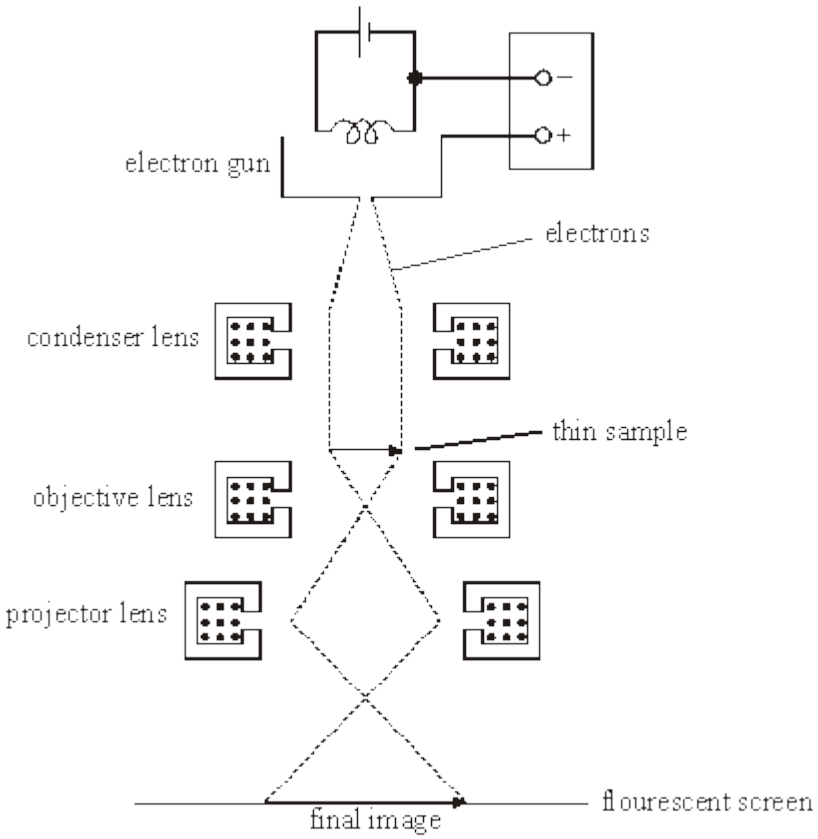
1 In a transmission electron microscope, electrons from a heated filament are accelerated through a certain potential difference and then directed in a beam through a thin sample. The electrons scattered by the sample are focused by magnetic lenses onto a fluorescent screen where an image of the sample is formed, as shown in the figure below.



(a) State and explain **one** reason why it is important that the electrons in the beam have the same speed.

.....

.....

.....

.....

(2)

(b) When the potential difference is increased, a more detailed image is seen. Explain why this change happens.

.....

.....

.....

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.....

.....

(3)
(Total 5 marks)

2 (a) State **two** characteristics of an operational amplifier.

.....

.....

(2)

(b) (i) Draw a circuit diagram showing an operational amplifier used as an inverting voltage amplifier.

(ii) Give suitable values for the components you have used in the circuit for a voltage amplification of magnitude 150.

.....

.....

.....

(4)

(c) When *negative feedback* is used with an amplifier the bandwidth increases.

(i) Explain what is meant by negative feedback as applied to the circuit drawn in part (b).

.....

.....

.....

(ii) Give **one** other advantage of using negative feedback in this application.

.....

(iii) State what is meant by the bandwidth of an amplifier.

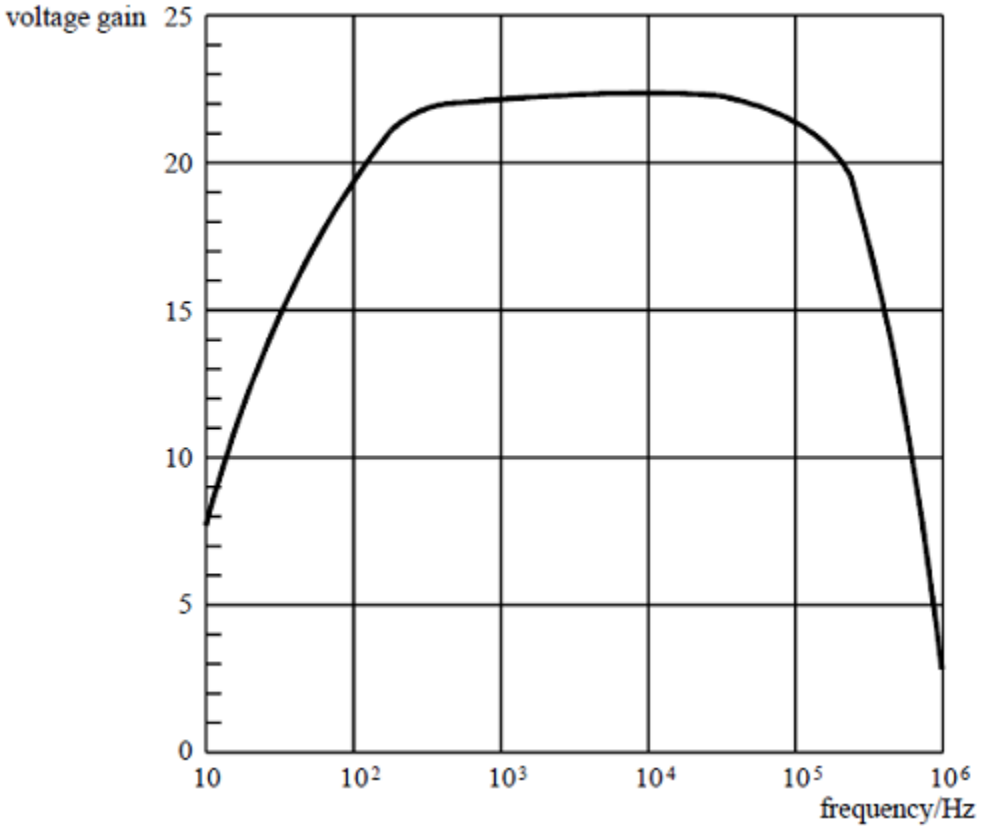
.....

.....

(iv) Indicate on the graph below, by means of a horizontal line, the bandwidth of the amplifier whose characteristic is shown.

.....

.....



