



**T Level Technical Qualification in
Design and Development for
Engineering and Manufacturing
(8714-32)**

**Occupational Specialism in
Electrical and Electronic
Engineering (322)**

**Guide Standard Exemplification
Material
Distinction**

Version and date	Change detail	Section
1.1 January 2023	Formatting of Task 1 evidence requirements	Task 1
1.2 March 2026	Minor Amendment to first paragraph	Introduction

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Introduction

The Guide Standard Exemplification Material within this document refers to the T Level Technical Qualification in Design and Development for Engineering and Manufacturing - Occupational Specialism in Electrical and Electronic Engineering sample assignment. The aim of these materials is to provide centres with examples of knowledge, skills and understanding that attest to distinction competence. In this document all exemplar evidence attests as examples of performance at the distinction grade boundary. The examples provided do not reflect all evidence from the sample assignment as the focus of this material is the quality and standards that need to be achieved rather than the volume of exemplar evidence provided. However, the examples provided are representative of all tasks in the sample assignment. The evidence presented here has been developed to reflect a distinction grade within each task but is not necessarily intended to reflect the work of a single candidate. It is important to note that in live assessments a candidate's performance is very likely to exhibit a spikey profile and standard of performance will vary across tasks. A distinction grade will be based on a synoptic mark across all tasks.

The materials in this Guide Standard Exemplification Material (GSEM) are separated into three sections as described below. Materials are presented against a number of tasks from the assignment.

Task

This section details the tasks that the candidate has been asked to carry out, what needs to be submitted for marking and any additional evidence required including any photographic evidence. Also referenced in this section are the assessment themes the candidates will be marked against when completing the tasks within it. In addition, candidate evidence that has been included or not been included in this GSEM has been identified within this section.

In this GSEM there is candidate evidence from:

Task 1

Task 2

Task 3

Task 4

Candidate evidence

This section includes exemplars of candidate work, photographs of the work in production (or completed) and practical observation records of the assessment completed by centre assessors. This will be exemplar evidence that was captured as part of the assessment and then internally marked by the centre assessor.

Commentary

This section includes detailed comments to demonstrate how the candidate evidence attests to the standard of distinction competence by directly correlating to the grade descriptors for this occupational area. Centres can compare the evidence against the performance indicators in the marking grid descriptors within the assessor packs, to provide guidance on the standard of knowledge, skills and understanding that need to be met for distinction competence.

It is important to note that the commentary section is not part of the evidence or assessment but are evaluative statements on how and why that piece of evidence meets a particular standard.

Grade descriptors

To achieve a distinction, a candidate will typically be able to:

Demonstrate a comprehensive use of software/ technologies to model, evaluate and produce electrical and electronic engineering diagrams and simulations that meets the requirements of the brief.

Demonstrate excellent technical skills when developing models and prototypes, resulting in a model that is fully functional.

Apply comprehensive knowledge and understanding of testing processes, resulting in a model that has been tested against all of the design criteria.

Critically interpret information to plan, assess risk, follow safe working practices and apply the technical skills to practical tasks and procedures to an exemplary standard in response to the requirements of the brief, producing an excellent quality of work.

Apply comprehensive knowledge and understanding of the design principles required for electrical and electronic engineering resulting in proposals and solutions that meet all requirements of the brief.

Work safely and make well founded and informed decisions on the selection and appropriate use of tools, materials and equipment within the environments that they are working in, resulting in tasks that are carried out to a high degree of accuracy.

Use accurate industry and technical terminology consistently in both written and verbal contexts.

Task 1 – Design

(Assessment themes: Health and safety, Design and planning, Manufacturing, Reports)

For task 1, candidates need to produce the following pieces of evidence:

- a) design specification
- b)
 - i) design calculations, including all workings
 - ii) justifications of design options for the sensors
 - iii) circuit diagram and wiring diagram
 - iv) PCB layout
- c) outcomes of the virtual modelling of the proposed circuit design, either as screen captures or printouts
- d) records of the results of testing the physical model of the circuit
- e) bill of materials.

For Task 1, the following additional evidence may also be submitted:

- any notes produced of research undertaken including citation of sources and internet search history.

1a) Design specification

Candidate evidence

Purpose:

This design specification has been developed in order to support the development of a circuit to be used in a conveyor belt system in a despatch area. The organisation needs to be able to use the conveyor to accurately identify boxes in order to distribute them correctly. If the mechanics of the conveyor are unable to differentiate between different boxes, then there is a risk to the organisation of boxes being sent to different locations. If this were to happen, this could potentially cause major issues for the organisation for a range of reasons, such as being able to track the boxes or meet their timeframes for delivery and may impact upon their reputation. For this reason, I need to consider the design requirements and parameters carefully when developing the design.

Design requirements:

The following key design criteria have been provided in relation to the requirements of the conveyor and are paramount to its development. I will pay close attention to each of these requirements in the design.

- To detect if a box travelling along the conveyor is less than 200 mm high (+/-10%) and 300 mm long (+/-10%). If it is larger than these sizes, it must be directed down chute B, otherwise it must be directed down chute A. If it exceeds EITHER of the sizes it should be directed down chute B.
- The chute servos should be sufficiently powerful to be able to move a box weighing 2 Kilograms.
- Start and Stop controls are needed to operate the conveyor. I know that there would also be a requirement for an Emergency Stop (E-Stop) as this is a requirement reflected under The Supply of Machinery (Safety) Regulations 2008 Clause 1.2.4
- To detect when a box reaches the holding area.
- A visual indicator (light) to indicate when a product should be directed down chute A.
- A visual indicator (light) to indicate when a product should be directed down chute B.
- A visual indicator (light) and audible output to indicate when a product is in the holding area.
- The standard box width is 250 mm.

Development/work considerations:

As part of the development of the circuitry, I will be required to develop a physical model of the circuit before I progress to manufacturer and test the actual model. For these activities, there is a fundamental requirement that I work safely and ensure the safety of others when using equipment and live energy. The following considerations will be made at all times during the development of the design:

- adherence to all workplace and industry regulations with regards to equipment, circuitry and the workplace, for example meeting the Health and Safety at Work Act and following Institution of Engineering and Technology wiring regulations
- undertaking safety checks, and risk assessments before starting any work. Where any risks or hazards are identified, I will ensure appropriate controls are in place before starting work.

The design:

There are a range of areas I must look at in order to develop the design and reflect the design criteria.

Detection methods:

The fundamental principal of the circuit is the need for an appropriate detection method in order to distinguish between boxes of different sizes travelling on the conveyor. There are three principal methods that could plausibly be considered to use for detecting a box:

- 1) **A physical roller type switch which is pressed by a box as it travels along the conveyor.** This could be located either at the side of the conveyor or as part of the conveyor bed. However, the switch does exert a small force on the box, which may push a lighter package away from the switch, thus detection may not be reliable. Also, very small packages that are a little irregular e.g. a jiffy bag, may not be detected at all.
- 2) **Ultrasonic detection.** These can be used to measure distances or used simply as a detector. For measurement, humidity and air temperature can significantly affect their performance, and consistent accuracy may be difficult. Allowing a box to either break an ultrasonic beam, or reflect it back, would allow simple detection without the measurement inaccuracies.
- 3) **An infrared light beam detector.** This is whereby a box interrupts a beam of light which is shone across the conveyor. Ambient light can be a factor, so modulating the beam with a signal usually overcomes this. The infrared beam method is commonly used in many industries involving conveyors as a non-contact means of detection. It has shown to be reliable, and versatile.

The infrared light beam detection method will be used in this project. This reflects that it provides the most effective option to support the design, offering the best detection solution. The infrared beam may need a modulation signal to avoid ambient light issues - a simple square wave would suffice.

Differentiating boxes of different sizes:

In order to differentiate between boxes of different sizes, which is a key requirement of the design, I need to consider the length and height of the potential different boxes that would be placed on the conveyor.

Length measurement:

The actual length of the box is not needed, it is only necessary to determine if the box is larger than 300 mm. The box is assumed to travel at a constant speed along the conveyor, however many conveyor systems use a belt drive system which can and does slip slightly according to the loads on the conveyor, so the actual speed may vary slightly. The tolerance required is +/-10%. Standard electronic timing circuits such as a 555 timer is not sufficiently accurate or stable enough for this level of accuracy, due to component tolerance. Resistors are generally +/- 5%, but timing capacitors can be +/-20%, so using this type of circuit could result in outputs that are outside of tolerance.

In order to measure the length to this precision, two sensors could be mounted along the conveyor separated by a distance of 300 mm. In principle if a box is smaller than this only one sensor at a time would be activated, if 300 mm or larger, then both sensors would be activated simultaneously.

Two sensors will be used for length measurement. These should be positioned 300mm apart just above the conveyor bed.

Height measurement:

As with the length measurement, an exact height is not needed, it is only necessary to determine if the box has a height of less than 200 mm. Thus, a single sensor mounted 200 mm above the conveyor bed would be sufficient.

Other key criteria:

The following additional specification criteria need to be considered in order to meet the requirements of the design criteria.

Holding area:

It is only necessary to detect when a box enters the holding area, so a single sensor mounted just above the conveyor bed would be sufficient. A reset button is also required once the holding area has been cleared.

Indicators and warning devices:

It is a requirement that indicator lamps show when the two chutes are operated, and when a box enters the holding area. It would also be useful to have an indicator lamp to show if the conveyor should be running or not, thus 4 indicator lamps are needed. These can be LEDs.

A warning buzzer is also needed for the holding area. For this project to demonstrate the principle, a small low voltage low power device will be used, although a more powerful one could be connected, and the facility to do this will be incorporated into the design.

Servos:

Large industrial servos are expensive, a 9-watt 6-volt servo from RS components (RS part no. 184-6932) costs over £100, so a smaller servo will be used in this project. A small 4.8 V servo from Rapid Electronics (part no. 37-1330, £4.79) is typical of small servos used in radio-controlled models. The technical details however do not indicate how much power is drawn, but it is not likely to be near the 9 W of the RS servo. It would be reasonable to assume that no more than 0.5 A (2.4 watts) would be drawn, given the relative size of the servo.

Pulse Width Modulation is needed to drive servos. Regular pulses every 20 ms (approx.) are needed, with the width of the pulse being between 1 ms and 2 ms for minimum and maximum movement.

Start and Stop Controls:

A button to start the conveyor, and a button to stop the conveyor are needed. An Emergency Stop button is also required under The Supply of Machinery (Safety) Regulations 2008. A safety relay should also be used to ensure that no loss of safety function can occur. A safety relay monitors the condition of the switches to ensure contact wear or contact weld does not compromise the safety of the machine due to button failure. However, for this assignment a safety relay will not be included due to the time factor as one is not readily available at my workshop. Further, safety for this situation will not be compromised, as a physical conveyor system is not available and therefore does not pose a physical risk. An LED will be used to indicate if the conveyor motor would be running or not.

Thus, the inputs and outputs so far are:

Start Button (input)

Stop Button (input)

Emergency Stop button (input)

Holding area reset button (input)

4 off infrared beam detection sensors (inputs).

1 off infrared modulation signal (output)

2 off LED indicators to indicate servo operation (outputs).

1 off LED indicators to signal the holding area needs attention (output).

1 off Buzzer to signal the holding area needs attention (output).

2 off Servo PWM signals (outputs).

1 off Conveyor Motor (LED for this project).

Overall, 8 inputs and 8 outputs are required.

Commentary

The candidate has produced a detailed design specification which fully reflects the brief and builds upon the initial design criteria. Each design consideration has been clearly broken down and explained in technical detail. The candidate has demonstrated that they have considered a range of options for their design solution. For example, considering the different detection methods that could be used, with a detailed justification provided for the use of an infra-red light beam detector over other options.

The candidate has fully considered the tolerances required and has used the tolerance requirements to justify the type of circuitry to be used, and to discount the use of some other hardware options, such as 555 timers and RC networks.

