Engineering Cycle, Mixed Signal Processing and PCB Design

Task 1: Define the problem statement

Firstly, read the background above and understand what the client wants you to develop. List all the objectives related to the problem statement and develop a Gantt Chart to show how long this project might take to complete.

Alex, a board game enthusiast, desires a compact device that can function as a multi-sided dice generator. This device should meet the following key objectives:

- **Compact size:** No larger than 70mm x 50mm.
- **Multi-dice Functionality:** Dice types d4, d6, d8, d10, d12 and d20.
- **Visual display:** Reveals the result of each roll.
- **True randomness**
- **User-friendly interface:** A button to switch between dice types.
- **Extended battery life**

Based on the objectives, here’s a Gantt Chart for the estimated timeline of the project.

Activity	Week 1	Week 2	Week 3
Define the problem statement	■		
Research and analysis	■		
Brainstorming	■		
Concept Development – Hardware	■		
Concept Development – Software	■		
Feasibility Assessment		■	
Detailed Design and Planning – Schematic Design		■	
Detailed Design and Planning – PCB Design		■	
Detailed Design and Planning – Material and Resource Planning		■	
Field Ready Prototype and Testing and Evaluation			■
Optimization and Improvement			■
Design a 3D model case for the product			■

Table 1. Electronic Dice Project's Gantt Chart

Task 2: Research and analysis

Look at existing products and approved sellers to find which parts you need to make this client project. Make an Equipment table that follows this structure, please add more columns if needed.

For this task, I focused on identifying the components needed to design and build the product. I researched existing products and suppliers to find parts that met the project requirements, considering cost, availability, and compatibility. The goal was to ensure the components are efficient, compact, and aligned with the client's needs.

Component Research and Justification

The table below summarizes the key components I considered initially and the rationale behind their selection:

Supplier and Cost Overview

I sourced the components from approved suppliers like Mouser Electronics, Digi-Key, and Model Rockets to ensure high quality and reliability. The table below shows the details of the selected components, including cost, quantity, and manufacturer. Here are key observations from the initial list of components needed.

Product Nam	Product Desc	URL	Distributor	Manufacturer	Cost (inv VAT)	Quantity	Total
ATMEGA328P	8-bit Microcor	https://www.r	Mouser Electr	Microchip	£2.10	1	£2.10
7-segment (HI	LED Displays &	https://www.r	Mouser Electr	Broadcom Lim	£1.55	2	£3.10
Tactile Switch	Tactile Switch	https://www.r	Mouser Electr	Apem	£0.32	2	£0.64
Usb B Micro (L	USB Connecto	https://www.r	Mouser Electr	GCT	£0.56	1	£0.56
Lipo Battery (M	3.7V 150mAh	https://model	Model Rocket	PKCell	£8.75	1	£8.75
Step-Up Volta	Switching Volt	https://www.r	Mouser Electr	Texas Instrum	£3.02	1	£3.02

Table 2. Initially Needed Components List

1. <u>Total Cost</u>

   The total cost of the main components is approximately £18, including VAT but not including shipping, which fits within a reasonable budget for prototyping.

2. <u>Suppliers and Reliability</u>

   Most components were sourced from Mouser Electronics, with the battery sourced from Model Rockets. All suppliers are reputable, ensuring reliable components and availability.

3. <u>Compatibility</u>

   All components are compatible with the 3.3V–5V operating range of the system. For example, the LiPo battery and step-up voltage regulator ensure that the microcontroller and display receive stable power.

Observations and Challenges

- Component Size: The compact size of components like the ATMEGA328P-AU and the 7-segment display ensures that the project can meet the size constraint.

- Power Efficiency: I selected a LiPo battery from Model Rockets and a voltage regulator to optimize the dice for extended use, ensuring low power consumption, while the system is portable.
- Cost vs. Quality: While some cheaper alternatives were available, I prioritized components with a proven track record to avoid issues during prototyping.

Task 3: Brainstorming

For the microcontroller, there were a few options on the table. Initially, we thought about using an Arduino UNO, given its familiarity and ease of use. However, its size was a drawback for this project. We also considered the ATtiny85, which is compact but has only 3 pins, limiting the number of components it could support. The ATtiny84 offered more pins (12), but we felt it still might be too restrictive for the design's complexity. Finally, we chose the ATmega328P, a small and compact device, yet it offers enough I/O pins to handle all the necessary components without compromising functionality.

Next, we discussed the power supply. Since the device needs to be portable, we quickly dismissed the idea of using a standard 9V battery, which would be bulky and require frequent replacements. Instead, we opted for a rechargeable LiPo battery. To make recharging easy, we decided to integrate a USB-B micro connector for charging, ensuring that the device could be conveniently powered up without needing external chargers or frequent battery replacements.

For the display, the main challenge was finding something that would clearly show the numbers without consuming too much power or requiring too many pins. Initially, we investigated using an OLED or e-ink display, but these would require more complex programming and higher power consumption than necessary. We settled on two 7-segment displays because we could use multiplexing, which would allow us to control both displays with fewer pins, further optimizing the design.

Draw a high-level flow chart for the product.

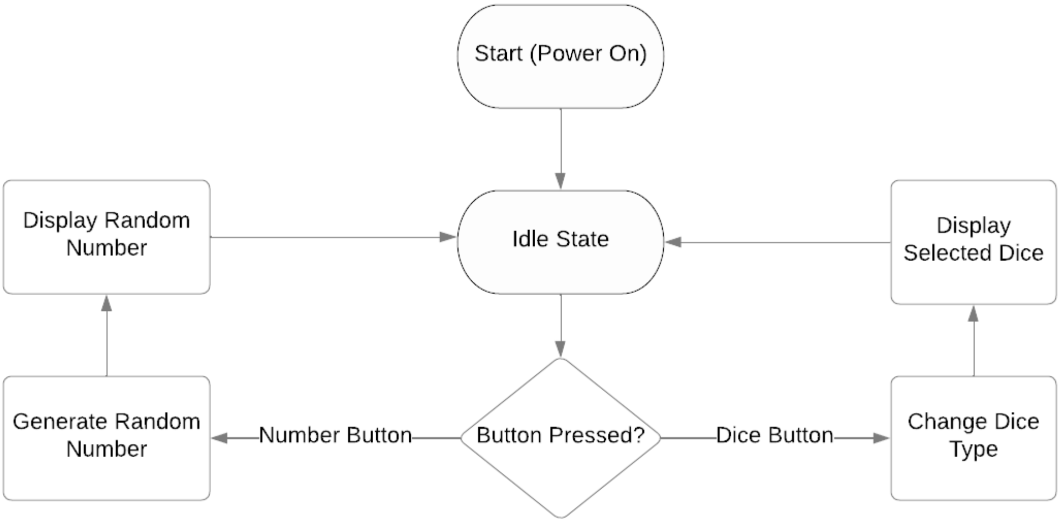

Figure 1. Electronic Dice Flow Chart

Draw a logic diagram for the software of the product.

