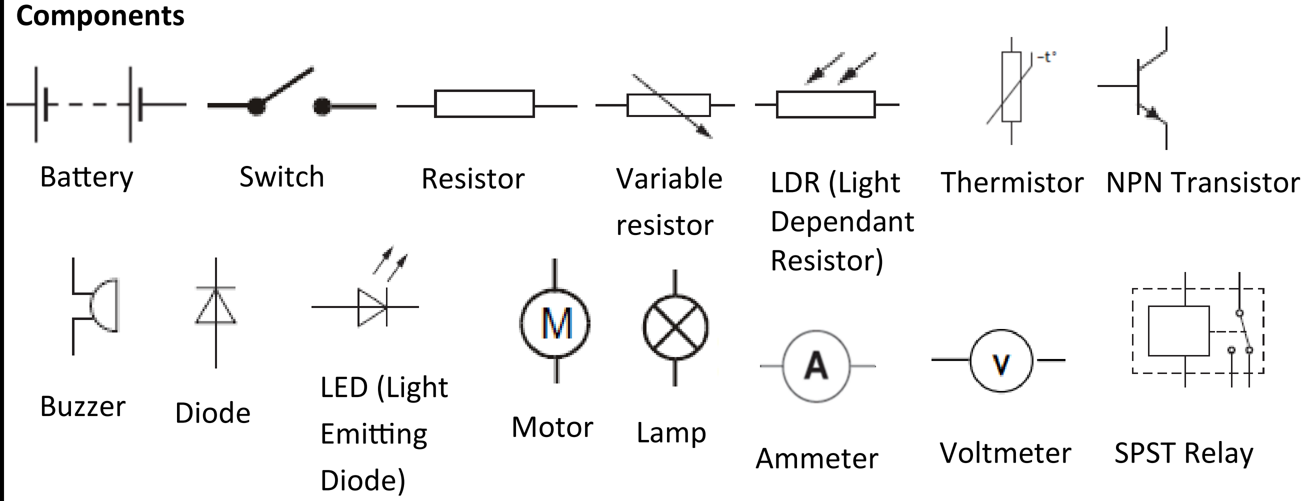
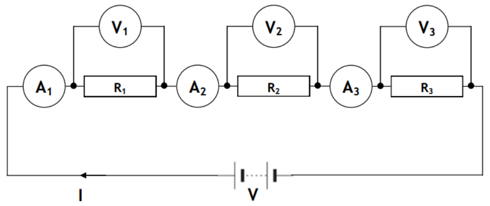
Analogue Electronics

Components



Resistors in Series



$V = V_1 + V_2 + V_3$ (Voltage splits)

$I = I_1 = I_2 = I_3$ (Current stays the same)

$R_T = R_1 + R_2 + R_3$

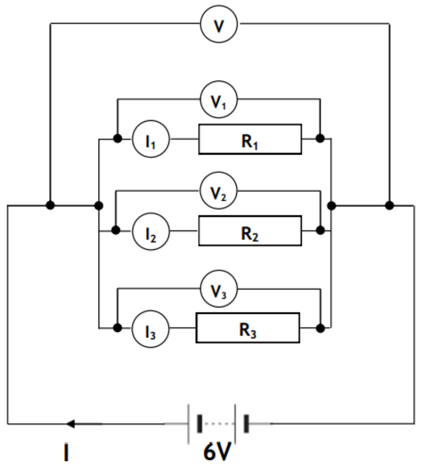
In a series circuit, if one component fails the circuit will be broken and current will not be able to flow.

The current is the same at any point in a series circuit.

The voltage across each component adds up to the supply voltage.

The total resistance in a series circuit is all of the resistances added together.

Resistors in Parallel



$V = V_1 = V_2 = V_3$ (Voltage stays the same)

$I = I_1 + I_2 + I_3$ (Current splits)

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \qquad R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

In a parallel circuit, if one component fails the current is still able to flow round the other branches which allows the other components to still function.

The current splits in a parallel circuit. I_T (total circuit current) is calculated using R_T (resistance total) and V_T (voltage total).

The voltage across each component stays the same in any part of the circuit. It is always equal to the supply voltage.

The total resistance in a series circuit can be calculated using either of two equations. The bottom one is easier for 2 resistances in parallel.

Ohm's Law

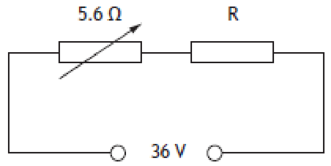
$$V = I \times R$$

Voltage (V) is measured in Volts (V).

Current (I) is measured in Amps (A).

Resistance (R) is measured in Ohms (Ω).

Ohm's law calculations



(a) Calculate the value to R to ensure that the circuit current is 2A.

