2017 S&C A2 Model solution

1.1. With reference to a product of your choice, explain how a manufacturer could use models and prototypes for:
• testing
• evaluation
• promotion *(16 marks)*

STRATEGY: *I noted the words 'product of your choice' straight away, so knew I'd need to give an example in each of these areas. There are 16 marks available, so I'm aiming to make about five different points in each of the three bullet point areas.*

A prototype of a product helps with testing as both destructive and non-destructive tests can be performed on a realistic mock-ups of the finished product, allowing for an accurate indication of how the finished product will perform under different conditions. A prototype will also bring together different sub-systems that will need to work together, such as an iPhone battery charging circuit and the main logic board.

Prototypes can also help establish the durability of the finished product. Dyson vacuum cleaners are repeatedly dragged roughly down flights of stairs to see how long they take to break, and things such as their power toggle bottoms pressed millions of times in testing rigs to see how long they will last.

To aid in evaluation, a physical model will enable clients and senior leaders in an organisation to experience the proposed final form and function of the product being designed. This can be used to test against the original design specification, to collect user feedback and where appropriate to evaluate the ergonomics of the product. The example of a food mixed would be to allow test users to experience changing attachments from whisk to beater to see how convenient and intuitive the process is.

Prototypes can be a useful way to introduce potential customers to the product as it approaches readiness to enter the marketplace. Manufacturers of cars can display a prototype at a trade show in order to drive interest and advance orders, for example. Photographs of prototypes can be used for TV, billboards or Social Media advertising to further generate interest.

1.2. With the aid of annotated sketches, describe in detail a suitable process for batch producing PCBs that allows the manufacturer to easily modify the design between batches. Your answer should explain how modifications are achieved.
Answers should reference a process that lends itself to batch production *(12 marks)*

STRATEGY: *This is a gift. Batch or one-off PCB production can be done in an etch tank as we do in school. Must make reference to how different batches could be produced in order to pick up all the marks. I'd definitely answer this question if at all possible in the exam.*

Once the circuit has been designed as PCB on a PC using specialist software, the artwork would be printed onto transparent paper. Should the design need modifying in future, the design could be changed on the PC and a new artwork created. To make a batch, several (usually rectangular) PCBs can be tessellated onto a sheet that matches the size of the photo-board that is available.

The artwork can be placed (inverted) onto the glass of a UV light box, and an appropriate piece of photo-board placed on top (protective plastic removed). This is them exposed to UV light for the time prescribed by the manufacturer (typically 3 mins).

The resulting PCB is then placed into the pre-heated developer tank for as long as is necessary (typically around 30s) to wash away the softened photo-resist layer. The board is then washed.

The board is then etched in pre-heated ferric Chloride while bubbles are passed through the solution until the unwanted copper is etched away (approx. 5 mins). The board is then rinsed in water and can then be drilled and sprayed with strip-resist to remove the remaining photoresist.

If desired, the PCB can be tinned to protect the copper tracks from oxidation.

2.3. Compare and contrast the use of **two** different methods of batch producing components using deformation/redistribution processes. *(16 marks)*

STRATEGY: *Must be two, must be batch-suitable. 16 marks up for grabs, so I'm looking for 8 marks worth per method. I know that deformation is hitting things to change their shape, like a blacksmith beating a horseshoe into shape in a forge. Redistribution is softening/liquefying a material and forming a new shape with it, such as vacuum forming, pewter/sand casting or injection/blow moulding. I could for something ambitious like sand casting, but I'm more inclined to stick in my comfort zone here…*

I will compare injection moulding and vacuum forming.

Injection moulding is the process by which thermoplastic material (e.g. ABS pellets) are drawn into a motorised Archimedean screw. The friction between the walls of the screw chamber, the screw and the pellets themselves causes them to heat up, supplemented by heating elements around the screw chamber, causing the pellets to liquefy. At the end of the screw, the molten plastic is forced under pressure into a two-part negative impression mould of the part that is to be created. Once filled with plastic, the mould is cooled and then the two parts separated. The part is then retrieved and the process can start again; this process is well suited to batch and continuous flow production.

Vacuum forming is the process of clamping then heating a sheet of thermoplastic material (HIPS, commonly) and then heating it until is softens. At this point, a mould is introduced from underneath and a vacuum pump is energised, drawing the plastic tightly around the mould. Once cooled, the part is removed and the mould can be re-used.

Setting up an injection moulding system is highly costly – in addition to the injection machine itself, each part that is to be designed requires its own mould which must be individually made from a suitable metal and must be precisely milled in order to ensure that mould halves fit together well.

A vacuum forming setup is far cheaper by contrast as it consists of fewer parts; essentially a heating element and a vacuum pump. Moulds can be made by hand from blocks of MDF or wood that can be formed using commonplace wastage methods, and sheet material such as HIPS is readily and cost-effectively available.

Once up and running, injection moulding is a faster method of producing parts; multiple toy soldiers can be made in a single mould and then snapped out by the consumer, for instance. Vacuum moulding necessitates heating each sheet of material individually and them applying the vacuum to the mould; still suitable for a batch setup, but not as quick.

Vacuum moulding provides a reasonably accurate finish in the completed product, but overall resolution of fine detail and edges can tend to be less well defined than in an injection moulding setup.

As briefly touched on above, vacuum forming provides greater flexibility to make changes than injection moulding, as it is possible to quickly make new moulds by hand. Injection moulding typically necessitates CNC milled moulds to be created which is considerably more time consuming.

3.4. Compare the suitability of open and closed loop control systems used in CNC machines. *(12 marks)*

STRATEGY: *We know which is which; need to compare them, so an example or two will be handy. Must be focussed on CNC machines and must comment on suitability.*

A closed loop system is one in which an output of the system feeds back into the system as an input. A simple example is an oven, where the heat output from the heating element is detected by a thermocouple inside the oven which is then able to regulate the temperature inside by toggling it on and off.

An open loop system is one in which there is no feedback from the system; a similar example would be a gas hob on a cooker.