(5)
(Total 11 marks)

3 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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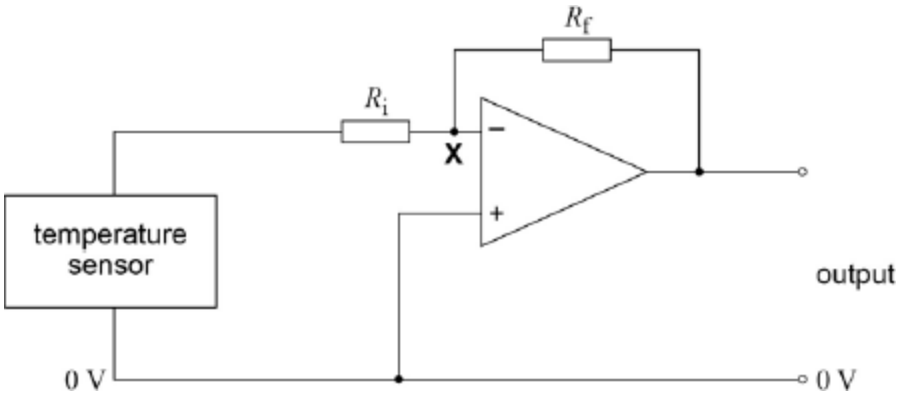
(2)
(Total 12 marks)

4 **Figure 1** shows a circuit that includes an ideal operational amplifier. A student uses this circuit to amplify the signal from the sensor before further processing by the system.

Figure 1



(a) Point X in **Figure 1** is said to be a virtual earth.

Explain the meaning of the term virtual earth in this type of circuit.

.....

.....

.....

(2)

(b) The temperature sensor produces a signal that changes by 10 mV for every degree Celsius change in temperature. The signal is 0 mV when the temperature of the sensor is 0 °C

The value of R_i is 22 kΩ and the value of R_f is 270 kΩ.

Calculate the output voltage V_{OUT} of the circuit in **Figure 1** when the sensor is at a temperature of 50 °C.

V_{OUT} = ... V

(2)

(c) The circuit is powered by a -15 V - 0 - +15 V supply. Explain why this circuit will not detect temperatures above 122 °C.

.....

.....

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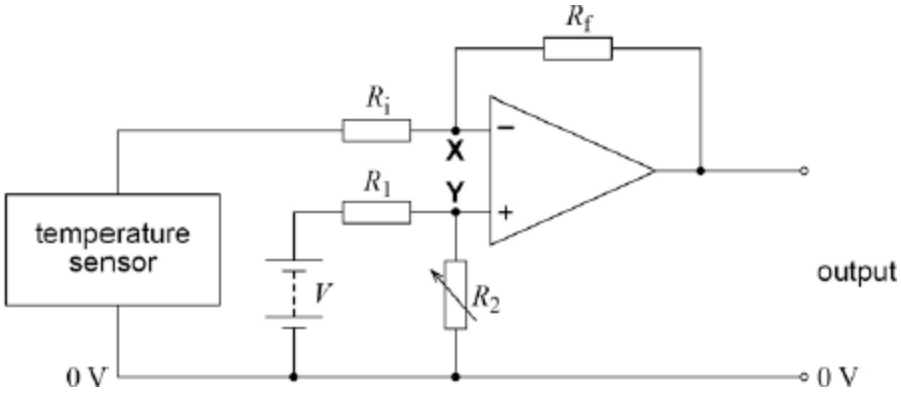
.....

(2)

(d) A student suggests a modification to the circuit in **Figure 1** to form a difference amplifier circuit for a thermostat. The modified circuit is shown in **Figure 2**.

Figure 2



The output controls a circuit that switches the heater off when the output is positive.

Explain how this circuit operates so that the heater switches off when the temperature reaches a pre-determined level.

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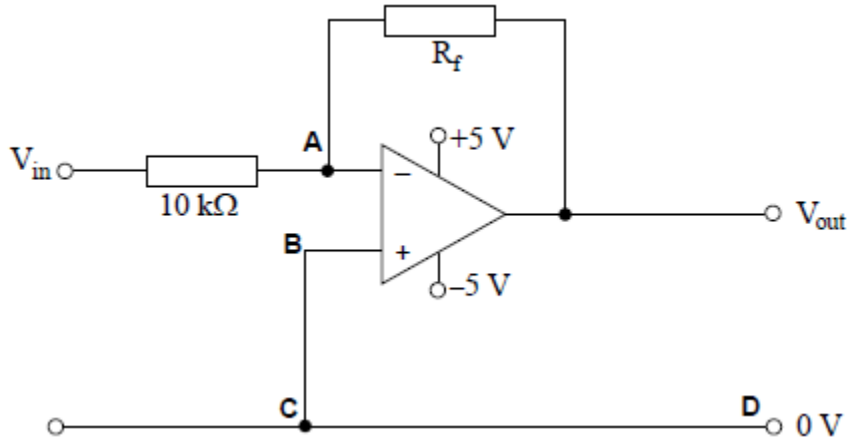
(3)
(Total 9 marks)

5 **Figure 1** shows an inverting op-amp amplifier subsystem.

Figure 1



(a) (i) Write in the box the letter that corresponds to the virtual earth point in **Figure 1**.

(1)

(ii) Explain the meaning of the term **virtual earth point**.

.....

.....

(2)

(iii) State the input resistance of this amplifier subsystem.

.....

(1)

(b) Calculate the value of R_f needed to give the amplifier subsystem a voltage gain of − 47.

.....

.....

