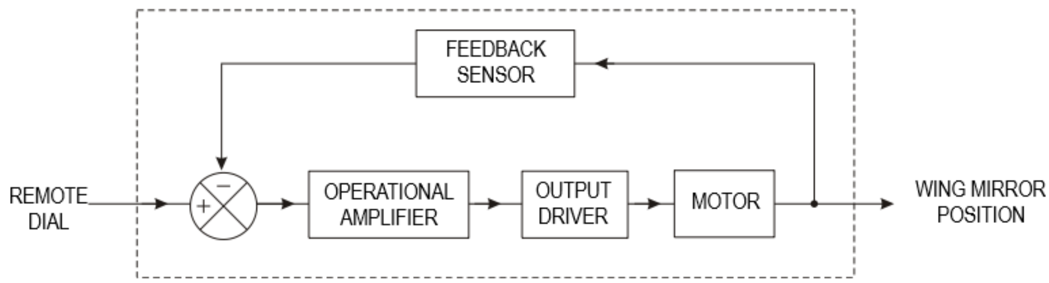
Higher Engineering Science

Systems & Control



Name: ______________________

Teacher: ____________________

Class: ______________________

Mrs Gault

Learning Intentions

- Complex system, sub-system and control diagrams
- The role of Feedback in a system
- Closed loop, automatic, two state and proportional feedback
- Use of error detection in a closed loop system

Success Criteria

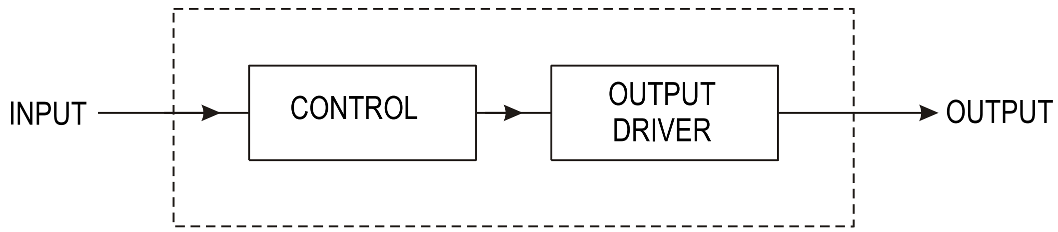
- I can describe the operation of complex system, sub-system and control diagrams.
- I can explain the role of feedback in a system.
- I can explain closed loop, automatic, two state and proportional feedback using graphs if needed.
- I can explain the purpose and function of an error detector in a closed loop system.

In this unit we will build on the skills learned in National 5 Engineering Science.

Systems Diagrams

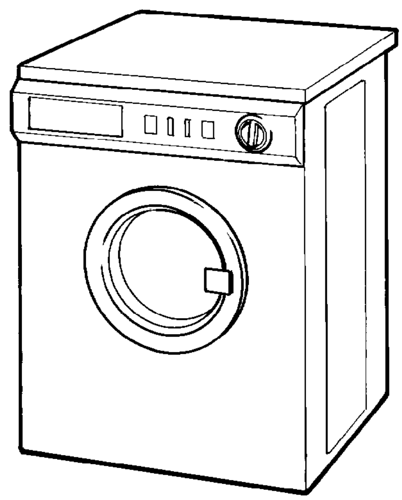
Most industrial product design is solved by the systems approach. This approach involves studying the desired function of the product, and then breaking this function down into a series of subsystems.

When applied to control systems, a **Systems Diagram** is a useful way of visually representing the desired function of the system. The systems diagram is a form of block diagram than contains all the subsystems within a dashed box, called the **systems boundary**. The systems boundary indicates the extent of the control system.

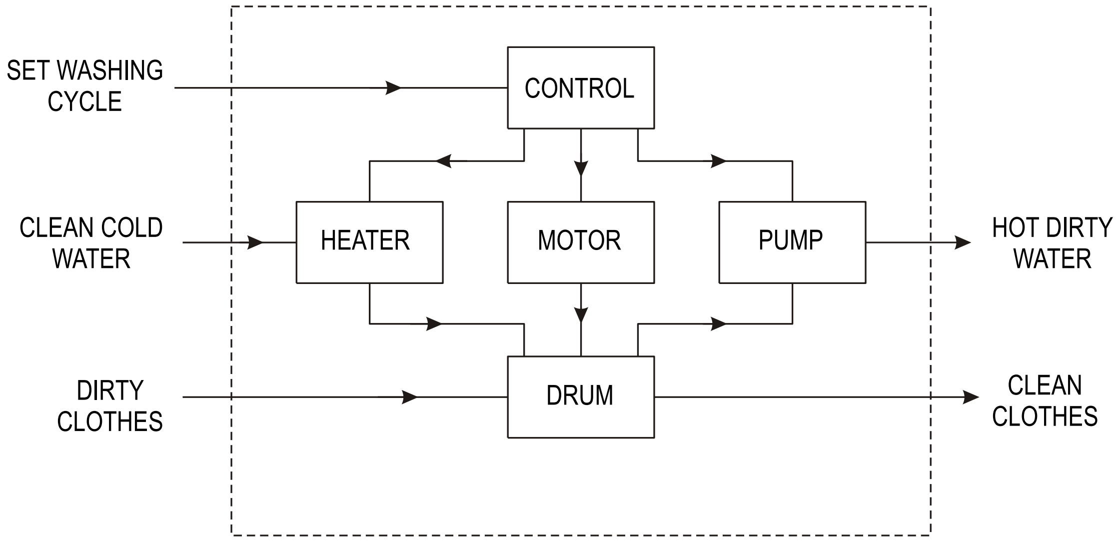


The "real world" input and output conditions of the system are shown as arrows entering, and leaving, the systems diagram.

A product which has a fairly complicated control system is an automated washing machine.



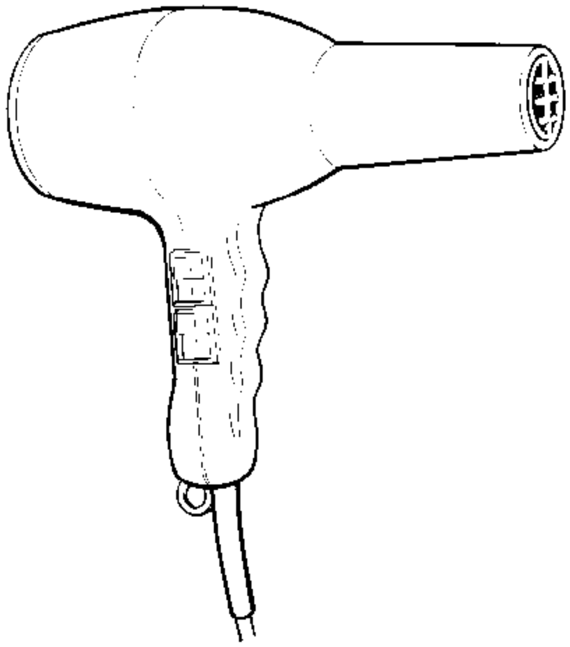
A simplified systems diagram of a washing machine is shown below.



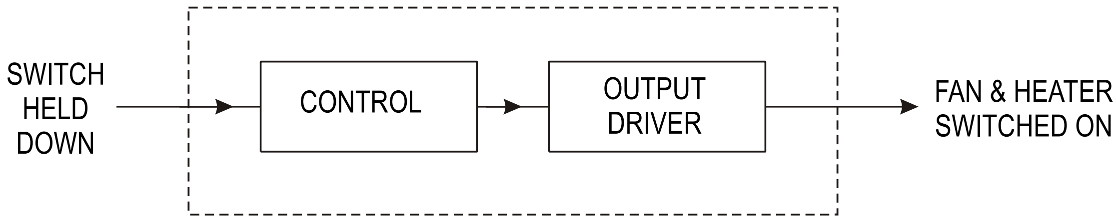
The function of the washing machine is to process dirty clothes to produce clean clothes. This is clearly represented within the systems diagram.

Open Loop Control

At the simplest level a control system can process an input condition to produce a specified output.

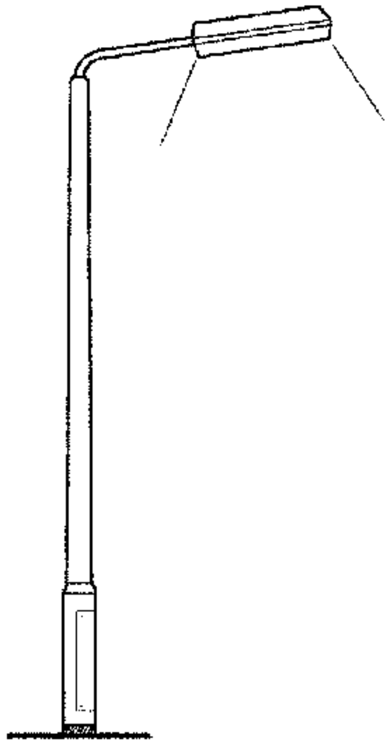


A good example of this type of system is a hand-held electric hairdryer. The heating element and fan motor are switched on when the appropriate switches are held down.

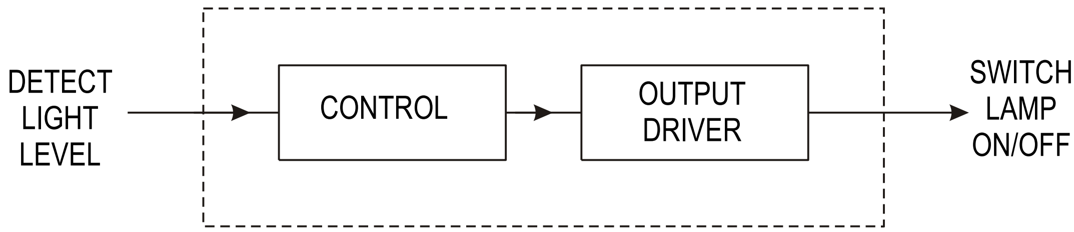


This is an example of **Open Loop Control**, where an input is processed to produce an output. With the hairdryer example the heater and fan motor are held on until the switches are released. The air being blown out of the hairdryer is not temperature monitored or adjusted - the air is simply just blown out at whatever temperature the heater is capable of achieving.