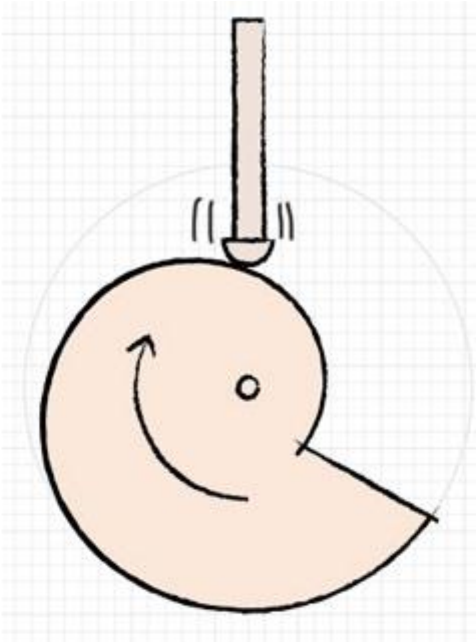
In a laser cutter, both closed and open loop systems are employed in different aspects of its operation. When the machine is initially powered on, the machine will have no idea of where the print head is located (as laser cutters are driven by stepper motors). To allow indexing to take place, both the X and Y axis stepper motors are driven in One Direction until the head comes into contact with microswitches mounted at fixed points at the end-of-travel for each axis. The motion output causes the microswitches to be actuated, providing the closed loop – the machine then has a known starting point to navigate the bed of the machine from.

In CNC milling machines, it is important that the tool on the machine is able to spin at a suitable speed in order to ensure that material is being completely cut away before the cutter moves on. To facilitate this, output shafts are commonly equipped with relative motion sensors (plastic disks with sections blacked out) and a photodiode/LDR + light source either side of it. As the cutter is constantly accelerating and decelerating, whenever the machine senses that its motors are falling behind where they should be, torque can be increased to catch back up the next time the motor has more force available than is required. As a result, accuracy is increased. Additionally, CNC machines (including the 3D printer) can sometimes lose their calibration (e.g. if a belt slips), causing the rest of the print to be offset from the part already printed. If 3D printers regularly re-homed themselves, this could be avoided (at the cost of slower prints).

A coordinate measuring machine (CMM) uses a stepper-driven probe that repeatedly extends until it touches the object being measured (closing a microswitch) before moving on to the next measurement (working in either two or three axes). The feedback from the switch is used by a computer to either build a 3D model of the part being analysed or to confirm that a manufactured part has been manufactured to the manufacturing tolerances dictated by the client’s specification. As these machines can be calibrated, the accuracy of these machines can be very high.

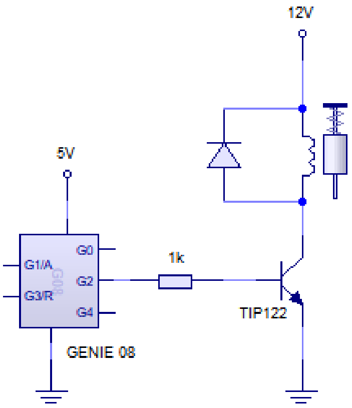
3.5. With the aid of annotated sketches and with reference to specific examples, describe in detail the operation and limitations of a system for each of the following situations.
- Conversion of clockwise rotary motion to reciprocating motion
- Amplification of voltage
- The output of a sequence of musical notes
- The conversion of an electrical input to a precise angular movement *(16 marks)*

STRATEGY: *Must include sketches, limitations AND specific examples. This is a nice question, as it breaks neatly into a series of 4-mark questions that can be tackled in a straightforward way with examples. If I was struggling to find a question to tackle, even if I wasn't sure about one of these (e.g. the musical notes), I could still bank on 12 marks out of 16 here.*



Rotary to reciprocating motion can be achieved through mechanisms such as a 'cam and follower' or a 'crank, link and slider'. The cam and follower allows an engineer to control the rate and frequency of rise, dwell and descent of the output motion by changing the shape of the cam. It overall vertical displacement can also be regulated by changing the difference between the closest point to the centre of rotation and the furthest. Cams and followers are commonly used in car engines, on the cam-shaft.

In the sketch to the right (known as a 'snail' or 'drop' cam), the output motion rises steadily, then drops suddenly. The limitation of this cam is that the motor must always drive clockwise to avoid binding on the drop of the cam. There is also friction developed between the cam and follower, which would necessitate lubrication or use of low-friction materials (e.g. self-lubricating nylon) to mitigate this effect.

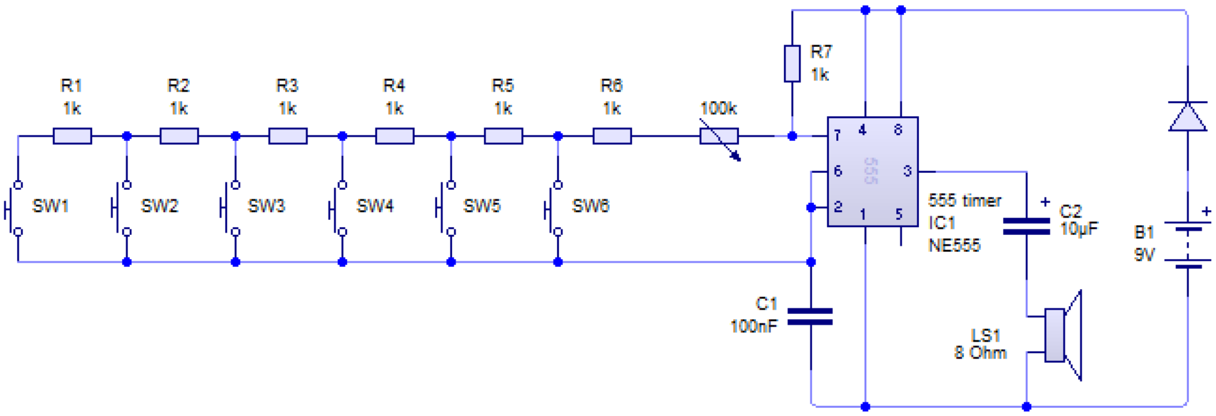


Voltage can be amplified through the use of an NPN transistor or a relay to switch a larger (or even AC) voltage current. This could be used to actuate a solenoid lock in a safe, for instance.

In the PIC controlled circuit to the left, the 12V solenoid cannot be driven by the ≈3.5V potential difference at the output pin on the PIC. A power transistor (a TIP122 Darlington Pair in this case). These are used with relays in home automation systems.