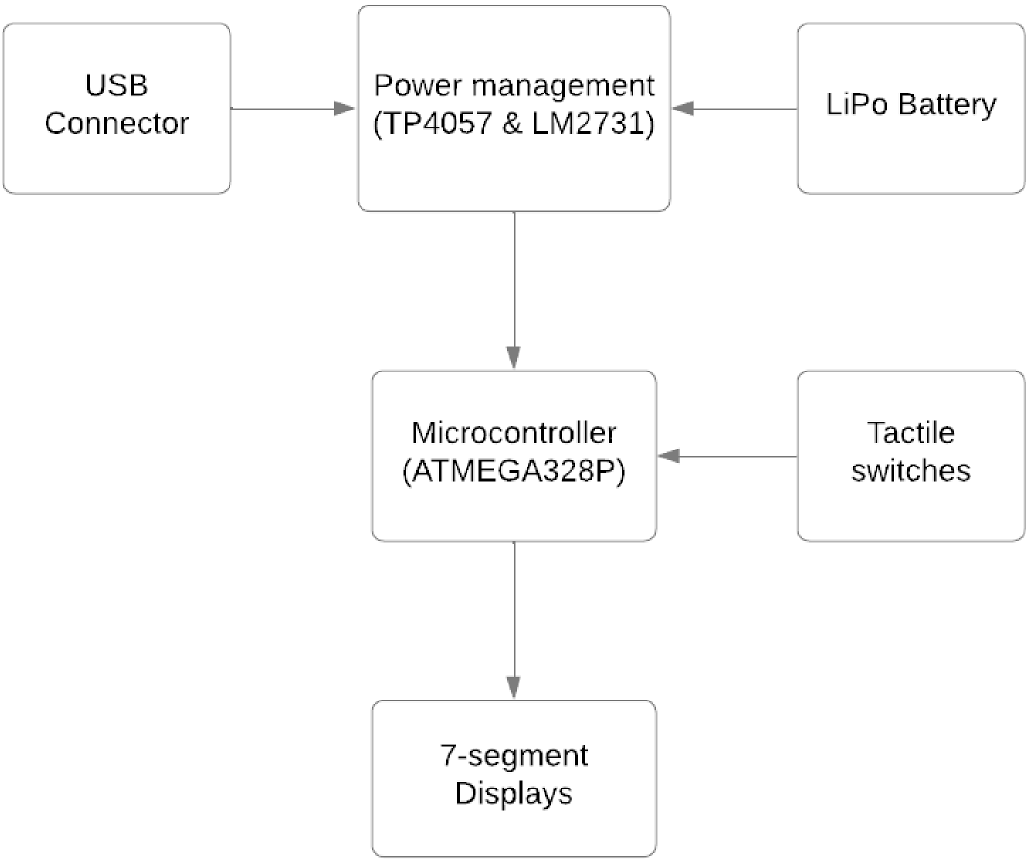

Figure 2. Electronic Dice Logic Diagram

Task 4: Concept Development – Hardware

The initial hardware prototype for the project involves using an Arduino UNO, which incorporates the ATmega328P microcontroller, along with two buttons and two 7-segment displays to visualize the results. The system simulates a dice rolling mechanism with multiple dice types (d4, d6, d8, d10, d12, and d20). Here's a breakdown of how the hardware is connected:

- **Buttons**: The first button is used to switch between different dice types (d4, d6, etc.). Each press cycles through the different dice options and shows on the display the selected dice. The second button is responsible for generating a random number within the selected dice range.
- **7-Segment Displays**: The output is visualized on two 7-segment displays, which are used to show the dice result. The segments (A-G) of both 7-segment displays are wired together to the same GPIO pins of the ATmega328P.

The cathodes of the two displays are connected to separate GPIO pins on the microcontroller. This allows for multiplexing, where each display can be controlled individually by activating its corresponding cathode while turning off the other display. This way, we can display different numbers on each display despite sharing the segment connections.

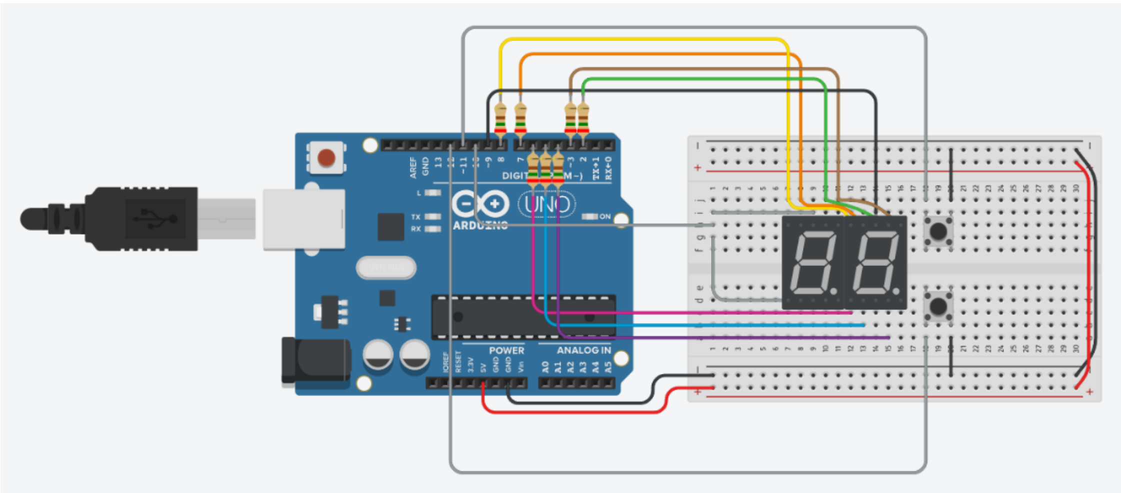

Figure 3. Electronic Dice Hardware Concept

Task 5: Concept Development – Software

Once the main hardware concept was outlined, including the microcontroller, buttons, and displays, the next step was to integrate the corresponding software. The software is tightly coupled with the hardware, ensuring that all components work seamlessly together to achieve the intended functionality. The code controls the dice rolling system, manages user inputs, and displays the results in real time on two 7-segment displays. Here's a breakdown of the code and how it functions:

1. Pin Assignments:
   - Pins pinA through pinG control the segments of the 7-segment display (common across both displays).
   - display1Pin and display2Pin are used for multiplexing between the two displays, allowing each digit to be shown one at a time.
   - buttonDiceType is for selecting the type of dice, and buttonRoll triggers the roll to generate a new random number.

Dado.ino

```
// Pins for the segments of the display
const int pinA = 2;
const int pinB = 3;
const int pinC = 4;
const int pinD = 5;
const int pinE = 6;
const int pinF = 7;
const int pinG = 8;

const int display1Pin = 9;  // First display
const int display2Pin = 10; // Second display

const int buttonDiceType = 11; // Type of dice
const int buttonRoll = 12;     // Random number

int diceType = 6; // Initial dice: d6
int number = 1;   // Generated Number
int displayValue = 6;
```

Figure 4. Electronic Dice Initialization

2. Initial Variables and Constants:
   - diceType starts at 6, representing a d6 dice by default.
   - displayValue stores the number currently displayed on the displays.
   - digitSegments array holds the binary encoding for each digit to control which segments are turned on for each number.

3. Setup Function:
   - Configures segment pins and display control pins as outputs.
   - Sets up buttons with INPUT_PULLUP mode, enabling internal pull-up resistors.

```
// Configuration of each digit
const byte digitSegments[10] = {
  0b0111111, // 0
  0b0000110, // 1
  0b1011011, // 2
  0b1001111, // 3
  0b1100110, // 4
  0b1101101, // 5
  0b1111101, // 6
  0b0000111, // 7
  0b1111111, // 8
  0b1101111  // 9
};

void setup() {
  // Pins of the segments as outputs
  pinMode(pinA, OUTPUT);
  pinMode(pinB, OUTPUT);
  pinMode(pinC, OUTPUT);
  pinMode(pinD, OUTPUT);
  pinMode(pinE, OUTPUT);
  pinMode(pinF, OUTPUT);
  pinMode(pinG, OUTPUT);

  // Control pins as outputs
  pinMode(display1Pin, OUTPUT);
  pinMode(display2Pin, OUTPUT);

  // Button pins as Inputs
  pinMode(buttonDiceType, INPUT_PULLUP);
  pinMode(buttonRoll, INPUT_PULLUP);
}
```

Figure 5. Electronic Dice Setup Function

4. Loop Function:
   - When buttonDiceType is pressed, it calls changeDiceType function to cycle through different dice types (d4, d6, d8, d10, d12, and d20).
   - When buttonRoll is pressed, it calls rollDice function to generate a random number within the current dice range.
   - After handling button inputs, the displayNumber(displayValue); function is called to show the current number on the 7-segment displays with multiplexing.

5. Dice Type Switching (changeDiceType):
   - It cycles through the dice types in this order: d4 → d6 → d8 → d10 → d12 → d20, then back to d4.

```
void loop() {

  if (digitalRead(buttonDiceType) == LOW) {
    delay(200);
    changeDiceType();
  }

  if (digitalRead(buttonRoll) == LOW) {
    delay(200);
    rollDice();
  }

  // Constant multiplexing to display the value on both displays
  displayNumber(displayValue);
}

void changeDiceType() {
  switch (diceType) {
    case 4: diceType = 6; displayValue = 6; break;
    case 6: diceType = 8; displayValue = 8; break;
    case 8: diceType = 10; displayValue = 10; break;
    case 10: diceType = 12; displayValue = 12; break;
    case 12: diceType = 20; displayValue = 20; break;
    case 20: diceType = 4; displayValue = 4; break;
  }
}
```

Figure 6. Electronic Dice Loop Function

6. Dice Rolling (rollDice):
   - It generates a random number between 1 and the maximum value of the selected dice type and stores it on the DisplayValue variable.