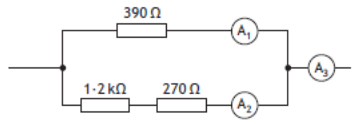
Step 1 - We know the total current and the total voltage so we can use Ohm's law to calculate the total resistance.

$$V_T = I_T \times R_T$$
$$36 = 2 \times R_T$$
$$\frac{36}{2} = R_T$$
$$R_T = 18\Omega$$

Step 2 - We can now work out what the resistance of R is as we know that the total resistance in a series circuit is just the resistances added together.

$$R_T = R_1 + R$$
$$18 = 5.6 + R$$
$$18 - 5.6 = R$$
$$R = 12.4\Omega$$

Combined resistance calculations



(a) Calculate the total resistance of this circuit.

First work out the total series resistance, then work out the parallel resistance using the total series value.

$$R_T = R_1 + R_2$$
$$R_T = 1200 + 270$$
$$R_T = 1470\Omega$$

$$R_P = \frac{R_1 \times R_T}{R_1 + R_T}$$
$$R_P = \frac{390 \times 1470}{390 + 1470}$$
$$R_P = \frac{573300}{1860}$$
$$R_P = 308\Omega$$

(b) (i) The reading on ammeter A_1 is 0.031A. Calculate the voltage across the 390Ω resistor.

Using Ohm's law to calculate the voltage.

$$V = I \times R$$
$$V = 0.031 \times 390$$
$$V = 12V$$

(b) (ii) Calculate the current A_2.

We know that voltage is the same in each branch of a parallel circuit, so Ohm's law again using 12V. Remember to add the resistances.

$$V = I \times R$$
$$12 = I \times 1470$$
$$\frac{12}{1470} = I$$
$$I = 8.2mA$$

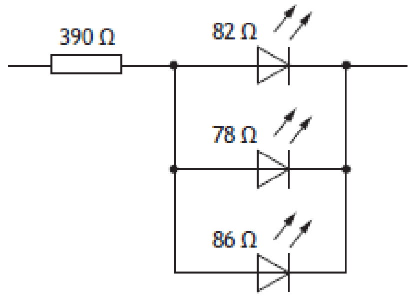
(b) (iii) Calculate the current A_3.

We know that the current splits in a parallel circuit so we need to add the current at A_1 and A_2 together to get the total current at A_3.

$$A_3 = A_1 + A_2$$
$$A_3 = 0.031 + (8.2 \times 10^{-3})$$
$$A_3 = 0.039A$$

Combined resistance calculations

Start these questions by solving the total resistance of the parallel branch. We then treat the parallel branch as a single resistance to calculate the total circuit resistance in series.



(a) Calculate the resistance of the 3 LEDs in parallel.

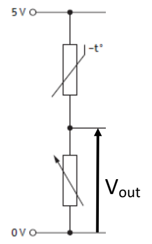
$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$
$$\frac{1}{R_P} = \frac{1}{82} + \frac{1}{78} + \frac{1}{86}$$
$$\frac{1}{R_P} = 0.03664$$
$$\frac{R_P}{1} = \frac{1}{0.03664}$$
$$R_P = 27\Omega$$

(b) Calculate the total resistance of the circuit.

$$R_T = R_1 + R_P$$
$$R_T = 390 + 27$$
$$R_T = 417\Omega$$

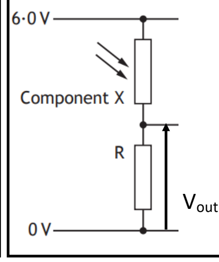
Voltage Dividers - Input sub-system

Thermistor at top = Heat sensor (TURD)



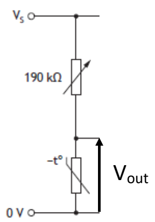
*As the temperature **increases**, the resistance of the thermistor **decreases**, causing the voltage across it to also **decrease**. This causes the share of the voltage across the variable resistor (V_{out}) to **increase**. The variable resistor acts as a sensitivity control.*

LDR at top = Light sensor (LURD)



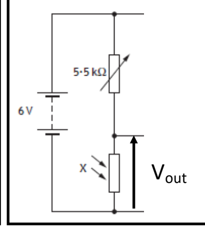
*As the light level **increases**, the resistance of the LDR **decreases**, causing the voltage across it to also **decrease**. This causes the share of the voltage across the fixed resistor (V_{out}) to **increase**.*

Thermistor at bottom = Cold sensor (TDRU)



*As the temperature **decreases**, the resistance of the thermistor **increases**, causing the voltage across it (V_{out}) to also **increase**. This causes the share of the voltage across the variable resistor to **decrease**. The variable resistor acts as a sensitivity control.*

LDR at bottom = Dark sensor (LDRU)



*As the light level **decreases**, the resistance of the LDR **increases**, causing the voltage across it (V_{out}) to also **increase**. This causes the share of the voltage across the variable resistor to **decrease**. The variable resistor acts as a sensitivity control.*

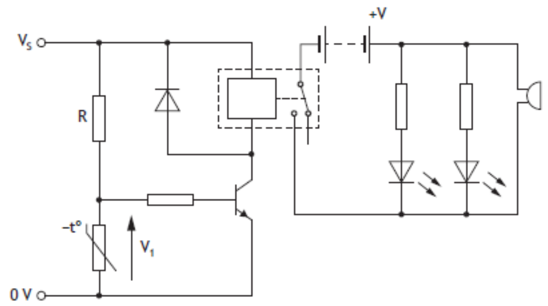
Describing Circuits

(a) Describe the operation of the circuit. Make reference to the resistance of the thermistor and the voltage V_1.