A number of additional relevant requirements have also been identified and discussed, showing a thorough understanding of the wider considerations of the brief. For example, considering the potential for adding circuitry to enable the use of a higher voltage power supply if the standard low voltage supply is not available.

Candidate evidence

1b i) Design calculations

A tolerance of +/- 10% is required for the height (200 mm) and length (300 mm) of the boxes.

For height:

$$\text{Maximum possible value} = 200 + (200 \times 0.1) = 220 \text{ mm}$$

$$\text{Minimum possible value} = 200 - (200 \times 0.1) = 180 \text{ mm}$$

For length:

$$\text{Maximum possible value} = 300 + (300 \times 0.1) = 330 \text{ mm}$$

$$\text{Minimum possible value} = 300 - (300 \times 0.1) = 270 \text{ mm}$$

Calculations for protective resistors for LEDs:

The LEDs are nominally 2V devices with a current draw of around 10-20 mA. Thus, a series resistor is required. This voltage drop must be taken account of when calculating the value of the resistor.

$(5-2)/10 \text{ mA} = 300 \text{ ohms}$. A 330 ohm resistor is typically used to prevent long term damage to the LED.

Using Ohm's Law – $V = I \times R$, so $R = V / I$

At 20 mA

$$R = (5-2) \text{ V} / 20 \text{ mA}$$

$$R = 3 / 0.02$$

$$R = 150 \Omega$$

At 10 mA:

$$R = (5-2) \text{ V} / 10 \text{ mA}$$

$$R = 3 / 0.01$$

$$R = 300 \Omega$$

As too small a resistor value could cause the LED to be damaged or destroyed, I will assume a maximum current draw of 20 mA. The closest actual resistor value to 300 Ω is 330 Ω , so I will use this value to protect each of the three LEDs used in the system.

Servo motor output power:

The servo motors to be used are rated at 4.8 V as explained in the specification. They each draw a current of 0.5 A. So, output power is found using Watt's Law:

$$P = I \times V$$

$$P = 0.5 \text{ A} \times 4.8 \text{ V} = 2.4 \text{ W}$$

1b ii) Justifications of design options for the sensors

Configuration of circuitry

Control System.

There are three principal methods of control that could be used:

- 1) Discrete Electronics, using logic gates and transistors. This is likely to get fairly complex, and if any flaws or errors are made in the design or construction of the system these could be very difficult to find and correct. However, no programming is required.
- 2) Microcontroller based system. The electronic interfacing should be relatively straightforward, with the complex details being taken care of in software.
- 3) PLC control. This would be the easiest, although more expensive route. Further, there is a requirement for the assessment to produce a printed circuit board. Which would not be necessary with a PLC as the inputs and outputs would simply connect directly to it.

A microcontroller-based system will be used, as the discrete electronics route is likely to become unwieldy very quickly. Further, any logical or sequencing issues are much easier to address in software than in hardware.

The Microchip PIC range of microcontrollers are straightforward to use, and the development / programming software is readily obtainable from Microchip's website. My workshop has the facilities set up to use these microcontrollers.

There was availability of PIC16F18877 chips, which have 35 input / output pins available. Only 16 I/O are needed for this work, but the chip has some extra facilities such as PWM control, Analogue to Digital conversion, Comparator and Logic Cell functions, some of which are very likely to be useful.

Potentially, the most complex part is the input detection of a modulated light beam. It was decided to use Infrared LEDs and phototransistors as these are readily available, have a fast response time (Some LDRs would struggle at this frequency), and ambient light is less of a problem.

The carrier can be generated using a PWM module on the microcontroller. This frequency can easily be changed in software if needed. However, the photodiode detectors may only give a small signal from the received beam and may not be enough to directly drive a logic input. The microcontroller has analogue inputs, but the on-board ADC has a maximum sampling rate of about 70 KHz, which would not be fast enough to sample 4 channels, as 40 KHz sampling rate per channel would be needed. There are also two comparator inputs, which could be potentially utilised, as well as a 5 bit Digital to Analogue Converter, which could provide a programmable reference voltage for detection the switching threshold voltage. However, there are 4 detector inputs and only 2 comparators, so at least two external comparators are needed, unless multiplexing is involved. However, that may then also complicate the software design later on, in order to separate out the signals again.

It is therefore easier to use external comparators but use the DAC as a programmable reference. In order to maintain consistency across the detectors, all four will use an external comparator.

After the comparator stage, the detected signal is still potentially a square wave, and needs to be processed into a 'carrier detected' or 'carrier not detected' signal. If the comparator signal is fed into the Data input of a D-type flip-flop, and the original carrier signal fed into the Clock input, with the D-type configured for a falling clock edge, then a 'broken' beam would give a logic '0' output and an unbroken one a logic '1' output.

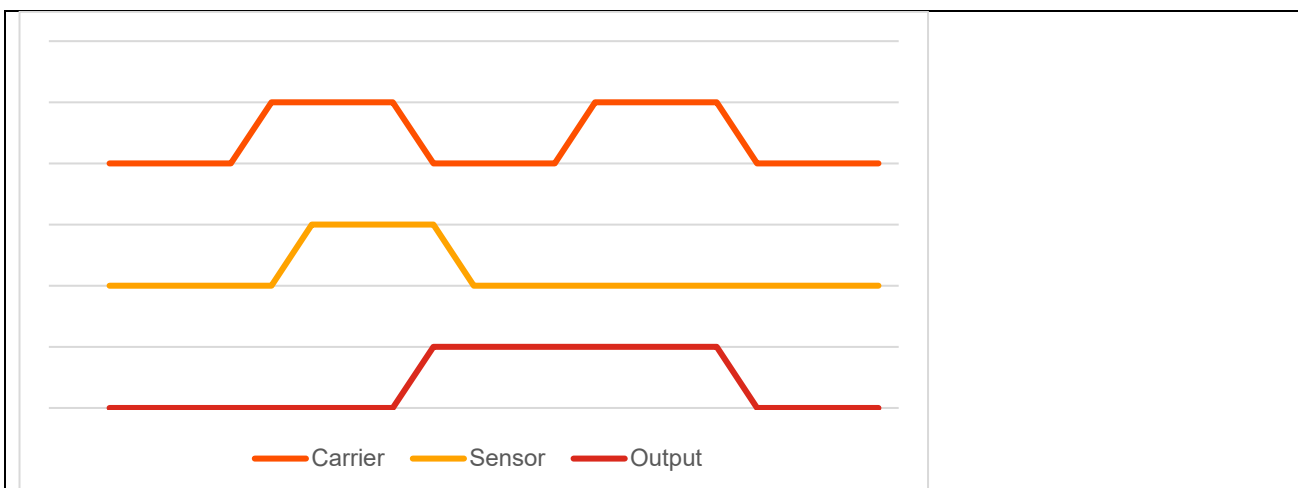


Figure 1. Timing diagram showing carrier detection / absence of carrier using a D-type flipflop.

The microcontroller has 4 Configurable Logic Cell (CLC) units so the output from each comparator could be fed into a CLC. The CLC can perform the D-type function and pass that output along to a timer / counter within the micro, for length measurement.

For an unmodulated system, the 4K Hz PWM and CLCs would not be needed, the comparator outputs would link directly to the timers and software logic.

The PWM outputs for the servos (and 4KHz carrier) have some limitations on which pins they can be used on. The PIC micro has five I/O ports, marked with the letters A to E. Ports A to D have 8 I/O, Port E has only 3. Only Port A can support 3 PWM outputs, Ports C to E can only support one PWM output per port. Further, 2 pins on Port B are dedicated to downloading programs to the chip. These pins CAN be used as I/O but only if the programmer is disconnected after download, which would be inconvenient during software development. The inputs to the CLCs are also limited, primarily to ports B and C.

The 4 buttons and 4 LEDs / Conveyor Motor can be used on any I/O pin.

Thus, the I/O pin allocation will be:

Function	PORT A	PORT B	PORT C	PORT D	PORT E
DAC output	RA2				
4KHz PWM Carrier Signal	RA3				
PWM Servo 1	RA4				
PWM Servo 2	RA5				
Reserved for Programmer		RB6, RB7			
External Comparators		First Sensor RB0 Second Sensor RB1	Height Sensor RC7 Holding Sensor RC6		
Buttons			Start RC0 Stop RC1 E-Stop RC2 Holding area Reset RC3		
LEDs / Motor				RD0 Chute A LED RD1 Chute B LED RD2 Holding area LED	RE0 Holding area Buzzer RE1 Conveyor Motor

It is normal practice to use pull-up resistors on microcontroller inputs, and have the input switch to ground, or logic '0'. This is due to improved noise immunity and reliability in industrial control systems. 10 K ohm resistors are normally used with a PIC micro.

The current output of the PIC micro is limited to 20 mA per pin, which is fine for driving an LED, but not for motors and buzzers, therefore external switching transistors will be needed for those. Further, most PWM motors need more than the 5 V supply a PIC micro requires, so Open Collector transistors will be needed for those outputs. A ULN 2803A chip contains eight 500 mA 30 V rated transistors, so these will be used. The conveyor motor in a real system would likely be a 3-phase 400 V industrial motor, and 24 V DC is usually the control circuit voltage, so these transistors should be able to switch a contactor which in turn would power the conveyor. Most relays / contactors of a suitable size would not draw more than 500 mA to operate the coil. If a larger current was required, the transistors could be wired in parallel to increase the current capacity.

Connections to the external devices not mounted on the control circuit board are required, so screw type terminal strips will be used for this.

The microcontroller requires a 5 V supply. For development purposes, this can be provided by the programming device, but for standalone operation a 5 V supply is needed. A simple PSU board can be built which will accept up to 18 V AC or 24 V DC and provide the necessary 5V DC supply to the microcontroller. The programmer must NOT be connected if the external 5 V supply is on – damage to the programmer could result, hence the PSU board will be kept separate from the control board to avoid potential conflict issues, and to allow for easier testing and development.

1b iii) Circuit diagram / wiring diagram

A circuit schematic based on the use of a PIC16F18875 microcontroller and a ULN2803 Darlington driver is shown in Figure 2 below. The wiring connections that will be needed via the input and output ports are also shown. This is revision no. 1.0.

