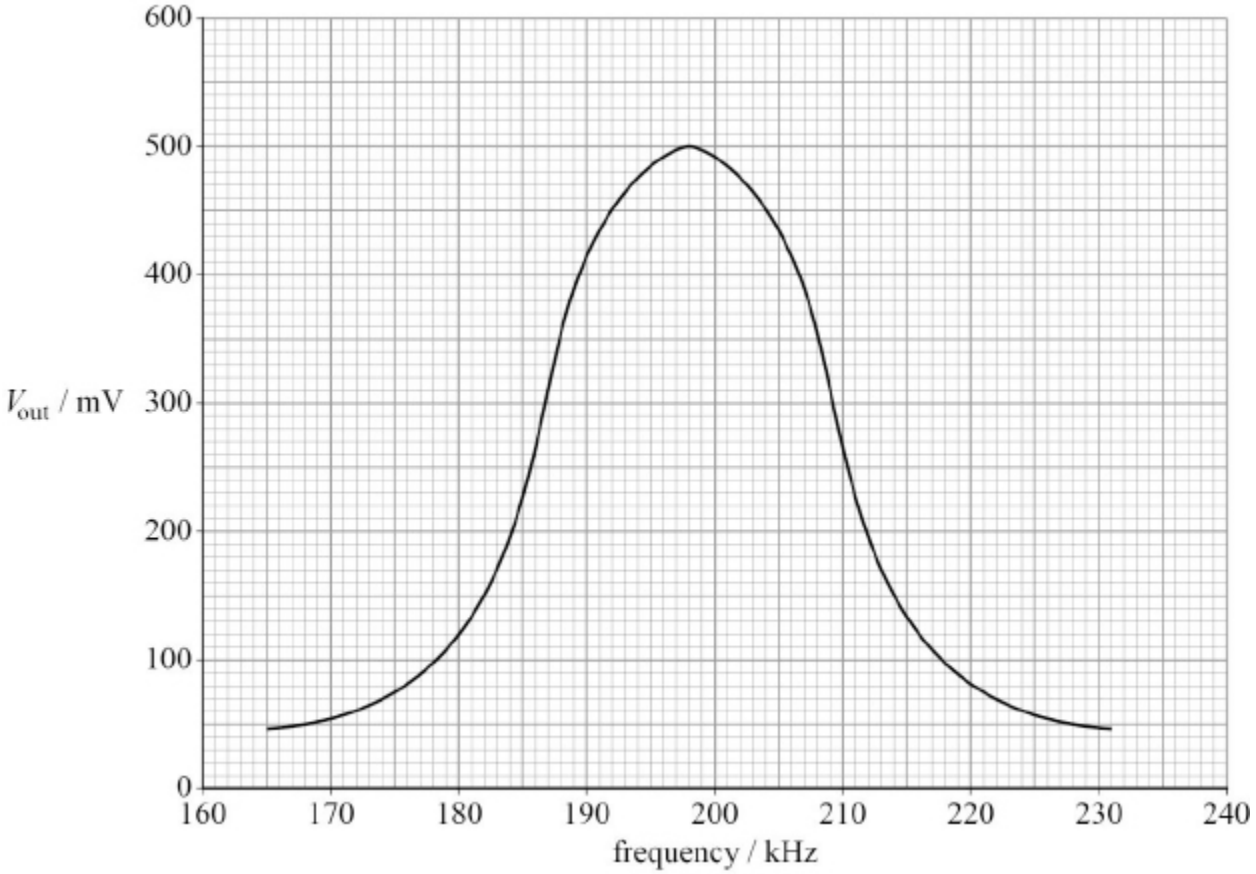
Comment on the suitability of these capacitors for this application and state your preference.

Capacitor	Range / pF
W	2–9
X	3–10
Y	4.5–20
Z	10–50

(2)

(c) **Figure 2** shows part of the frequency response curve for a different filter circuit.

Figure 2



Determine the bandwidth of the filter circuit.

bandwidth = _____ kHz

(2)

(d) Calculate the Q factor of the filter circuit in part (c).

Q factor = _____

(1)

(e) The radio station is tuned using a different filter circuit with a very low Q factor.

State and explain **one** effect of this change on the sound heard by a listener.