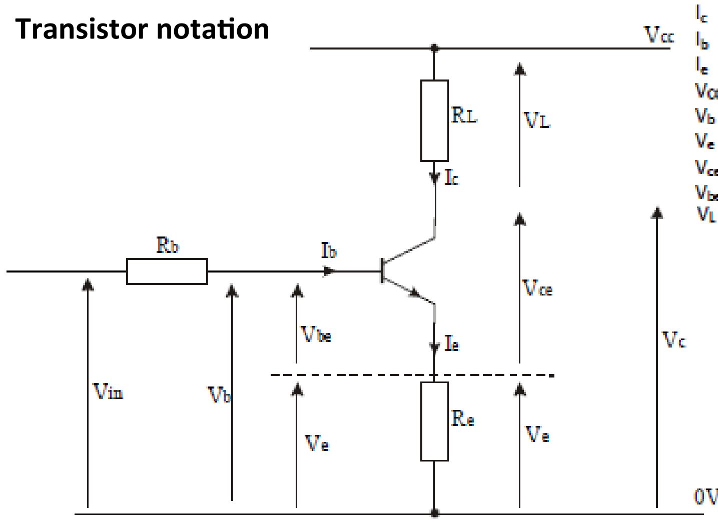
When the temperature decreases to a low temperature, the resistance of the thermistor will increase, causing V1 to increase. Once it increases above the threshold voltage, the transistor will saturate causing the relay to close the switch which will light the LEDs and sound the buzzer.

(b) The fixed resistor R is replaced with a variable resistor. Explain the effect on the operation of the circuit by replacing the fixed resistor (R) with the variable resistor.

The resistance of the variable resister can be altered which will change the temperature that the circuit will switch on at.



Transistor notation



- I_c - Collector current
- I_b - Base current
- I_e - Emitter current
- V_{CC} - Voltage of supply (relative to ground line)
- V_b - Voltage at the base junction (relative to ground line)
- V_e - Voltage at the emitter junction (relative to ground line)
- V_{ce} - Voltage between the collector and emitter junction
- V_{be} - Voltage between the base and emitter junction
- V_L - Voltage over the load resistor

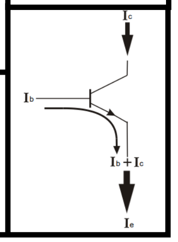
$V_b = V_{be} + V_e$

$V_{CC} = V_L + V_{ce} + V_e$

$I_e = I_b + I_c$

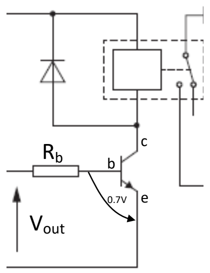
$$current\ gain = \frac{Collector\ current}{Base\ current}$$

$$h_{FE} = \frac{I_c}{I_b}$$



Transistors - Process sub-system

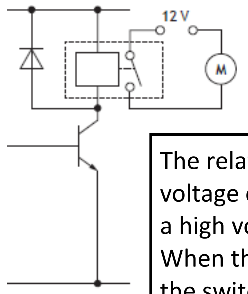
The diode protects the transistor from back EMF (Electro-magnetic Flux). It is a polarity conscious device and can only allow current to flow the way that the arrow points. Connected as shown it will not allow current to flow from the top to the transistor.



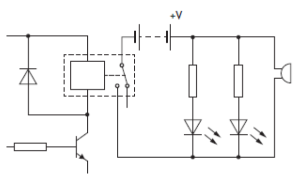
The function of a transistor is to act as an electronic switch. The transistor switches on when the voltage between the base and the emitter (V_{be}) reaches 0.7V. This then allows a current to flow between the collector and the emitter which causes the relay to close the switch.

The base resistor is there to protect the transistor. The voltage across the base resistor will be V_{out} - 0.7V.

Relays & other components - Output sub-system



The relay allows a low voltage circuit to control a high voltage circuit. When the relay closes the switch, it completes the circuit causing the motor to spin.



When the relay closes the switch in this circuit, the LEDs light and the buzzer sounds. Various output components can be connected to a relay circuit.

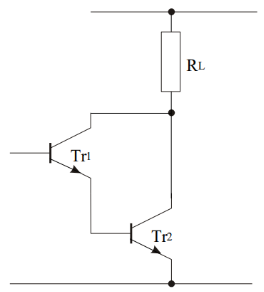
Darlington Pair

In order to obtain higher gains, more than one transistor can be used, the output from each transistor being amplified by the next (known as cascading).

Increasing the gain of the circuit means:

1. the switching action of the circuit is more immediate;
2. a very small base current is required in switching;
3. the input resistance is very high.