7. Displaying the Number (displayNumber):
   - This function splits the number into tens and units.
   - Each digit is displayed on its respective display using multiplexing, with a brief delay to switch between digits smoothly.

8. Setting Segments (setSegments):
   - This function uses bitwise operations to activate the correct segments for a given digit by controlling each segment pin.

```
void rollDice() {
  number = random(1, diceType + 1);
  displayValue = number;
}

void displayNumber(int num) {
  int tens = num / 10;
  int units = num % 10;

  // Show first digit
  digitalWrite(display1Pin, HIGH);
  digitalWrite(display2Pin, LOW);
  setSegments(digitSegments[tens]);
  delay(40); // Delay for the multiplexing

  // Show second digit
  digitalWrite(display1Pin, LOW);
  digitalWrite(display2Pin, HIGH);
  setSegments(digitSegments[units]);
  delay(40);
}

// Turn on segments depending on the case
void setSegments(byte segments) {
  digitalWrite(pinA, segments & 0b0000001);
  digitalWrite(pinB, segments & 0b0000010);
  digitalWrite(pinC, segments & 0b0000100);
  digitalWrite(pinD, segments & 0b0001000);
  digitalWrite(pinE, segments & 0b0010000);
  digitalWrite(pinF, segments & 0b0100000);
  digitalWrite(pinG, segments & 0b1000000);
}
```

Figure 7. Electronic Dice RollDice Function

Task 6: Feasibility Assessment

In this task, I evaluated the technical, economic, and operational feasibility of the product design, by analysing the finalized component selection, costs, and compatibility. This way, I ensured that the design aligns with the project’s constraints and objectives.

Below is the finalized table of components, including their descriptions, suppliers, costs, and quantities:

Product Name	Product Description	URL	Distributor	Manufacturer	Cost (inv VAT)	Quantity	Total
ATMEGA328P-AU	8-bit Microcontrollers	https://www.r	Mouser Electronics	Microchip	£2.10	1	£2.10
7-segment (HDSP-513A)	LED Displays & Acces	https://www.r	Mouser Electronics	Broadcom Limited	£1.55	2	£3.10
250R Resistor (OK15G5E-R52)	Carbon Film Resistor	https://www.r	Mouser Electronics	Ohmite	£0.09	7	£0.63
Tactile Switch (PHAP3344R)	Tactile Switches TAC	https://www.r	Mouser Electronics	Apem	£0.32	2	£0.64
TP4057	SOT23-6 BATTERY MA	https://www.c	DigiKey	UMW	£0.42	1	£0.42
Usb B Micro (USB3080-30-00-A	USB Connectors Micr	https://www.r	Mouser Electronics	GCT	£0.56	1	£0.56
JST-PH 2 Pin Connector (B2B-P	CONN HEADER VERT	https://digikey	DigiKey	JST Sales America Inc.	£0.16	1	£0.16
Led Charging (TLPR5600)	LED RED DIFF SIDE VI	https://www.c	DigiKey	Vishay Semiconductor Optc	£0.60	1	£0.60
Led Charged (TLPG5600)	LED GREEN DIFF SIDI	https://www.c	DigiKey	Vishay Semiconductor Optc	£0.60	1	£0.60
Ceramic Capacitor (CL05B103J	CAP CER 0.1UF 50V X	https://www.c	DigiKey	Samsung Electro-Mechanic	£0.10	2	£0.20
Electrolitic Capacitor (8650806	CAP ALUM 10UF 20%	https://www.c	DigiKey	Würth Elektronik	£0.18	2	£0.36
1k Resistor (CF1/2CT52R102J)	RES 1K OHM 5% 1/2V	https://www.c	DigiKey	KOA Speer Electronics, Inc.	£0.11	2	£0.22
2k Resistor (CF1/4CT52R202J)	RES 2K OHM 5% 1/4V	https://www.c	DigiKey	KOA Speer Electronics, Inc.	£0.09	2	£0.18
Lipo Battery (M105318)	3.7V 150mAh LiPo ba	https://model	Model Rockets	PKCell	£8.75	1	£8.75
Step-Up Voltage Regulator (LM2	Switching Voltage Re	https://www.r	Mouser Electronics	Texas Instruments	£3.02	1	£3.02
1.2k Resistor (CFM12JT1K20)	RES 1.2K OHM 5% 1/	https://www.c	DigiKey	Stackpole Electronics Inc	£0.08	1	£0.08
3.9k Resistor (CF14JT3K90)	RES 3.9K OHM 5% 1/	https://www.c	DigiKey	Stackpole Electronics Inc	£0.08	1	£0.08
SMD Power inductor (SRR1210-	Power Inductors - SM	https://www.r	Mouser Electronics	Bourns	£0.96	1	£0.96
10k Resistor (MCT0603MD1052	Thin Film Resistors - S	https://www.r	Mouser Electronics	Vishay / Beyschlag	£0.34	2	£0.68
						Total	**£23.34**

Table 3. Final List of Components

Technical Feasibility

The selected components meet the design's technical requirements and are compatible with each other to achieve the functionality of the product. Below is a detailed analysis of how each component contributes to the system:

1. <u>Core Components</u>
    - **Microcontroller (ATMEGA328P-AU):** It provides sufficient GPIOs to control the two displays and reads inputs from the tactile buttons, while it supports low-power operation.
    - **7-segment displays (HDSP-513A)**: The use of two of these components creates a compact two-digit display for showing dice roll results clearly. Efficient power consumption and compatible with the regulated 5V supply.

2. <u>Input Components</u>
    - **Tactile Switches (PHA3344R)**: Two buttons necessary, one for cycling through dice types and one for generating the random number. I selected Single Pole Single Throw (SPST) switches, which ensure reliable user input with robust tactile feedback.

3. <u>Power Management Components</u>
    - **LiPo Battery (3.7V, 150mAh)**: Compact and lightweight battery chosen mainly to meet the device's portability requirements, while providing sufficient capacity for prolonged usage, powering the microcontroller, displays and peripheral components. Additionally, the selected battery includes a built-in security circuit, ensuring it never truly powers off, thus protecting the device from abrupt power loss and preserving system stability during usage.

- **Step-Up Voltage Regulator (LM2731YMF)**: Boosts the 3.7V output of the battery to 5V, ensuring stable voltage for all the components in the product, while it efficiently regulates power to avoid unnecessary losses and extending battery life.
- **Battery Charging IC (TP4057)**: Allows recharging the LiPo battery via a micro-USB connector, ensuring safe charging with built-in overcharge protection.
- **Capacitors**
    - **Ceramic Capacitors (0.1µF)**: Used for decoupling to stabilize voltage and filter noise in the power supply, ensuring smooth operation of the microcontroller and display.
    - **Electrolytic Capacitors (10µF)**: Provide additional power stability, particularly for the voltage regulator during periods of higher current draw.

4. <u>Passive Components</u>
    - **250Ω Resistors**: Current-limiting resistors for the 7-segment displays, ensuring that LEDs are not overdriven.
    - **1kΩ and 3.9kΩ Resistors**: Pulldown or pullup resistors for tactile switches to ensure stable signal readings from the buttons.

5. <u>Connectivity Components</u>
    - **Micro-USB Connector**: Robust and compact design that allows the device to be charged conveniently using standard USB power sources,
    - **JST Connector**: Provides secure and compact connections for the battery, making assembly and maintenance easier.

6. <u>Additional Considerations</u>
    - **Multiplexing for 7-segment Displays**: By multiplexing (the microcontroller alternates between the tens and units digits quickly enough to make it appear as though both digits are displayed at the same time) the two displays, I successfully reduced the number of GPIO pins needed to control the segments.

    - **Size Constraints**: The use of compact components such us the microcontroller or the battery fit in the key-fob-sized requirements. Additionally, SMD versions of passive components further minimize the overall PCB size.