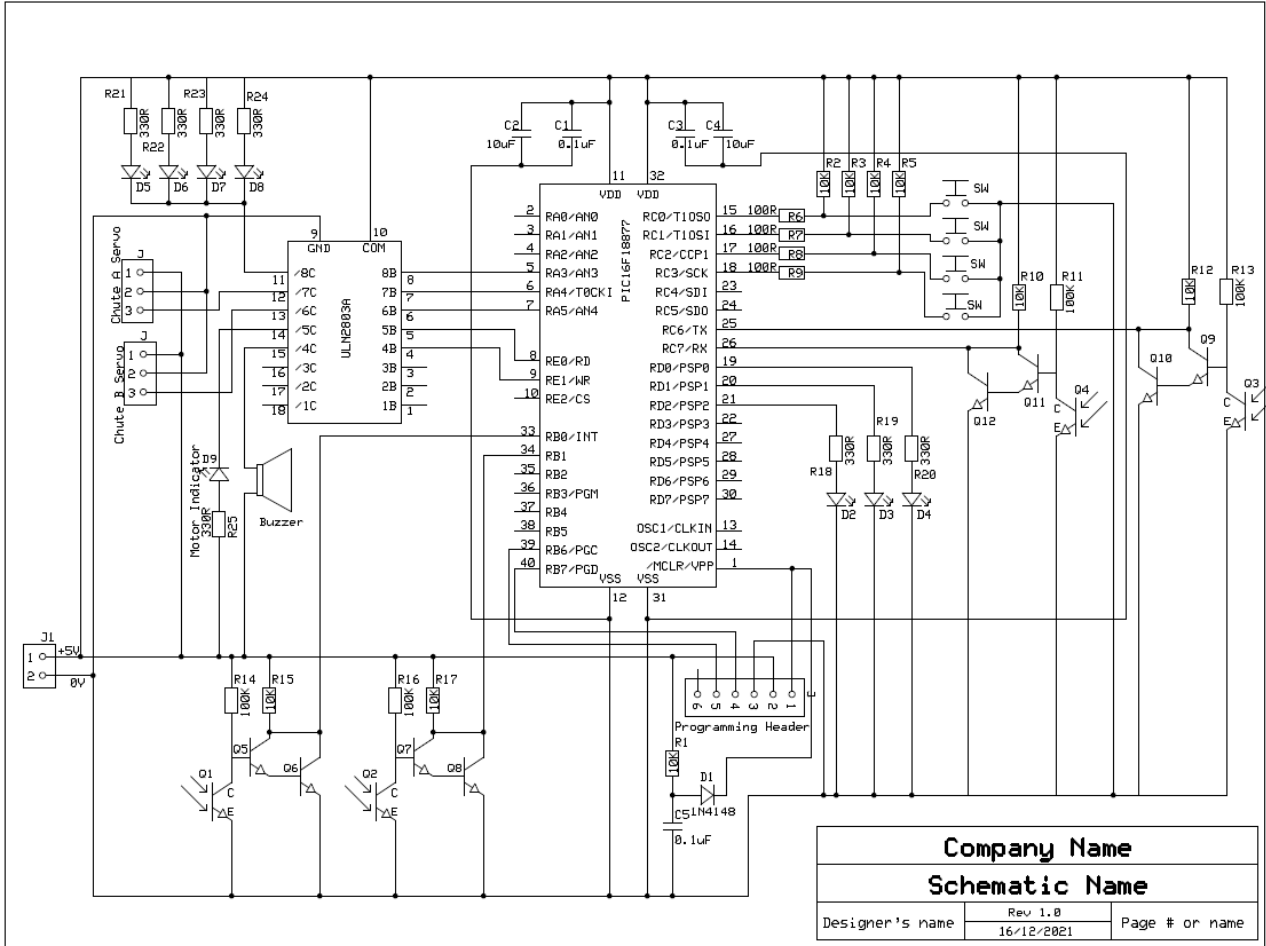
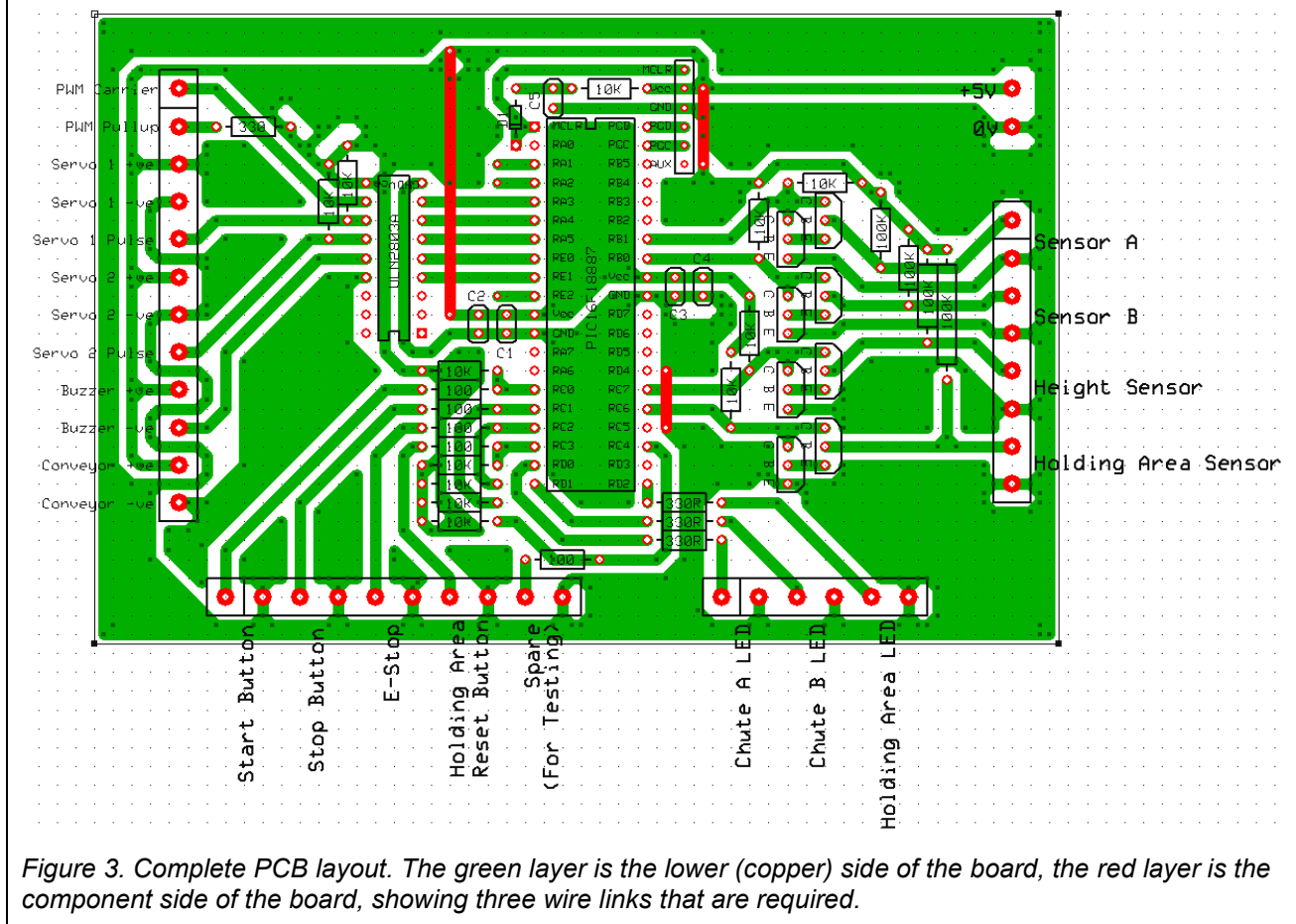


Figure 2. Complete Circuit Diagram with wiring connections shown

1b iv) PCB layout

A printed circuit layout has been produced using CAD software and is shown in Figure 3 below.



Commentary

The candidate has identified and provided detailed technical justifications for the selection of all required sensors for the system, explaining how all requirements of the design, brief, criteria and specification are satisfied. The candidate has analysed how the signals produced by the sensors would be understood and acted upon by the microcontroller, showing an excellent understanding of the wider technical considerations that must be taken into account when selecting sensors and input devices for a circuit.

The candidate has produced relevant and accurate calculations that support the design process, including the minimum and maximum values for the tolerances of the sensors. They have calculated appropriate values for the current limiting resistors, taking into account both the voltage drop across the LEDs and the minimum and maximum current draws expected.

The candidate has discussed the circuitry to be used with detailed and in-depth justifications as to why each is to be used. For example, analysing the need for a Darlington driver IC and explaining how this would be integrated with the rest of the circuitry. They have produced a circuit schematic, wiring diagram and PCB layout which are fully accurate, use correct conventions and meet all of the design criteria, including the extended criteria identified in the specification.

1c) Outcomes of the virtual modelling and circuit simulation

Candidate evidence

Multisim is the electronic modelling tool available to me. This allowed simulation of the hardware aspects of the proposed system. I set up a comparator circuit to simulate the operation of the proposed programming for the microcontroller.

The comparator was entered into Multisim modelling software as a schematic. Phototransistors were not available to model in this software, so regular transistors were used instead, with a potential divider circuit on the base to simulate the IR sensor input. The lower resistor, R2 was changed between 100 ohms indicating a received signal, and 100 K ohms indicating no signal received. (Figures 4 and 5).

The simulation initially did not give fully accurate results. Although a 5 V supply was used, the comparator outputs swung between +21 V and -21 V, which is clearly not possible on a 5 V supply. However, the input signal measurements appeared to be valid as expected for each condition outlined in the criteria. The simulation did show that the general principle that the idea was reasonably sound and would meet the needs of the criteria, but the confidence in these results was not as high as it could be. It was decided to build a physical comparator circuit with phototransistor inputs on breadboard to see what the actual results would be. This ensures modelling is fully accurate as sometimes components in software do not produce the same results as physical components.

The screenshots below show the measured values of the signals taken using virtual instruments, including a virtual multimeter.

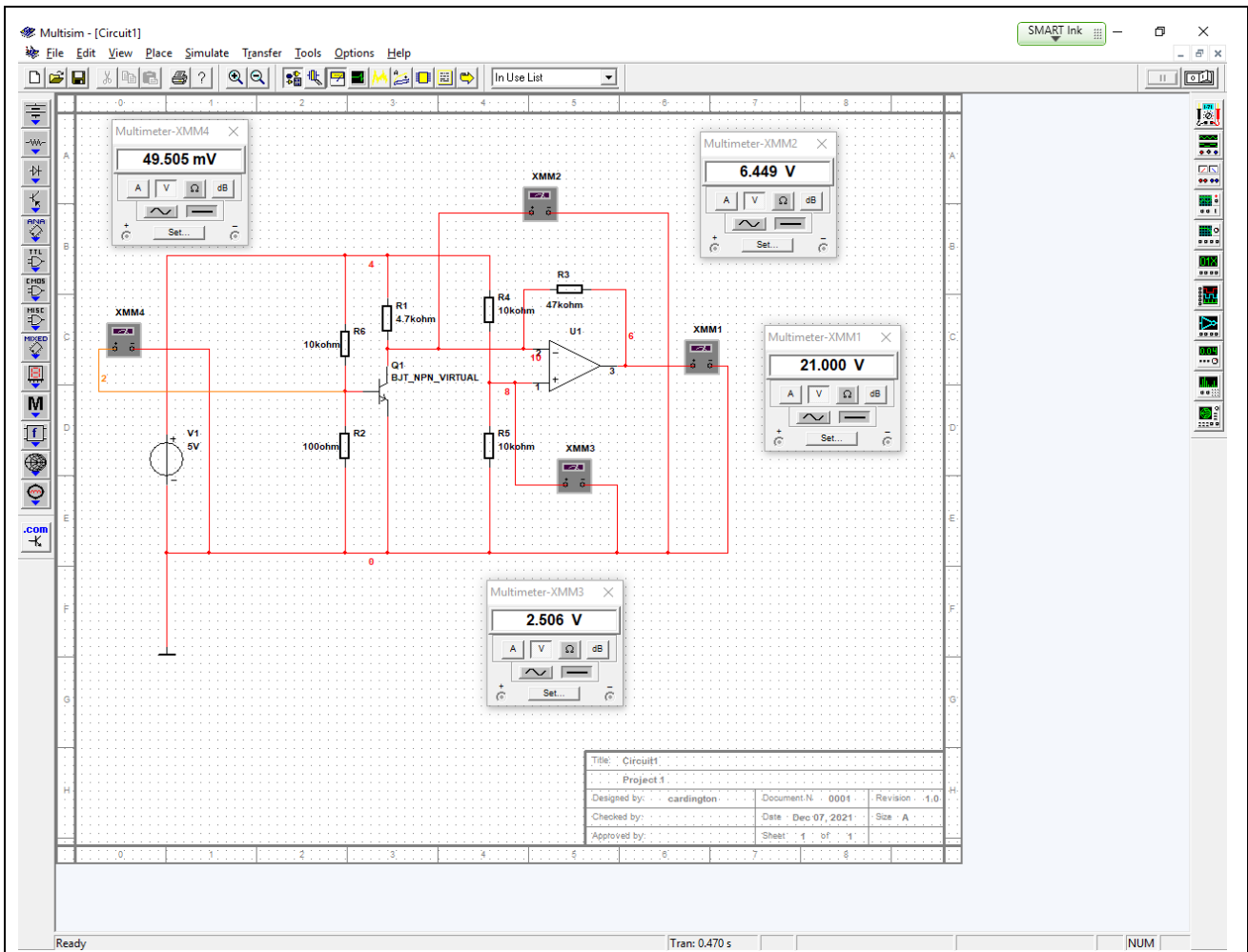


Figure 4. Simulation of received signal.