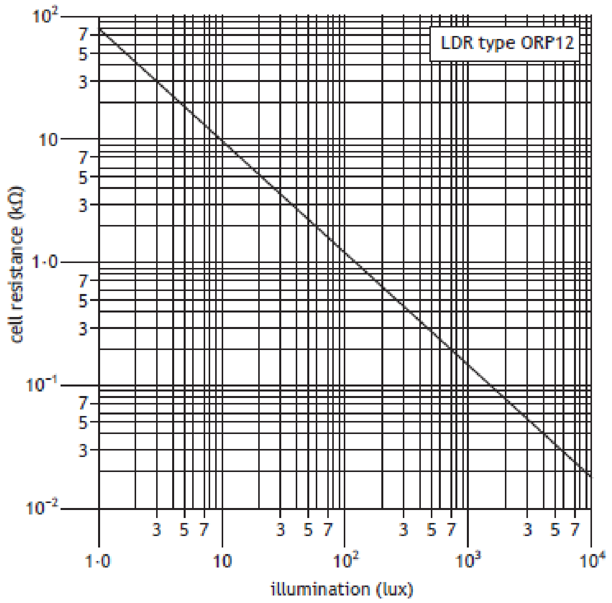
A popular way of cascading two transistors is to use a Darlington pair



$$A_I = h_{FE1} \times h_{FE2}$$

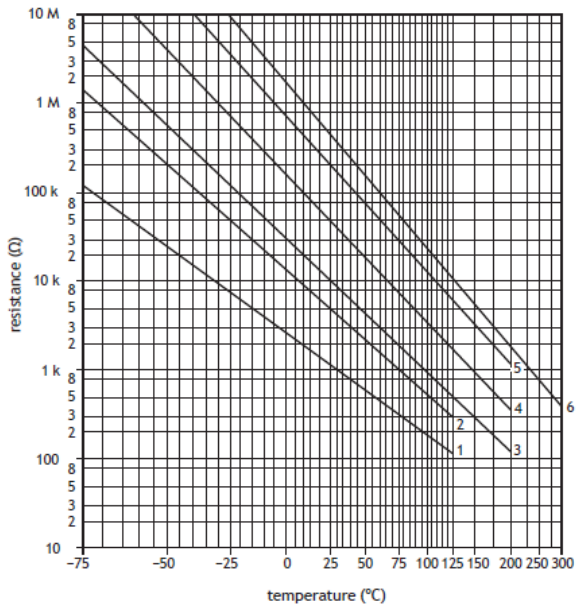
LDR Graph

The LDR graph can be tricky to read. Pay close attention to the values at 1 or 10 to make sure you know whether it's 1s, 10s, 100s or 1000s that you are working with. Remember that the resistance is measured in kΩ.



Thermistor Graph

The Thermistor graph also jumps up in large increments on the resistance scale. Be careful to follow the correct thermistor type line to work out your value.



Voltage Divider Calculations

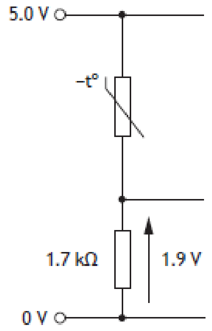
A voltage divider is a series circuit.

Voltages across the two components added together equal the supply voltage.

The current is the same through both components.

To find the total resistance, add the resistances of both components together.

(a) Calculate the resistance of the thermistor.



Step 1 - we know a voltage and a resistance from the bottom part of the circuit so we can calculate current.

$$V = I \times R$$
$$1.9 = I \times 1700$$
$$\frac{1.9}{1700} = I$$
$$I = 1.1mA$$

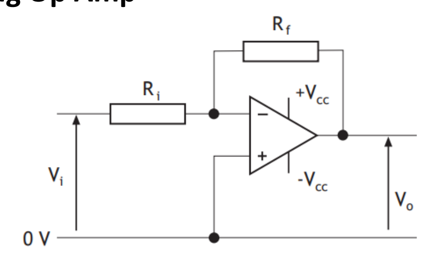
Step 2 - We can now work out the voltage across the thermistor by knowing that the total voltage is the voltage across both components added together.

$$V_S = V_1 + V_2$$
$$5 = V_1 + 1.9$$
$$5 - 1.9 = V_1$$
$$V_1 = 3.1V$$

Step 3 - now we can use Ohm's law again to calculate the resistance of the thermistor using the voltage across the thermistor and the current that stays the same.

$$V = I \times R$$
$$3.1 = (1.1 \times 10^3) \times R$$
$$\frac{3.1}{(1.1 \times 10^3)} = R$$
$$R = 2818\Omega$$

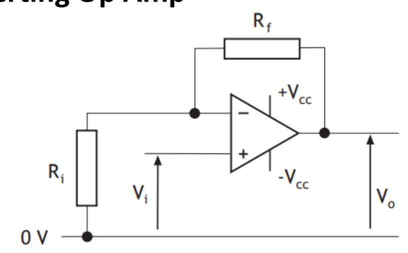
Inverting Op Amp



$A_v = \frac{V_o}{V_i}$ $\quad A_v = -\frac{R_f}{R_i}$ $\quad V_o = -\frac{R_f}{R_i} V_i$

Inverting op amp is used to change a positive input to a negative output or a negative input to a positive output.