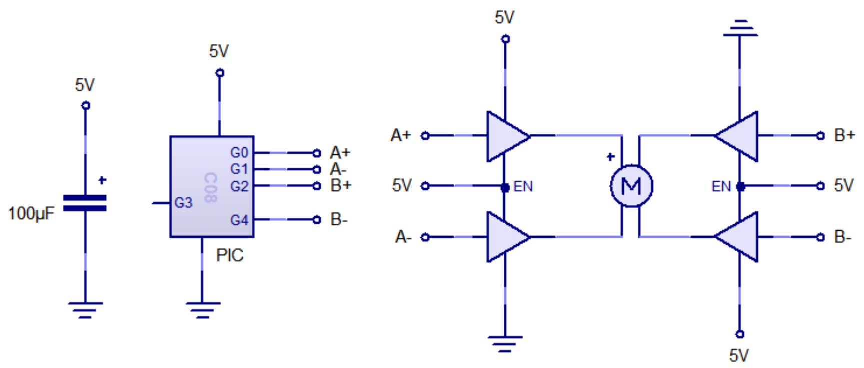
When the base/emitter voltage exceeds 0.7V, a high current is able to flow from the collector to the emitter, powering the solenoid with 11.3V (0.7V lost through the transistor) which is sufficient to drive the solenoid. The weakness here is that when the output is turned off and the solenoid returns to its original position, it will temporarily generate a back electro-motive force (back EMF) which can damage the transistor. This is addressed through the use of a flyback diode, which will soak up the back EMF, protecting the circuit. The other limitation of this approach is that the current to be drawn cannot exceed the maximum current rating of the transistor; this could be further increased through the use of a relay instead.

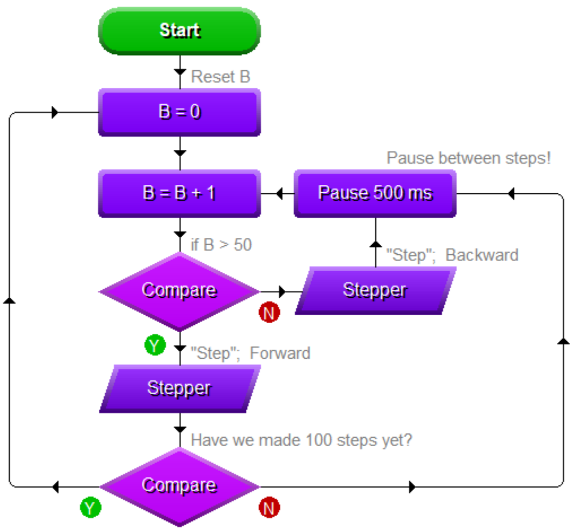
Generating musical notes requires the production of an output pulse of varying frequency. This could be achieved through creating a waveform between 400Hz and 20kHz, using either a PIC output pin set up for PWM (pulse-width modulation) or with a 555 timer configured for astable mode. This could be used as part of a children's musical toy.



In the circuit above, a series of potential dividers is created, depending on which PTM is pushed. The output pin (3) is low until a switch is closed, at which point the output oscillates between high and low until released. The pitch of the notes can be further tweaked by adjusting the 100k variable resistor. The limitation of this system is that the output is a square-wave which produces a less pleasing tone that an analogue sine-wave, and would require a separate circuit to be designed to achieve this affect.

An <u>electrical input can be converted into a precise angular movement</u> by the use of a bipolar stepper motor or a servo motor. These are commonly used in CNC machines such as a 3D printer.



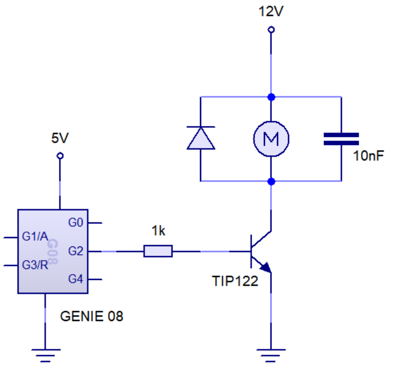


In the circuit above, a microcontroller is connected via four output pins to an H-bridge which amplifies the current available to the motor. By energising the two coils inside the stepper, a 1.8-degree rotation can be achieved at each step. The program (right) uses a variable to take 50x 1.8-degree steps over and over in each direction. A limitation of stepper motors is that as they work using a magnetic field, they tend to offer less torque that other motors. They also require 'ramping' in order to be able to achieve higher speeds, to ensure the output shaft has sufficient time to move into position after each step.

3.6. With reference to specific situations, compare the suitability of mechanical systems and electrical systems for reducing the speed of rotation of an electric motor's output. *(12 marks)*

STRATEGY: *Must talk about both electrical and mechanical. PWM vs gears/pulleys is the way to go here. I'll try to remember to use subject-specific vocabulary where possible.*

In a system such as a cooling fan for a laptop, one way of achieving a speed reduction is to employ Pulse Width Modulation (PWM); I could also use a stepper motor and programmatically change the delay between each step in the motor's excitation sequence via an H-bridge driver IC. Using PWM, variable speeds can be achieved by creating a simple PIC-powered control system programmed such as:




```
while True:
     output 2 high
     pause 10ms
     output 2 low
     pause 10ms
end while
```