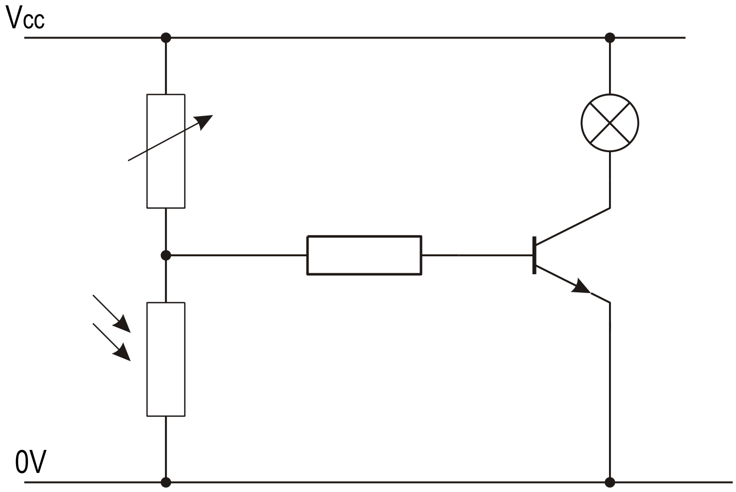
Another example of an open loop system is an automatic street lamp.



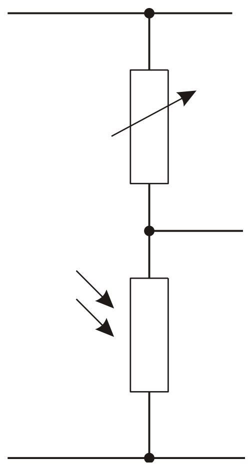
The systems diagram for the street lamp is shown below.



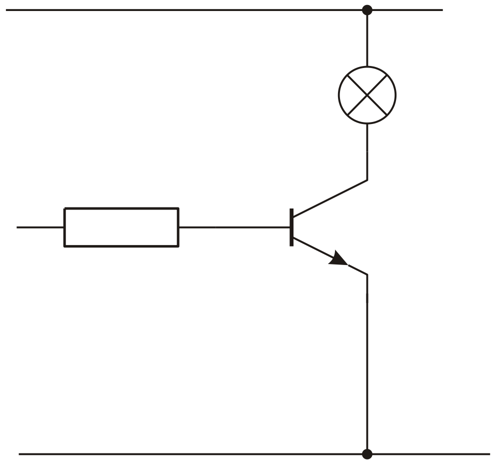
A model of the street lamp can be represented by the following circuit diagram:



The input to the circuit, light, is processed by the control subsystem to produce an electrical signal. In this example the potential divider arrangement provides a varying voltage signal.



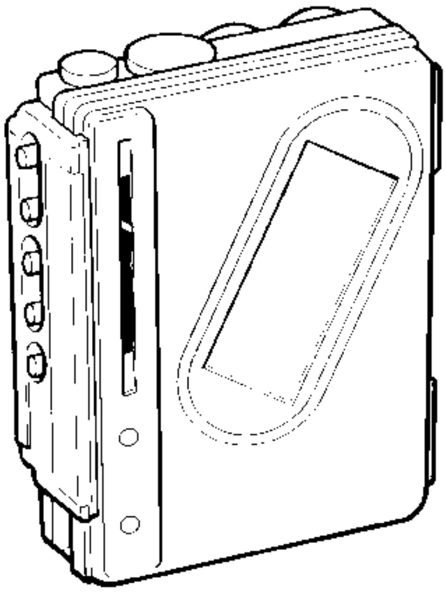
The electrical signal is processed by the output driver subsystem to produce the output. In this example the output is light from the signal lamp.



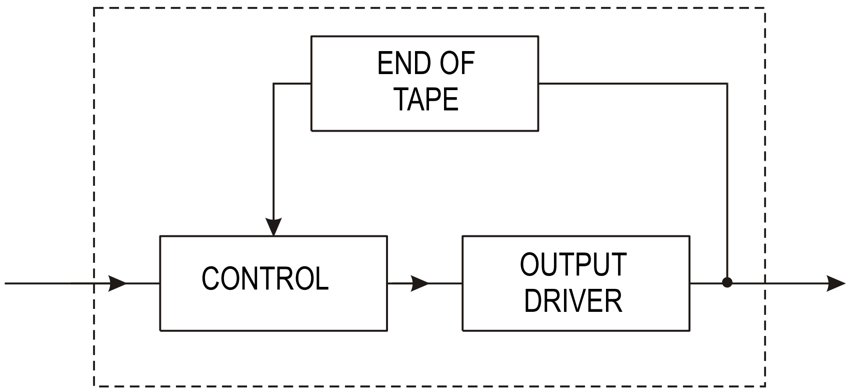
An open loop control system represents the simplest and cheapest form of control. However, although open loop control has many applications, the basic weakness in this type of control lies in the lack of capability to adjust to suit the changing output requirements.

Closed Loop Control

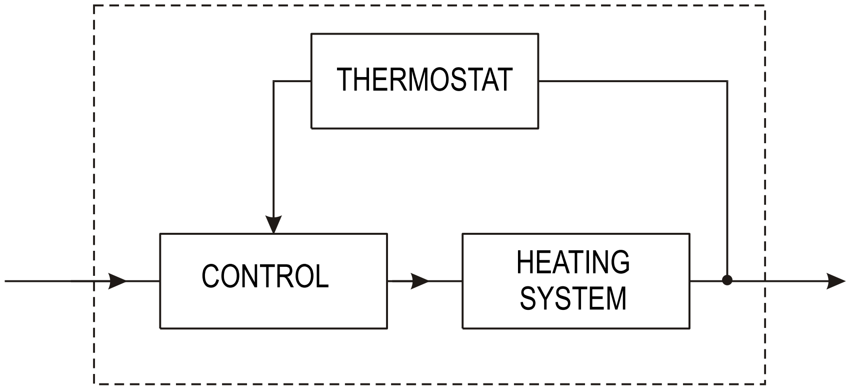
Closed loop control systems are capable of making decisions and adjusting their performance to suit changing output conditions.



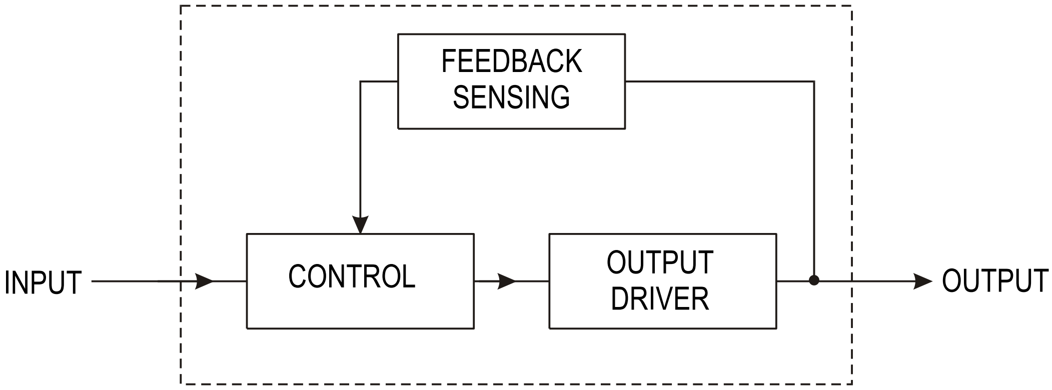
A personal cassette player is capable of detecting the end of the tape and switching the motor off, hence protecting the tape from snapping (or the motor burning out).



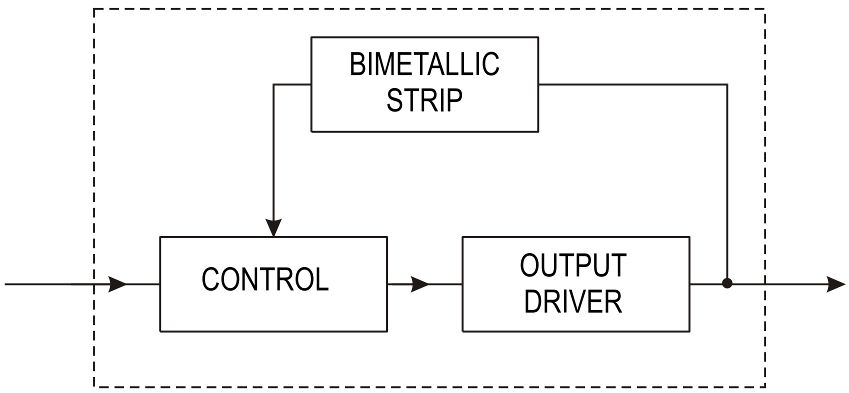
The central heating in most modern houses is controlled by a thermostat. It senses changes in temperature and turns off the heating system automatically when the required temperature is reached. Likewise when the temperature level drops below the minimum acceptable level the heating system is automatically switched back on.



All closed loop control systems include a **feedback sensing** subsystem within the systems diagram. The control subsystem will process the feedback signal by making a 'decision' on whether the state of the output should change.



Another example of a simple closed loop control system is an electric toaster. In this case the feedback sensing system is a mechanical bimetallic strip. This strip bends when heated - the higher the temperature the more the strip bends.

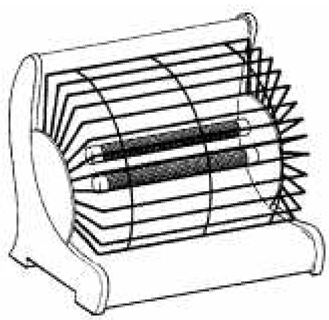


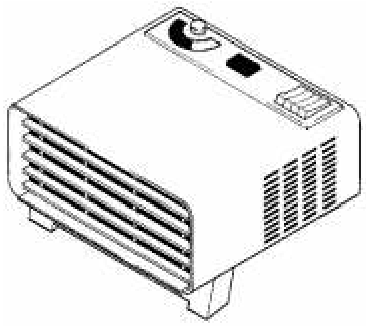
When the toaster cage is lowered into the toaster it compresses a spring, and the cage is 'hooked' into position by a catch attached to a bimetallic strip. A switch also connects the heating element, which starts to heat up. The heating element starts to cook the bread, and also starts to heat the bimetallic strip. When the bimetallic strip has been heated to the required temperature it bends enough to mechanically release the spring holding the cage down. This automatically ejects the toast and switches the heating element off.

Assignments:

1) Explain what is meant by the term 'systems diagram'.
2) Describe the differences between an open loop and closed loop control system.
3) Describe the purpose of the feedback sensing subsystem in a closed loop control system.