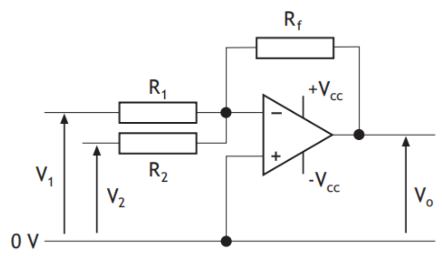
Non-inverting Op Amp



$A_v = \frac{V_o}{V_i}$ $\quad A_v = 1 + \frac{R_f}{R_i}$ $\quad V_o = \left(1 + \frac{R_f}{R_i}\right) V_i$

Non-inverting op amp is used to amplify the voltage into the op amp. It does not invert the voltage.

Summing amplifier



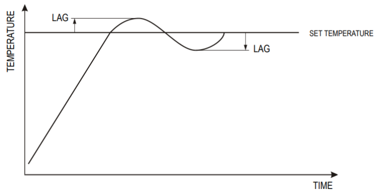
$A_{v1} = -\frac{R_f}{R_1}$ $\quad A_{v2} = -\frac{R_f}{R_2}$ $\quad A_{vn} = -\frac{R_f}{R_n}$

$V_o = (A_{v1} V_1) + (A_{v2} V_2) + \ldots$

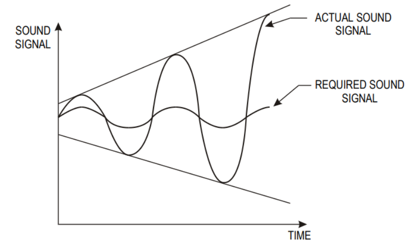
$V_o = -R_f \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \ldots\right)$

The summing amplifier is used to combine the voltages of two or more inputs into one single output.

Negative Feedback

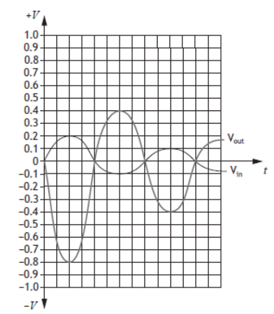


Positive Feedback



9. (continued)

An amplifier is required to boost the signal from the camera so that it can be transmitted. The graph below shows the desired output voltage for the given input.

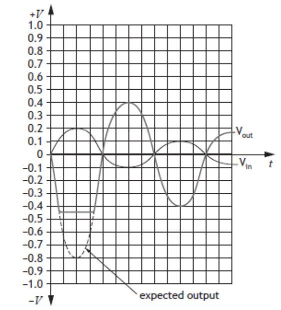


(e) State an op-amp configuration that will produce the desired output. 1

(f) Calculate the required gain of the op-amp. 1

9. (continued)

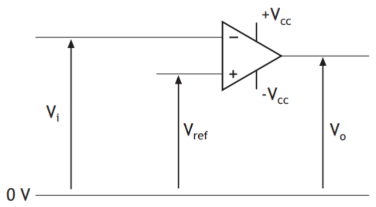
When testing the circuit, the output produced the following trace.



(g) State why the op-amp circuit produces the output shown. 1

	(e)		Inverting	1	
9.	(f)		Gain = -0.8/0.2 = -4 (1 sf)	1	Any suitable point on the t-axis can be used to calculate the answer. Clearly identifiable values from peaks and troughs must be used.
	(g)		The op-amp is saturating/clipping.	1	1 mark for suitable reason.

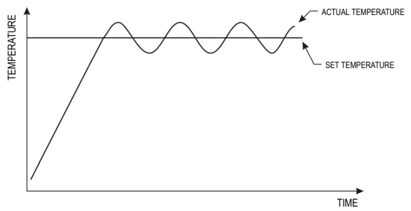
Comparator



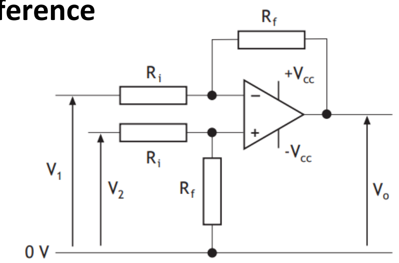
If $V_i < V_{ref}$, then V_o saturates positively

If $V_i > V_{ref}$, then V_o saturates negatively

Any system using an Op Amp as a comparator is known as two-state closed-loop control. The desired output it rarely met because the system is either on or off.