The selected components are expected to operate seamlessly together under the specified voltage conditions (5V, which preventing flickering or glitches). With this efficient power management, the device is projected to offer extended usage on single charge while maintaining functionality.

Economic Feasibility

This assessment is evaluated based on the total cost of components, sourcing reliability, production scalability, and the cost-benefit considerations of design decisions. Below is an in-depth analysis of the cost and financial implications of the project:

1. Component Cost Analysis
    - The total cost of components, including VAT, is £22.63 for a single unit. This cost is reasonable for a prototyping phase where parts are sourced individually and not in bulk (Shipping not included).

2. Bulk Production Potential
    - **Savings in Bulk Orders**: Many components can be purchased at significantly reduced prices when ordered in bulk, like passive components or microcontrollers. A rough estimate shows that bulk purchasing could decrease the component cost per unit by 20-30%, bringing the cost closer to £16 per unit in a hypothetical larger scale production.
    - **Scalability**: By transitioning to Surface Mount Devices (SMD) for passive components, assembly time and labour costs can be reduced in large scale manufacturing. A single PCB design can accommodate all components for automated assembly, which lowers production costs.
    - **Value vs. Cost:** In the prototype stage, £22.63 per unit is justified by the need for high-quality components to ensure functionality during testing. Moreover, the ability to recharge the device adds value to the design, avoiding the recurring cost of disposable batteries. On the other hand, for a retail product it would be essential to find cost reduction strategies to achieve a profitable margin while keeping the final product affordable.

3. Challenges
    - **Initial Cost for Prototyping**: Prototyping often incurs higher costs due to the lack of economies of scale.
    - **Logistics**: The need to source the components from multiple suppliers increases the shipping costs and complexity. Consolidating suppliers or sourcing locally could benefit the overall cost

4. <u>Future Cost Optimization</u>
    - **Component Consolidation**: Explore integrated IC solutions that combine microcontroller, power management, and charging capabilities to reduce the total component count and cost.
    - **Supplier Negotiations**: Negotiate with suppliers for better pricing when ordering in bulk.

The project is economically feasible for prototyping and offers significant potential for cost reduction in bulk production. By balancing quality, functionality, and affordability, the design ensures a competitive product with a strong value proposition. Future cost optimization strategies will further enhance its viability for commercial production.

Operational Feasibility

The operational feasibility of the product focuses on the ease of assembly, user functionality, portability, and maintainability. Below is a detailed analysis of how the design meets these operational objectives:

1. <u>Ease of Assembly</u>
    - **Component Placement:** The use of through-hole components, like the tactile switches and resistors, simplifies prototyping and assembly during the initial design stage. However, for larger scale production it would be necessary to transition to SMD components. A well-optimized PCB design ensures that components are logically and efficiently placed, minimizing assembly errors.
    - **Modular Design:** Critical parts, such as the battery or the USB connector, are easily replaceable, which ensures straightforward repairs or upgrades if needed. Additionally, the use of a JST connector allows for simple disconnection and reconnection without soldering, if needed.

2. <u>User Functionality</u>
    - **Dice Rolling Process:** The design provides a simple and intuitive interface by using only two buttons, one for selecting the dice and the other for rolling it. The user sees the both the selected dice and the generated number on the 7-segments displays, with multiplexing ensuring smooth digit transitions.
    - **Multi-Dice Compatibility:** The device supports multiple dice types, as required by the client, which increases the utility and appeal of the device.
    - **Portability:** The compact design ensured the dice is lightweight and easy to carry and the use of a rechargeable LiPo battery eliminates the need for

disposable ones, making it more user-friendly and environmentally sustainable.

- **Display Clarity:** The two displays provide bright and readable numbers even in low-light conditions.

3. Power Efficiency
   - **Battery Life:** The 3.7V 150mAh LiPo battery provides sufficient capacity for extended use, especially with the low-power ATMEGA328P-AU microcontroller. Efficient power management is achieved using the step-up voltage regulator to provide a stable 5V output, ensuring all components operate optimally without wasting energy.
   - **Charging Process:** The TP4057 charging IC allows the device to be conveniently recharged via a micro-USB port, ensuring ease of use and minimizing downtime.

4. Maintainability
   - **Repairability:** Key components like the LiPo battery and tactile switches are modular and can be easily replaced in case of failure.
   - **Software Updates:** The ATMEGA328P-AU can be reprogrammed via its ISP (In-System Programming) interface, enabling software updates or bug fixes without hardware changes.
   - **Component Durability:** High-quality components ensure long-term reliability.
5. Challenges and Risks
   - **Assembly Precision:** Implementing multiplexing requires precise wiring and logic to ensure functionality, given that errors during assembly could lead to display glitches.
   - **Power Optimization:** While the device is designed to efficient, real-world testing is required to validate the expected battery life under usage patterns.
   - **Size Constraints:** Assembling all components into the size requirements while maintaining functionality and durability require careful PCB design and component placement.

The design is operationally feasible, balancing ease of use, assembly simplicity, and portability. While challenges such as size constraints and power efficiency require testing and optimization, the design meets the project’s requirements and is well-suited for prototyping and eventual production.

Task 7: Detailed Design and Planning – Schematic Design

The electronic dice circuit is designed to generate random dice rolls and display the results on a dual 7-segment LED display. The design is divided into two main phases:

1. **Power Management Phase:** This phase handles the power input, battery charging, and voltage regulation to ensure a stable 5V supply for the circuit. It includes a micro-USB input, TP4057 battery charging IC, and LM2731 step-up voltage regulator.
2. **Control and Display Phase**: This phase consists of the ATMEGA328P microcontroller, tactile switches, and two 7-segment displays. The microcontroller handles user inputs from the switches to select dice types and roll numbers. It also manages the multiplexing and control of the 7-segment displays, ensuring the rolled number is clearly shown to the user.

Power Management Phase

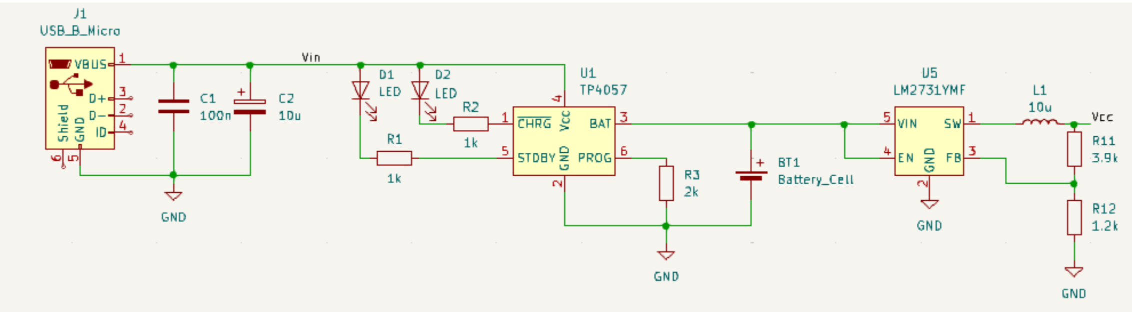

Figure 8. Power Management Phase Electric Scheme

In this section, the connections of each component in this phase will be explained in detail.

1. <u>Power Input (USB Connector)</u>
    - **Component: J1 (USB_B_Micro)**:
        - This connector provides power input to the system via a micro-USB port.
        - Pin 1 (VBUS): The power pin receives 5V from a standard USB source.
        - Pin 5 (GND): The ground connection.
    - **Capacitors:**
        - These are decoupling capacitors placed close to the USB connector to stabilize the input voltage and filter out noise.

    - C1 (100nF) handles high-frequency noise, while C2 (10µF) smooths out low-frequency fluctuations.

2. <u>Battery Charger TP4057 and Battery Cell</u>
   - **Charger IC: TP4057 (U1)**:
     - The TP4057 is a lithium-ion battery charging IC that ensures safe and efficient charging of the connected battery cell.
     - Pin 1 (CHRG): Connects to LED D1, which indicates charging status.
     - Pin 2 (STDBY): Connects to LED D2, which indicates when the charging is complete.
     - Pin 3 (PROG): Connected to resistor R3 (2kΩ), which sets the charging current, of approximately 500mA.
     - Pin 5 (BAT): Connected to the positive terminal of the battery.
     - Pin 6 (VIN): Receives the stabilized 5V from the USB input (Vin).
     - Pin 4 (GND): Ground connection for the charger circuit.
   - **Battery Cell (BT1):** A 3.7V lithium-ion battery is connected at this point, charged by the TP4057.