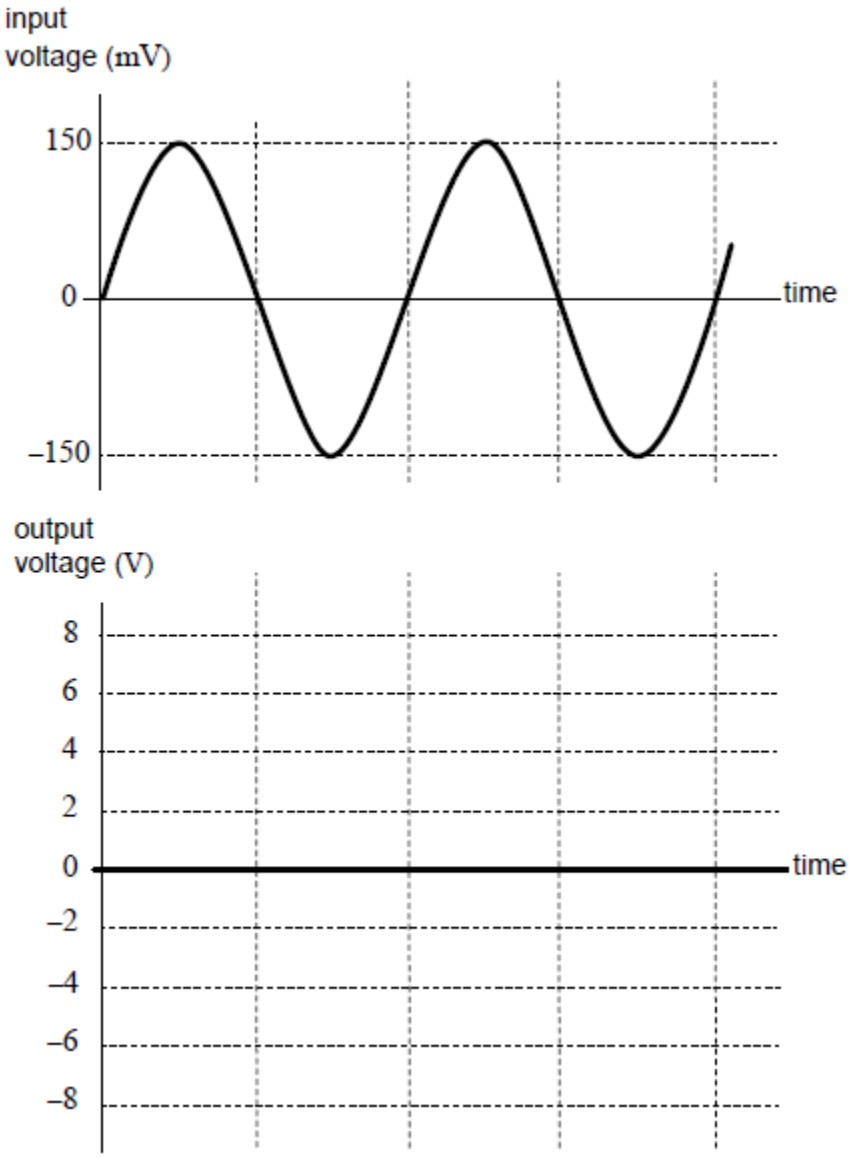
(3)

(c) The amplifier subsystem in part **(b)** is used to increase the signal voltage from an electric guitar.

The voltage from the guitar to the amplifier input is shown in **Figure 2**.

Draw onto the lower part of **Figure 2** the output signal from the amplifier subsystem.

Figure 2



(4)
(Total 11 marks)

6 According to semiconductor theory, the forward voltage across a silicon diode increases linearly with temperature, so long as the current through the diode remains constant.

When a current of 1 mA passes through a particular diode, a student measures a forward voltage of 0.619 V at 0 °C and 0.718 V at 100 °C.

(a) Show, using a calculation, that the change in voltage per °C is approximately 10^{-3} V / °C.

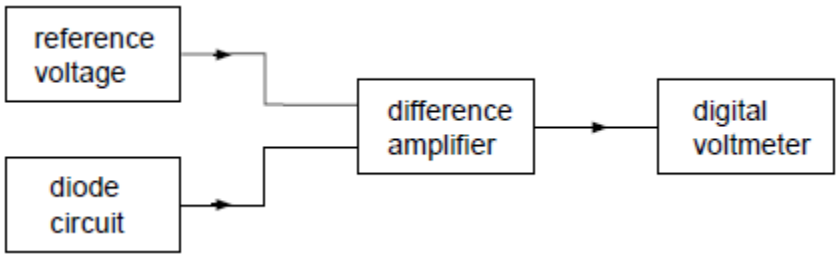
.....

.....

(1)

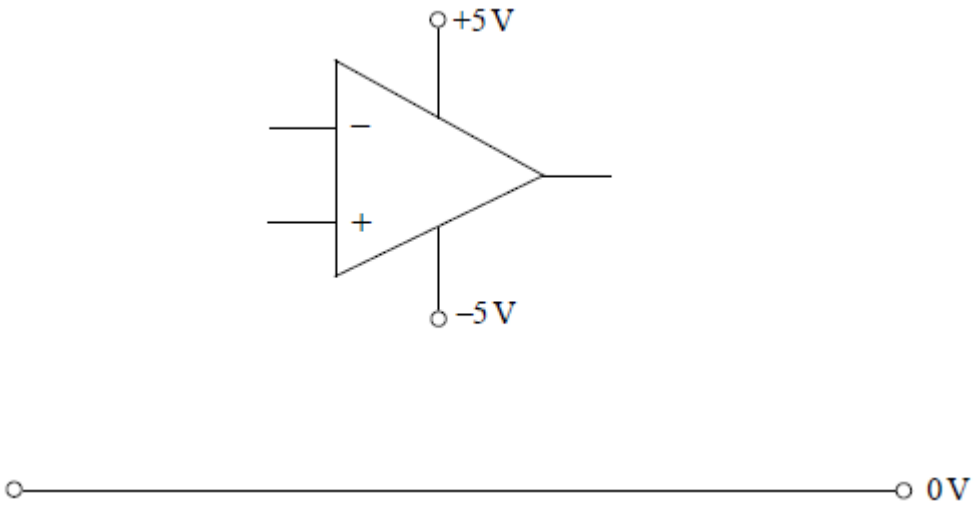
(b) The student decides to use this diode for a room thermometer project and devises the system diagram in **Figure 1**.

Figure 1



Complete the circuit diagram in **Figure 2** for a difference amplifier by adding **four** resistors.

Figure 2



(4)

(c) The output display for the room thermometer is a 0 to 5 V digital voltmeter that represents temperatures from 0 °C to 50 °C.
Show, using a calculation, that the difference amplifier needs to have a voltage gain of 100.

.....

.....

.....

(3)

(d) The student uses 15 kΩ input resistors in his difference amplifier.
Calculate the value that both the other resistors must have to produce a voltage gain of 100.