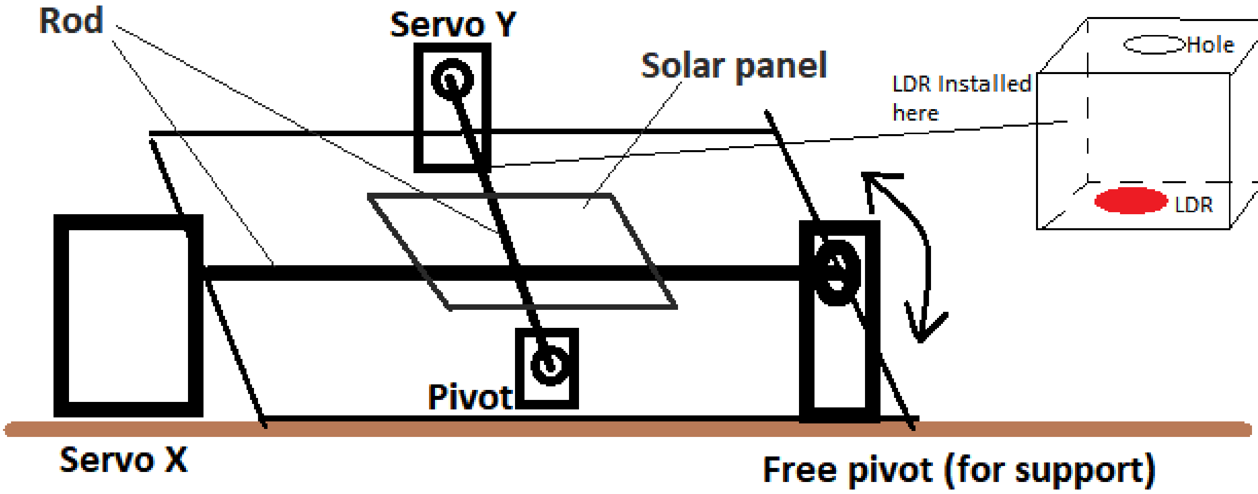
The program above will cause the motor to be rapidly toggled on and off, such that it is only running at a 50% duty cycle. As such, it will never be able to accelerate to its top speed. As long as the frequency is sufficiently fast, a human user of the system would be unable to sense the constant acceleration and deceleration cycles. This is particularly useful when a flexible range of speeds is desired, such as in the cooling scenario outlined above, allowing for the computer to run more quietly when not under load (especially as the motor does not need high torque to operate in this example). To accomplish other speeds, the 10ms delays in the example above could be replaced with two variables which can then be changed in code to change the mark/space ratio so that there is a lower 'high' time.

A mechanical way to achieve a speed reduction might be to use a chain-and-sprocket or a belt-and-pulley system. By changing the ratio between the driver and driven gear, different output speeds can be achieved; as this question is specifically about speed reduction, the number of teeth on the driven gear must always be larger. The advantage of this method of control is that the amount of torque delivered is inversely proportional to the speed reduction (i.e. halving the output speed doubles the torque) – this is not the case with PWM, as there is (in the example cited) half the amount of power being put into the system. As such, a system such as an electric bicycle would benefit from this type of drive system to help get up hills. On the other hand, having this system results in a fixed speed at each ratio, hence the reason that bicycles have multiple gears on the front and rear sprockets to provide different ratios depending on the rider's needs. The gearbox also requires additional parts, occupies extra space and increases the weight and cost of the product.

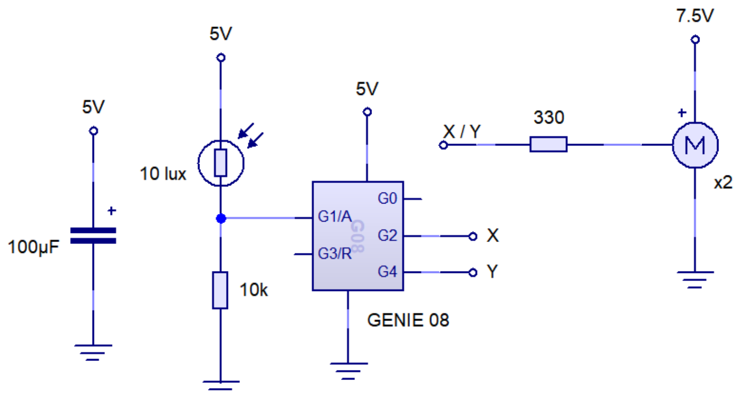
4.7. With the aid of annotated sketches, describe in detail a system that will track the sun's path across the sky and adjust a solar panel so it is always perpendicular to the rays from the sun. (16 marks)

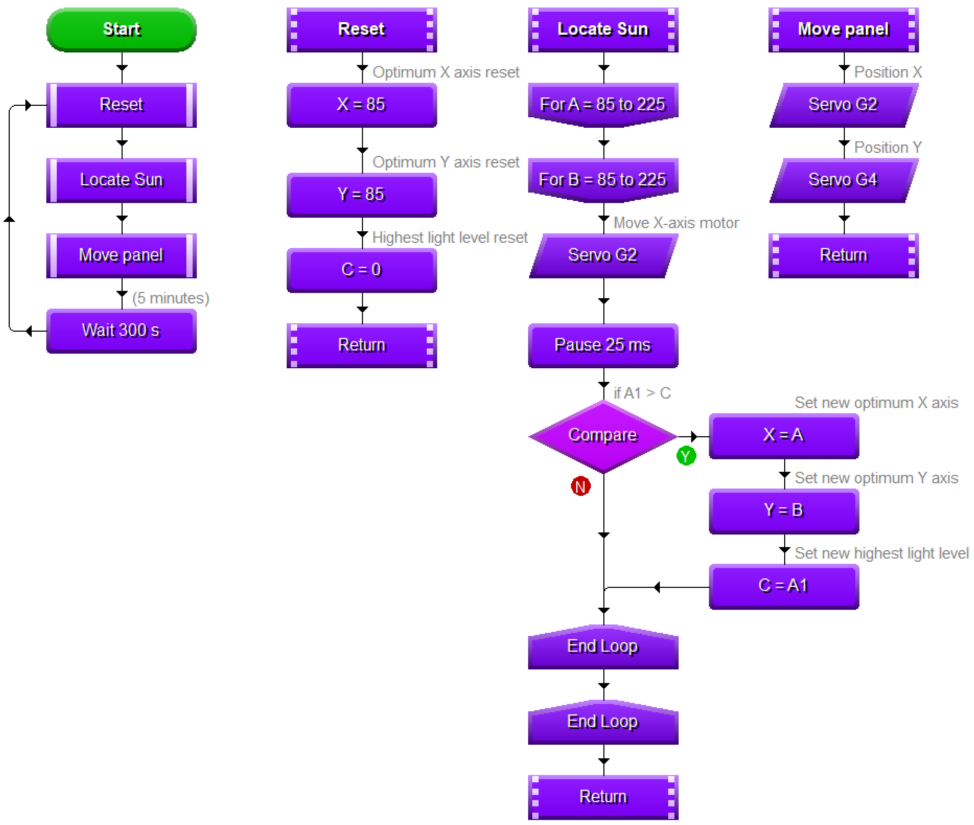
STRATEGY: *Tricky one, this. We know that the sun rises in the East and sets in the West, but depending on the time of year, its height in the sky is different. In order to track the sun, we'll need to be able to angle the solar panel in two different axes, and keep updating its position. As the easiest thing to measure from the sun will be light rather than heat, clearly an LDR that can be rotated around will be part of the solution. We know from experience that when they say 'a system', the examiner will want a circuit, program, sketch(es) and some discussion.*

To solve this problem, I'll create a platform that can rotate in the X and Y axis, using a pair of perpendicular servo motors controlled by a PIC chip. The sun-light will be sensed by an LDR mounted in a recessed box, so that the maximum number of photons will strike the LDR when it is directly facing the sun. The servo for the Y Axis is mounted on the platform that is rotated by the X servo. The sunlight sensor module will be mounted on the platform for servo Y.