3. <u>Voltage Regulator</u>
   - **Voltage Regulator IC: LM2731YMF (U5)**:
     - This step-up voltage regulator increases the battery's 3.7V to a stable 5V output for the rest of the circuit.
     - Pin 5 (VIN): Accepts input voltage from the battery.
     - Pin 1 (EN): Enable pin is tied to VIN, ensuring the regulator is always on when the battery is connected.
     - Pin 3 (FB): Feedback pin connected to a resistor divider (R11 and R12) to set the output voltage, of 5V.
     - Pin 2 (SW): The switching output is connected to an inductor (L1) to boost the voltage.

Control and Display Phase

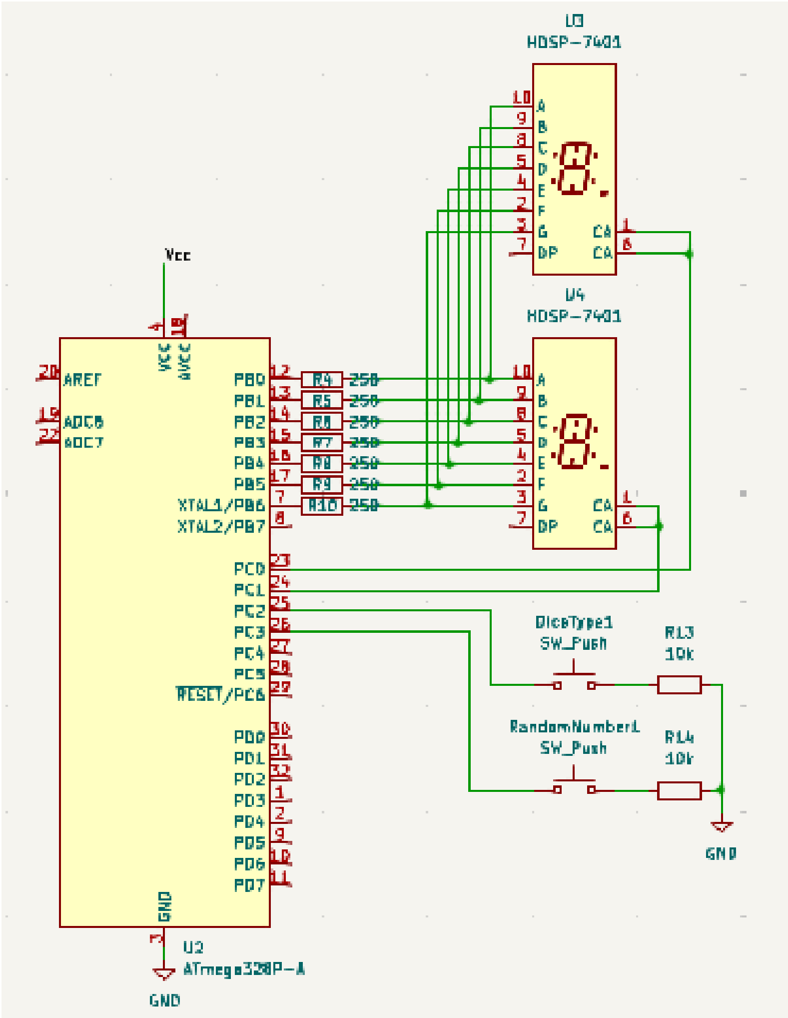

Figure 9. Control and Display Electric Scheme

In this section, the connections of each component in this phase will be explained in detail.

1. <u>Microcontroller: ATMEGA328P (U2)</u>
   - **Power Supply**:

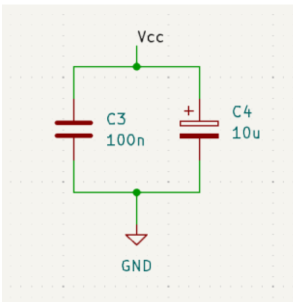

Figure 10. ATMEGA328P Power Supply

- Connected to Vcc with decoupling capacitors (C3 and C4) to stabilize the power supply and filter noise.

- The ground pin (GND) is connected to the circuit's common ground.
- **Connections:**
    - PB0–PB6 (Pins 12–18): Control the segments (A–G) of the two 7-segment displays.
    - PC0–PC1 (Pins 23, 24): Are used to multiplex the displays by activating the common cathode of each display (U3, U4) alternately.
    - PC2–PC3 (Pins 25, 26): Connected to the tactile switches for user input.

2. Tactile Switches
- **Dice Type Selection**:
    - Connected to PC2 of the microcontroller.
- **Dice Roll Switch**:
    - Connected to PC3 of the microcontroller.
- **Pull-Down Resistors**:
    - Each switch is connected to ground through pull-down resistors (R13 and R14).

3. 7-Segment Displays (U3, U4)
- **Display Type**:
    - Common cathode displays are used for showing two-digit dice roll results.
- **Segment Control (Pins A–G)**:
    - Each segment is connected to a GPIO pin of the microcontroller (PB0–PB6) through current-limiting resistors (R4–R10, 250Ω each).

Task 8: Detailed Design and Planning – PCB Design

The project has reached the PCB design stage, with a finalized layout that integrates all components and adheres to the project's compact size constraints. The PCB measures 38x48 mm, fitting the key-fob size requirement, while ensuring functionality, durability, and manufacturability.

Final PCB (All Layers)

The image below represents the completed PCB design, showing all layers and components. It includes:

- Front copper traces connecting components.
- Back copper traces for signal routing and ground planes.
- Placement of all components such as the microcontroller, resistors, capacitors, LEDs, switches, and 7-segment displays.

This view provides a complete picture of how the circuit is routed, ensures optimal space utilization within the small dimensions, and remarks the dimensions of the PCB.

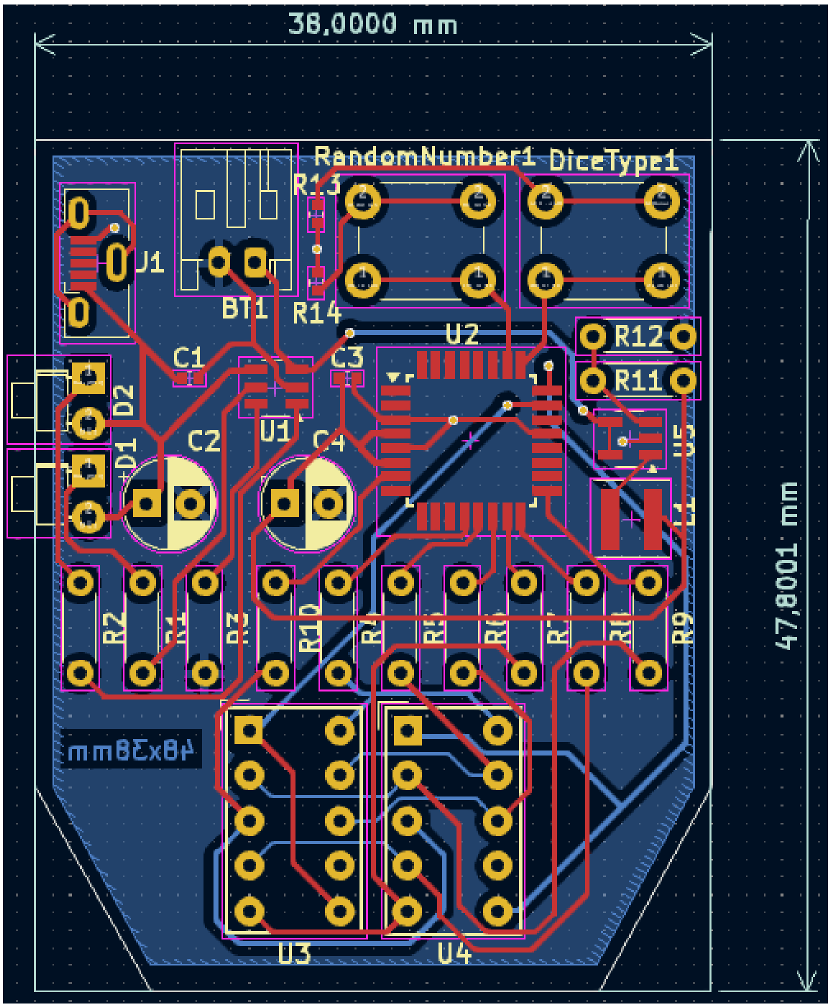

Figure 11. Electronic Dice PCB

Front Copper Layer

The second image highlights only the front copper layer, where most connections and signal routing occur. This layer focuses on:

- Power distribution from the battery and voltage regulator to components.
- Critical signal traces connecting the microcontroller to the 7-segment displays and switches.