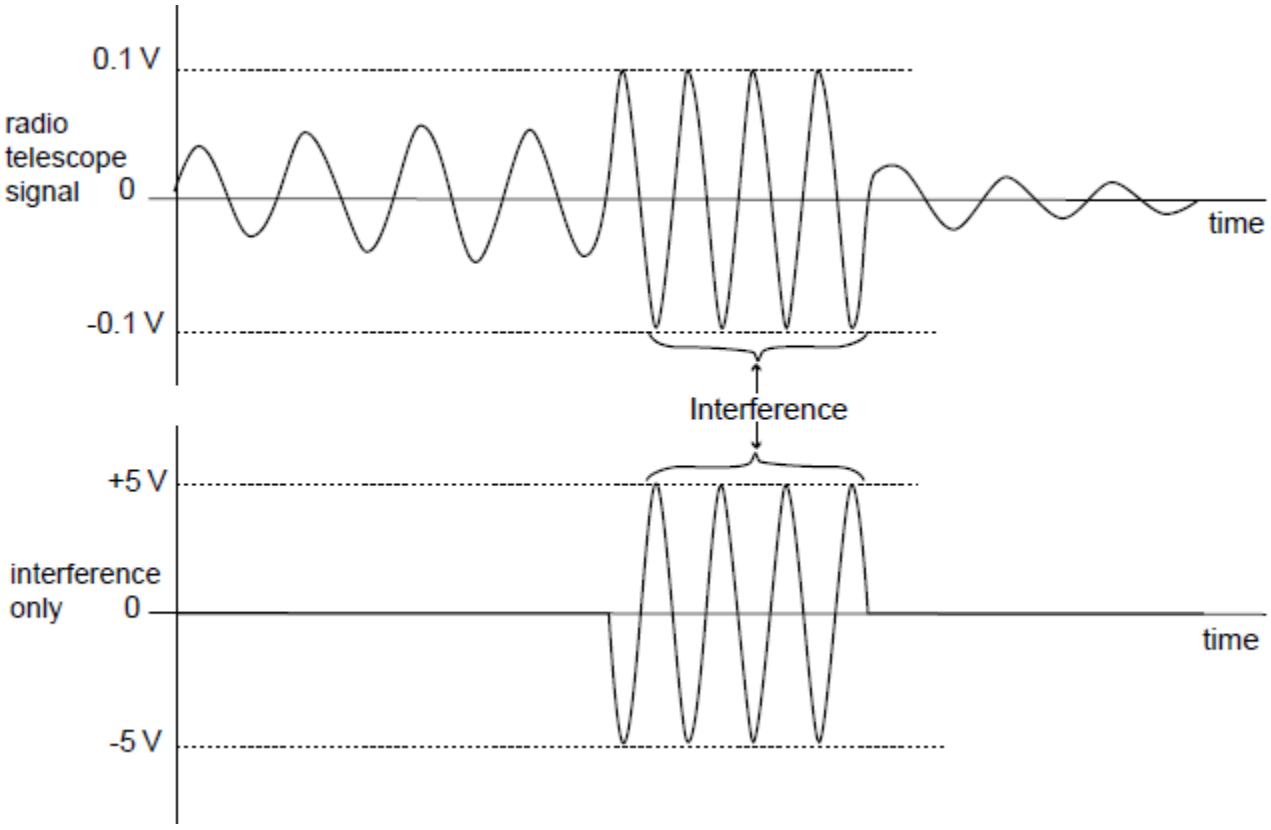
.....

.....

.....

(3)
(Total 11 marks)

7 A radio telescope suffers interference from local industrial equipment. To reduce the interference it is decided to combine the radio telescope output signal with the signal from a receiver that receives only the interference.
The two signals are shown below.



Before the signals are combined, the interference signals must have the same amplitude. This is achieved by amplifying the radio telescope signal.

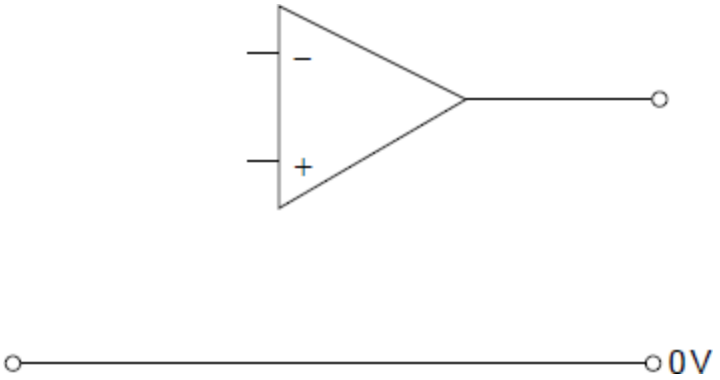
(a) (i) Calculate the voltage gain needed from this amplifier.

.....

.....

(3)

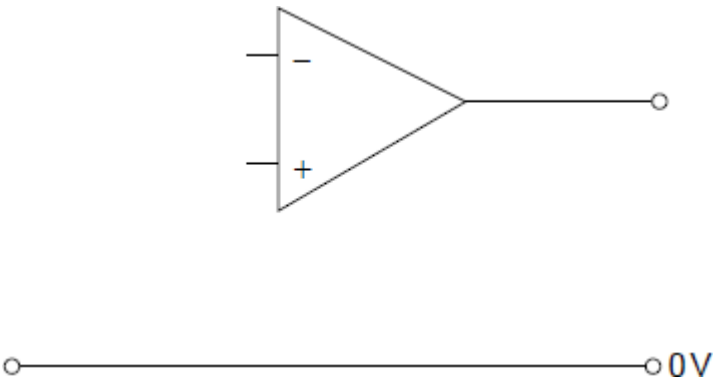
(ii) It is decided to use a non-inverting amplifier where the voltage gain can be adjusted from 11 to approximately 100.
Complete the circuit diagram for the non-inverting amplifier and include suitable values for the resistors.



(3)

(b) The amplified radio telescope signal and the interference signal are added together with a summing amplifier.

(i) Complete the circuit diagram below for a summing amplifier and include suitable values for the resistors.



(3)

(ii) Explain how adding the two signals reduces the interference signal in the output.

.....

.....

(2)
(Total 11 marks)

8 (a) The demodulator stage in a radio receiver has an output voltage of 10 mV but can only deliver a very small current. This stage is then connected to an af amplifier.

(i) Explain why the af amplifier should have a high input resistance.

.....

.....

.....

(1)

(ii) What type of op-amp based circuit should be used for the af amplifier?

.....