The circuit is shown here. By connected the LDR up as part of a potential divider circuit, the different intensities of sunlight can be detected. While only one is shown, two servo motors will be connected up, wired in the same way (one on output 2, one on 4).





The program works in three stages. The code uses three variables: X, Y and C. C is the most light that the circuit has detected (0 initially). The idea is that the servos work together to sweep through the sky, taking a light-reading after each movement. Once done, whichever position provided the highest light reading is the one that the solar panel will be returned to. After 5 minutes, the process repeats. This way, the solar panel will follow the sun across the sky at all times of year.

4.8. Discuss why electrically powered public transport systems are best suited for areas with high population densities. *(12 marks)*

STRATEGY: *There's always a long-answer question available in the exam. This one is quite nice; the emphasis on high population density must come out in the answer; I'll try and give a few examples as I go along. With questions like these, keep coming back to the question as you write your answer. Are you answering the question on the page, or the question you wish they'd asked? It's very easy to creep off-topic.*

There are a number of different options for electric public transport in areas such as cities, such as over-ground/underground trains/trams that are powered from the National grid, and battery-powered vehicles such as electric busses.

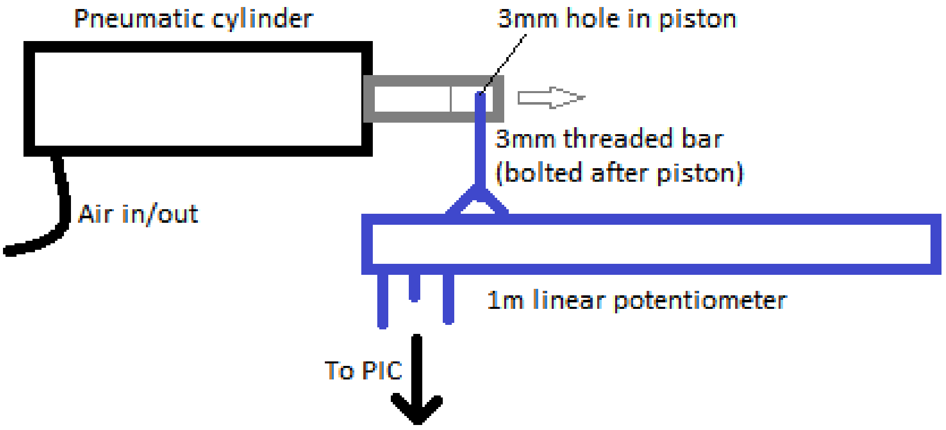
In order to create an intra-city electric tram network, considerable up-front cost is required: buying miles of land, laying tracks, up-grading power supplies, buying the trams, insurance and staff to drive/maintain/clean them. As such, this would only be an economically viable option in major population centres such as London or Edinburgh in order to ensure that there is sufficient use of the system to make it sustainable in the longer term. The use of electricity in this way means that there is no need to stop to re-fuel as would be the case with a diesel locomotive and servicing is more straightforward due to fewer parts involved in their design and construction. Electric trams also enjoy zero-emissions (at the point of delivery, at least – the power station they get their energy from will likely be burning coal), reducing air pollution in the city itself.

Electric vehicles such as taxis and busses have a lower range than traditional internal combustion engine vehicles, and will require convenient access to three-phase power in order to charge them overnight. They are also typically more expensive than an equivalent diesel model. Therefore, as in the last paragraph a high population density would ensure that they are able to be heavily used throughout each day for shorter runs between stops, improving their viability. They too have zero-emissions leading to better air quality within the city, although the manufacturing process for their batteries is uses a great deal of energy. By being battery-powered, busses and taxis enjoy the flexibility to drive anywhere as opposed to the dependence on rails that a tram/train system creates. Many cities have 'super-charger' points for rapid charging dotted around them in car parks and at different locations. A taxi-driver in a city will have more option as to where she might charge up as opposed to if she was operating in a rural area.

5.9. With the aid of annotated sketches, describe in detail a system for constantly monitoring the extension of a pneumatic cylinder and showing this on a 4 digit 7- segment display in mm.

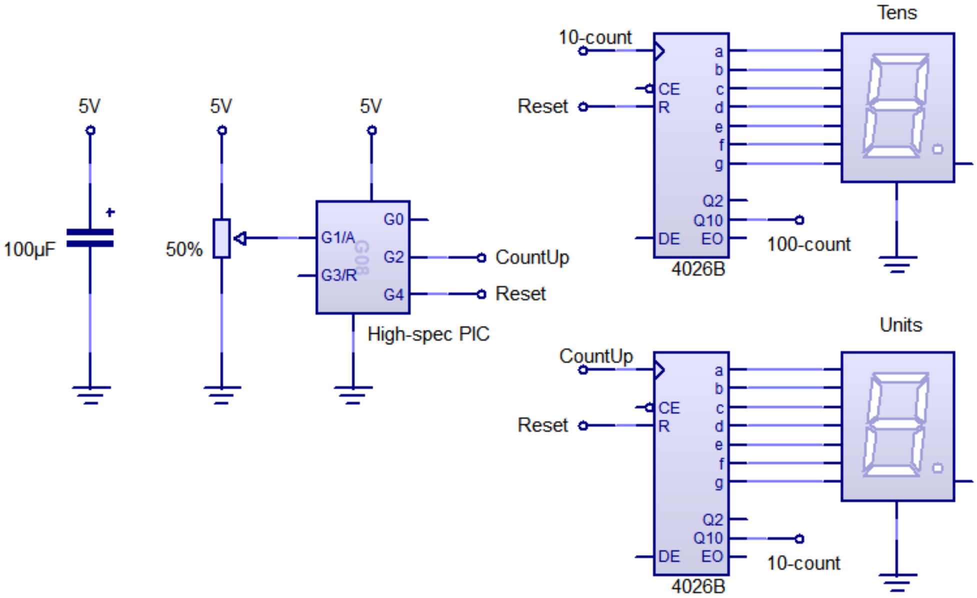
The maximum extension of the cylinder is 1000 mm and the system should have an accuracy of ±1 mm. *(16 marks)*