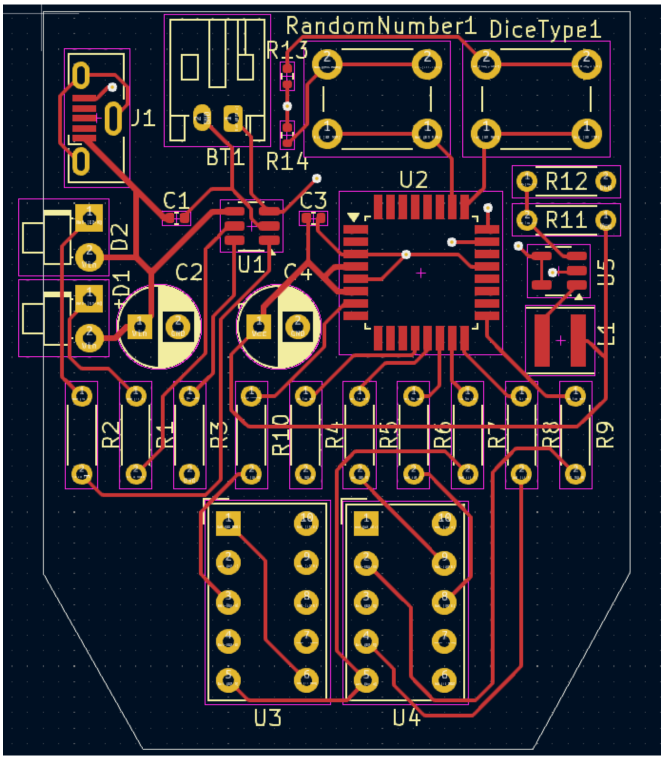

Figure 12. Front Copper Layer

Back Copper Layer

The third image isolates the back copper layer, primarily used for:

- Ground planes to reduce noise and stabilize the circuit.
- Supporting additional routing where space on the front layer is insufficient.

The inclusion of a back copper layer ensures a balanced and reliable PCB design, even with compact dimensions.

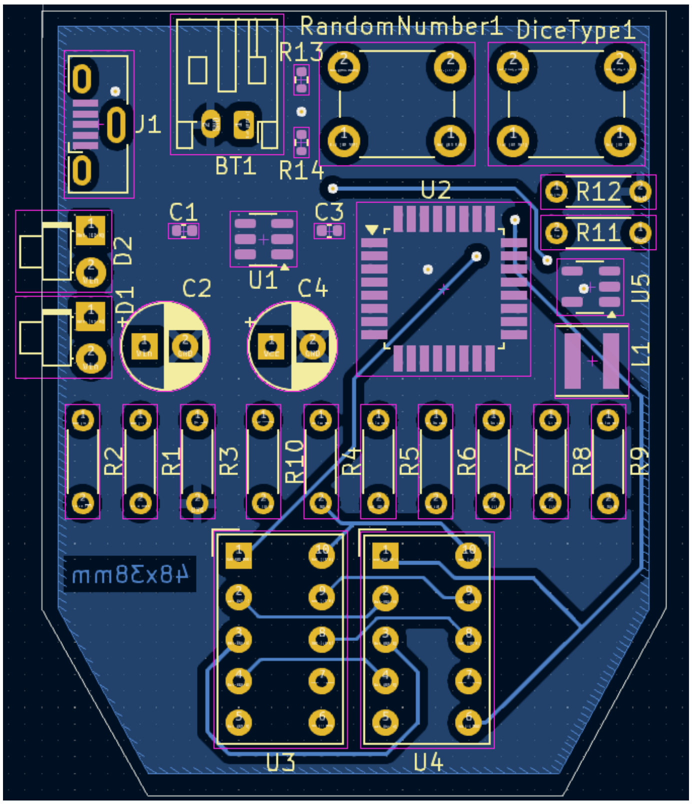

Figure 13. Back Copper Layer

3D View

The fourth image provides a 3D rendering of the assembled PCB, showcasing the layout and physical placement of components. Key features include:

- Two 7-segment displays prominently positioned for clear visibility.
- Tactile switches for user input, aligned at the top for ergonomic access.
- Microcontroller and other passive components efficiently placed to minimize trace lengths.

This visualization confirms the design's practicality and highlights the compact arrangement within the 38x48 mm footprint.

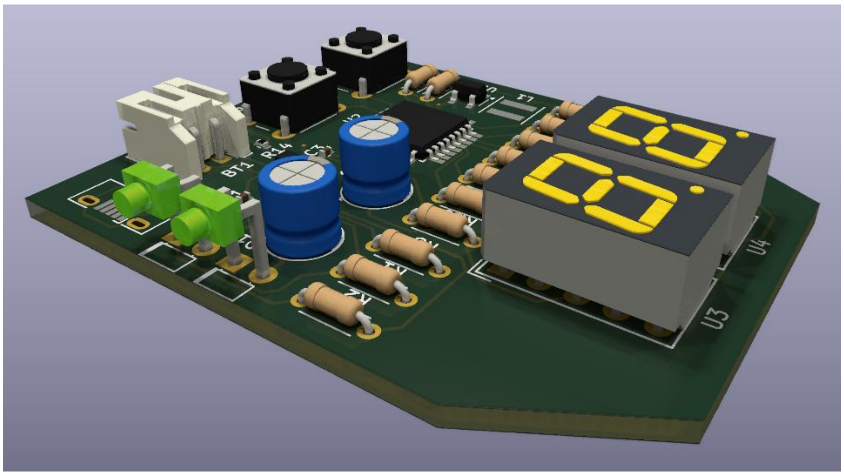

Figure 14. Electronic Dice PCB's 3D View

Task 9: Detailed Design and Planning – Material and Resource Planning

Using the approved seller's list from Task 2, I verified the availability of all components required for the electronic dice PCB design. Below is the finalized Bill of Materials (BoM), including each component's description, quantity, supplier, and total cost.

Product Name	Product Description	Distributor	Manufacturer	Cost (inc. VAT)	Quantity	Total
ATMEGA328P-AU	8-bit Microcontrollers - MCU 32KB In-system Flash 20MHz 1.8V-5.5V	Mouser Electronics	Microchip	£2.10	1	£2.10
7-segment (HDSP-513A)	LED Displays & Accessories Red 643nm 0.56in 7 Segment	Mouser Electronics	Broadcom Limited	£1.55	2	£3.10
250R Resistor (OK15G5E-R52)	Carbon Film Resistors - Through Hole 1.5 Ohm 1/4W 5% 250 Volt	Mouser Electronics	Ohmite	£0.09	7	£0.63
Tactile Switch (PHAP3344R)	Tactile Switches TACT SWITCH PCB MOUNT	Mouser Electronics	Apem	£0.32	2	£0.64
TP4057	SOT23-6 BATTERY MANAGEMENT ICS R	DigiKey	UMW	£0.42	1	£0.42
Usb B Micro (USB3080-30-00-A)	USB Connectors Micro B Skt, Bottom-SMT, R/A, 30u" NoPeg, W/shell stake, T&R	Mouser Electronics	GCT	£0.56	1	£0.56
JST-PH 2 Pin Connector (B2B-PH-K-S)	CONN HEADER VERT 2POS 2MM	DigiKey	JST Sales America Inc.	£0.16	1	£0.16
Led Charging (TLPR5600)	LED RED DIFF SIDE VIEW T/H R/A	DigiKey	Vishay Semiconductor Opto Division	£0.60	1	£0.60
Led Charged (TLPG5600)	LED GREEN DIFF SIDE VIEW T/H R/A	DigiKey	Vishay Semiconductor Opto Division	£0.60	1	£0.60
Ceramic Capacitor (CL05B103JB5NNND)	CAP CER 0.1UF 50V X7R 0402	DigiKey	Samsung Electro-Mechanics	£0.10	2	£0.20
Electrolytic Capacitor (865080642006)	CAP ALUM 10UF 20% 50V SMD	DigiKey	Würth Elektronik	£0.18	2	£0.36
1k Resistor (CF1/2CT52R102J)	RES 1K OHM 5% 1/2W AXIAL	DigiKey	KOA Speer Electronics, Inc.	£0.11	2	£0.22
2k Resistor (CF1/4CT52R202J)	RES 2K OHM 5% 1/4W AXIAL	DigiKey	KOA Speer Electronics, Inc.	£0.09	2	£0.18
Lipo Battery (M105318)	3.7V 150mAh LiPo battery.	Model Rockets	PKCell	£8.75	1	£8.75
Step-Up Voltage Regulator (LM2731YMF)	Switching Voltage Regulators 0.6/1.6 MHz Boost Converters With 22V Internal FET Switch in SOT-23 5-SOT-23 -40 to 125	Mouser Electronics	Texas Instruments	£3.02	1	£3.02
1.2k Resistor (CFM12JT1K20)	RES 1.2K OHM 5% 1/2W AXIAL	DigiKey	Stackpole Electronics Inc	£0.08	1	£0.08