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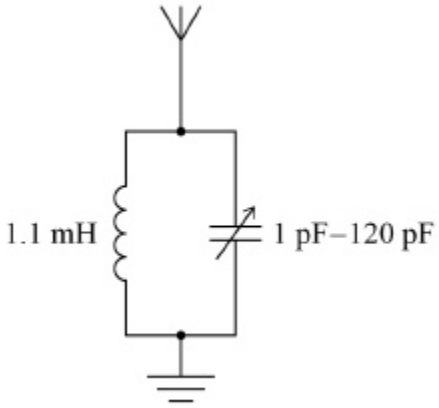
(1)

(Total 7 marks)

2. **Figure 1** 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 1



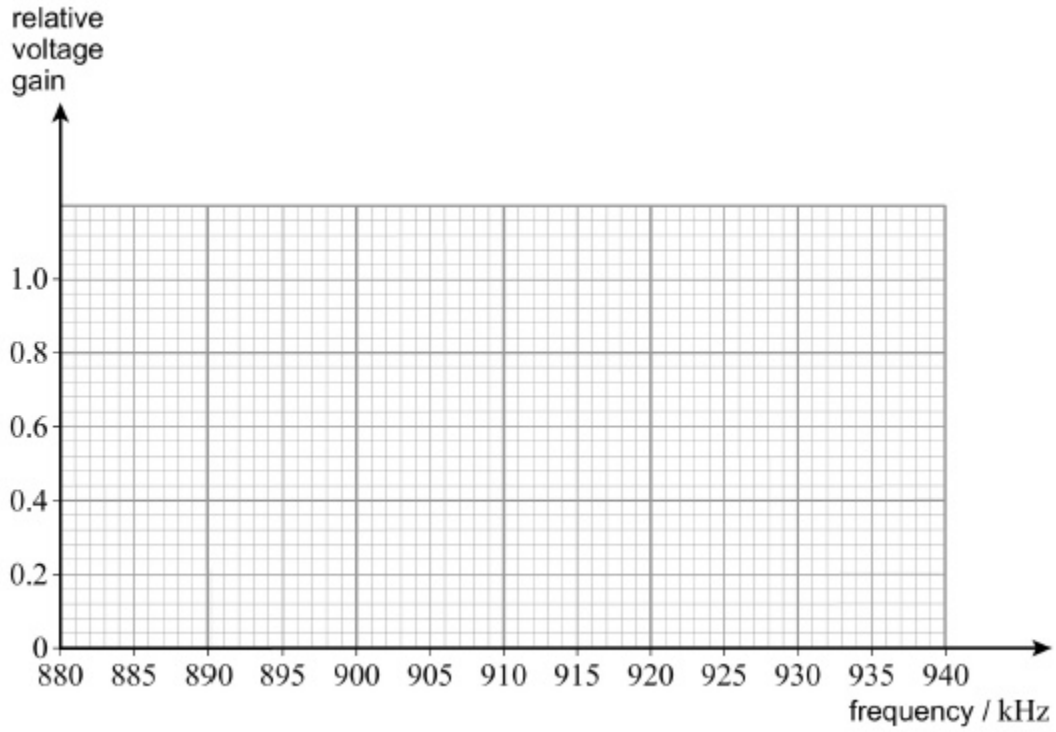
(a) Calculate the value of the capacitance when the circuit resonates at a frequency of 910 kHz.

capacitance = _____ pF

(2)

(b) Draw on **Figure 2** an ideal response curve for the resonant circuit, labelling all relevant frequency values based upon a 10 kHz bandwidth.

Figure 2



(3)

(c) The *Q*-factor for the practical tuning circuit has a smaller value than the ideal one assumed in question (b).