(1)

(iii) The voltage gain of the af amplifier is to be 28.
Draw a suitable circuit in the space below.
Choose and calculate suitable values for the resistors.
Label these components with their correct values on your diagram and label the input and output connections to the circuit.

(5)

(iv) Calculate, using data given earlier in this question the output signal voltage from this circuit.

.....

(2)

(b) The op-amp IC used has a gain-bandwidth product of 1 MHz.
Calculate the bandwidth of this af circuit and comment on its suitability for this application.

.....

.....

.....

.....

.....

(3)

(c) The amplified audio signal is then fed to a push-pull output stage using two MOSFETs. Draw a suitable circuit in the space below, label the p-channel and n-channel MOSFETs.

(4)
(Total 16 marks)

9 A student reads in a medical physics book that the electrocardial potential difference across a typical person's chest has a peak value of 2 mV. She wishes to record this on her computer, which requires a peak input signal of 1 V and decides to build a difference amplifier.

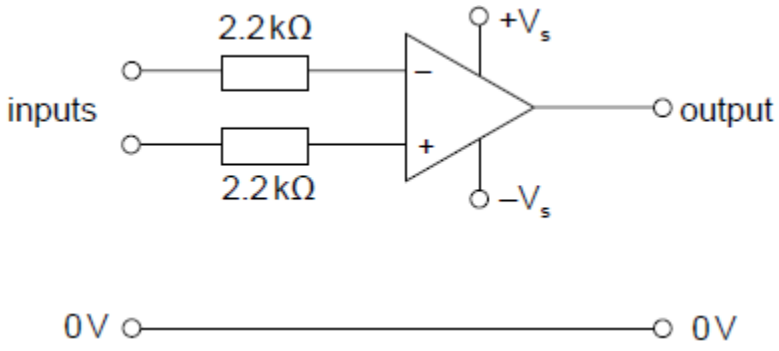
(a) Calculate the voltage gain required from the difference amplifier.

.....

.....

(3)

(b) Complete the circuit diagram below for the difference amplifier by adding **two** resistors.



(4)

(c) Calculate a suitable value for the resistors in part (b).

.....

.....

.....

(3)

In practice, the results were very disappointing. Her teacher suggested that it was because the input resistance of the difference amplifier was too low and that each input should be buffered by an op-amp voltage follower.

(d) (i) State the approximate input resistance of the difference amplifier inputs.

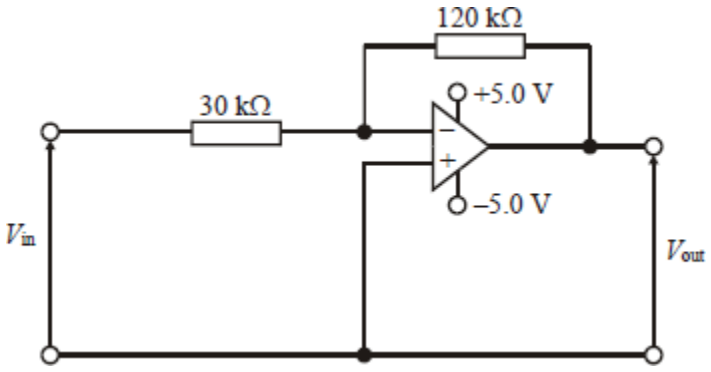
.....

(1)

(ii) Draw the circuit diagram of an op-amp voltage follower.

(2)
(Total 13 marks)

10 The diagram below shows an op-amp used in an amplifier circuit.



(a) Name the type of amplifier circuit shown. .....

(1)

(b) Calculate the output voltage V_{out} when the input voltage V_{in} = 0.50 V.

.....

.....

(2)

(c) The input is now connected to a sinusoidal source of rms output 2.0 V and frequency 50 Hz.

(i) Calculate the peak input voltage.

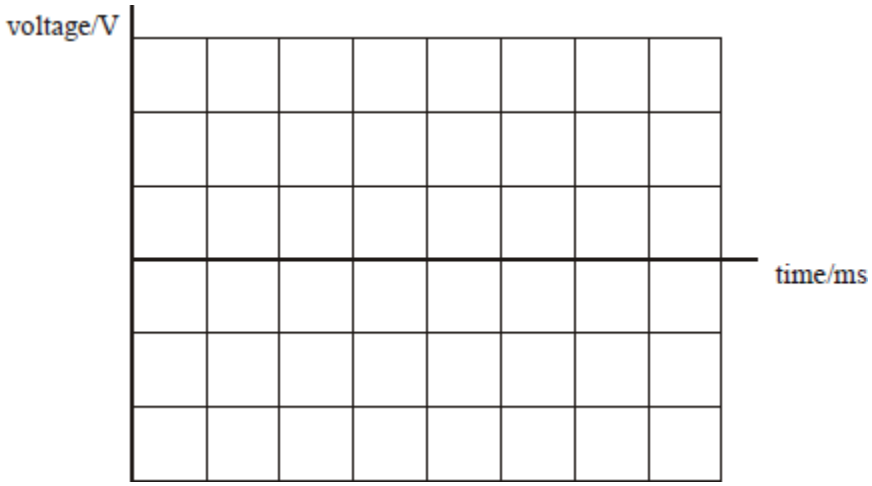
.....

.....

(ii) On the axes below draw a trace showing **two** cycles of the input signal and label it **A**.

On the same axes, draw the **two** corresponding cycles of the output signal and label it **B**.

Add suitable scales to the axes.



(6)
(Total 9 marks)

11 The circuit in **Figure 1** is that of an operational amplifier being used as an inverting amplifier. The power supply to the amplifier is ±15 V.

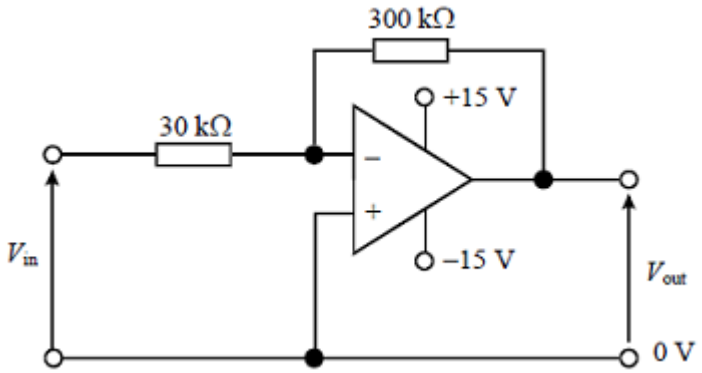


Figure 1

(a) (i) Calculate the voltage gain for the amplifier circuit.