Assignment 4





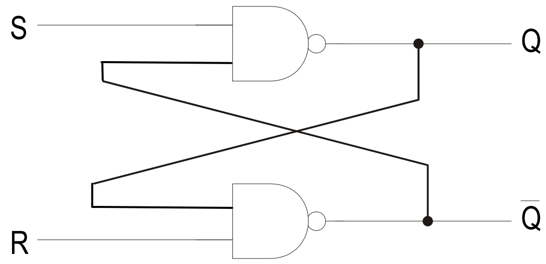
The figures above show two types of electric fire. The second electric fire is a more modern device fitted with a thermostat.

a) Name the type of control system used in each type of electric fire
b) Draw a system diagram for each type of electric fire.
c) Name a type of electronic sensor that may be used for measuring temperature.

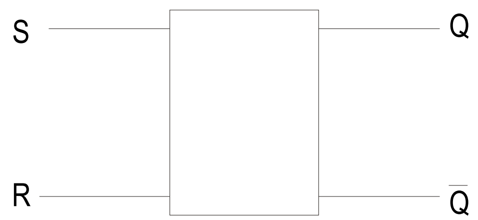
Bistable Two State Closed Loop Control

The most basic 'decision' which a closed loop control system can be required to make involves switching the system off (or resetting the system) when the output reaches a maximum or minimum output state level. Many safety systems incorporate this form of control as a means of switching off a system when a dangerous condition is reached.

This form of control can be based around a sequential logic device called the S-R bistable or latch. An S-R bistable can be represented by one of two symbols.

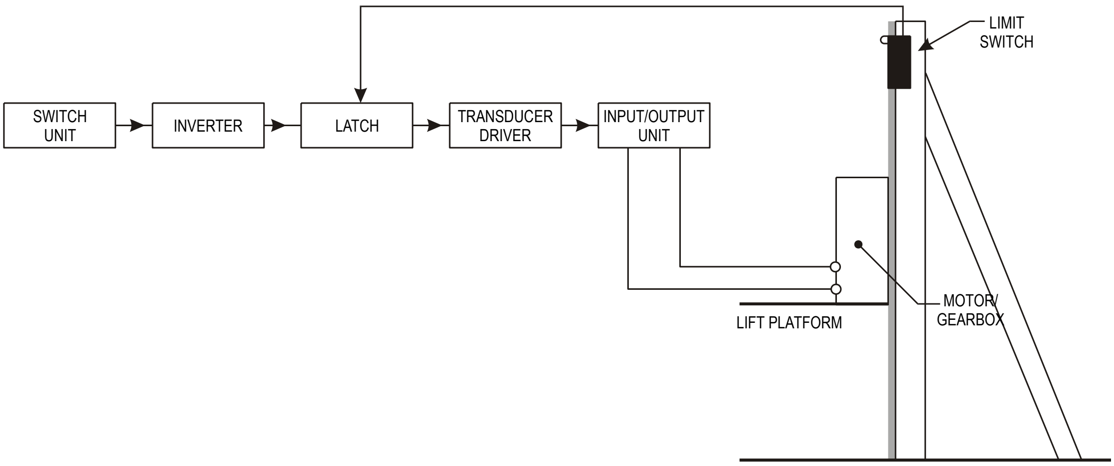


CROSS-COUPLED
NAND GATE
S-R BISTABLE

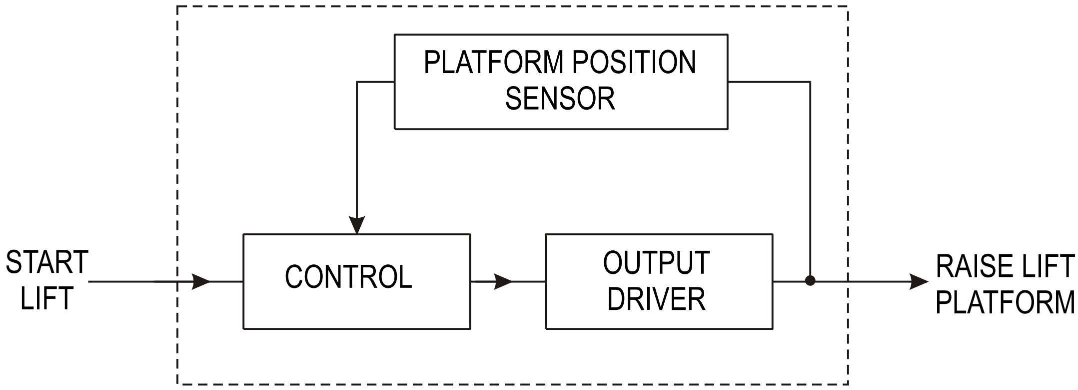


S-R BISTABLE
SYMBOL

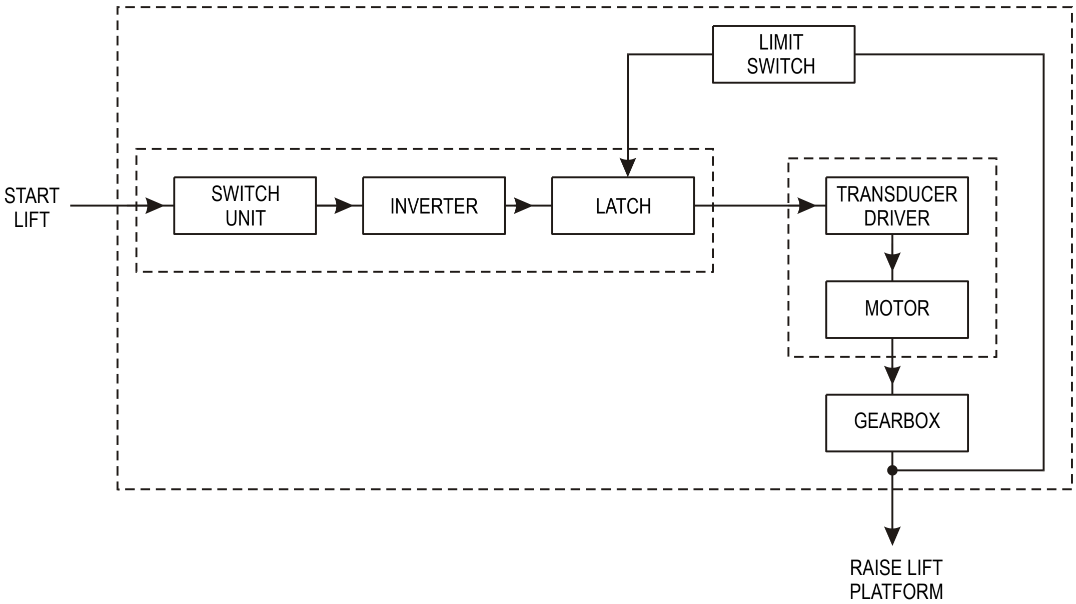
Assignment 5



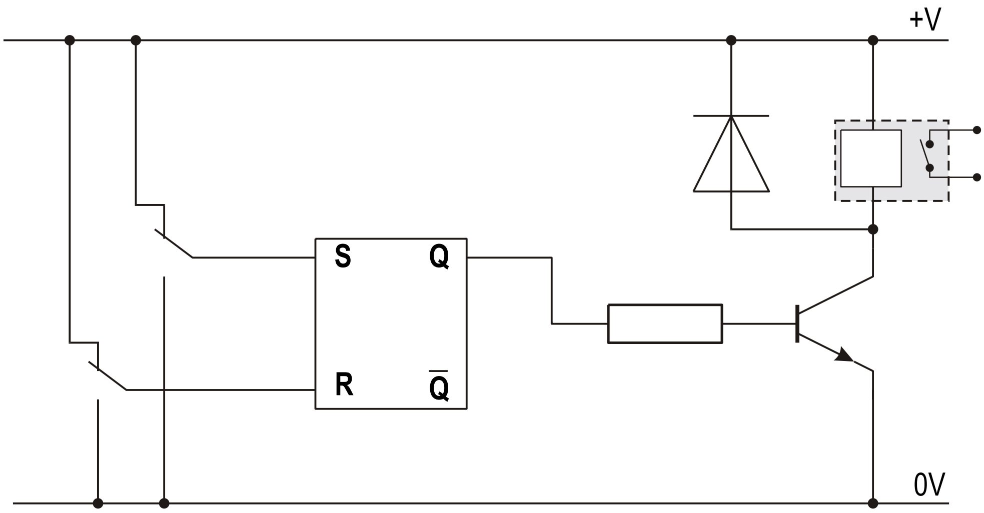
The systems diagram for a simple lift control system is shown below.



A limit switch at the top of the lift detects when the lift platform has reached the top of the run. The block diagram below shows the system diagram sub-systems broken down into smaller blocks.

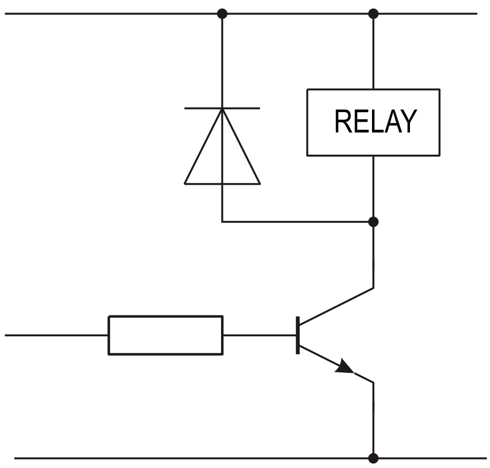


A circuit diagram of the system is shown below.



a) Simulate the circuit shown on Yenka adding a mechanical gearing system to replicate the lift so that it moves at a safe speed. Show calculations.
b) Clearly explain how the system operates.