3.9k Resistor (CF14JT3K90)	RES 3.9K OHM 5% 1/4W AXIAL	DigiKey	Stackpole Electronics Inc	£0.08	1	£0.08
SMD Power inductor (SRR1210-100M)	Power Inductors - SMD 10uH 20% SMD 1210	Mouser Electronics	Bourns	£0.96	1	£0.96
10k Resistor (MCT0603MD1052BP500)	Thin Film Resistors - SMD MCT 0603-25 0.1% AT P5 10K5	Mouser Electronics	Vishay / Beyschlag	£0.34	2	£0.68
				Total		**£23.34**

Table 4. Materials Needed

Observations

1. <u>Suppliers:</u>
    - Most components are sourced from Mouser Electronics and DigiKey due to their reliability and comprehensive selection.
    - The LiPo battery was sourced from Model Rockets, a trusted supplier for compact power sources.

2. <u>Availability:</u>
    - All components are available and compatible with the PCB design. There is no risk of delay due to unavailability.

3. <u>Cost Efficiency:</u>
    - The total cost is reasonable for a functional prototype, staying within budget constraints.

This finalized BoM ensures all necessary components are ready for assembly and testing.

Task 10: Field Ready Prototype and Testing and Evaluation

In this task, I focused on testing the electronic dice system through a simulated breadboard setup using software tools. This practical simulation allowed for evaluating the functionality of key components, such as the buttons, random number generation, and the display of results on the 7-segment displays. By conducting the tests in a simulated environment, potential issues in the design were identified and resolved without the need for a physical prototype. This simulation served as a crucial step in validating the logic and performance of the circuit, ensuring that the system meets the intended design requirements.

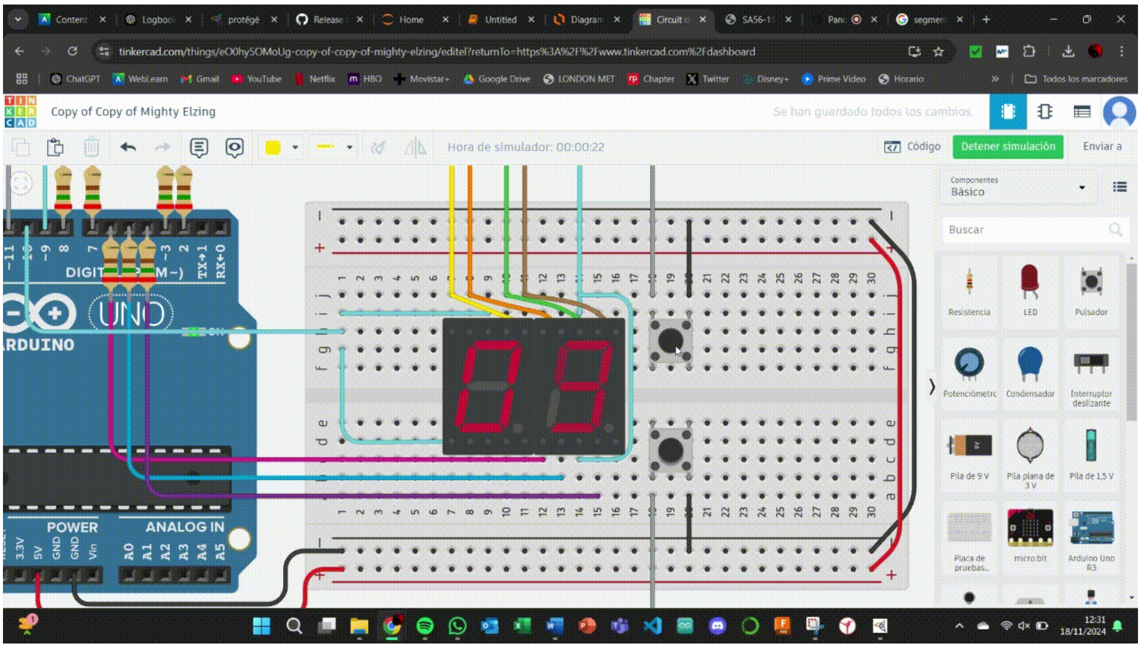

Figure 15. Field Ready Type Simulation

Task 11: Optimization and Improvement

The current design of the electronic dice meets the functional and size requirements, but there are several areas where it can be improved to enhance efficiency, size, and usability. Below are the proposed improvements:

Transition to SMD Components

One of the most effective ways to make the design smaller is by replacing through-hole components with Surface Mount Devices (SMD).

- Using SMD resistors and capacitors can significantly reduce the PCB size.
- Smaller components result in shorter traces, which improves signal integrity and reduces electromagnetic interference (EMI).

This change could potentially reduce the PCB dimensions below 38x48 mm, making the design more compact and portable.

Implement Sleep Mode

Currently, no sleep mode has been implemented, meaning the device will consume power continuously, even when idle. Adding a sleep mode could significantly improve battery life:

1. How to Implement:
    - Use the microcontroller's built-in sleep features to enter a low-power state when the device is inactive.
    - Wake the microcontroller only when a button press is detected.

2. Benefits:
   - Reduces power consumption during idle periods.
   - Extends the battery life, making the dice more energy-efficient and practical for long-term use.

Optimize Power Management

1. Current Design:
   - The step-up regulator (LM2731) ensures a stable 5V output but introduces inefficiency at low loads.

2. Proposed Improvement:
   - Consider switching to a more efficient regulator with a power saving mode or a buck-boost regulator to adapt to the varying load conditions of the dice.
   - Add a power switch to manually disconnect the battery when not in use.

Improve Display Brightness Control

The 7-segment displays are always powered at full brightness, which might be unnecessary in all lighting conditions.

- Implement PWM control for the displays to adjust brightness dynamically.
- Use a light-dependent resistor (LDR) to create an adaptive brightness feature based on ambient light.

Add sound feedback

A small piezo buzzer could provide an audible click or tone when the dice is rolled, improving the user experience.

Task 12: Design a 3D model case for the product

The case for the electronic dice has been designed with attention to detail to accommodate all components, ensure portability, and maintain durability. Below, the different perspectives of the design are analysed.

1. **Initial view with only visible edges**

This view highlights the basic shape and features of the case, including:

- Clean geometry with bevelled edges for a modern aesthetic.
- Two rectangular cutouts on the top for the dual 7-segment displays and the tactile switches.
- A dedicated compartment to store the battery, which includes a removable cover for easy access.
- Lateral holes for the USB connector, and the two LEDs.

- Legs so that the case can be standing on any plain surface.
- A compact design that prioritizes functionality while keeping the overall footprint minimal.