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

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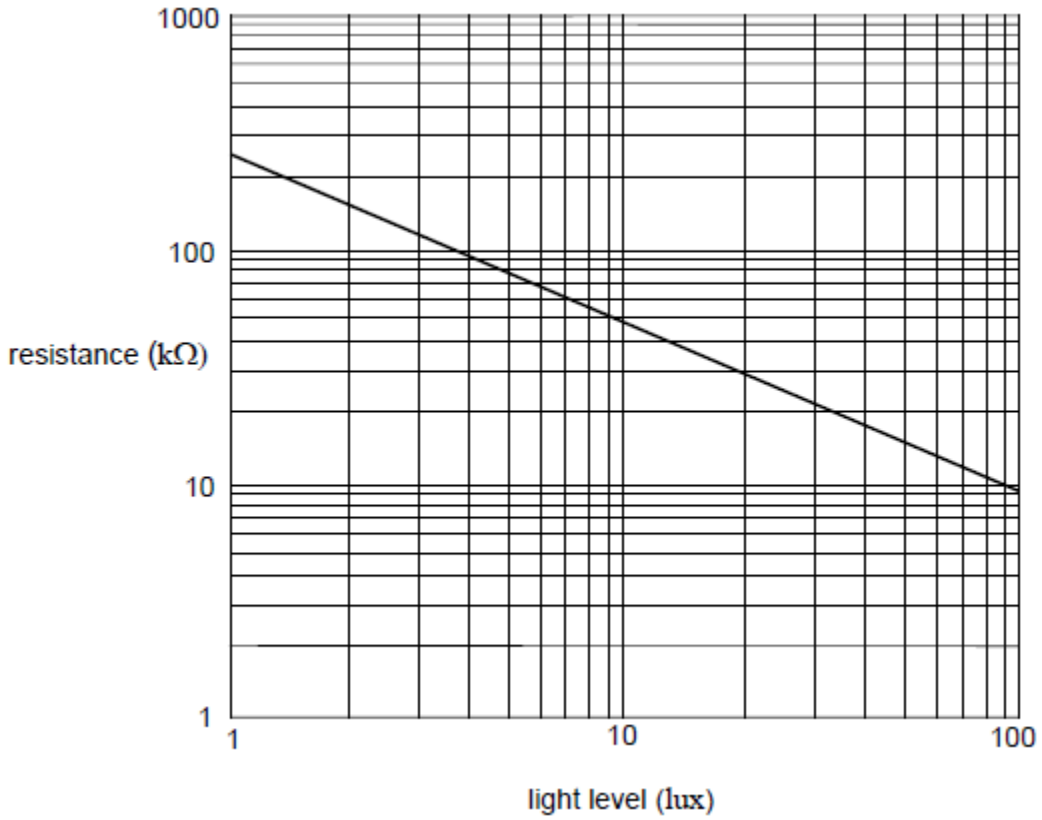
(2)

(Total 7 marks)

3. An LDR is being used as a light sensor in a system that will switch on a porch light when it gets dark.
The characteristic for the LDR is shown in **Figure 1**.

Figure 1



(a) (i) Explain how the use of the logarithmic scale in **Figure 1** is helpful when displaying this characteristic.

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(1)

(ii) The LDR has a resistance of 60 kΩ when the light level causes the system to switch on the porch light.

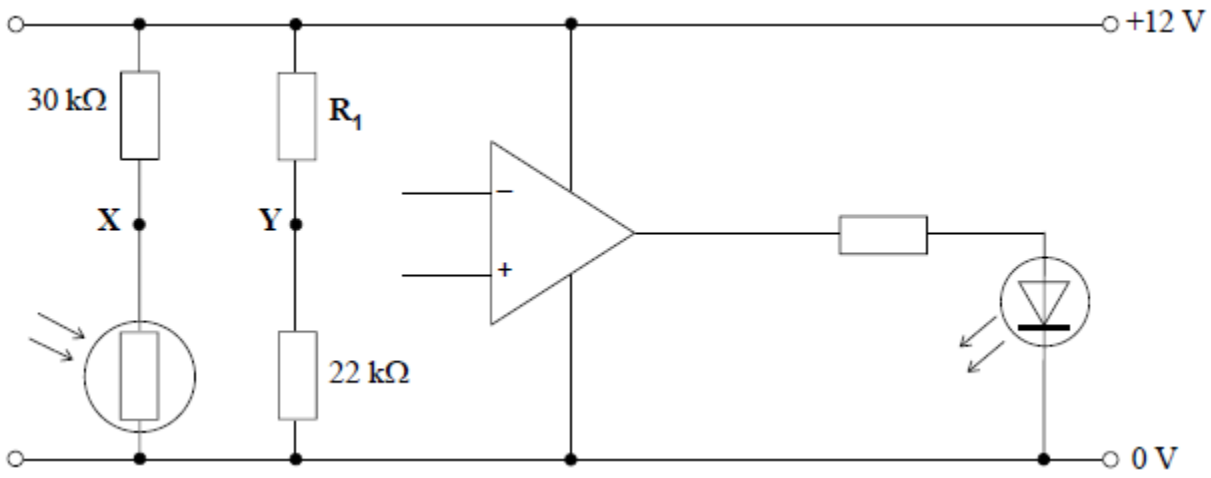
State the value of this light level by reading from the graph in **Figure 1**.