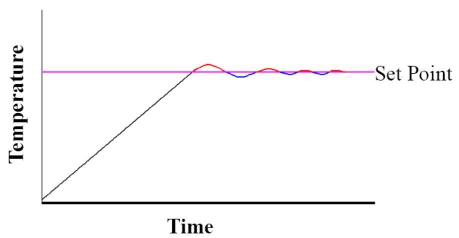


Difference

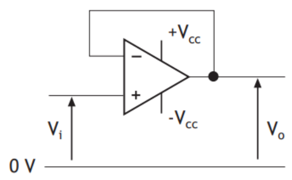


$A_v = \frac{V_o}{(V_2 - V_1)}$ $\quad A_v = \frac{R_f}{R_i}$ $\quad V_o = \frac{R_f}{R_i}(V_2 - V_1)$

A difference amplifier amplifies the difference between the reference level and feedback signal. This helps to prevent the "overshoot" and "time lags" that can be seen in a comparator-based system. Because of this it allows for the desired output to be reached, as the difference between the two signals will eventually be 0.



Voltage Follower

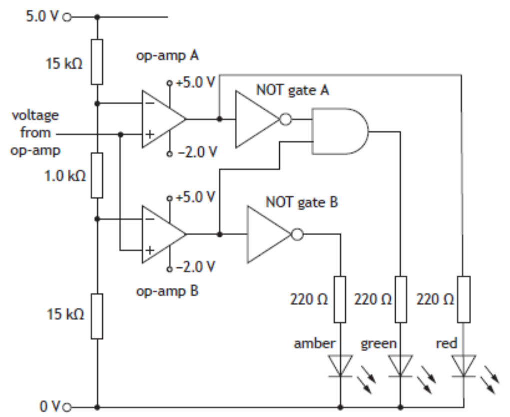


$V_o = V_i$

The Voltage Follower is an op amp configuration which always has a voltage gain of 1.

12. (continued)

The output voltage is fed into a logic circuit to indicate whether an appropriate weight of materials is in the container.



An amber LED lights if there is not enough material. A green LED lights if there is the correct amount of material. A red LED lights if there is too much material. When the op-amps saturate negatively they will output 0 V.

12. (continued)

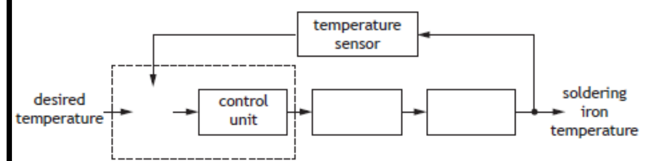
(c) Describe, with reference to the comparators, logic gates, and LEDs, what happens as the input signal rises from 0 V to 5.0 V. 3

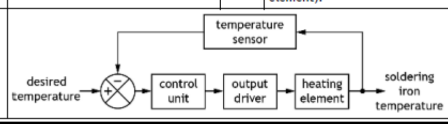
	(c)		Initially both op-amps will be saturated low. The AND gate will be off and NOT gate B will be on. This will make the amber LED light only. As the voltage rises, op-amp B will saturate high causing NOT gate B, and the amber LED, to switch off and this will cause the AND gate to switch on (causing the green LED to light). As the voltage rises further, op-amp A will saturate high causing the AND gate to switch off. This will cause the green LED to switch off and the red LED to light.	3	1 mark for identifying that a lower voltage will cause the amber LED to light. 1 mark for identifying that when the voltage rises op-amp B goes on and op-amp A remains off it will cause the green LED to light and the amber light to switch off. 1 mark for identifying that a high voltage will cause both op-amps to be on and will cause only the red LED to light.

5. A variable temperature soldering iron is shown.

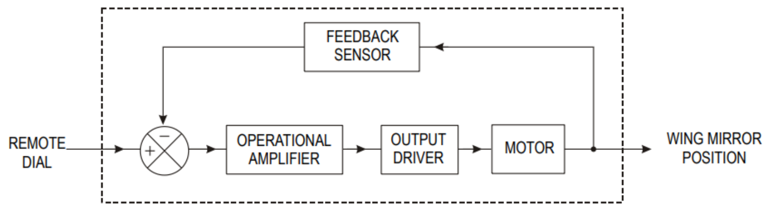
The soldering iron uses a two-state control system to turn the heating element on and off, and to monitor its output to maintain the desired temperature.

Complete the control diagram for the soldering iron below. 3



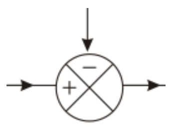
5.				3	1 mark for error detector, negative feedback configuration. 1 mark for output driver (or driver/transistor/MOSFET/Transducer Driver/TD). 1 mark for heating element (or element).
					

Control



In closed loop control, the output value is constantly monitored and compared to the desired (or reference) value. If a difference exists between the "actual value" and the "reference value", it realises that an error has occurred and will change the input into the system to reduce the output error to zero.

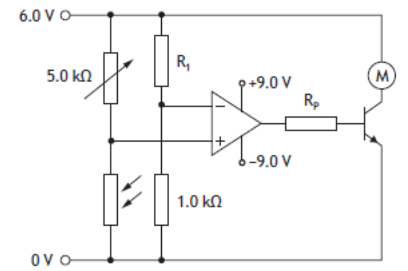
Error detector



When drawing an error detector in a system diagram, you must always make sure the + is connected to the desired input and the - is connected to the feedback loop.