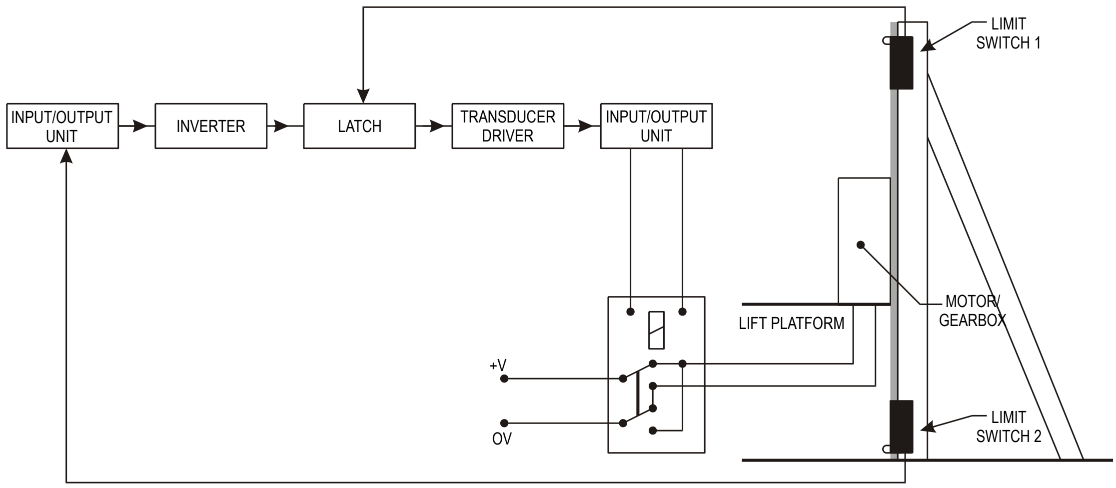
The 'transducer driver' circuit used in this instance is a **relay driver** circuit.



c) Explain the purpose of the relay, transistor and diode within the relay driver circuit.

Assignment 6

The output condition using this type of control does not have to be limited to on or off but can be applied to any two desired output states.

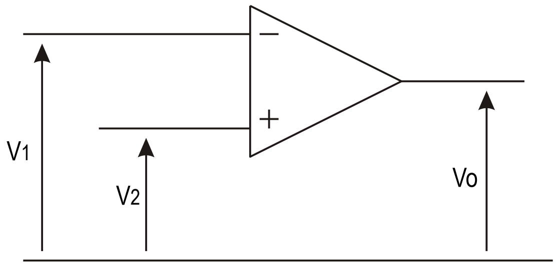


a) Simulate the circuit shown on Yenka adding a mechanical gearing system to replicate the lift so that it moves at a safe speed. Show calculations.

b) Draw a system diagram of the control system.

c) Clearly explain how the system operates.

Closed Loop Control Systems - Two state control

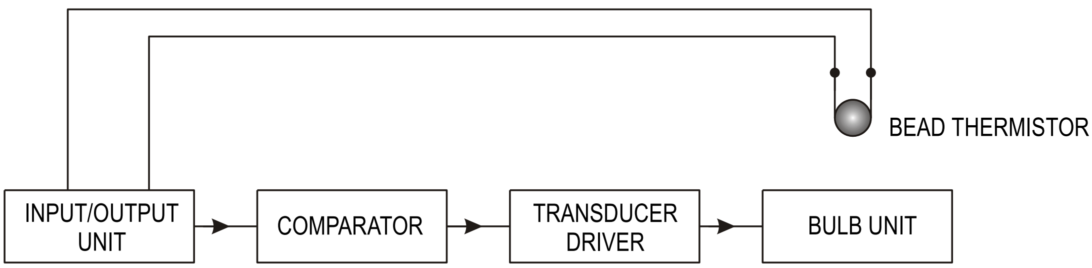


Many control systems involve processing analogue signals such as heat, light and movement. Therefore analogue closed loop control systems require analogue processing devices such as the **operational amplifier (op-amp)**.

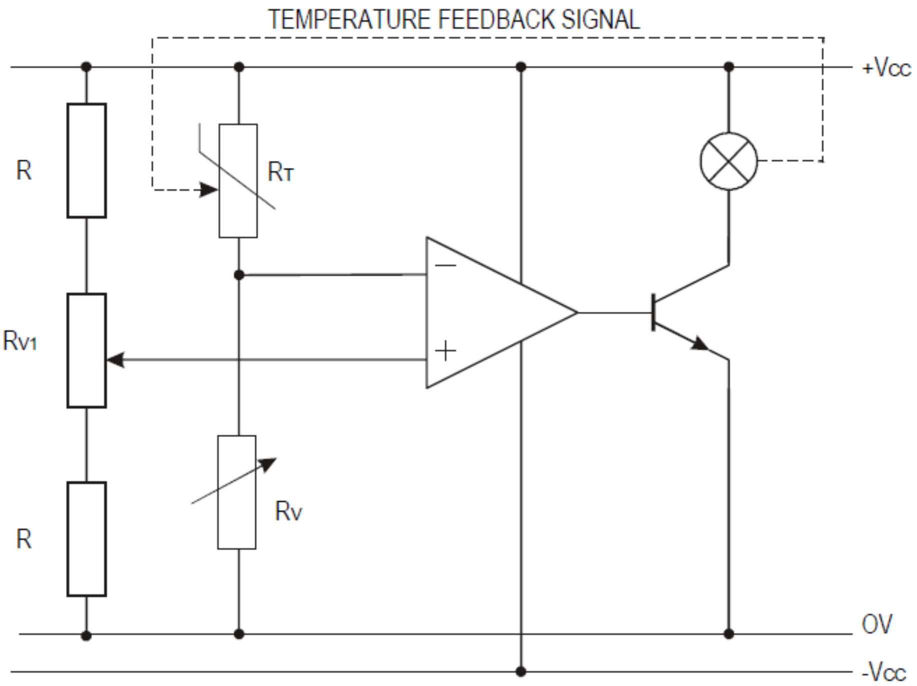
One of the most common control applications involves using the op-amp as a **comparator**. In it's simplest form a comparator just compares two voltage signals, V1 and V2. If V1 is higher than V2 the output, Vo, is 'low', if V1 is lower than V2 the output is 'high'. A comparator provides on/off or two state control.

Assignment 7

The block diagram below simulates an automatic heating system. When the bulb heats up the temperature rise is detected by the bead thermistor, which sends a feedback signal back to the comparator.



A circuit diagram of the system is shown below.

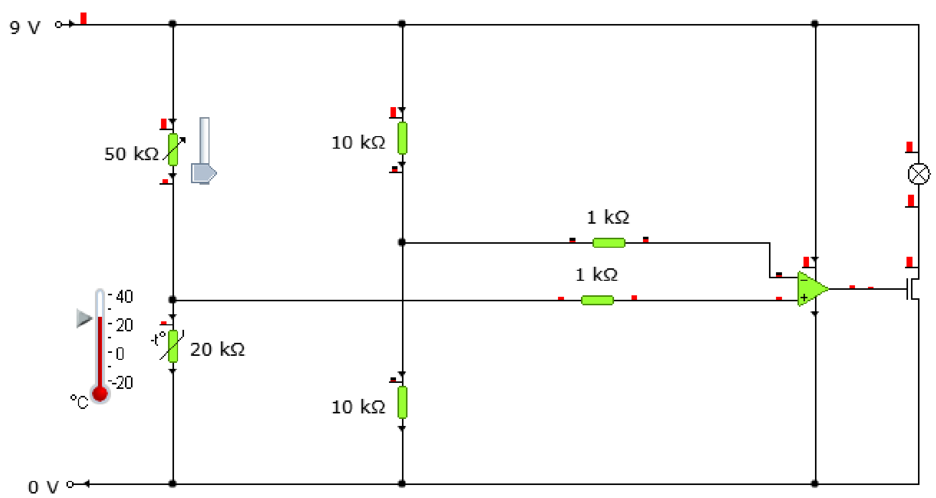


The variable resistor, RV1 (connecting to the non-inverting input of the op-amp) is used to set the **reference level** (or threshold). This sets the desired temperature of the bulb.

Build and test the circuit shown, using Yenka. Calibrate the system to the following performance criteria:

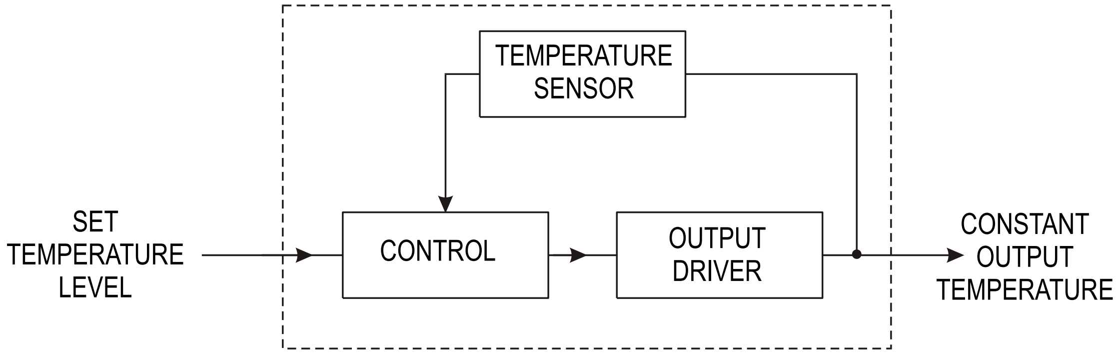
- When the bulb heats above the reference level the thermistor should sense the temperature and send a signal to the comparator which will switch the bulb off.
- When the bulb cools below the reference level the bulb should switch on again.
- The system should operate continuously.

a) Describe how the circuit operates.
b) Explain clearly how you calibrated the system.

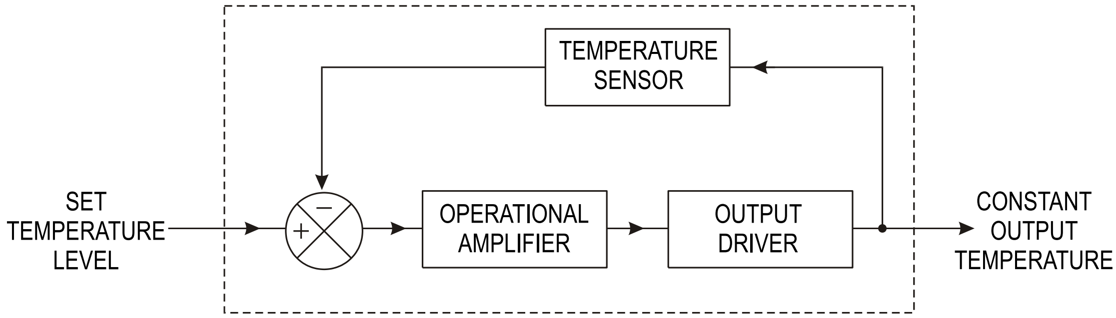


Control Diagrams

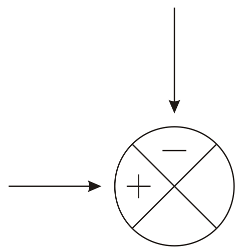
The heating control system described in assignment 1 can be represented by the following **systems diagram**.