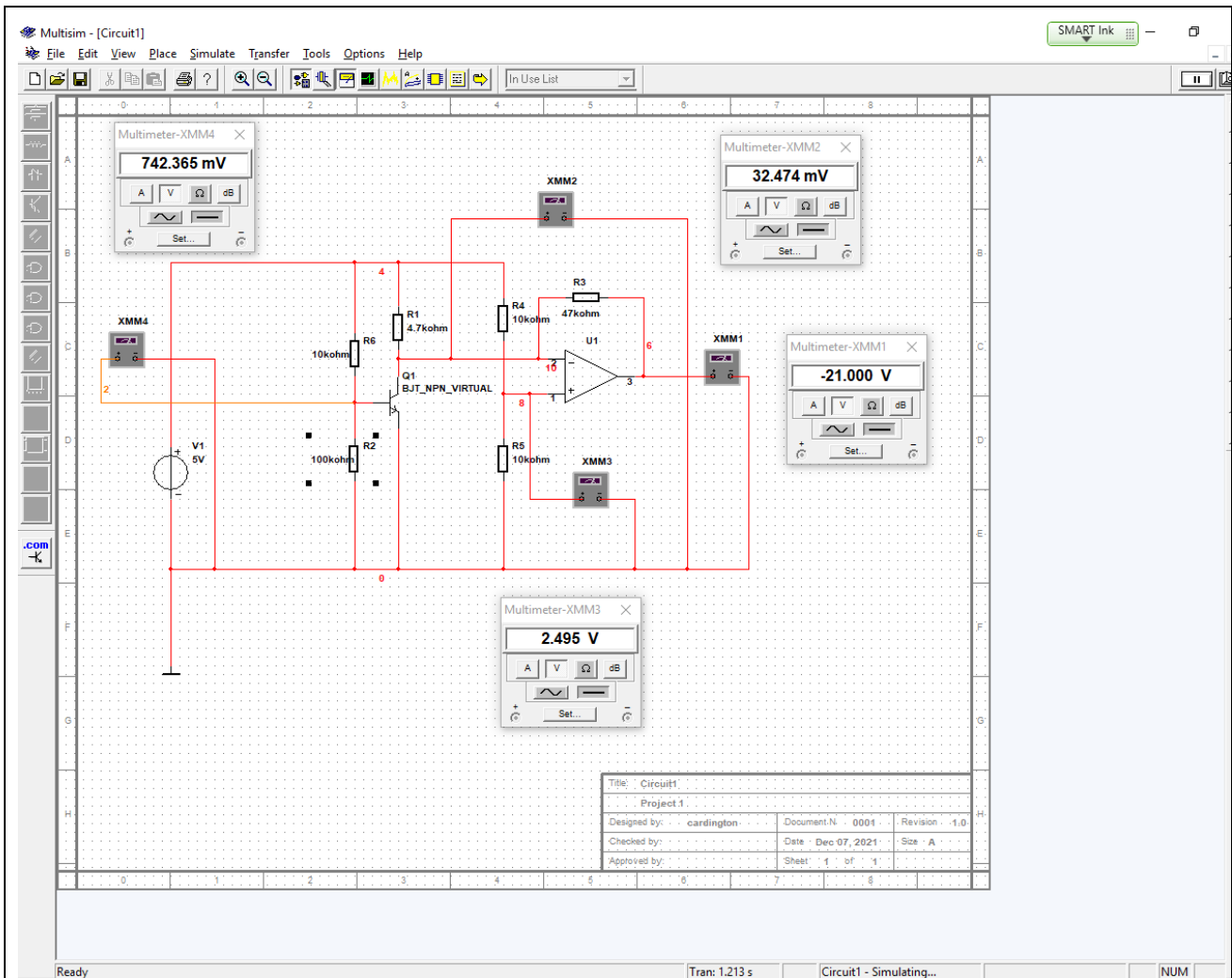


Figure 5. Simulation of no signal received.

Commentary

The candidate has produced a detailed model of the hardware aspects of the system and used a comparator to simulate the proposed programming of the microcontroller for the design. They have tested the operation of the circuitry and used virtual instruments to take measurements of the input and output signal values. For example, using a virtual multimeter to measure the output voltages for different input signal conditions.

They have identified some discrepancies between the expected output values and those recorded in the simulation and recognised the need to conduct further tests using a physical model. Screenshots are clear and show both the circuitry modelled and the measurements taken.

1d) Records of the results of testing the physical model of the circuit

Candidate evidence

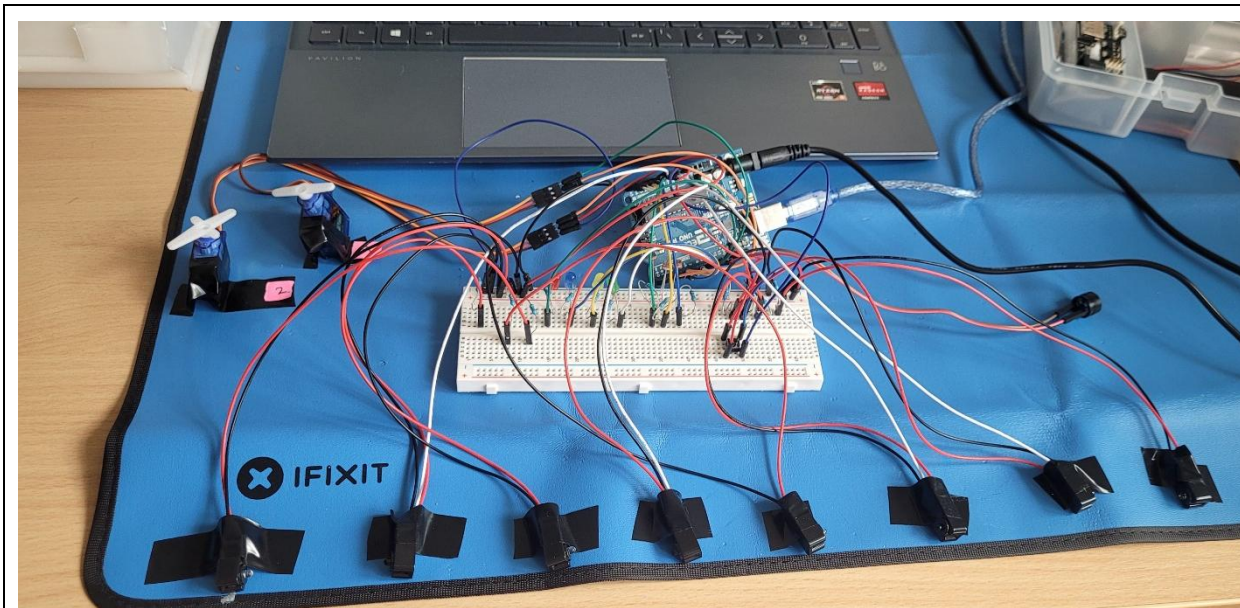


Figure 6. Testing of the physical model.

I used breadboard to produce a physical model of my circuitry and tested it against the design criteria. The whole system would need to be mounted to the conveyor system at the correct height using the intended circuitry. This breadboard arrangement proves my work along with using the correct programming and provides me an opportunity to improve or tweak my work with minimal cost impact to the customer.

With the IR break beam sensor at 260 mm from the infrared LED, the comparator output varied from 4.5 V to 1.5 V. Some experimentation with resistor values was done to try to get an optimal result, and this was the best that could be achieved. Unfortunately, 1.5 V is still well above the 0.8 V threshold for a logic '0' so the comparator concept was abandoned. A simple Darlington pair using BC547 NPN transistors was tried on breadboard and found to give 0.6 V for logic '0' and 4.8 V for logic '1', so it was decided to use this arrangement instead of the comparators.

codeEE | Arduino 1.8.12
File Edit Sketch Tools Help

```
int IRSensor = 2; // connect ir sensor to arduino pin 2
int LED = 13; // connect Led to arduino pin 13

void setup()
{
  pinMode (IRSensor, INPUT); // sensor pin INPUT
  pinMode (LED, OUTPUT); // Led pin OUTPUT
}

void loop()
{
  int statusSensor = digitalRead (IRSensor);

  if (statusSensor == 1)
  {
    digitalWrite(LED, LOW); // LED LOW
  }

  else
  {
    digitalWrite(LED, HIGH); // LED High
  }

}

int IRSensor = 3; // connect ir sensor to arduino pin 3
int LED = 14; // connect Led to arduino pin 14
void setup()
{
  pinMode (IRSensor, INPUT); // sensor pin INPUT
  pinMode (LED, OUTPUT); // Led pin OUTPUT
}

void loop()
{
  int statusSensor = digitalRead (IRSensor);
```

Using the Arduino software, I wrote a program for this to operate as if it was on a conveyor belt system. I tested my program with the self-diagnostic and error logging process. Some small coding errors were found and rectified, by using the appropriate coding language. I uploaded the program to the Arduino and successfully ran the program to prove functionality.

Commentary

The candidate has produced an appropriate physical model and tested it against the proposed design criteria. Through testing and measured results, they have identified ways in which the proposed design can be improved and explained ways of achieving this. For example, using a Darlington pair arrangement instead of the initial comparator idea.

Explanation of the outcomes of physical modelling is detailed and includes analysis of the measurements taken and their meaning in terms of the requirements of the proposed design.

The candidate identified and labelled the digital PWM (pulse, width, modulation) location output clearly, using a numbered paper label. They also used appropriately coloured wires, red for positive and black for negative consistently.

1e) Bill of materials

Candidate evidence

A PCB was designed based on the Darlington pair coupled sensors, and a Bill of Materials compiled.

Component Name	Part No. / Value	Cost per unit £	Quantity	Total cost £
IC1	PIC16F18877	3.16	1	3.16
IC2	ULN2803A	2.00	1	2.00
IC Socket	40 pin	0.40	1	0.40
IC Socket	18 pin	0.20	1	0.20
C1, C3, C5	0.1uF capacitor	0.18	3	0.54
C2, C4	10uF capacitor	0.22	2	0.44
R1, R2, R3, R4, R5, R10, R12, R15, R17	10K resistor	0.05	9	0.45
R6, R7, R8, R9	100 ohm resistor	0.05	4	0.20
R11, R13, R14, R16	100K resistor	0.05	4	0.20
R18, R19, R20, R21, R22, R23, R24, R25	330 ohm resistor	0.05	8	0.40
D1	1N4148 diode	0.08	1	0.08
D2, D3, D4, D9	Red LED 5 mm	0.09	5	0.45
D5, D6, D7, D8,	L-7113F3C Kingbright 940 nm IR LED	0.20	4	0.80
Q1, Q2, Q3, Q4	SFH310FA Osram photo transistor	0.77	4	3.08
Q5, Q6, Q7, Q8, Q9, Q10, Q11, Q12	BC547 NPN transistor	0.30	8	2.40
12 pin terminal strip		0.80	1	0.80
10 pin terminal strip		0.70	1	0.70
8 pin terminal strip		0.50	1	0.50
6 pin terminal strip		0.30	1	0.50
2 pin terminal strip		0.20	1	0.50
6 pin programming header for PicKit2		0.30	1	0.50
SW1, SW2, SW3, SW4	Normally open push button switch	0.18	4	0.72
5 V buzzer	Wired buzzer	1.12	1	1.12
Lead free solder reel 1 mm		3.00	1	3.00
Multi-strand wire reel	Red, black and blue insulation colours	6.00	3	18.00
Copper clad board	Single sided board	3.00	1	2.00
Total cost				£43.14

Commentary

The candidate has produced an accurate bill of materials that contains all the materials, components and consumables needed to manufacture the circuitry. Appropriate quantities have been provided and costs calculated. All aspects of circuit manufacture have been considered, including the copper board required to produce the PCB and solder for assembly.

Exact part numbers and specific technical details about each item have also been provided where appropriate, allowing the ease of sourcing and purchasing each item.

Candidate's notes

Bibliography

[1] The Supply of Machinery (Safety) Regulations 2008.