STRATEGY: *A pneumatic cylinder doesn't provide any feedback; we'll need to design something that can measure really accurately. When I first saw this, I struggled for ideas at first; an ultra-sonic distance sensor throws quite a wide sound-wave which I don't think would give reliable distances. A LIDAR module would probably do the job, too. In the end, I remembered that one can purchase rather big linear (as opposed to rotary like we most commonly use) potentiometers (I found a 1.2m one online with a quick search). After that, the rest of this problem is pretty straightforward. Must remember to comment on how I'm going to* *actually calibrate this to get the accuracy that's needed. One of the harder questions on the paper, this.*



I'll use a linear potentiometer to sense the motion. This can be bolted to the housing of this machinery that the cylinder is being attached to. The fully negative position of the piston is indicated with a thin grey line.

To connect the piston to the cylinder, a 3mm hole will be drilled through the centre of the piston near the end, and a short piece of M3 threaded bar will be pushed through it. A nyloc nut will be put over the end to stop it falling out. The other end of the bar will be bonded to the slider of the linear potentiometer. The method will depending on its form from the factory, but likely be able to create a bracket to allow the bar to either screw into position or be mechanically clamped for a secure fit (to ensure accuracy).

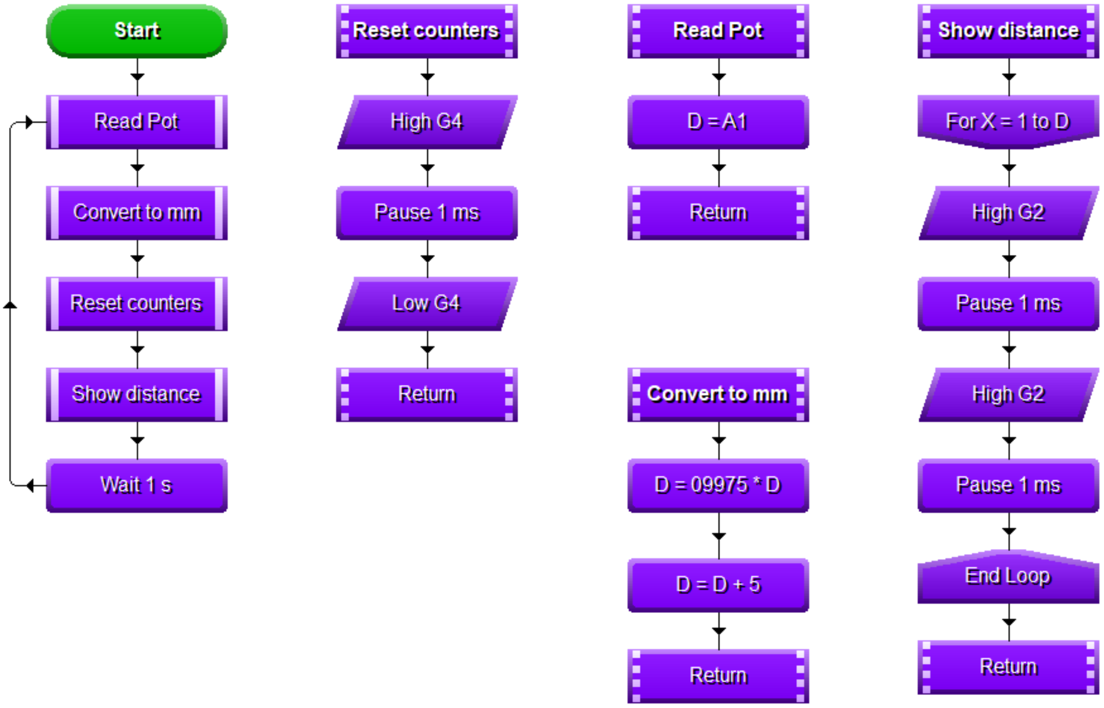


The circuit (above) has the potentiometer connected to an analogue input pin on a PIC. As I need 1000mm and +/- 1mm accuracy, a PIC with a 11-bit ADC (0-2047) would be needed at a minimum; 10-bit might not be accurate enough. I have used a series of 7-seg decoded decade counters (units and tens shown and labelled). By taking the 10-output from each digit and using it as the input to the next digit, I could show infinitely large values by chaining more and more ICs together (power supply permitting). I've tied all the reset pins together, so that they are all reset together.

For the program, I would need to first calibrate the circuit by looking at the value read by the PIC when the cylinder is fully negative and positive. For this example, I've assumed '5' when negative, and '2000' when fully positive. I then need to write my code to interpolate all in-between values. Where the potentiometer reading is '**D**', the distance in mm would be:

Distance = (((2000 – 5) / 2000) x **D**) + 5
= ((1995 / 2000) x **D**) + 5
= 0.9975**D** + 5

My program (below) would run the code using the given values. I've broken the code into subroutines to make each individual step more readable. It starts by reading the potentiometer, then converting the value into mm, resetting the 7-seg displays and finally pulsing the decade counter array **D** number of times to display the total. After 1s, the process repeats.

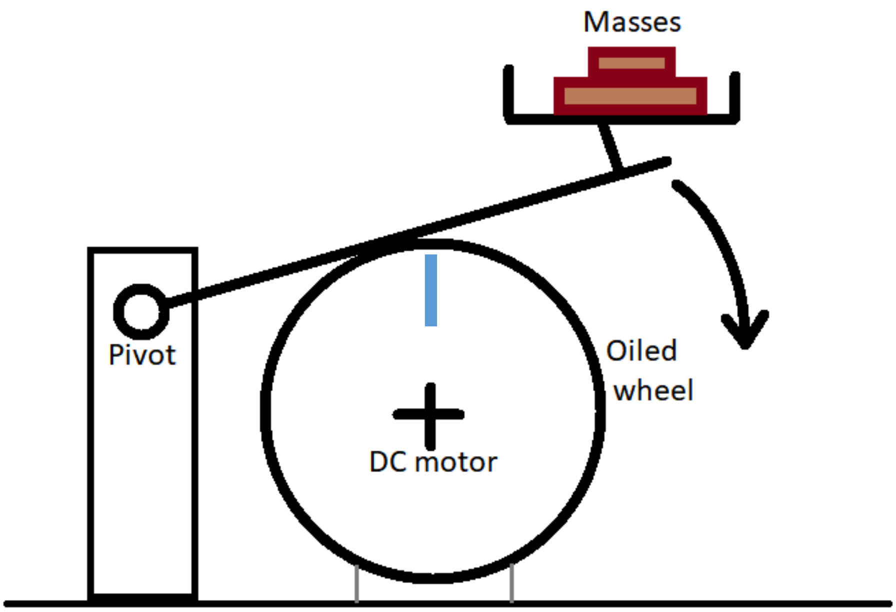


5.10. With the aid of annotated sketches, describe in detail a test that could be carried out to determine the effectiveness of different lubricants over extended periods of time.