A light sensor is used to identify when the plastic is dirty. When it senses a value of less than 210 lux a motor spins to move clean plastic in front of the camera.

The control circuit is shown below.



9. (continued)

(a) Calculate the value of R_1 required to saturate the op-amp positive at 210 lux. 3

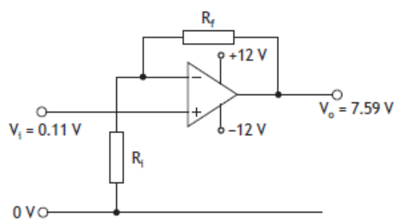
The motor requires 55 mA of current to operate.

The op-amp saturates to 78% of the supply voltage. V_{be} is 0.70 V when saturated. The transistor h_{fe} is 220.

(b) Calculate the required value of R_p. 4

9.	(a)		R_{ldr} = 600 Ω R_{ldr} values between 600 Ω and 630 Ω acceptable. $R_v/R_{ldr} = R_1/R_f$ 5000/600 = R1/1000 **R1 = 8.3 kΩ (2 sf)** **Alternative solution** V_{+ve} = (600/5600) × 6 = 0.64285714 V 0.64285714 = 6 × (1000/(R_1+1000) 0.64285714 × (R_1 + 1000) = 6000 R_1 × 0.64285714= 6000 - 642.85714 **R_1 = 8.3 kΩ (2 sf)**	3	1 mark for correct resistance of LDR. 1 mark for substitution. 1 mark for final answer with units.
	(b)		Max output from op-amp = 9 × 0.78 = 7.02 V I_b = 55/220 = 0.25 mA R_b = (7.02 - 0.70)/ 0.00025 R_b = 25280 **R_b = 25 kΩ (2 sf)**	4	1 mark for op-amp output (no unit required). 1 mark for base current (no unit required). 1 mark for voltage over the base resistor (no unit required). 1 mark for final answer with correct unit.

2. A design for an operational amplifier (op-amp) circuit is shown below.

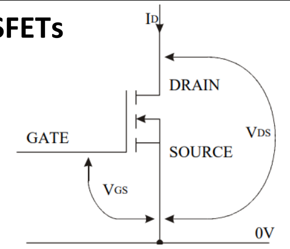


(a) Calculate the gain for this circuit when the input voltage is 0.11V.

(b) Determine appropriate resistor values for R_i and R_f.

2.	(a)		$A_v = V_o / V_i$ A_v = 7.59 / 0.11 **A_v = 69 (2 sf)**	1	1 mark for final answer with correct unit.
	(b)		$A_v = 1 + (R_f / R_i)$ 69 = 1 + (R_f / R_i) R_f / R_i = 68 **R_f = 68 kΩ (2 sf)** **R_i = 1.0 kΩ (2 sf)**	2	1 mark substitution. 1 mark for proportionally correct values for R_f and R_i with correct units. (Any two values with correct ratio).

MOSFETs



$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

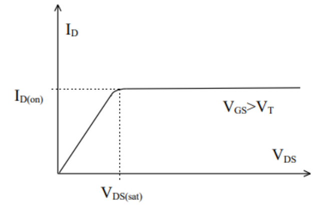
g_m is measured in Amps per Volt (AV^{-1})

MOSFETs can be designed to handle very high drain currents, this means that they can be used to drive high current output transducer drivers without the need for relay switching circuits (unlike the bipolar transistor). As MOSFETs are sensitive to high voltages, a reverse biased diode should be used to protect it from back EMF.

Saturation occurs when $V_{DS} = V_{GS} - V_T$.

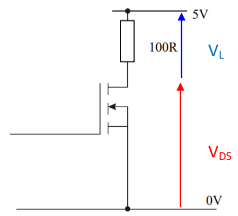
If V_{DS} is ≥ $V_{DSsaturation}$, I_D is constant (for a given value of V_{GS}) (I_D is then known as $I_{D(on)}$).

When saturation occurs $I_D = I_{D(on)}$



WORKED EXAMPLE

The threshold gate voltage for the MOSFET shown below is 2 V. Calculate the gate voltage required to ensure that a saturation current of 10 mA flows through the load resistor.



$$V = I \times R$$
$$V = (10 \times 10^{-3}) \times 100$$
$$V = 1V$$

$$V_S = V_L + V_{DS}$$
$$5 = 1 + V_{DS}$$
$$V_{DS} = 5 - 1$$
$$V_{DS} = 4V$$

$$V_{DS} = V_{GS} - V_T$$
$$4 = V_{GS} - 2$$
$$V_{GS} = 4 + 2$$
$$V_{GS} = 6V$$

6. An engineer designs a control system for hair straighteners to maintain a steady temperature. A comparator or a difference amplifier could be used in this application.

Describe the operation of these amplifiers in controlling temperature.