However when an op-amp is used in a control system it is usual to draw a **control diagram** instead.



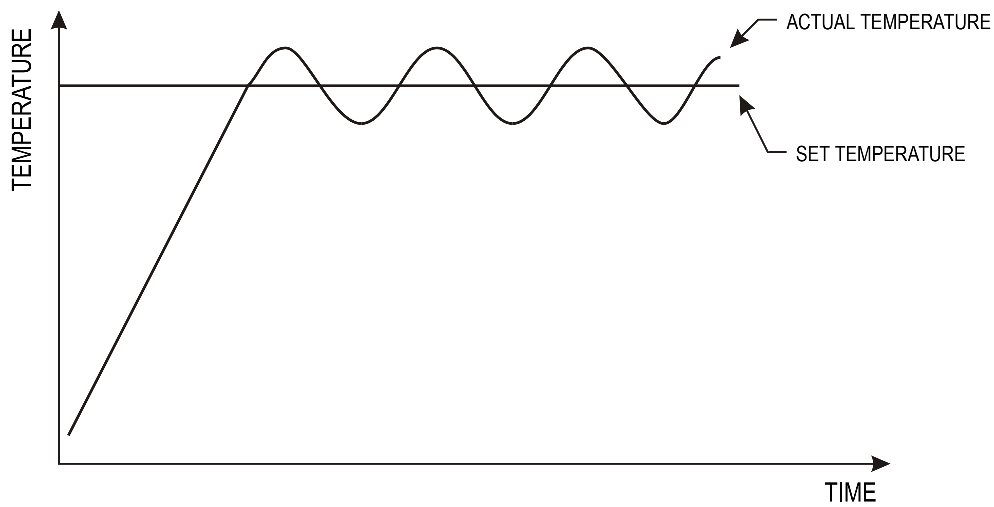
The control diagram breaks the generalised 'control' subsystem of the systems diagram into more specific blocks.



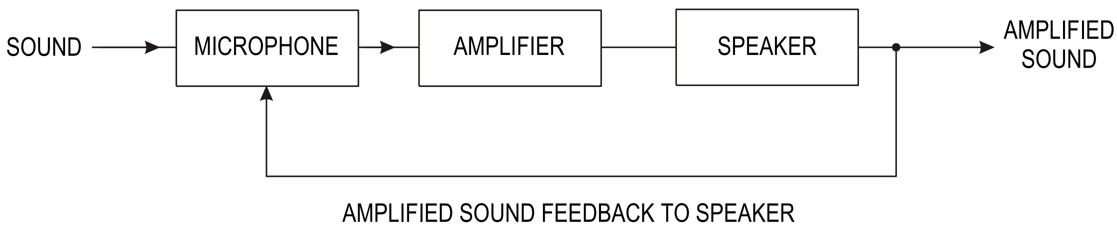
The **error-detection symbol** is also used to indicate that the control involves two signals. The feedback signal is connected to the negative symbol to indicate the use of **negative feedback**.

Negative and Positive Feedback

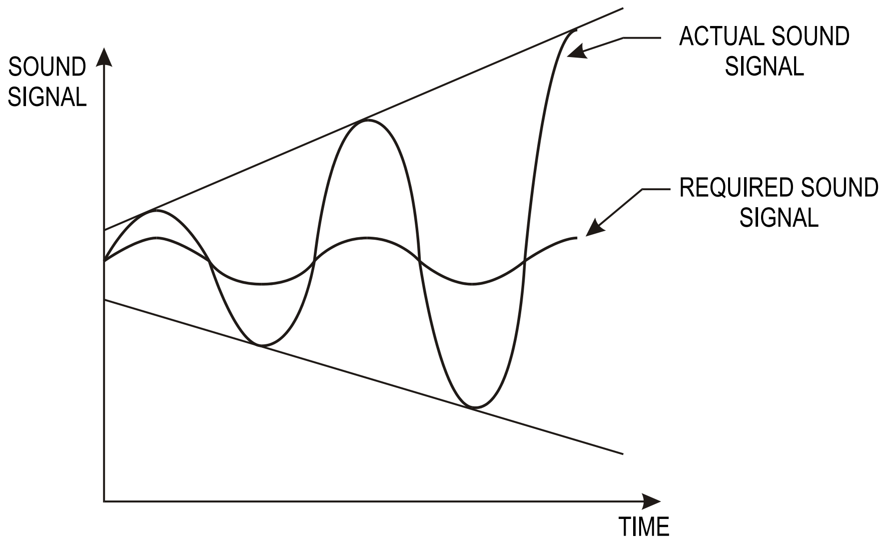
The purpose of closed loop control is to ensure that the output is maintained, as closely as possible, to the desired output level. In the case of a central heating system, a graph of the temperature in a room might appear as in the graph below.



As can be seen from the graph, the control system is constantly trying to pull the temperature of the room back towards the set temperature level by reducing the error. This type of control uses **negative feedback** to reduce the error.



The opposite effect can be created by reinforcing the error, as can sometimes happen with public address systems when the microphone is held too close to the speakers. A sound is picked up by the microphone, amplified, and then output through the speaker. The amplified sound is then picked up, re-amplified and so on. The net result is a high pitch sound, which can be represented by the graph below.



This is an example of **positive feedback**. Although positive feedback does have some useful applications, negative feedback is far more widely used in control systems.

Assignment 8

Explain the following terms when applied to control systems:

open loop

closed loop

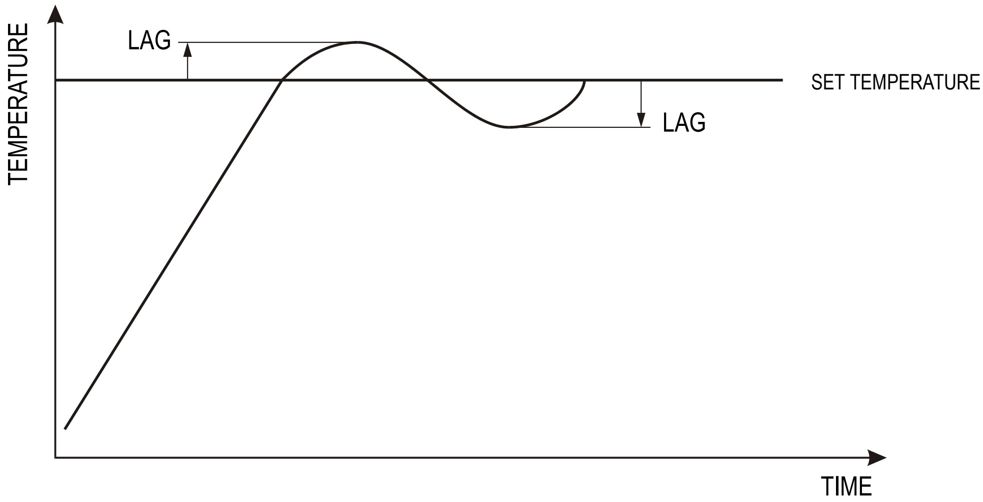
negative feedback

positive feedback

error detector

Proportional Closed Loop Control Systems

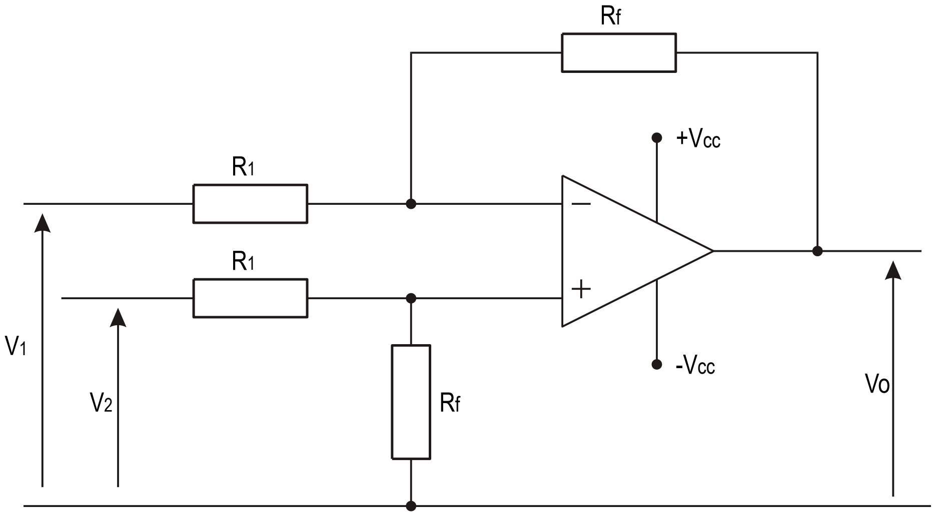
The main problem with comparator based control systems is that there is a time 'lag' built into their operation. This means that the desired output state is never actually reached.



The graph of the temperature control system shown in assignment 7 clearly shows the effect of lag.

When the reference level ("set temperature") is reached the heating system will continue to heat the room for a short period until the heating element cools down. This raises the temperature in the room above the set or desired temperature level. When the temperature in the room cools down to the reference level the heating system will be switched on. Whilst the heating element is reaching its operating temperature the room continues to cool below the reference level.

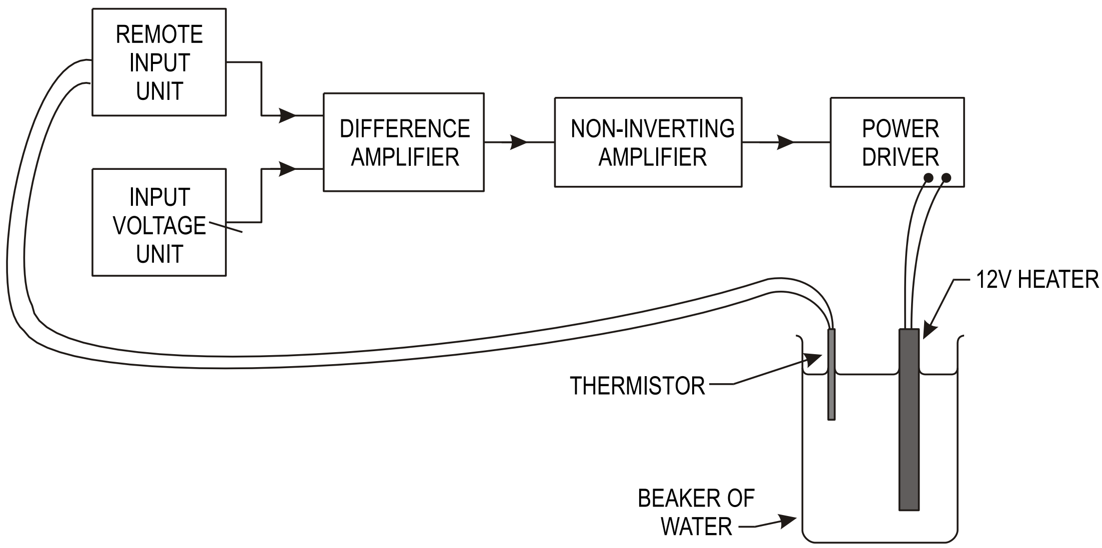
Proportional closed loop control systems are applied as a means of proving a more accurate form of analogue closed loop control. The operation of proportional control is based around the op-amp configured as a **difference amplifier**.