Your answer should show the testing system, the data that would be recorded and how this would be used to determine effectiveness of each lubricant. *(12 marks)*

STRATEGY: *We could look at oil vs grease or different oils. Must cover an extended period, and all the different points in the second half of the question.*

I will test the effectiveness of several different brands of oil. In this example, I will test how long the oil is able to keep the motorised wheel turning for.



In the sketch below, a 20mm wide, 2mm thick mild steel bar lays on top of a 20mm wide, 1mm thick strip of mild steel which is wrapped around a motorised acrylic wheel. Oil is applied to the circumference of the wheel prior to the start of the experiment. Masses are applied at the start of the experiment such that the motor is able to turn the wheel at around 10rpm (the blue mark on the wheel can be used by the engineer with a stopwatch to calculate this). The same mass is then used for the other oils to be tested.

The setup is then left to run, and the output speed is checked every 30 minutes. These can be recorded in a table until the motor is no longer able to turn the wheel.

After the machine has been cleaned (and the motor replaced), the process can be repeated for each lubricant. The resulting speeds can be plotted onto a line graph (speed vs time) to demonstrate the characteristics of each lubricant.

6.11. With reference to a passenger lift, describe in detail the input, process and output requirements of the system in order to function reliably and safely.

Your answer to this question can be in the form of a diagram. *(16 marks)*

STRATEGY: *An interesting question. Got to make sure that I talk about input, process and output and keep on-task about safety/reliability. Worth remembering with everyday items that there are inputs/outputs that the user sees, and those that they don't. Both are important.*

In terms of **input** components, a lift has call buttons outside the lift to summon it, and more inside to identify the desired floor. In order to be safe, these should be made from either plastic or bonded to Earth if steel is used. For reliability, it is my experience that they are generally made from stainless steel –this is to provide protection from vandalism and to make them hard-wearing. The switches themselves will be specialised high-durability switches that are designed to receive rough treatment over a sustained period and to remain functional.

Inside the lift shaft, the doors will have sensors (microswitches, possibly) behind a rubber gator along the edge of the lift doors. If a passenger's limb is in the door as it is closing, the motor's direction can be quickly reversed for a few seconds to prevent injury. By protecting these behind a rubber seal, the life of the sensor can be extended.

Inside the lift shaft, input sensors (e.g. magnet and reed switch or LDR and light-beam) can be used to detect when a lift is approaching and has arrived at its target floor. By using a non-contact sensor, there will be increased working lift for the sensor and less chance of system failure. For increased safety, multiple sensors could be used at each floor, to avoid false-readings and to indicate when a part has failed.

For **processing**, a lift will be microcontroller-powered with a redundant failover control system in the event that an error occurs and a battery backup in case of a power cut. The microcontroller will likely generate log-files of its work (e.g. sensor readings, button presses, etc) which can be reviewed by a maintenance technician to help diagnose problems and anticipate any future maintenance work.

At the top of the lift, the motor system will need to be driven by specialised H-bridges (for reversible motion), capable of driving AC (almost certainly 3-phase) motors that draw large amounts of current. The drive circuit for the H-bridges will need to be able to detect when the lift is overloaded and not to move in these circumstances, so that it does not fail.

The programming should also feature appropriate time-delays between inputs being pushed and action (e.g. so that doors don't close as soon as a floor is selected).

The primary **output** from the system will be a high-torque electric motor moving the steel cable attached to the lift car (a smaller motor is used to operate the doors). In order to be able to safely operate, the motor should not have to deliver more than a certain percentage of its maximum power (e.g. 70%) at any time, so as to limit wear on the motor and to have additional power in reserve in case of an emergency situation (e.g. debris falling onto the top of the lift from above by accident).

The lift car itself will have an inertia-driven safety system, causing steel pawls to spring out into the ratchets that travel up the length of the lift shaft. If the cable breaks, these will arrest the fall and keep the passengers safe until they can be rescued (**Teacher Note:** You're not expected to know this. I only know because I saw it on TV).

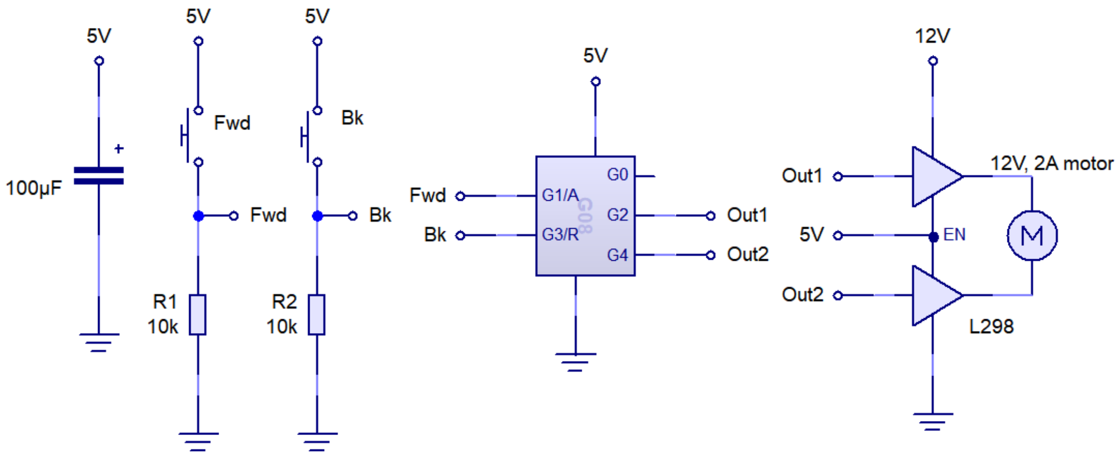
The lift car will have lights for the passengers' comfort and safety. In order to improve its reliability and ensure they do not fail in the event of a power cut (leading to panic), a battery backup will be attached to the car which will charge from the mains and activate automatically in the event of a power cut to keep the lights on.