.....

.....

(ii) The input signal is sinusoidal of peak voltage 1.0 V. The first graph in **Figure 2** shows the variation of the input signal. Sketch on the second set of axes the corresponding form of the output signal. Indicate values on the voltage axis.

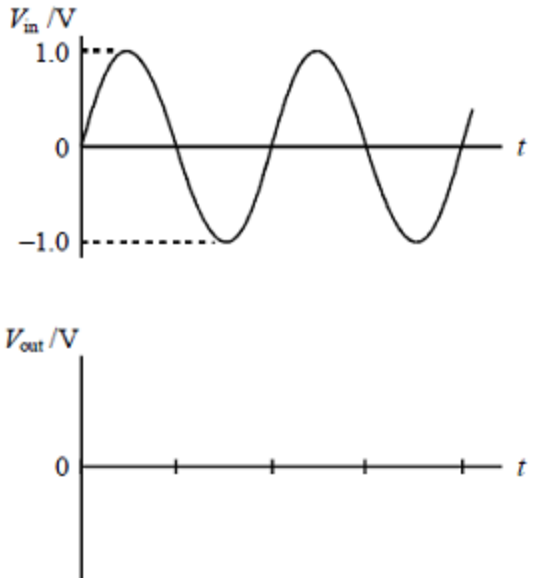


Figure 2

(5)

(b) The feedback resistor is now changed for a resistor of resistance 600 kΩ. Sketch a graph on the axes in **Figure 3** showing the new output signal, for the same input waveform. Indicate values on the voltage axis.

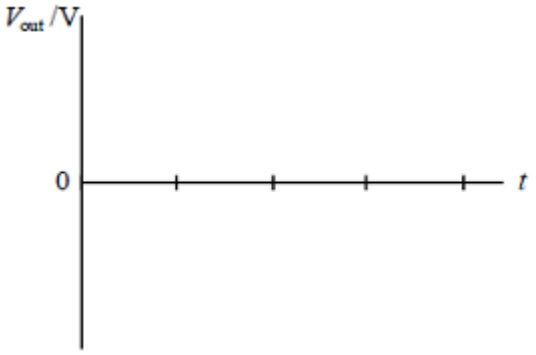


Figure 3

.....

.....

(2)
(Total 7 marks)

12 **Figure 1** shows the circuit of a summing amplifier which uses an operational amplifier with *negative feedback*. The power supply to the operational amplifier is ±12 V.

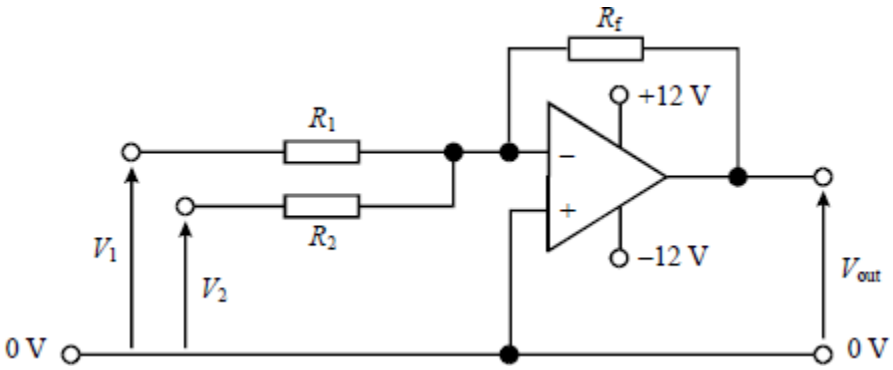


Figure 1

(a) (i) State what is meant by negative feedback. Explain how this is achieved in the above circuit.

.....

.....

.....

.....

(ii) Give **two** reasons for using negative feedback in an amplifier.

.....

.....

.....

(4)

(b) The input voltages to the amplifier in part (a), V_1 and V_2, vary with time according to the graphs shown in **Figure 2**. Given that R_1 = 40 kΩ, R_2 = 20 kΩ and R_f = 40 kΩ show on the third set of axes the variation of V_{out} with time. Indicate values of V_{out} on the axis.