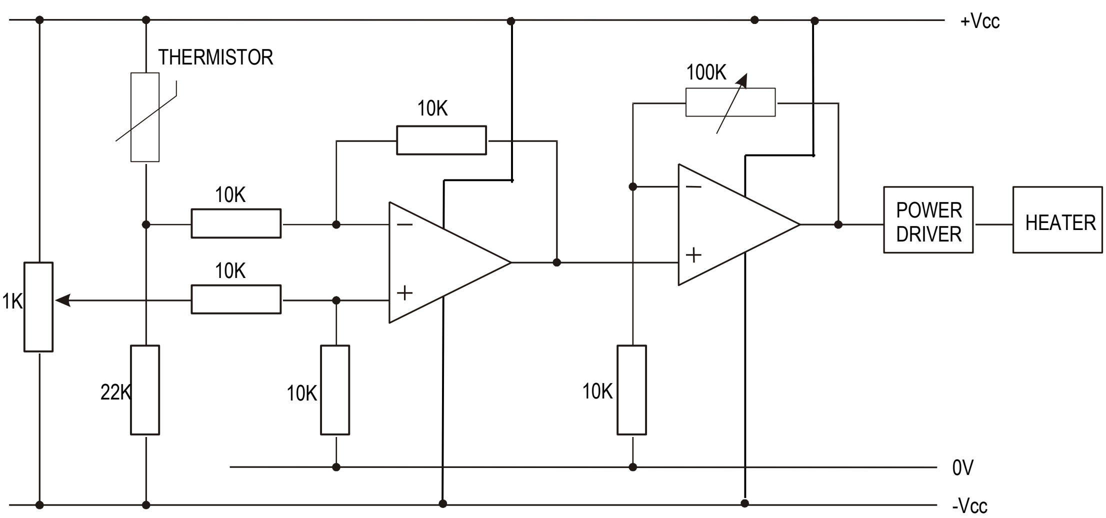
The **difference amplifier** amplifies the difference between the **reference level** and the **feedback signal**. Therefore if there is a large error there will be a larger output signal than when there is a small error. This help prevents the 'overshoot' and 'time lags' seen in the comparator based systems.

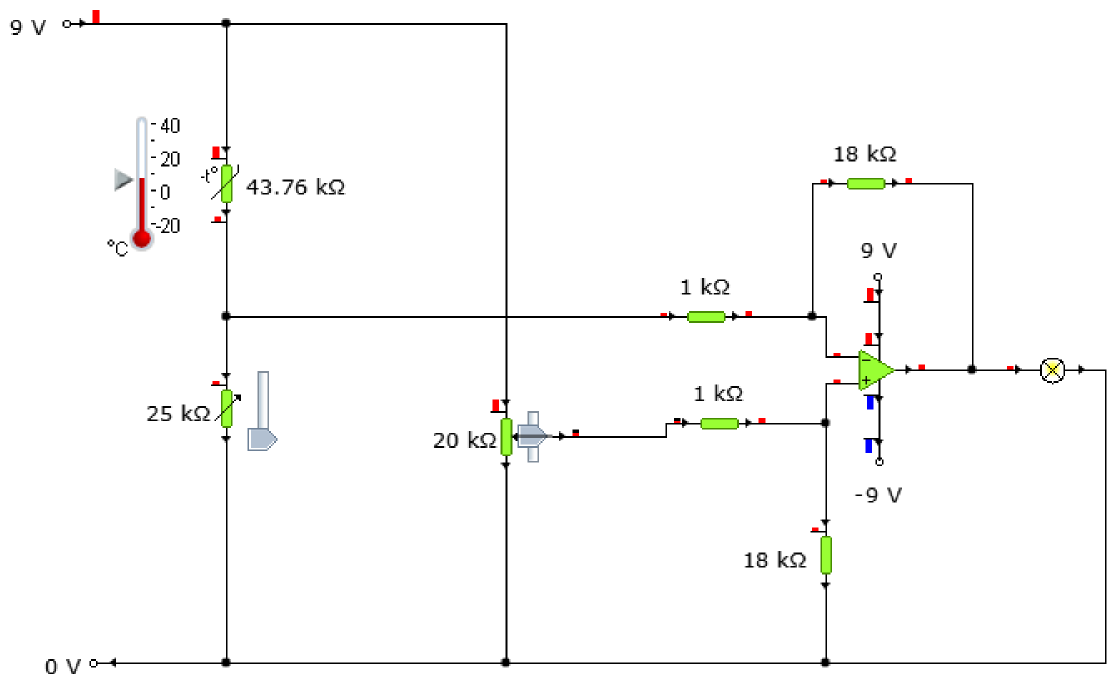
Assignment 9

The block diagram below simulates the automatic water heating system within a washing machine.

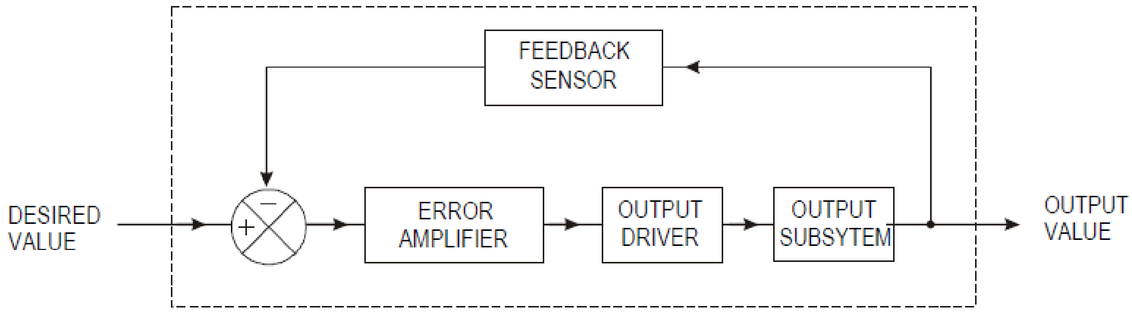


A circuit diagram of the system is shown below.





Now our generic systems diagrams are starting to reflect the use of the op amp in the control area
of the diagram:



Sometimes, an operational amplifier symbol is shown instead of the block.

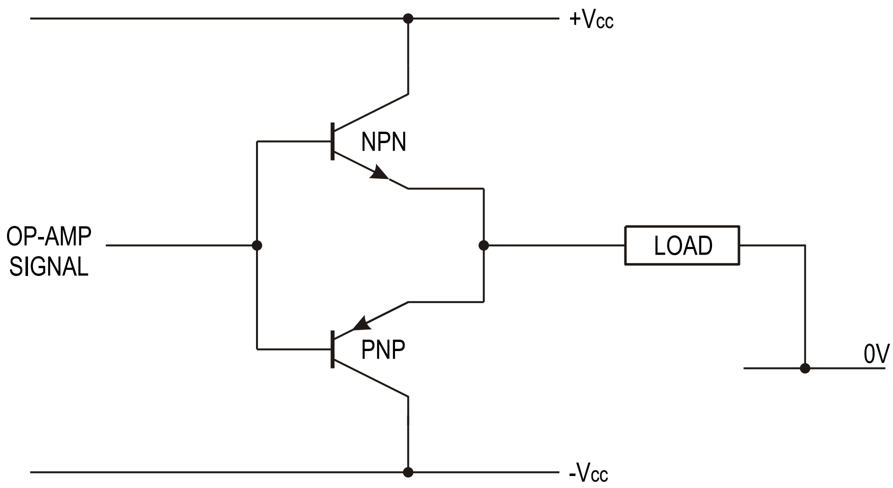
Task 27
Build the circuit shown on Yenka. Observe the response of the system when the reference level (desired temperature) is altered (by adjusting the variable resistor).

(a) Explain how the circuit above operates
(b) Draw a control system diagram for this system
(c) Explain in detail how the control system operates

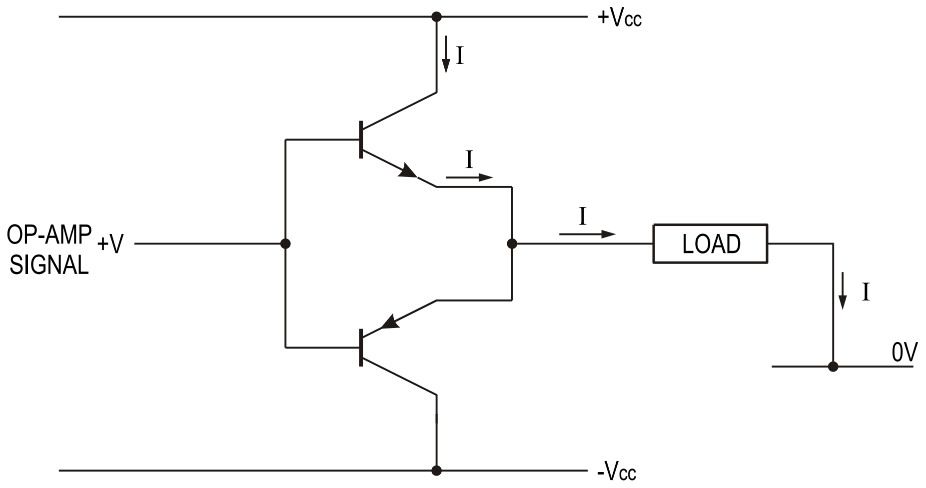
Push-Pull Follower Analogue Driver

An important element in producing positional control, such as that required in the servo, is a dual rail **push-pull follower** analogue driver circuit, that allows the motor to spin in both directions. The op-amp cannot source sufficient current to drive most output components, and so the dual rail push-pull follower is required to drive the output components.