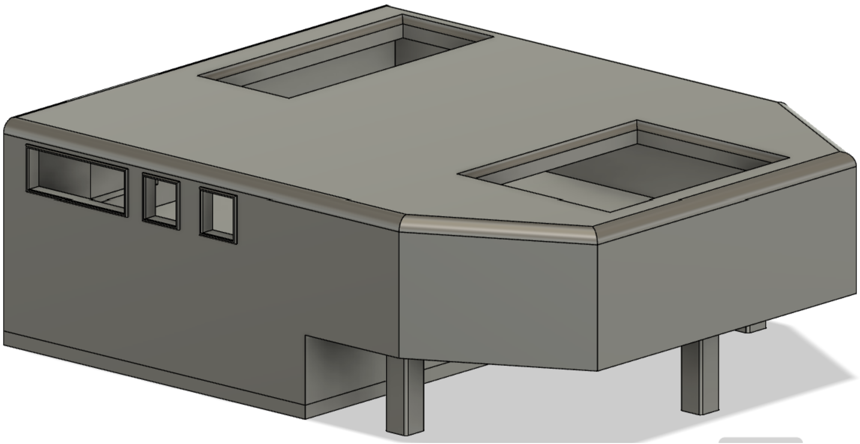

Figure 16. Electronic Dice's Case

2. **Initial view with all edges**

This transparent view allows the internal structure to be seen:

- Internal Component Layout: The positions of internal supports and mounting structures for the PCB and components are clearly visible.
- Precision Cutouts: Openings for the USB port, tactile switches, and other components are visible and aligned with their respective functionalities.

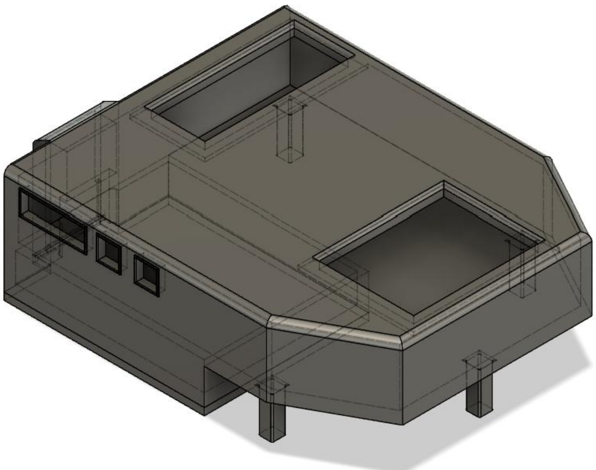

Figure 17. Case With All Edges Visible

3. **Frontal view**

The frontal view shows:

- The two cutouts for the 7-segment displays and the tactile switches, ensuring they are flush with the surface for clear visibility.
- A smooth, symmetrical design that maintains simplicity and ease of use.

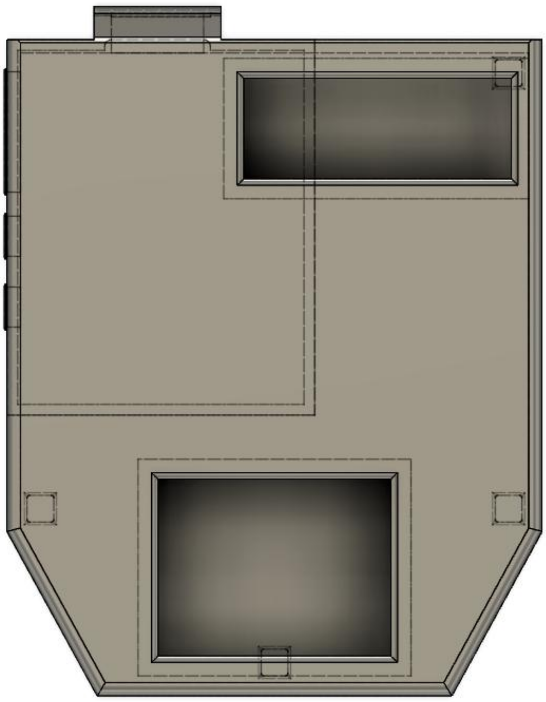

Figure 18. Frontal View

4. **Top rear corner view**

This perspective provides insight into:

- The angular design of the rear section, which accommodates the LiPo battery.
- Additional mounting posts and structural elements that reinforce the case for durability and equilibrium.

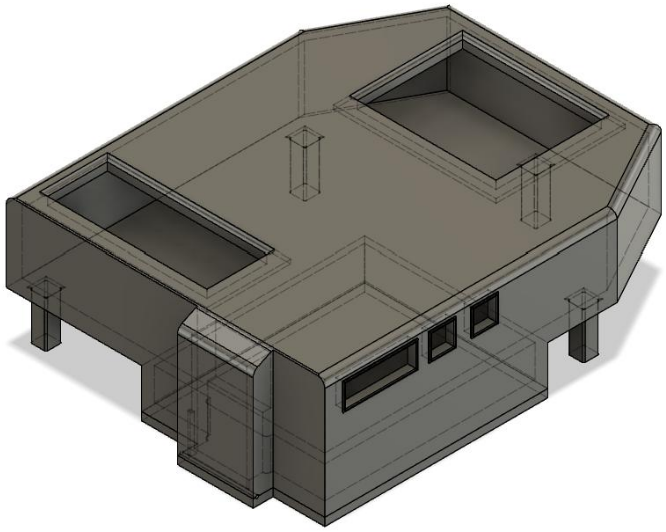

Figure 19. Top Rear Corner View

5. **Top schematic with dimensions**

This schematic provides precise measurements of the case:

- Overall Dimensions: The case measures 40.2 mm x 51.5 mm, ensuring it remains compact and portable.

- Cutout Sizes: Detailed dimensions for the 7-segment display cutouts and side openings show careful planning for component placement.

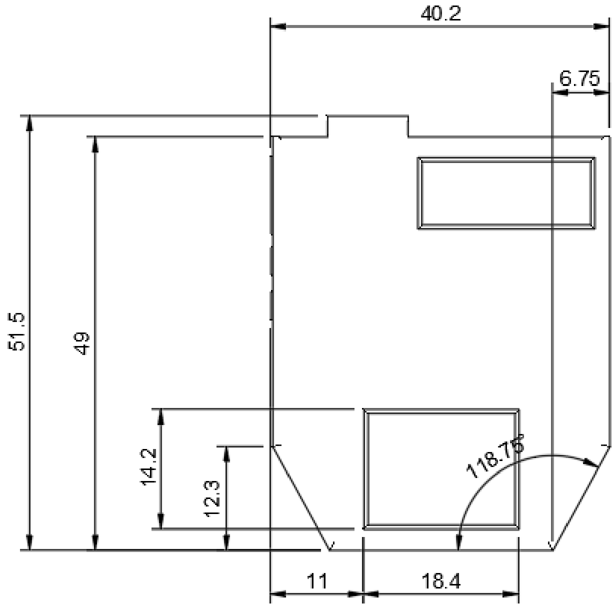

Figure 20. Top Schematic

6. Frontal and right-side schematic with dimensions

This view offers a detailed look at:

- The height of the case (16 mm), ensuring sufficient clearance for internal components.

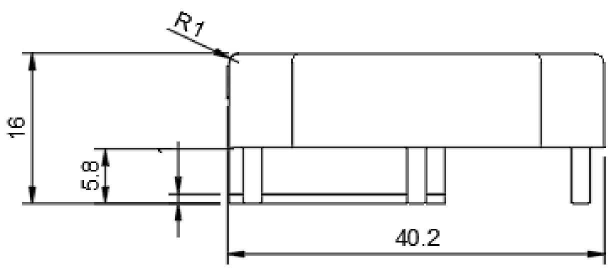

Figure 21. Frontal Scheme

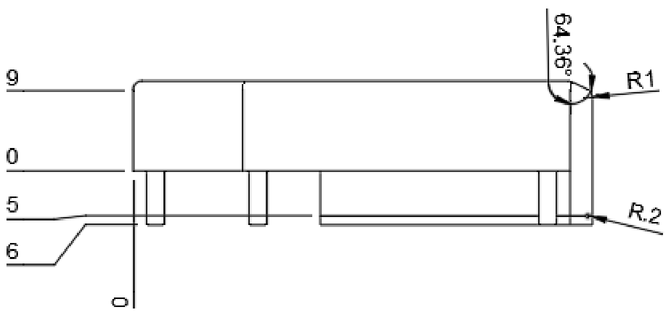

Figure 22. Right-Side Schematic