light level _____ lux

(1)

(b) **Figure 2** shows the circuit for detecting the light level.
The design makes use of an op-amp acting as a comparator.
A red LED acts as an output indicator to aid testing of the detector circuit.

Figure 2



Draw on **Figure 2** the connections from points **X** and **Y** to the op-amp inputs so that the red LED switches on when the light level falls below the required value.

(1)

(c) (i) Calculate the voltage at point **X** when the red LED switches on.

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(2)

(ii) The reference voltage at **Y** is produced by two fixed-value resistors.

Calculate the value for resistor $\mathbf{R_1}$ in order to achieve the required circuit operation.

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(2)

(d) The red LED was found to stay on dimly even when the light level was well above the value expected to switch it off.

Explain why this might happen and how the problem could be solved.

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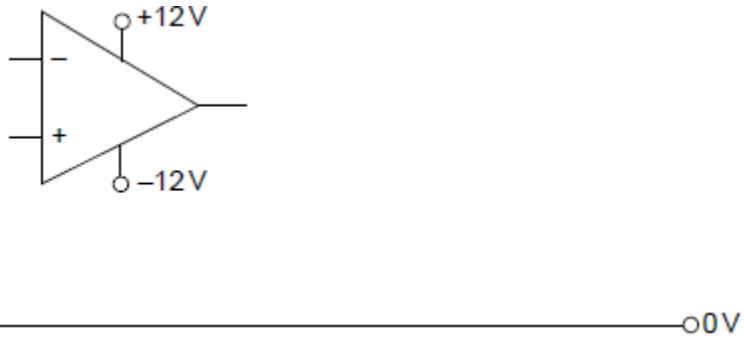
(3)

(Total 10 marks)

4. A circuit is required to amplify the output voltage from a microphone by a factor of 100. The input resistance of the amplifier must be 4.7 kΩ to match the internal resistance of the microphone.

(a) In the space below, complete the circuit diagram of a suitable op-amp amplifier and give suitable resistor values to match the specification. The circuit can be inverting or non-inverting.



(4)

(b) The op-amp is powered by a ±12 V supply. Assuming an ideal op-amp is used, calculate the maximum amplitude of the input signal before the output becomes saturated.

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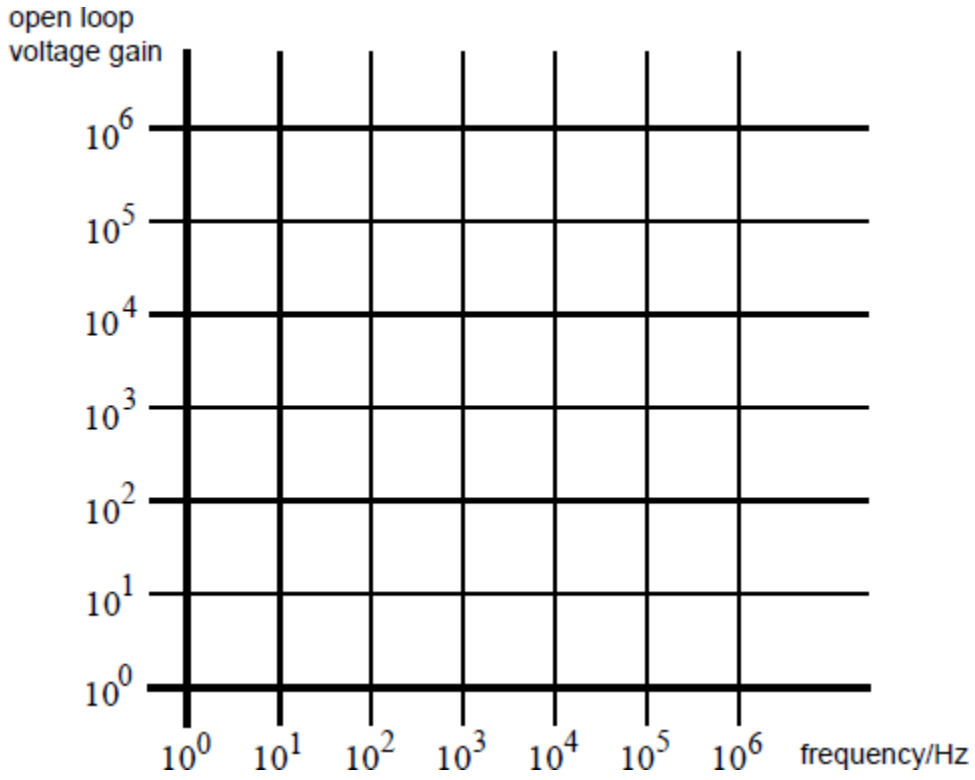
(2)