You must refer to both amplifiers in your answer. 3

Difference amplifier ______________________________

____

Comparator ______________________________

____

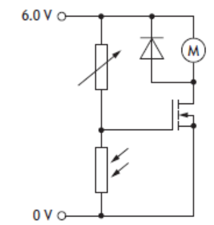
Difference amplifier or comparator ______________________________

____

6.			Difference amplifier: • provides proportional control • ouput varies proportionally with error in inputs • output signal reduces as desired output is approached, and is able to remain consistent at the desired output. Comparator: • provides two-state control • output is either fully on or fully off depending on the feedback signal • output will continually overshoot and undershoot (hunting), and the output never remains consistent at desired level.	3	Up to two correct descriptive comments for each.

9. (continued)

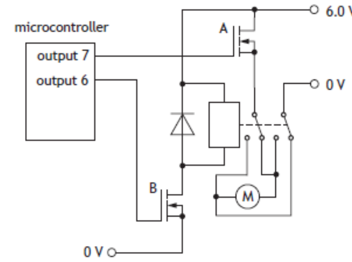
An alternative motor with a MOSFET driver is also considered. The MOSFET has a resistance of 2.3 Ω when fully saturated and the motor is rated as 0.40 W at 6.0 V.



(c) Calculate the drain-source current when the MOSFET is fully saturated. 3

9. (continued)

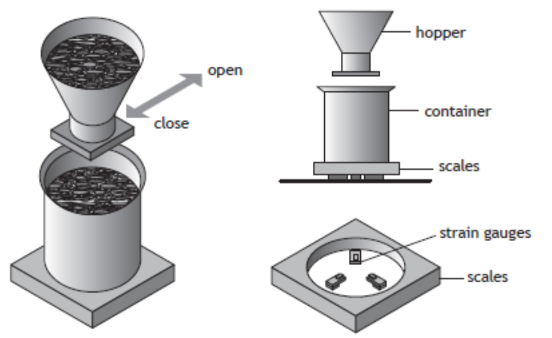
As part of the car's control system, the windows are to be opened and closed automatically. The following control circuit is produced by an electronic engineer.



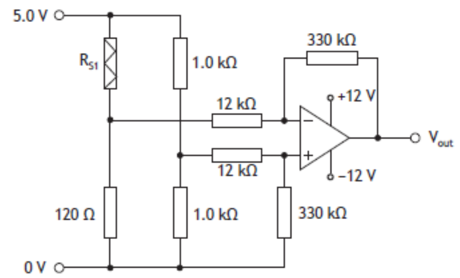
(d) Explain, with reference to the circuit above, the impact that switching output 7 high then output 6 high has on the motor. 2

	(c)		$R_{motor} = V^2/P$ = 36/0.4 = 90 Ω I = 6/(90 + 2.3) = 0.06500542 **= 65 mA (2 sf)**	3	1 mark for resistance of motor (no unit required). 1 mark for total resistance (no unit required). 1 mark for final answer with correct unit.
	(d)		Switching on output 7 activates the top MOSFET and allows current to flow to the motor causing it to spin. Output 6 will control the relay which will change the direction of rotation of the motor.	2	1 mark for indicating the effect of each output pin. Cause and effect required for each statement.

12. A science laboratory is investigating the use of an electronic control system to weigh chemical materials. The materials are released into a container from a hopper and are weighed using a scale comprised of three strain gauges.



A prototype circuit using a difference amplifier is produced to test one of the strain gauges as it weighs the materials.



12. During an initial test R_{s1} was found to be 121.5 Ω.

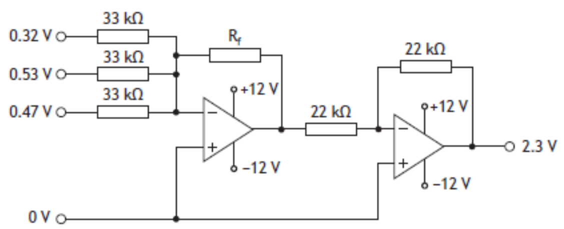
(a) Calculate V_{out}. 3

12. (continued)

A difference amplifier circuit like the one shown in part (a) on *page 40* is used for each of the three strain gauges.

A further circuit is designed to combine their outputs. It must produce an output of 2.3 V when the correct amount of materials are added to the container.

When the materials are added, the input and output voltages produced are shown below.



(b) Calculate a suitable value for R_f. 2

12.	(a)		V @ inverting input = 5 × (120/241.5) = 2.48447205 V V @ non-inverting input = 5 × (1/2) = 2.5 V V_{out} = (2.5- 2.48447205) × (330/12) = 0.42701863 V **= 0.43 V (2 sf)**	3	1 mark $V_{inverting}$ (no unit required). 1 mark $V_{non-inverting}$ (no unit required). 1 mark for V_{out} with correct unit.
	(b)		Summing amp output = -2.3 V -2.3 = -(R_f/33) × (0.32+0.53+0.47) R_f = 57.5 kΩ **R_f = 58 kΩ (2 sf)**	2	1 mark for output of summing amp (no unit required). 1 mark for R_f with correct unit