<https://www.legislation.gov.uk/ukSI/2008/1597/schedule/2/made>. Last accessed 5.12.2021.

[2] Microchip PIC16F18877 Datasheet.

Task 2 – Manufacture and test

(Assessment themes: Health and safety, Manufacturing, Reports)

For task 2, candidates need to produce the following pieces of evidence:

- a) risk assessment
- b) PCB
- c) prototype
- d) test records for the results of testing the circuitry.

- Assessor observation of:
 - the production of the PCB
 - building of the soldered prototype
 - testing of the circuitry.

Photographic evidence which shows:

- unassembled PCB clearly showing the track layout (figures 7-10)
- back of the assembled PCB showing all soldered joints (figure 11)
- front of the assembled PCB showing positioning and fitting of components (figure 12)

Video evidence which shows:

- functionality of the prototype.

2a) Risk assessment

Candidate evidence

Hazard(s)	Risk(s)	Control(s)	Likelihood	Severity
Pre-work checks				
Working area not prepared for starting work	Slips, trips and falls. Fire risks from any waste or flammable material not removed.	Physical check of the work area to confirm operationally ready. Remove any waste or flammable materials from immediate work area. Advise others in the work area of the activities to be undertaken.	1	1
Manual handling of tools and equipment when building the prototype	Back injury.	Do not lift over maximum lifting limit.	1	1
Equipment malfunction / faulty components	System heating up when working on it causing risk of burns/scalds. Electrical shocks from faulty equipment.	Check equipment before use – including when last PAT tested and confirm calibration records. Ensure proper use – including that appropriate training of the equipment has been provided before use. Safe isolation.	2	2
Production of the PCB				
Use of developer solution for the PCB – such as Sodium Metasilicate and Sodium Hydroxide (Fortex Liquid PCB Developer) with corrosive properties	Exposure to substances hazardous to health, causing health concerns (such as irritation to the skin, eye burns).	Confirm the types of substances being used and ensure that manufacturer instructions and directions for use are followed at all times. Wear appropriate PPE when handling substances. Wash hands and clean the work area to remove any residual substance following the work activity.	2	2

Use of hand tools and equipment, when etching, soldering and drilling	Burns from contact with iron. Cutting/hand injuries. Equipment malfunction/faulty components.	Ensure correct training has been undertaken before use of all equipment. Review use of equipment whilst in use, checking for any issues that could lead to risk. Ensure proper use at all times. Wear safety glasses. Check equipment following use for any damage, and before replacing for future use.	1	1
Soldering the components				
Using soldering equipment to solder the component	Risk of fire burns through contact with iron.	Ensure correct training has been undertaken before use. Regularly check the equipment at intervals recommended through safety guidance whilst soldering. Confirm understanding of correct emergency procedures to be taken in the event of a fire or burn accident in the workspace.	2	2
Inhalation of/exposure to solder fumes whilst soldering the component	Build-up of solder fumes if operating in an enclosed area, risking health of operatives and users in the workspace (such as asthma, dermatitis).	Ensure the use of high-quality fume extractors. Fume extractors are to be placed close to the workpiece to draw fumes to it, and away from the operative. Immediately report any signs of illness to a manager in the workspace if they occur during or following soldering activity.	2	2

Likelihood		Severity	
1	Very unlikely to happen	1	Minor injury
2	Unlikely to happen	2	Major injury
3	Possible to happen	3	Loss of limb
4	Likely to happen	4	Death of an individual
5	Very likely to happen	5	Multiple deaths

Commentary

The candidate has produced a detailed risk assessment that considers all stages of the manufacturing process in a logical order. They have separated each of the hazards and associated control measures into the individual activities required for manufacture of the complete prototype and have considered, in depth, the range of hazards and risks that may occur at each stage. Through taking this approach, the candidate has demonstrated an excellent understanding of the process to be followed – and for the range of health and safety concerns that would need consideration throughout the practical aspects of the task.

For each stage of the process, the candidate has holistically considered the risks/hazards that may occur at that stage – and considered a range of appropriate control measures that show a developed understanding for limiting or mitigating the risks. Considerations are detailed in that they consider all steps of each stage, for example, considering what needs to be done prior to starting work, as well as the actions to be taken through undertaking the work, and where applicable, the actions to be taken when the work has been completed.

The candidate has considered the degree of likelihood and severity of each risk, with an accurate rating provided against a considered scale.

2b) PCB production

Candidate evidence

PCB manufacture

I used the etching process to produce my PCB. A tinning process was then applied to allow for ease of soldering and to protect the copper tracks underneath. Holes were then drilled for the mounting of components.

The following photographs show the PCB following the completion of each of these processes.

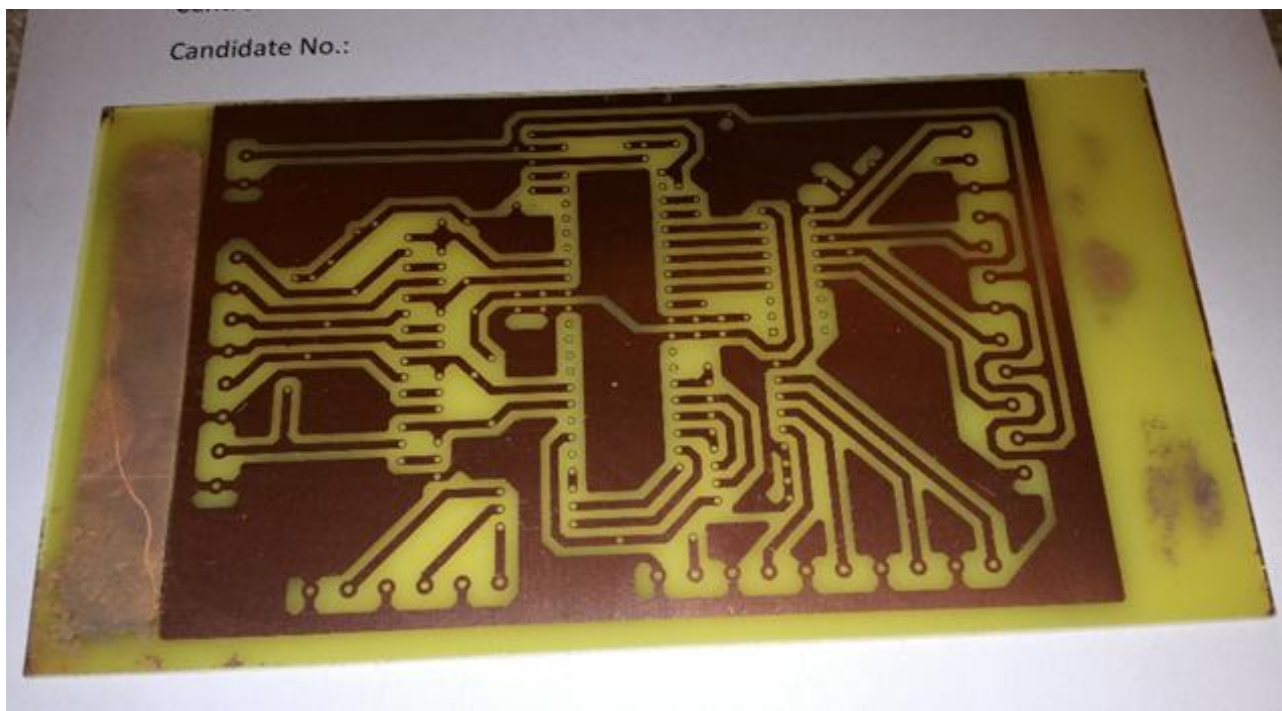


Figure 7. Etched PCB – track layout shown.

Candidate no:

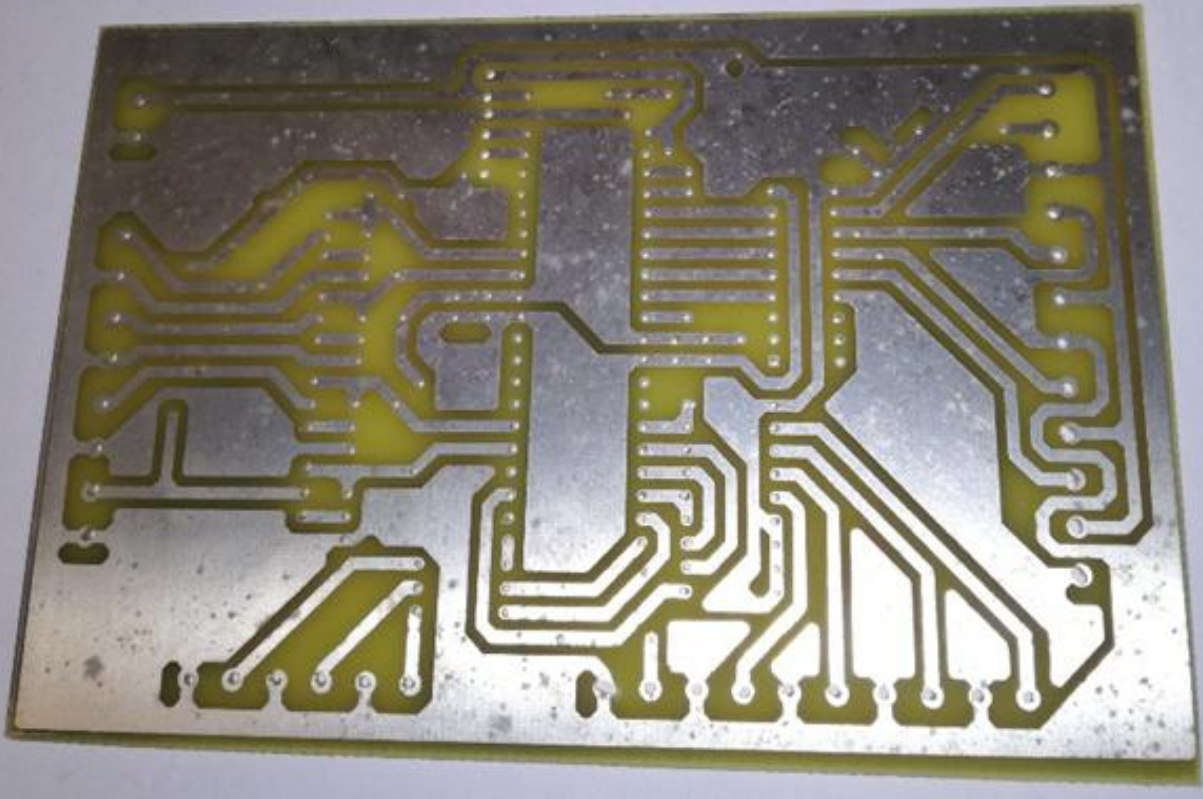


Figure 8. PCB after tinning solution applied. The solution is applied correctly and the board is cut to size neatly and accurately.