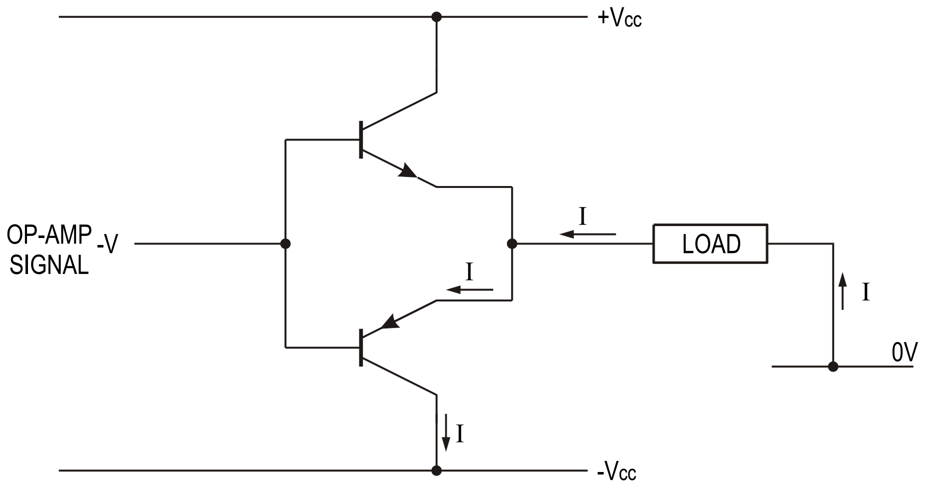
The dual rail push-pull follower is based around a two transistor circuit as shown below.



When the signal from the op-amp is positive the NPN transistor will switch on, and current will flow through the load from the positive supply rail, +Vcc, to the ground rail, 0V.

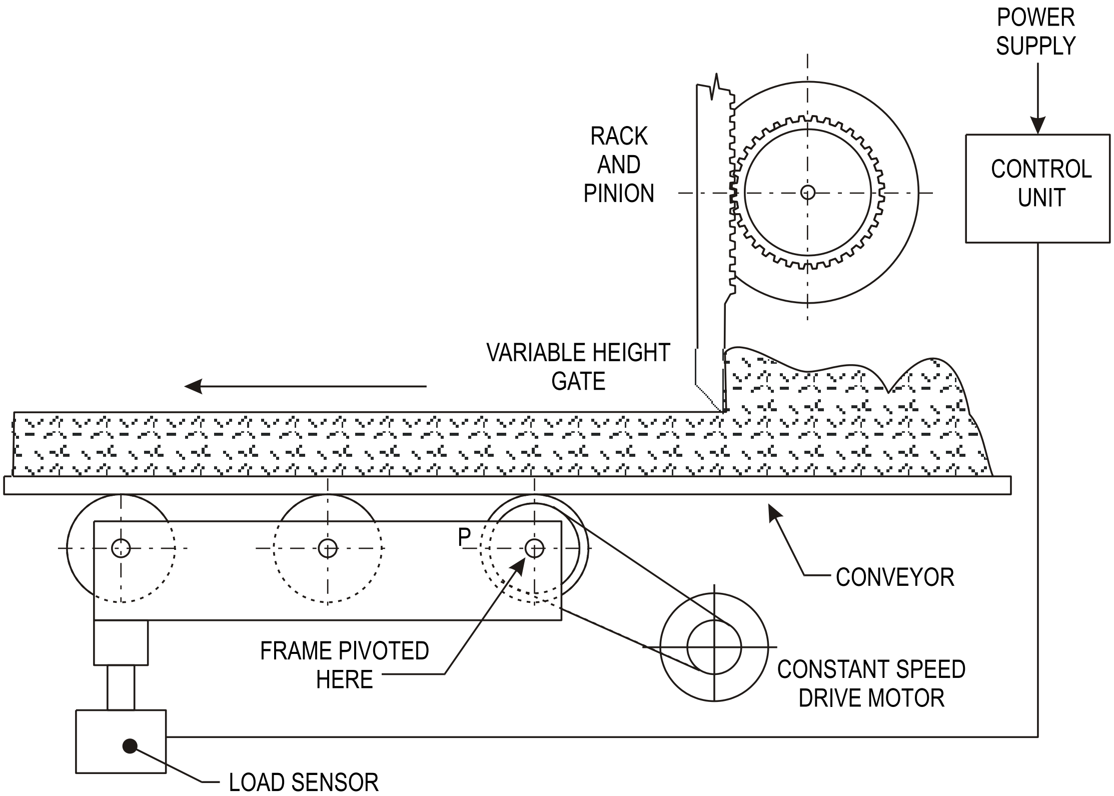


When the signal from the op-amp is negative the PNP transistor will switch on and current will flow through the load from the ground rail, 0V, to the negative supply rail -Vcc.



Assignment 10

A proportional control system is used to regulate the flow rate of coal onto a conveyer belt. The system should sense the weight of coal on the conveyer belt and automatically adjust the gate height to ensure that a constant flow of coal is supplied.



a) Draw a systems diagram of the flow rate control system.

b) Explain the term 'proportional control'.

c) Name the configuration of op-amp used in proportional control systems.

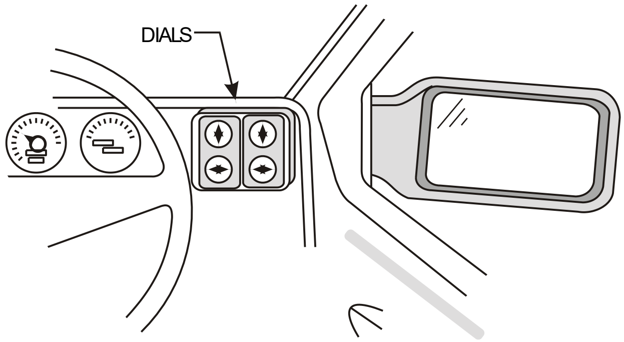
d) Draw a circuit diagram of the op-amp.

e) Name a suitable output driver circuit which could be used with the control system.

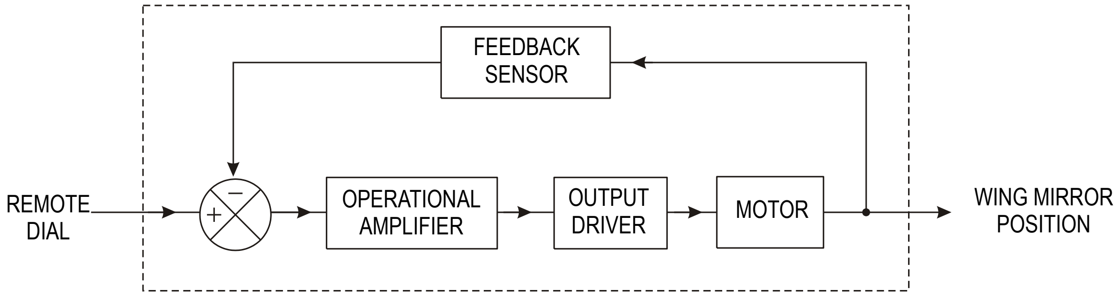
f) Draw a circuit diagram of the driver circuit.

Assignment 11

The figure illustrates a system for controlling the wing mirrors on a car by adjusting remote dials on the dash.



A control diagram of the system for rotational movement in the X-axis (one mirror) is shown in the figure below. Similar systems are used for the Y-axis and for the other mirror.



a) With reference to the control diagram, explain clearly how the system operates.

b) Name the type of control used in this system.

c) Name the configuration of op-amp required.

d) State two reasons why the op-amp cannot be used to drive the motor directly.

e) Name a suitable output driver which could be used with this system.

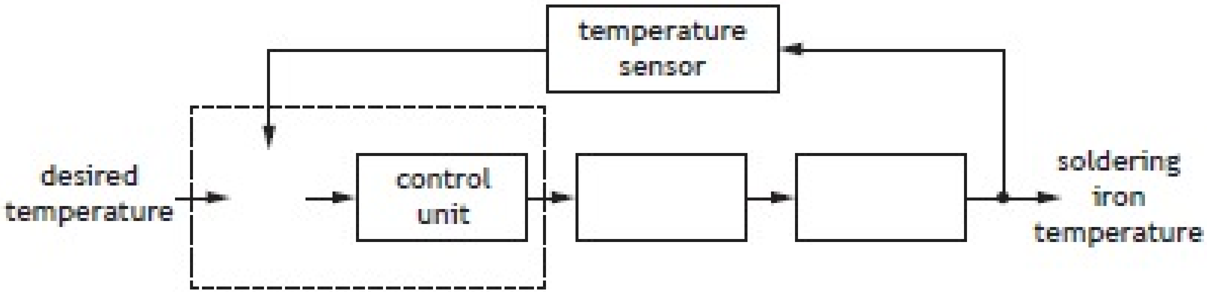
f) Draw a circuit diagram of the output driver.

2023 Past Paper

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



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 ____________________

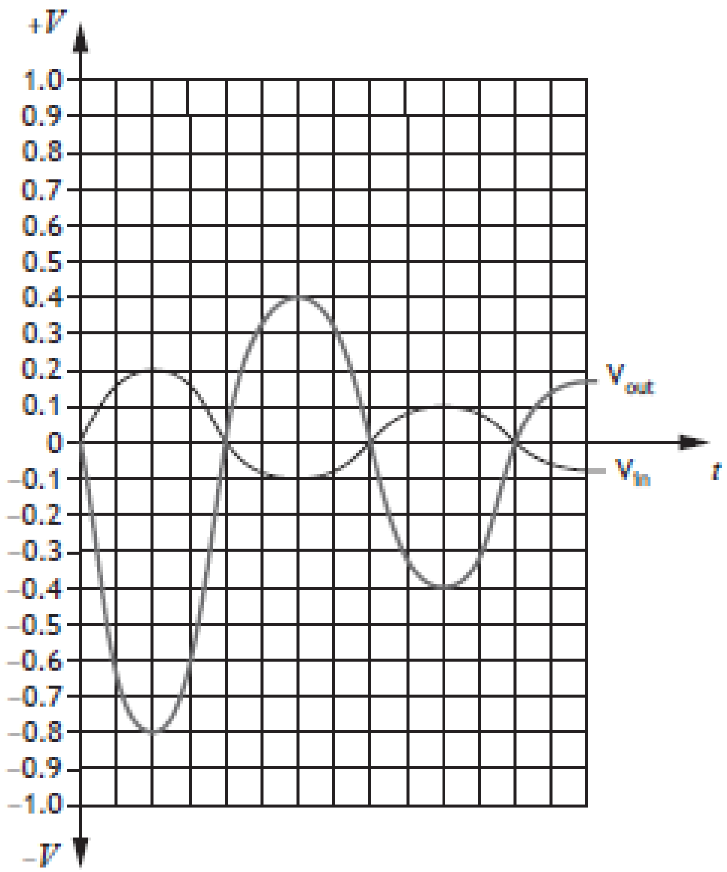
____

____

____

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.