(c) The op-amp has a gain-bandwidth product of 1 MHz. Draw on the graph below how the open loop voltage gain of the op-amp varies with frequency.



(3)

(d) Calculate the frequency above which the voltage gain of the amplifier is less than 100.

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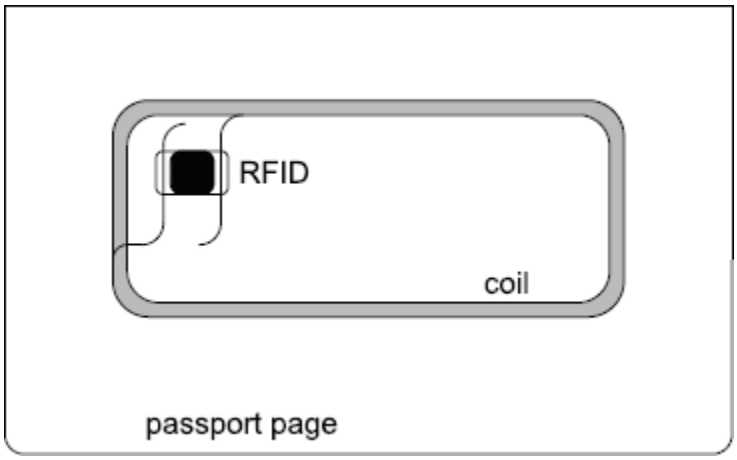
(2)

(Total 11 marks)

5. Modern UK passports contain a Radio Frequency Identification Device (RFID) chip connected to a coil of wire.



(a) The RFID chip operates at a frequency of 13.56 MHz. The RFID chip has an effective capacitance of 20 pF in parallel with the coil.
Calculate the required inductance of the coil.

(4)

(b) Calculate the length of a half wave dipole aerial for this frequency. Explain why a coil of wire is used at the immigration control desk for reading the data on the RFID instead.

(3)

(c) The quality factor, Q, of a tuned circuit is $\frac{f}{\Delta f}$.

If the bandwidth, Δf, of the tuned circuit in a passport is 100 kHz, calculate the quality factor of the tuned circuit.

(1)

(d) Assume the bandwidth given in part (c) represents the highest bit rate that can be used to transfer data from the RFID. Estimate, using a calculation, the length of time it would take to read 1 KB of data.

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(2)

(Total 10 marks)

6. Stereo music recordings are made by having two separate microphones, one to the left and one to the right of the musicians. For these signals to be transmitted by radio they have to be processed so that a listener with a mono radio receives all of the information, while a listener with a stereo receiver can receive both the left and right channel signals separately.

(a) For the mono radio listener, the left and right signals are added together and transmitted normally.
Draw the circuit diagram for an op-amp circuit that can add together two audio signals.

(3)

(b) The magnitude of the voltage gain of the summing circuit is 1. On your diagram for part (a) mark suitable resistor values.

(2)

(c) So that the two separate channels can be obtained for the stereo listener, the left and right signals are subtracted from each other, and this information is also transmitted but in a way that cannot be heard by the mono listener.
Draw the circuit diagram for an op-amp circuit that can subtract one signal from the other.

(3)

(d) The magnitude of the voltage gain of the subtraction circuit is 1. Mark on your diagram in part (c) suitable resistor values.

(2)

(e) The stereo radio receives two signals, L+R and L– R. Explain how the left and right signals can be extracted from these combined signals.

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(2)
(Total 12 marks)