Candidate no:

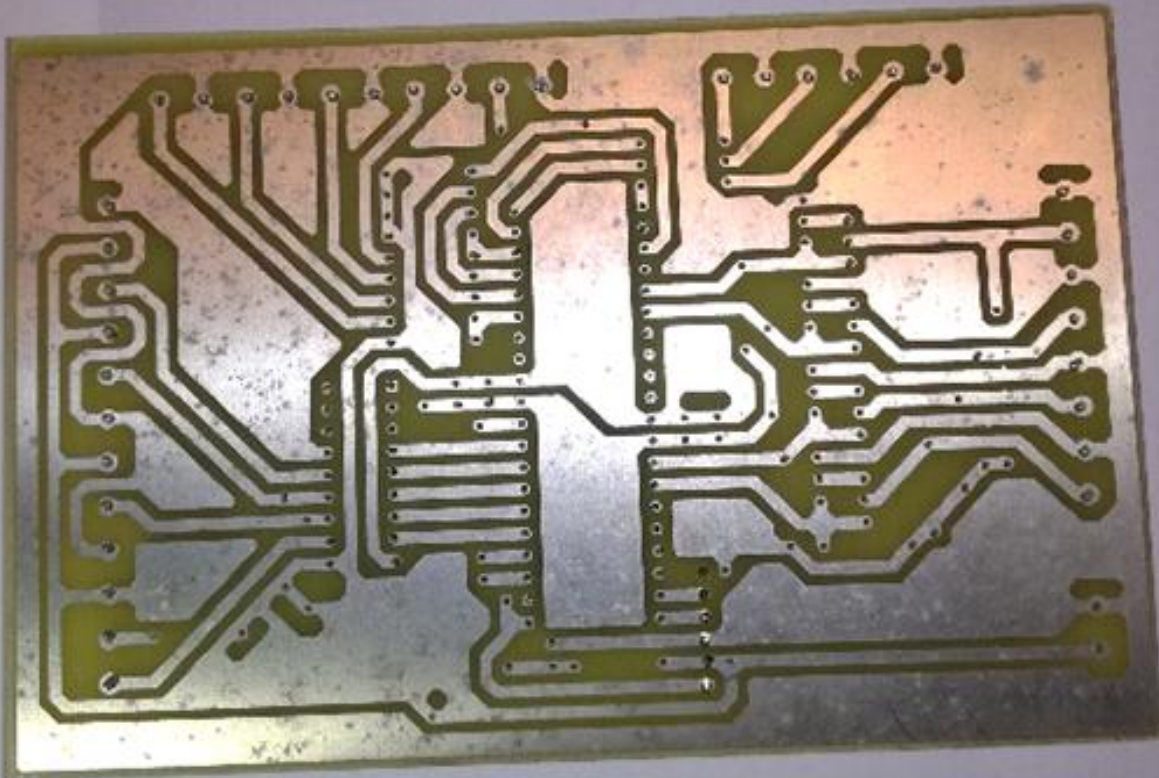


Figure 9. PCB copper side after drilling. The drilling is carried out carefully and with precision, selecting the appropriate drill bits for the size of the holes required.

Candidate no:

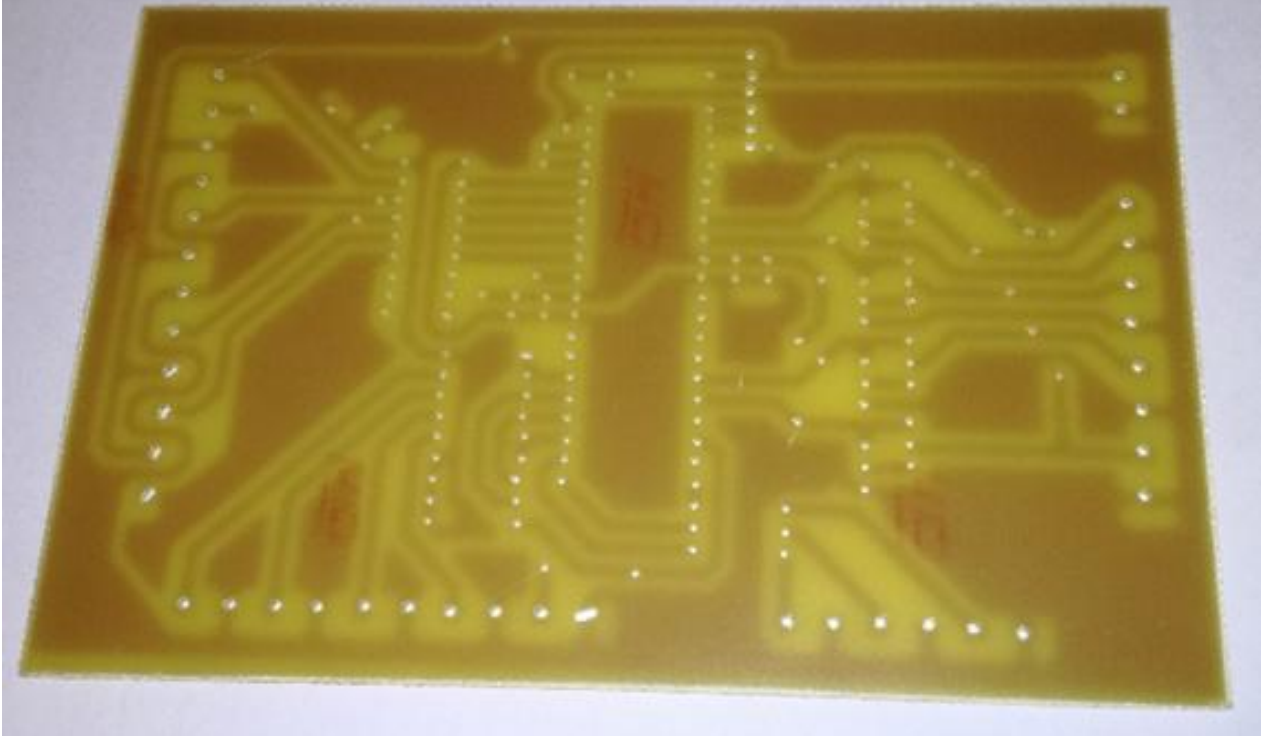


Figure 10. PCB component side after drilling. The drilling is carried out carefully and with precision, selecting the appropriate drill bits for the size of the holes required.

Practical observation form – PCB

Assessment ID	Qualification number
8714-322	8714-32
Candidate name	Candidate number
Candidate A	CG12345
Centre name	Assessment theme
City & Guilds	Health and Safety Manufacturing

Complete the table below referring to the relevant marking grid, found in the assessment pack. **Do not** allocate marks at this stage.

Task	Notes – <i>detailed, accurate and differentiating notes which identify areas of strength and weakness are necessary to distinguish between different qualities of performance and to facilitate accurate allocation of marks once all evidence has been submitted.</i>
PCB	<p>The candidate correctly printed their mask onto clear acetate. They safely and accurately exposed the copper clad board to UV light and developed it in a developer solution containing Sodium Metasilicate and Sodium Hydroxide (Fortex Liquid PCB Developer). They then used a ferric chloride solution to etch the PCB. Safety procedures were followed at all times. Tongs were used to handle the copper board and gloves. Overalls and safety glasses were worn throughout.</p> <p>Following etching, the candidate cleaned the PCB and applied a tinning solution to the track layout. They then used a PCB drill to drill holes for component mounting. 1.2mm holes were used for the connectors and programming header, as these have larger pins, with 0.8 mm holes being used as standard for all other components.</p> <p>All steps were completed competently, accurately and with precision. This has resulted in a high-quality PCB that will be fully functional if correctly assembled and shows a high quality of finish.</p>

Assessor signature	Date
<i>Assessor A</i>	03/04/2022

Commentary

The candidate has produced a high-quality PCB using the photo etching process. They have demonstrated excellent practical skills and shown a thorough understanding of the process by completing each activity with accuracy and precision.

The candidate followed correct safety procedures throughout, as outlined in the appropriate sections of their risk assessment. For example, using tongs and gloves to avoid direct contact with dangerous chemicals during the developer and etching stages of PCB manufacture. Appropriate PPE was worn throughout to ensure a high level of safety for both themselves and those around them.

The output of the process was a very well-produced, high-quality PCB with a functional track layout, a high quality of finish and steps taken to ensure ease of soldering during the assembly process. For example, applying a tinning solution to the track layout and using drills of different sizes to ensure an exact fit for the different types of components. The reduction of waste material was also considered, with only the essential copper removed to produce the track layout, thus reducing the amount of etchant solution and energy required.

2c) Soldered prototype

Candidate evidence

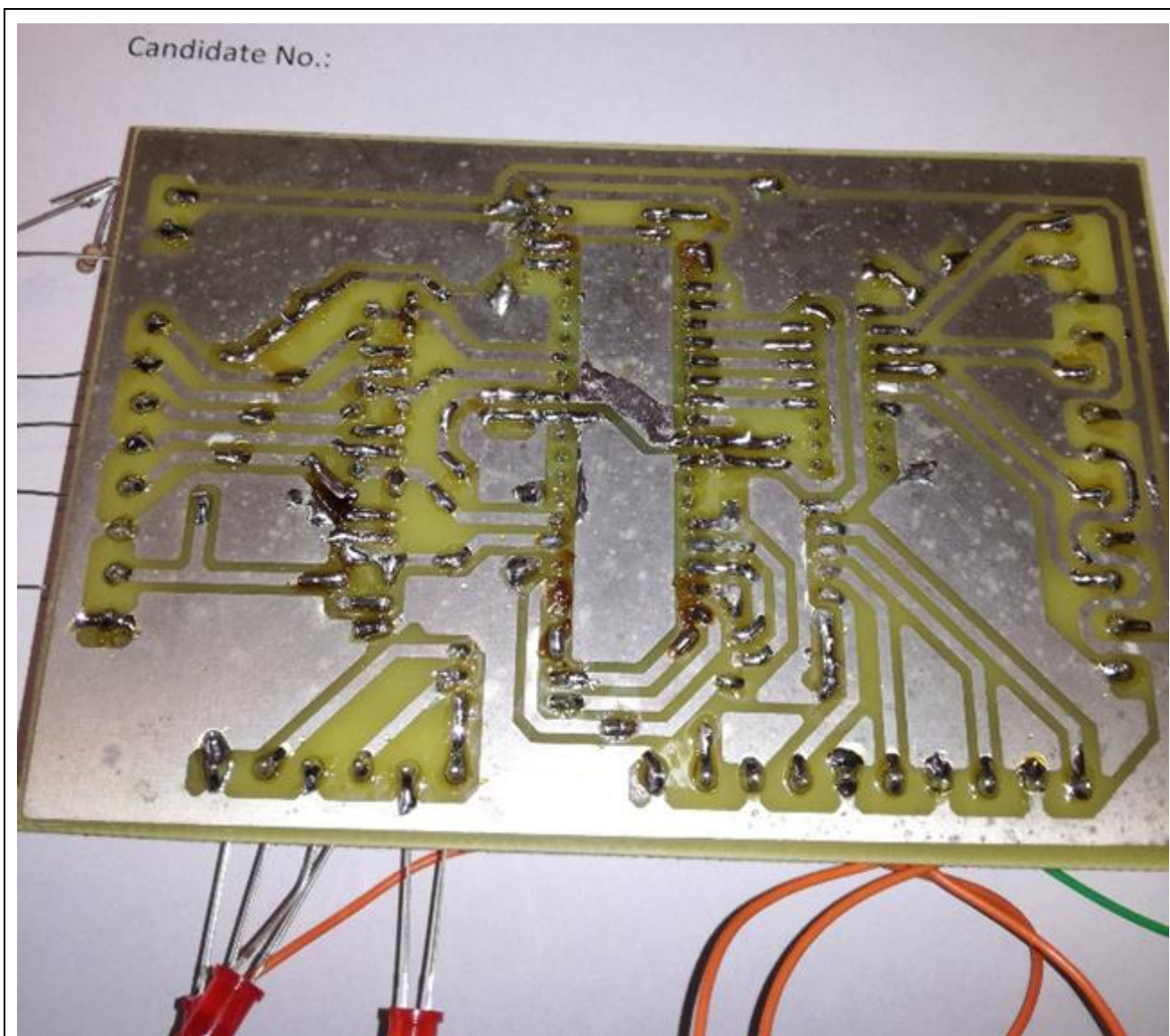


Figure 11. Copper side after components are soldered in. The soldering is accurate and functional.