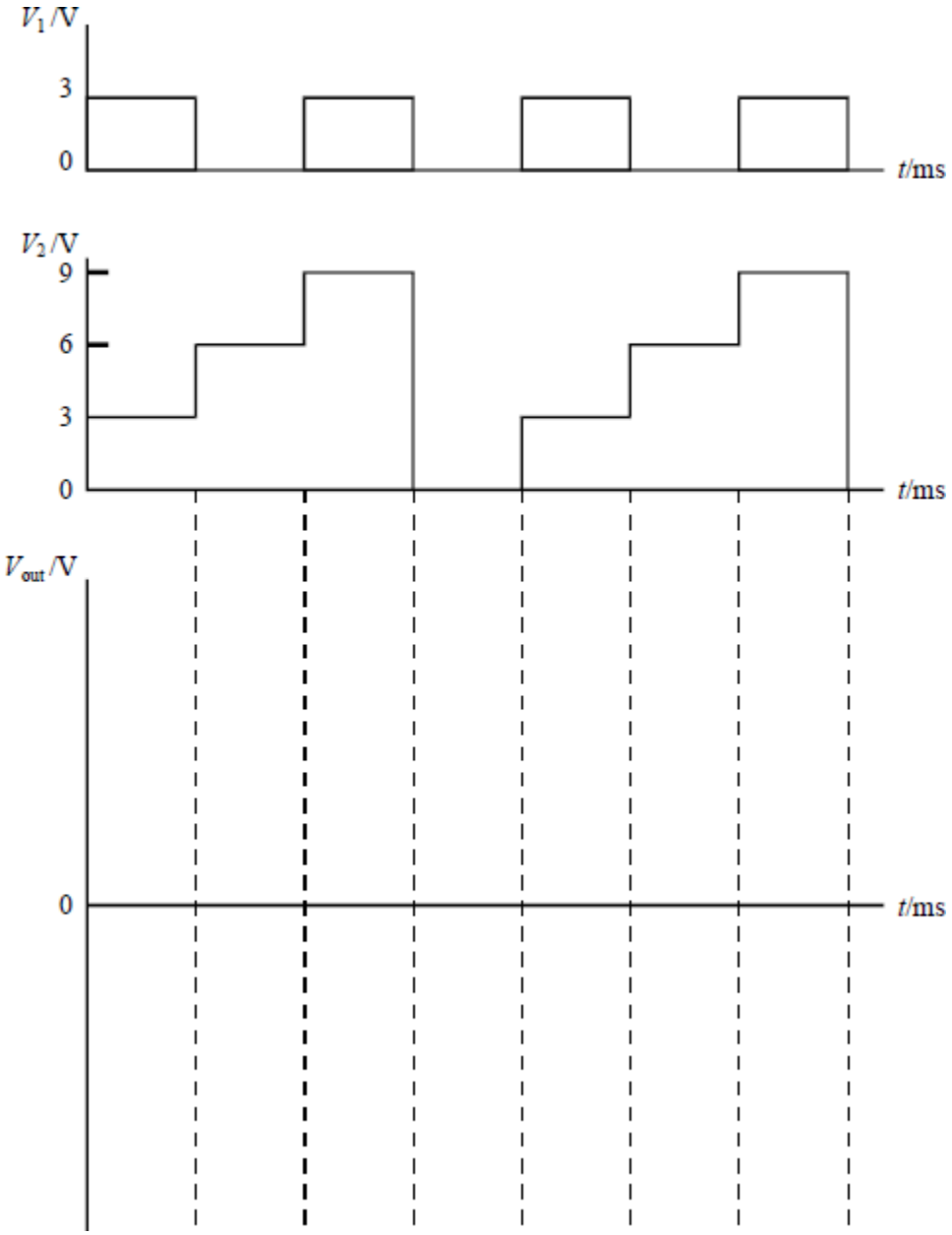


Figure 2

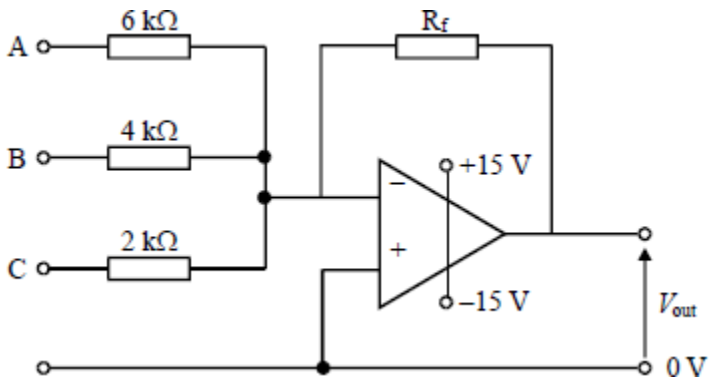
.....

.....

.....

(4)
(Total 8 marks)

13



In the circuit shown, an input of +1.2 V is applied simultaneously to each of the inputs A, B and C.

(a) Determine the current flowing through each of the input resistors and mark on the diagram the direction of each current.

.....

.....

.....

.....

(b) Determine the value of the output voltage, V_{out}, if R_f = 10 kΩ.

.....

.....

.....

(c) If R_f is changed to a resistor of 20 kΩ state, with a reason, the value of V_{out}.

.....

.....

(Total 6 marks)

1

(a) force on an electron in a magnetic field depends on speed **(1)**
electrons at different speeds would be focussed differently so image would be blurred **(1)**
[or electrons at different speeds would have different (de Broglie) wavelengths
therefore resolution would be reduced]

2

(b) increase in pd increases speed **(1)**
increase in speed/momentum/E_k causes reduction of (de Broglie) wavelength **(1)**
reduced (de Broglie) wavelength gives better resolution **(1)**

3

[5]

2

(a) high input impedance
very large voltage gain any two **(1) (1)**
low output impedance

2

(b) (i) circuit diagram to show: correct feedback and output **(1)**
correct inputs **(1)**

(ii) $R_a \geq 1$ kΩ **(1)**
gives R_f = 150 kΩ **(1)**

4

(c) (i) fraction of output fed back through R_f **(1)**
is 180° out of phase with input **(1)**

(ii) increased stability or less distortion or controlled gain **(1)**

(iii) range of frequencies within which voltage gain
does not fall by 1 / √2 or power by 1 / 2 **(1)**

(iv) bandwidth given by gain of $\frac{22}{\sqrt{2}}$ = 16 **(1)** (15.6)

horizontal line at gain = 16 and inside curve

max 5

[11]

3

(a) Two input resistors to the inverting input ✓,
feedback resistor to the inverting input from the output ✓,
non-inverting input to 0V ✓

3

(b) All resistors the same value ✓,
1kΩ<R<4MΩ ✓

2

(c) Two input resistors, one to each op-amp input ✓,
feedback resistor to the inverting input from the output ✓,
resistor from non-inverting input to 0V ✓

3

(d) All resistors the same value ✓,
1kΩ<R<4MΩ ✓

2

(e) (L + R) + (L - R) = 2L ✓,
(L + R) - (L - R) = 2R ✓
or equivalent by diagram or description

2

[12]

4

(a) It is not actually connected to 0V ✓
OR
Operational amplifier has a very large open loop gain

The voltage between V_+ and V_- inputs has to be zero [or tiny] otherwise will saturate✓

2

(b) V_{OUT} = -270K / 22K x V_{IN} = -12.3 V_{IN}
OR

V_{IN} = 50 x 0.01 = 0.5 V ✓

V_{OUT} = -12.3 x 0.5 = -6.1V ✓

2

(c) At 122 °C V_{OUT} = 122 x 0.01 x 12.3 = 15.0 V ✓
so any higher temp will give no further increase in V_{OUT} ✓ WTTE
OR
Max V_{IN} = 15.0 / 12.3 = 1.22 V ✓

Max input temperature = 1.22 / 0.01 = 122 °C ✓

2

(d) Level is fixed by controlling the pd at the + input)
OR
Turns off at higher temperature if V at + terminal higher✓
Output of the circuit is determined by R_f / R_i(V2 – V1) ✓

When V1 = V2 the output changes from + to - (causing heater to switch off) ✓

3

[9]

5 (a) (i) A

(at inverting input)

1

(ii) a point on the circuit where the voltage is 0v / ground
but not connected to 0v / is almost 0v / simulates 0v
assuming that the op-amp has not saturated