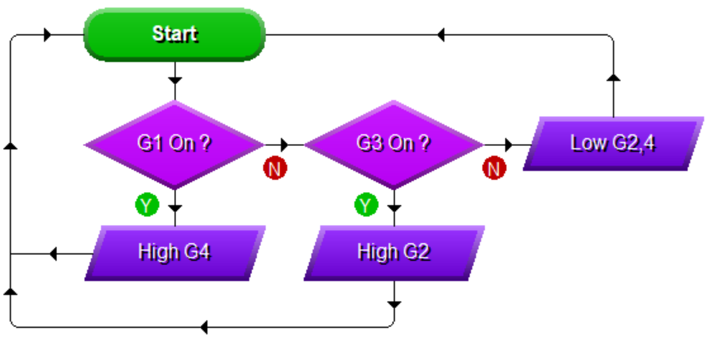
6.12. With the aid of annotated sketches, describe in detail how a 2 BIT, 5 Volt, 0.1 Amp output from a microcomputer can be used to produce each of the following outcomes.

- Switch a 12 volt, 2 Amp DC motor on or off and determine its direction of rotation
- Cause a double acting cylinder to extend, retract, or be motionless *(2 x 6 marks)*

STRATEGY: *The 2-bit part of the question will probably throw lots of candidates, but it really means having two different outputs. As long as you know a bit about pneumatics and half-H bridge drivers, this is an easy question to answer, as long as you were confident to do the other half (6.11) of the question. Incidentally, if you want to use relays to drive a DC motor, think about how you'll ensure that it can be turned off as well as thinking about the reversing side of things; a DPDT relay by itself will spin forever without a second relay to cut the power.*

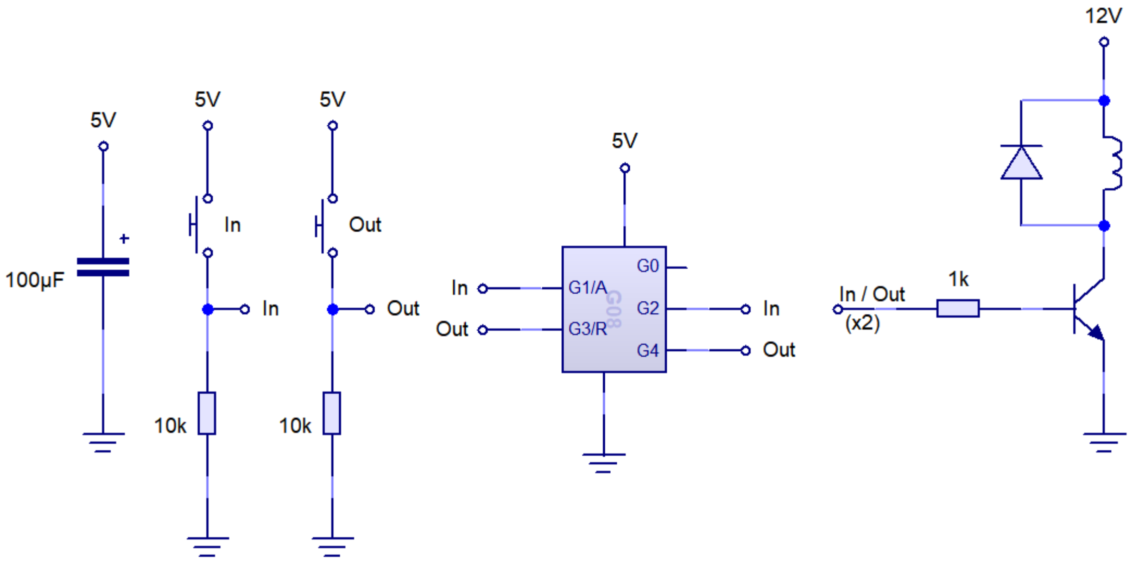
As this is quite a high current circuit, I'll use an L298 H-bridge to provide drive in both directions. While this is designed for stepper motors, its built-in flyback protection make it well suited for this purpose.



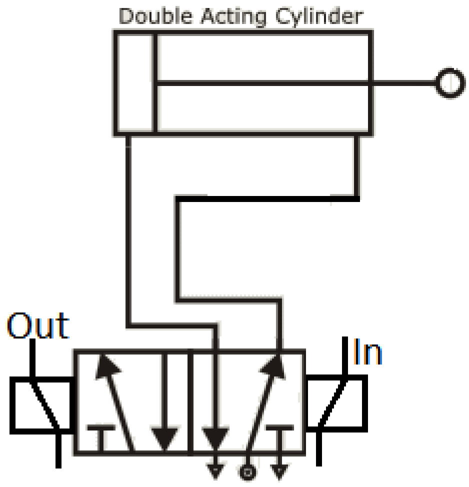


The program (left) polls each of the two PTM switches over and over, resulting in one of the three desired states: clockwise rotation, anti-clockwise rotation or 'off'. Because the program sits inside an infinite loop, the switches can be used over and over in any combination.

To create the pneumatic behaviour described, I'd use a very similar circuit to control a pair of solenoid valves in a double-acting cylinder. In the circuit diagram below (second solenoid labelled, but not drawn), a power transistor (e.g. TIP122) is used to drive the solenoid, and is protected by a flyback diode. The program would be identical to the one above, which provides all the desired behaviour (when both solenoids are off, neither the valve or cylinder has a spring return so the piston will remain static once fully positive/negative).



My pneumatic circuit is shown to the right. When the circuits are first powered up, nothing will happen. Once the ‘Out’ PTM switch is momentarily pushed, this will cause the 5/2 valve to change state, sending work air into the back of the cylinder which will make the piston go positive. Once fully extended, nothing further will happen until the ‘In’ PTM switch is energised, at which time the valve will return to its original state, causing work air to drive the piston back to its negative position.



END OF TEST