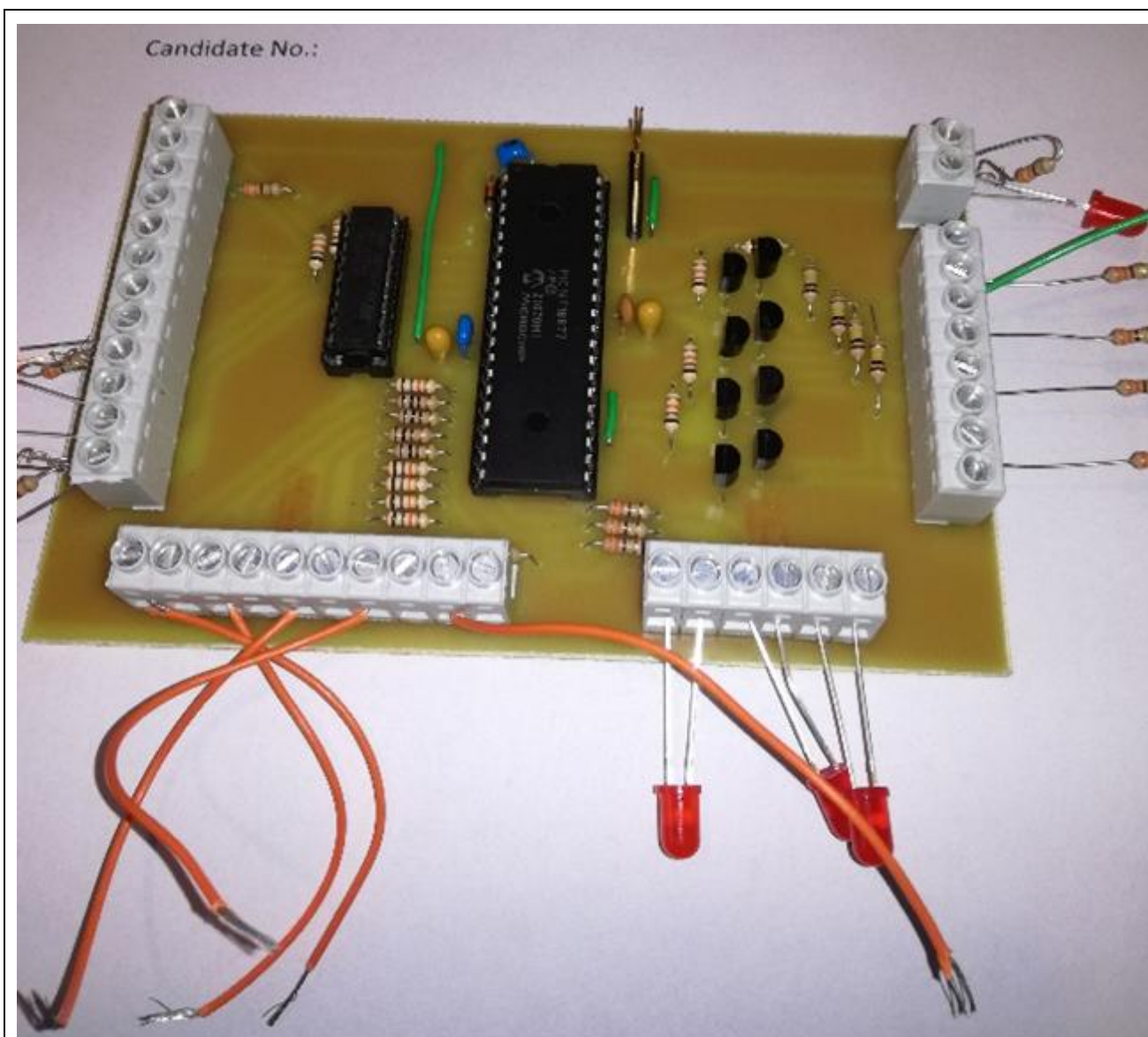


Figure 12. Component side after components are soldered in. The components are soldered in at the correct positions and the excess leads are trimmed after the soldering. The wires are cut accurately, and the connectors are tightened appropriately.

Practical observation form – Prototype

Assessment ID	Qualification number
8714-322	8714-32
Candidate name	Candidate number
Candidate A	CG12345
Centre name	Assessment theme
City & Guilds	Health and Safety Manufacturing

Complete the table below referring to the relevant marking grid, found in the assessment pack. **Do not** allocate marks at this stage.

Task	Notes – <i>detailed, accurate and differentiating notes which identify areas of strength and weakness are necessary to distinguish between different qualities of performance and to facilitate accurate allocation of marks once all evidence has been submitted.</i>
Construction of the prototype	<p>The candidate accurately fitted the components into the correct positions on the PCB following a logical, left to right order. They checked that all components were flush with the board and corrected those that were not.</p> <p>The candidate used soldering equipment accurately and safely, including a soldering iron, stand and sponge, to solder the component legs to the pads on the PCB. They used pliers and a helping hand as aids to assist with holding components in place whilst soldering, and to ensure a higher quality of finish. The soldering was accurate and functional, with a good level of skill shown, but could have been more precisely done. Safety glasses were worn throughout, and the iron was left in the stand when not in use. Portable fume extraction was used throughout. Awareness of the safety of others was taken into account whilst using soldering equipment.</p> <p>Component leads were trimmed where necessary after soldering. Sockets were used for the two integrated circuits to avoid heat damage and electrostatic issues. Once soldering was complete, the ICs were inserted using anti-static mats to avoid damage to them.</p> <p>Wires were accurately cut to the correct sizes and fitted using block connectors. These were tightened appropriately.</p>

Assessor signature	Date
<i>Assessor A</i>	03/04/2022

Commentary

The candidate constructed and assembled a functional circuit that meets all of the requirements of the design criteria.

Assembly processes were completed in a fully safe manner with the safety of both themselves and others taken into account. For example, ensuring extraction was used at all times to protect both themselves and those around them during the soldering.

Accuracy in the use of tools and equipment was shown throughout all activities, resulting in a very good quality of finish overall. An excellent understanding of the process was shown throughout. For example, understanding the need to use, and correctly implementing the use of, IC sockets and anti-static equipment to avoid heat and electrostatic damage to the microcontroller and Darlington driver ICs.

2d) Testing

Candidate evidence

Testing and software development

The microcontroller program requires some initialisation of the chip, so the basic input / output configuration was written to configure the pins for the correct functionality. A routine to output data to the Port D LEDs was then written and tested, followed by a routine to read the button states and output them to the LEDs. This proved that the buttons and LEDs were working correctly. A routine to read the sensors and output them to the LEDs was then written and tested, although at this point the base of the transistors was simply grounded using a wire as a crude switch rather than the phototransistors that were to be mounted onto a test rig.

The Start / Stop function for the conveyor was then coded, and tested OK, with Motor LED indicating correctly. The setting and resetting of the holding area alarm was then coded and tested OK, with the holding area LED also indicating correctly.

The logic for detecting a box and its size was then tackled. It was realised that if both sensors were triggered at the same time, this did NOT necessarily mean that a single box was present. If a small box passed in front of the first sensor (Sensor A), then a gap followed by a second box, then if the first box passed Sensor B whilst the second box was in front of Sensor A the system needed to be able to determine that. Thus, a state machine diagram or table was needed so coding stopped to work on this. As this was developed it became apparent that the possible situations could be quite complex. 11 internal states with 4 possible exit points per state were eventually determined.

It was considered that a timer in the microcontroller could be used to time the box passing the sensors, but this was not done because of the previous points regarding accuracy and having two sensors would then be redundant.

As a box passes Sensor A, a counter could be incremented. When Sensor B is triggered, the count could be decremented. If the count is zero, we know that the same box has passed both sensors. Therefore, if the count is zero after Sensor B is triggered, and both sensors are at logic '1' we know with certainty that the box is NOT smaller than 300 mm. If the count is not zero when Sensor B is triggered, we know that the box is smaller than 300 mm. This algorithm was then coded and tested using the chute LEDs. This worked as expected, although the contact between the input and the ground wires was not debounced which may have caused some erratic behaviour that was occasionally observed.

The PWM signal for the IR sensors was then set up so that the functional testing could be properly carried out, together with the PLC setup to detect the carrier signal. This met the requirements as outlined in the criteria and the servo motors moved into position as expected.

Practical observation form – Testing of the circuitry

Assessment ID	Qualification number
8714-322	8714-32
Candidate name	Candidate number
Candidate A	CG12345
Centre name	Assessment theme
City & Guilds	Health and Safety Manufacturing

Complete the table below referring to the relevant marking grid, found in the assessment pack. **Do not** allocate marks at this stage.

Task	Notes – <i>detailed, accurate and differentiating notes which identify areas of strength and weakness are necessary to distinguish between different qualities of performance and to facilitate accurate allocation of marks once all evidence has been submitted.</i>
Testing of the circuitry	<p>The candidate set up a test rig to perform functional tests using a pre-assembled conveyor belt. They tested against each requirement of the design criteria in a fully logical fashion, stopping to investigate any issues that arose and correcting them before moving on.</p> <p>They selected and used appropriate test equipment correctly and with a high level of skill, producing test results that were both accurate and precise/repeatable. Checks were made prior to use of all items of test equipment to ensure they were properly calibrated and safe to use. All test equipment was used safely in accordance with SOPs and IET wiring and testing regulations.</p> <p>They correctly downloaded test programs to check all aspects of the design. Test results were correctly recorded, and a detailed analysis of the results written to accompany them.</p>

Assessor signature	Date
<i>Assessor A</i>	03/04/2022

Commentary

The candidate completed thorough testing of the circuit against all aspects of the design criteria. They selected fully appropriate test methods and test equipment, using them with a high level of skill to produce results that were accurate, precise and repeatable. For example, by ensuring all equipment was correctly calibrated before use. Test equipment was used safely and in accordance with all relevant legislation and guidance.

A detailed record and analysis of the results of testing was provided. This included the results of each test performed and the implications for the potential further development of the design beyond the initial design criteria and specification. For example, considering the effects of switch bounce and how this could be avoided in a future iteration of the circuit, and the potential implications of two sensors being triggered at exactly the same time.

Task 3 – Peer review

(Assessment themes: Reports)

For task 3, candidates need to produce the following pieces of evidence:

- candidate notes on the candidate feedback record form

The candidate notes are not included in this document as the notes will vary from candidate to candidate and are not used to inform any other task.

- peer review feedback form.

This is supporting evidence for assessors to see what feedback the candidate received and how they used it in their review for task 4, and will not be marked.

Peer review feedback form

Candidate name	Candidate number
Candidate B	CG01234
Centre name	Centre number
City & Guilds	12345

Question	Feedback
How well does the design meet the requirements in the brief?	<i>I think the design is very good overall. It meets all of the requirements of the brief and design criteria. The sensors are detecting the size of the boxes, the LEDs are lighting up as needed and the motors are moving into position to move the boxes down each chute. One thing you might consider is the use of a voltage regulator to ensure the power supply into the circuit remains fixed at all times.</i>
How appropriate is the equipment proposed for the design?	<i>Tools and equipment used seemed to be appropriate. I liked that they used pliers to ensure that the components were mounted flush on the board, as this makes it look much better than it would have done. They could have used a de-soldering tool to remove some of the excess solder on the board. This would have made it look even neater.</i>
What are the implications to the business of the proposed design?	<i>If there are issues with the power supply and a voltage regulator is not used, it could cause the voltage to go outside of the limits of some components. This could cause them to fail, leading to system downtime and a possible halt in production whilst maintenance and repairs are carried out.</i>
How can the design be optimised / improved?	<i>I think you should add a voltage regulator to the system to ensure the power supply voltage is always within the limits that are required by the circuitry.</i>

Candidate name	Candidate number
Candidate C	CG01234
Centre name	Centre number
City & Guilds	12345

Question	Feedback
How well does the design meet the requirements in the brief?	<i>This is a very good design. The sensors seemed to work well and detected when the boxes were not the right sizes. The LED lights lit up at the right time to indicate which chute the boxes were going down. The holding area LED and buzzer both work correctly. The reset switch might suffer from the effects of switch bounce, so this could be improved upon.</i>
How appropriate is the equipment proposed for the design?	<i>I think the correct tools and equipment were used to make the prototype. Candidate A could have used a CAM milling machine to produce the PCB and automatically drill the holes, but the etching process worked well.</i>
What are the implications to the business of the proposed design?	<i>If the reset switch suffers from switch bounce then the system might reset unexpectedly, potentially causing issue with the detection circuitry and boxes being missed, leading to reduced production efficiency.</i>
How can the design be optimised / improved?	<i>I would add a method of reducing the effects of switch bounce, such as a debouncing circuit. This could be produced as a separate circuit board and wired into the existing switch connections to avoid having to change the whole PCB design.</i>

Task 4 – Evaluation and implementation

(Assessment themes: Health and safety, Design and planning, Reports)

For task 4, candidates need to produce the following pieces of evidence:

- a) outcomes of virtual modelling
- b) revision control document
- c) evaluation and implementation report.