2 max

(iii) 10kΩ (must have units unless 10,000 which assumes standard)

***oe** 10,000Ω / 10K etc*

1

(b) correct formula rearranged
calculation / substitution
470kΩ

3 for just correct answer with units

3

(c) inverted,
same frequency,
shape shows evidence of correct gain
maximum amplitude 3v to 5v

4

[11]

6 (a) calculation of (0.718V − 0.619V) / 100 °C (= 99mV / °C)

1

(b) a series resistor to the inverting input,
a series resistor to the non-inverting input,
a resistor from the output to inverting input,
a resistor from the non-inverting input to 0V

4

(c) voltmeter will display 5V for 50°C change = 0.1V / °C
diode produces 50mV for 50°C change = 1mV / 1°C
so voltage gain needed is 0.1V / 1mV or 5V / 50mV (= 100)

Use of Vout / Vin given an appropriate temperature range

3

(d) use of difference amplifier formula rearranged
substitution 15k × 100
= 1.5 MΩ (1,500k)

For 3 marks must have units

3

[11]

7 (a) (i) Correct formula ✓,
substitution ✓,
calculation, 50 ✓,

3

(ii) Correct circuit (non-inverting) ✓,
Variable element in a correct place ✓,
Appropriate values (1kΩ - 10MΩ) (gain of 10 to ≈100) (must work as an amplifier) ✓

3

(b) (i) Correct circuit (summing amp) ✓,
Appropriate resistor values (1kΩ - 10MΩ) ✓,
Appropriate gain (0.1 - 3) ✓

3

(ii) Signals out of phase, inverted ✓,
so when added they cancel ✓

2

[11]

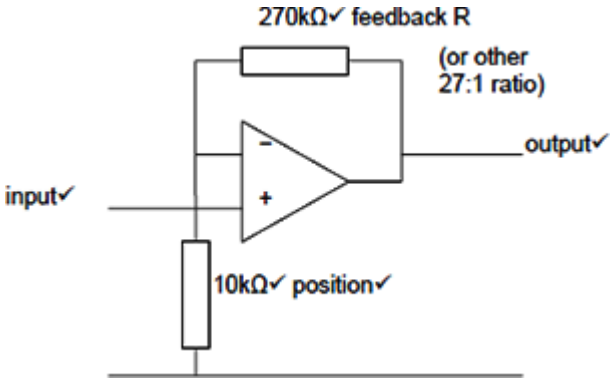
8 (a) (i) so it does not load the demodulator✓

1

(ii) non-inverting amplifier✓

1

(iii)



5

(iv) 10mV × +28 ✓ = 280mV✓

2

(b) $(1 \times 10^6) \div 28 = 35.7\text{kHz}$✓ ✓
suitable for audio sigs (max 20kHz) ✓

3

(c) push-pull source follower diagram✓
correct n channel symbol upper✓
correct p channel symbol lower✓
diode / resistor biasing ✓

4

[16]

9 (a) Formula, ✓
Substitution ✓
Gv=500 ✓

3

(b) Feedback resistor to output, ✓
Feedback resistor to – input, ✓
Resistor to + input, ✓
Resistor to 0V ✓

4

(c) Formula, ✓
substitution, ✓
1.1MΩ ✓

3

(d) (i) 2.2kΩ ✓

1

(ii) Voltage follower - Input to +, ✓
– to output ✓

2

[13]

10 (a) (i) inverting (amplifier) **(1)**

1

(b) use of $V_{out} = (-)\frac{R_f}{R_i} \times V_{in}$ **(1)**

$= (-)\frac{120}{30} \times 0.5 = -2.0$ V **(1)**

2

(c) (i) $V_{peak\ (input)} = 2.0 \times \sqrt{2} = 2.8(3)$ V **(1)**

(ii) input trace (A): sinusoidal with T = 20 ms **(1)**
and peak = 2.8 V **(1)**

for output voltage, $V_{peak\ (out)} = (-)\frac{120}{30} \times 2.8(3) = (\pm)11.3$ (V) **(1)**

(allow C.E. for value of $V_{peak\ (input)}$ from (i)

trace B: inversion w.r.t. trace A **(1)**
same period as trace A **(1)**
flat region (saturates) at ± 5 V **(1)**

max 6

[9]

11

(a) (i) (use of $G = -\frac{R_f}{R_a}$ gives) $G = -\frac{300(k\Omega)}{30(k\Omega)}$ **(1)**

= - 10 **(1)**

(ii) waveform to be:

sinusoidal with same frequency as input waveform **(1)**

inverted with respect to input waveform **(1)**

peak value of ± ≈ 10 V **(1)**

(allow C.E. for incorrect value of G from (i))

5

(b) waveform to be:

clipped **(1)**

at ≈ ±15 V **(1)**

2

[7]

12

(a) (i) negative feedback: part or all of the output is fed back to the input

180° out of phase **(1)**

achieved through R_f **(1)**

(ii) greater stability

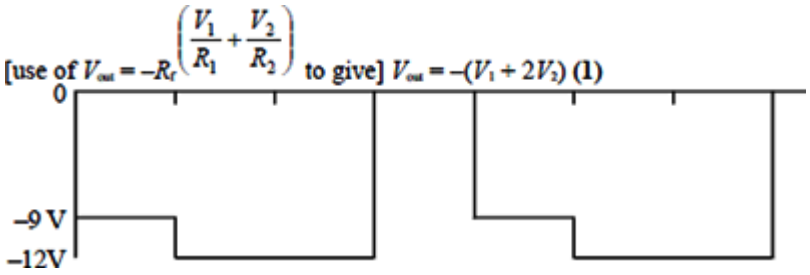
less distortion any two **(1) (1)**

increased bandwidth

gain predictable

4

(b)



negative values **(1)**

correct 9 V and 12 V **(1)**

saturation **(1)**

repeated **(1)**

max 4

[8]

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(a) $I_a = \frac{1.2}{6(k\Omega)}$ = 0.2 mA **(1)**

I_b = 0.3 mA and I_c = 0.6mA **(1)**
correct direction of current shown **(1)**

(b) current through R_f = 1.1(mA) gives V_{out} = 1.1 × 10^{-3} × 10 × 10^3 = 11V **(1)**
negative value **(1)**

(c) V_{out} (22 V)> supply voltage [or saturated] **(1)**
V_{out} = (–)15V **(1)**

[6]