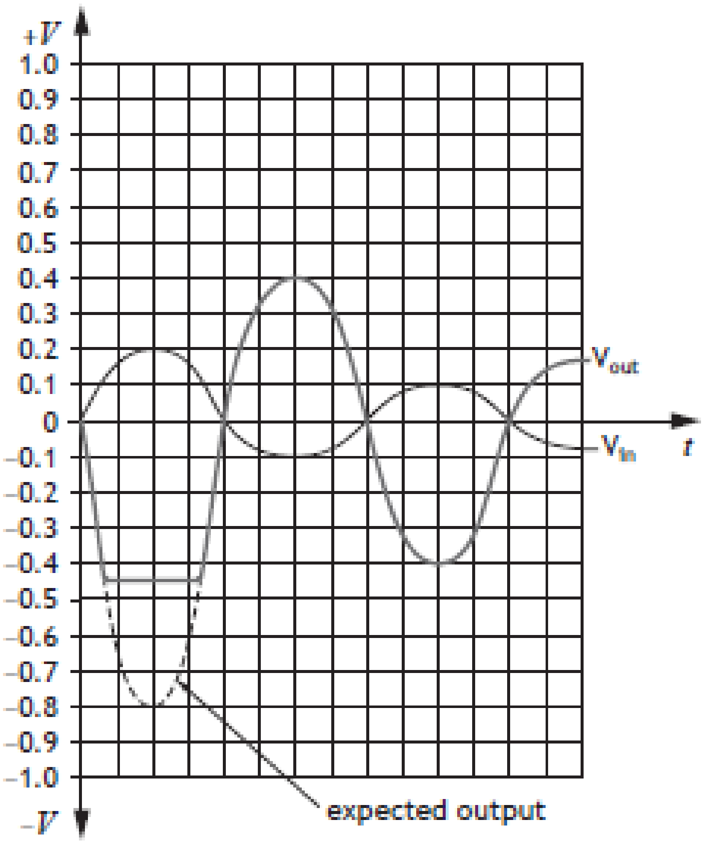


(e) State an op-amp configuration that will produce the desired output. **1**

____

9. (continued)

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



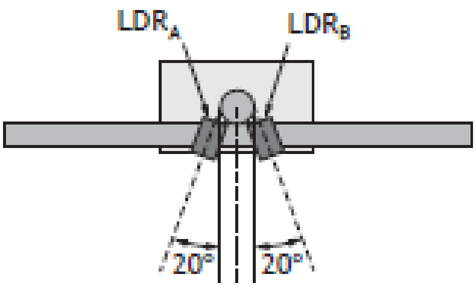
(g) State why the op-amp circuit produces the output shown. **1**

____

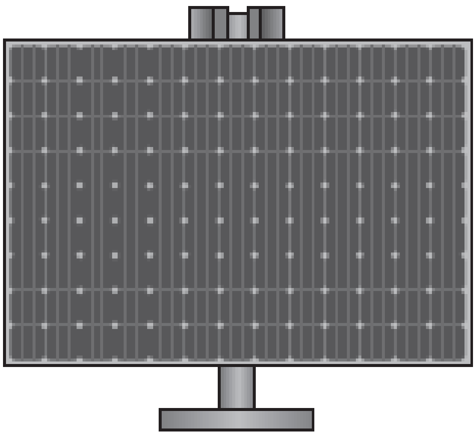
____

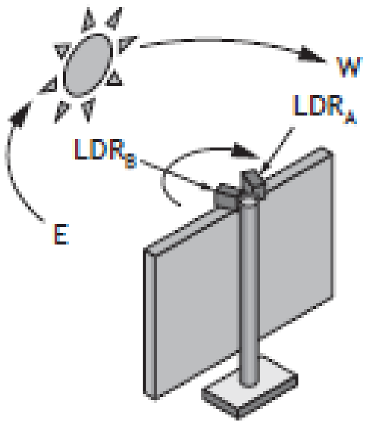
9. (continued)

While testing the circuit, V_A was found to be less than V_B and the motor rotated, moving the solar panel towards the sun's position.

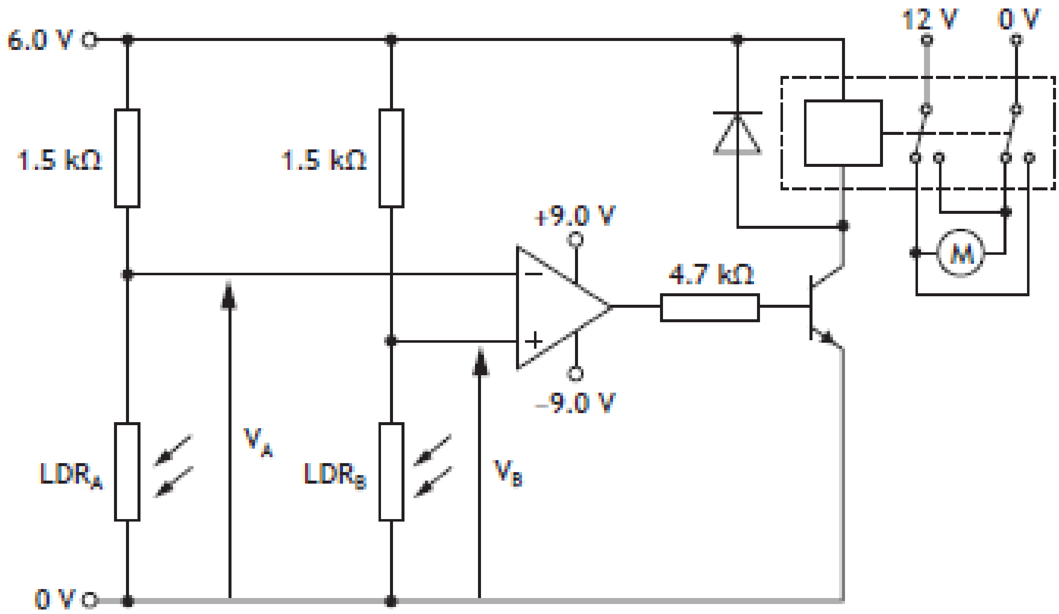


TOP VIEW





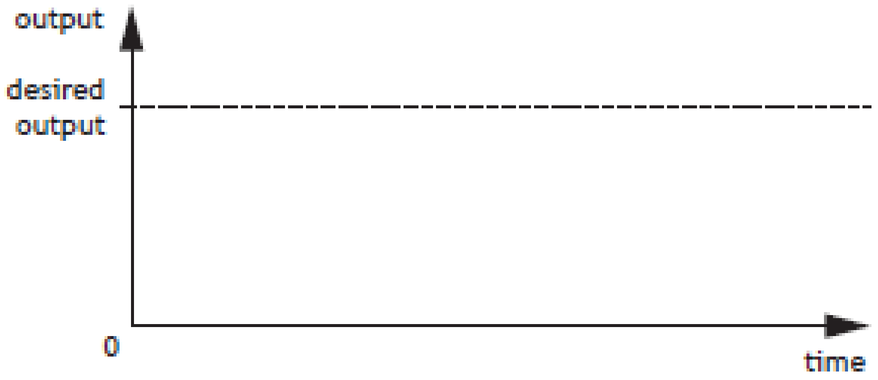
FRONT VIEW



9. (continued)

The op-amp control circuit uses two-state control.

(d) (i) Complete the graph below to show how the output of a two-state control system changes as it approaches the desired output. **2**



(ii) Describe the impact that this type of control would have on the mechanical output of the system. **1**

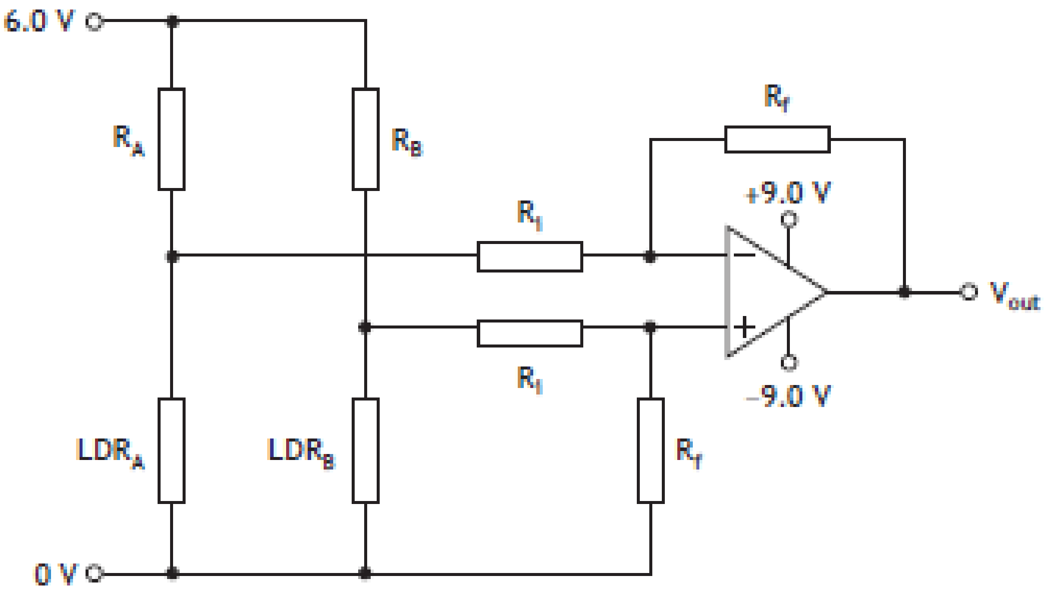
___

___

___

9. (continued)

An alternative control circuit is also tested.



(e) (i) State the type of control produced by this type of circuit. **1**

(ii) Describe the difference between the control produced by this circuit and a two-state control system. You can use diagrams or graphs to illustrate your answer. **3**