4a) Outcomes of virtual modelling

Candidate evidence

I used CAD software to produce and test additional circuitry that could be added to the main circuit board to improve how it works, based on the feedback I received. I designed a voltage regulator circuit that could be used in response to the feedback from Candidate B, and a switch debounce circuit in response to Candidate C.

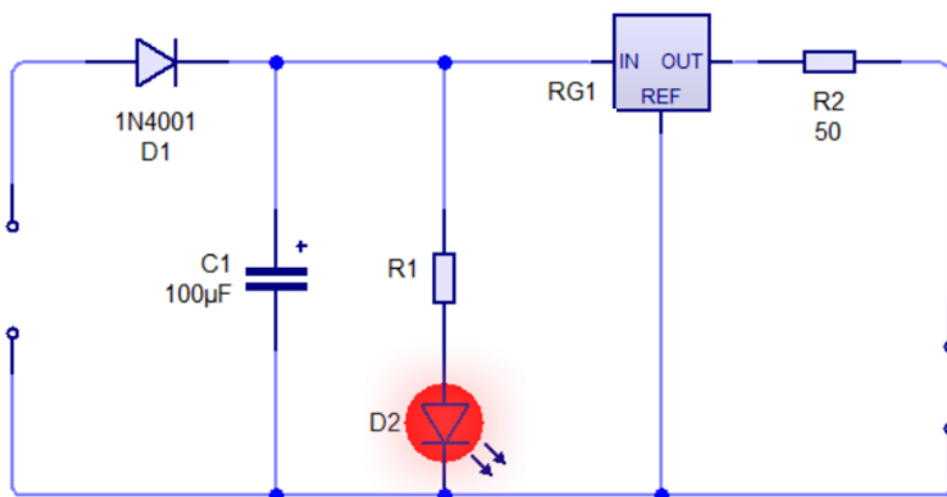


Figure 12. Suggested voltage regulator circuit model – LED added and tested to indicate operation

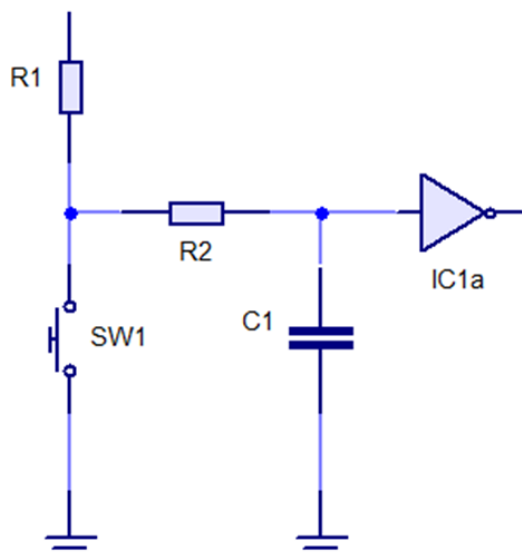


Figure 13. Suggested switch debounce circuit

When simulated, this reduced the effects of switch bounce to almost zero. It could be added wherever push switches are used within the system but was mainly designed to support the reset switch circuitry. This, along with the voltage regular circuit, would be designed separate circuits and wired into the existing main PCB to avoid this needing to be completely redesigned to accommodate them.

Commentary

The candidate has undertaken revisions to the original virtual modelling, demonstrating how they have considered the peer feedback they received in order to improve the design of the circuitry.

The modelling is presented clearly through detailed circuit diagrams that show the intended improvements. The candidate has supported their modelling with commentary that reflects how these amendments support the overall design – including how they can be incorporated into the overall existing planned design. For example, wiring into the main PCB, rather than requiring a full redesign of this.

4b) Revision control document

System type	Conveyor belt sorting system
System TAG number	A1B2C3
Department responsible for equipment	Design and Development department
System designed by:	Candidate A

Design description:

This is a circuit to ensure the correct sizes of boxes moving down a conveyor belt move into the correct chutes depending on their lengths and heights. IR sensors have been used to achieve this. If some boxes are not detected or moved down the correct chute, they can end up in a holding area. At this point an LED lights up and a buzzer sounds to show the box is in the holding area and needs attention. A PIC microcontroller and Darlington driver IC have been used to control the servo motor outputs, with appropriate software to ensure fully accurate functionality.

Changes to existing system:

As shown in the virtual modelling section above I created two new pieces of circuitry to add to the existing design; a voltage regulator circuit and a switch debouncing circuit. This was in response to feedback from candidate A (voltage regulator) and candidate B (switch debounce). Although both candidates agreed that my existing design fully meets the needs of the existing design criteria in the brief, these suggestions were useful as they further improved my design beyond this.

The voltage regulator circuit will ensure that the power supply voltage remains at a steady 5 V regardless of any changes to the input voltage. This will ensure that if there are issues with the input supply that the microcontroller and other components will not be damaged or affected by any potential increase or decrease in voltage, and therefore avoid the need for them to be replaced or repaired.

The switch debounce circuit will ensure that when the push button reset is used, only one pulse is recorded by the microcontroller. This will avoid any additional or unexpected resets from taking place, which would make the system more efficient and reduce the chance of sensing errors.

Changes to existing technical documentation:

The main changes that need to be made are to the circuit schematic and wiring diagrams (update to version 2.0 for each). The main circuit schematic needs to be amended to include the voltage regulator and the switch debounce circuitry. The regulator will need to be integrated into the power supply sub-system and the debounce circuit into the existing reset circuitry. This would then need to be connected to the reset pin of the PIC microcontroller. Additional wiring to join these new PCBs to the existing PCB would need to be shown on the wiring diagram.

Any technical manuals explaining the use of the system would need to be amended to include the additional circuitry. For example, where diagrams and instructions for use and maintenance are given within them.

The design criteria and specification could be amended to include additional points regarding achieving a steady power supply at all times and ensuring that the reset function does not suffer from the effects of switch bounce.

Comments:	
Overall, I am happy with the feedback received and have acted on the main points given by each candidate. I have suggested changes based on these that would further improve my design beyond the existing requirements of the design criteria and specification.	
Validation performed by:	<i>Assessor 1</i>
Prototype approved by:	<i>Assessor 1</i>
Date:	16/06/2022

Commentary

The candidate has read and taken into account the feedback from both peer reviewers. They have responded to the feedback regarding the potential inclusion of a voltage regulator and switch debouncing circuit. As these are both technically good suggestions that would improve the functionality beyond the initial requirements of the criteria, this shows an extended knowledge and understanding of the wider requirements of the design and of improvements that could make it a commercially viable system.

The candidate has produced a revision control document that covers all of the requirements and documentation that would need to be updated. They have correctly identified that the schematics, wiring diagrams and any technical manuals would need changing. They have also identified additional requirements that could be added to the design criteria and specification, in order to result in a better product if an improved version is designed in the future. They have suggested appropriate version numbers to use for the diagrams that need to be updated.

4c) Evaluation and implementation report

Evaluation –

I mainly used functional and software testing to check the function of my prototype. I used functional testing as it allowed me to see exactly how my prototype would function in the context of the actual production environment and on a physical conveyor belt. Software testing was also very important because my proposed circuit is microcontroller-based and any errors with the software programs would create issues with the hardware aspects of the design. It was important to take measurements of both the input and output signal voltages as these allowed issues to be found within each circuit sub-system and corrected before it is handed over to the client. These were recorded to ensure the client has the appropriate data to inform both future use and maintenance requirements.

The circuitry was based around the use of a PIC16F18877 microcontroller and a ULN2803A Darlington driver IC. This gave enough ports for the connections of all input sensors and output devices and ensured that the 20 mA output current was boosted to what was required by the server motors. It also allowed for programming of the pulse width modulation signals for the precise movement of the servo outputs. Infra-red beam sensor inputs were used to detect the box sizes and functioned very well during testing. LED indicator outputs were used to visually indicate the chute that each box was sent down and servos were to control the movement of the boxes down each chute. These were colour coded for ease of identification. Reset functionality was included to allow for the user to restart the operation of the system at any given time. In future, as explained in my revision control document, I will add a debouncing circuit to this to ensure it works smoothly and there are no unexpected reset pulses received by the microcontroller.

I was happy with the results of my PCB design, assembly and production. Given that the smallest feature size on the PCB that was possible was around 1/4 mm (10 thousandths of an inch), with 1/2 mm features (20 thousandths of an inch) usually being reliable and consistent, and as space on the board was not an issue, I used 1.5 mm (60 thou) tracks with 1 mm (40 thou) spaces between tracks to eliminate potential problems. I also used a tinning solution after etching to preserve the finish of the board and to make soldering easier. This worked well, but a slightly mottled effect occurred during this process due to the age of the equipment used. It did not adversely affect the assembly of the board and the quality of finish was still of a good quality.

Overall, the circuitry meets all of the design criteria as explained in the test record. However, there are some improvements that could make the system. In addition to the switch debouncing circuitry and improving the tinning process as explained above, I would take a little more care with my soldering, or possibly use more automation, to ensure that all solder joints are of the highest possible quality.

Implementation –

In order for a third party to implement the prototype they will need the following information and documentation:

- The initial design criteria from the brief and final design specification from task 1.
- The final circuit schematics, wiring diagrams and models from tasks 1 and 3, updated to reflect the improvements made during peer feedback (versions 2.0).
- The printed circuit board (PCB) layout from task 1 and the additional PCBs designed in response to feedback from task 3.
- Test programs to download onto the microcontroller in order to demonstrate successful operation of the IR sensors, LEDs and sound outputs, and servo motors.
- The risk assessment from task 2 to ensure that safe working practices are followed if further versions of this design are manufactured.
- Datasheets for the PIC16F18877 microcontroller and a ULN2803A Darlington driver ICs used, along with all relevant input and output devices. <https://www.microchip.com/en->

[us/product/PIC16F18877](https://www.ti.com/product/PIC16F18877) ,
https://www.ti.com/lit/ds/symlink/uln2803a.pdf?ts=1646297100929&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FULN2803A

There are a number of factors that need to be considered during implementation. The first of these is the cable types used to connect the infra-red sensors and output devices to the circuitry. These should be multi-strand, rather than single strand wire. This is because these devices could be subject to movement and mechanical stress, and if one strand breaks then conductivity is not lost, as is the case with single strand wire. I would recommend block screw connectors re-used. These provide a strong joint when tightened correctly but can be unscrewed if the wiring needs to be removed for maintenance or repairs.

There are a number of health and safety issues that must be considered when implementing the prototype. The correct power supply must be used to avoid damage to components and the chances of overheating. If the wiring or components are removed for inspection or future maintenance then IET wiring regulations (BS 7671) must be followed, following the requirements for low voltage applications. Care must be taken not to suddenly release stored electrical energy, particularly from capacitors and power supplies, when the circuit is in use. Operators must not look directly into any infra-red beam produced as this can be very harmful to the eyes.

Commentary

The candidate has produced an evaluation and implementation report that contains detailed information relevant to the design and finished prototype. They have explained the test methods used and provided justifications for their use. They have also explained in depth how their circuit meets the needs of the design criteria and discussed the improvements that could be made to result in a design that goes beyond the requirements of the initial criteria and is commercially viable. For example, the improvements identified to the reset circuitry.

The candidate has provided a list of documentation that is relevant to implementation, showing a good level of knowledge and understanding of their relevance and importance. They have explained the safe working practices that a third-party should follow when implementing the prototype, including requirements for future usage, maintenance and inspection. This shows that they fully understand the varied needs of the end user in terms of handover and implementation.

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