Department of Electronic & Telecommunication Engineering
University of Moratuwa

EN2160 - Electronic Design Realization

Report 01
Application of the Design Methodology

Torque Sensor

Group No. 17

AMARATHUNGA D.N.	210037G
PASIRA I.P.M.	210446J

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1 Introduction

A torque sensor is a critical component in collaborative robotics, enhancing the ability of robots to interact safely and effectively with humans in shared workspaces. Collaborative robots, or cobots, are designed to work alongside humans, assisting them in various tasks. Our goal is to develop a torque sensor that combines cost-effectiveness with a high level of accuracy. Below is a comprehensive explanation of our project plan, the approach we expect to follow, and the existing products in the market that adopt a similar approach.

2 Review Progress

2.1 Existing Products in the Market

There are two main types of torque sensors in the market based on the physical configuration:

1. **Shaft torque sensors:**

   Shaft torque sensors are typically separate units attached externally to the system that measure torque using the shaft's rotation. These sensors are typically configured as a cylindrical or tubular structure that wraps around the shaft. They feature a compact and robust design, often constructed from durable materials such as stainless steel or aluminum. This physical configuration allows the sensor to accurately detect and measure torque as the shaft rotates, providing valuable insights into the performance and operation of rotating machinery and equipment.

   Measuring Torque with a Shaft Torque Sensor

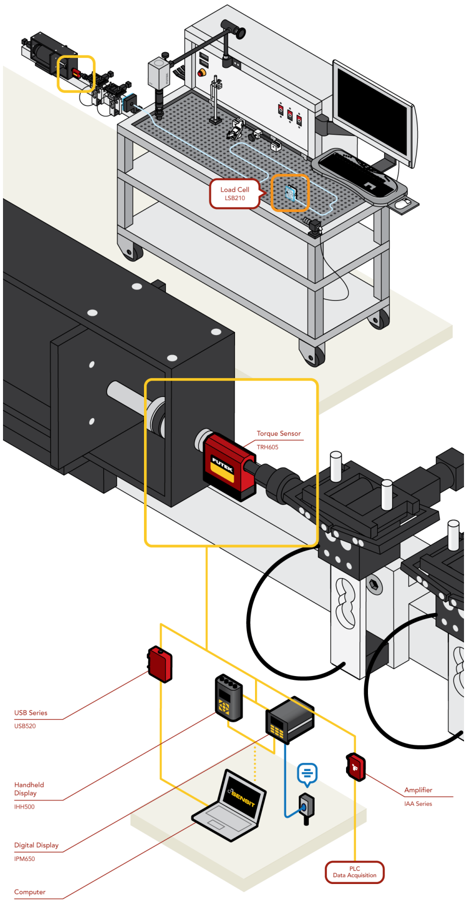
   Measuring Tool's Torque Output

Figure 1: Shaft Torque Sensor

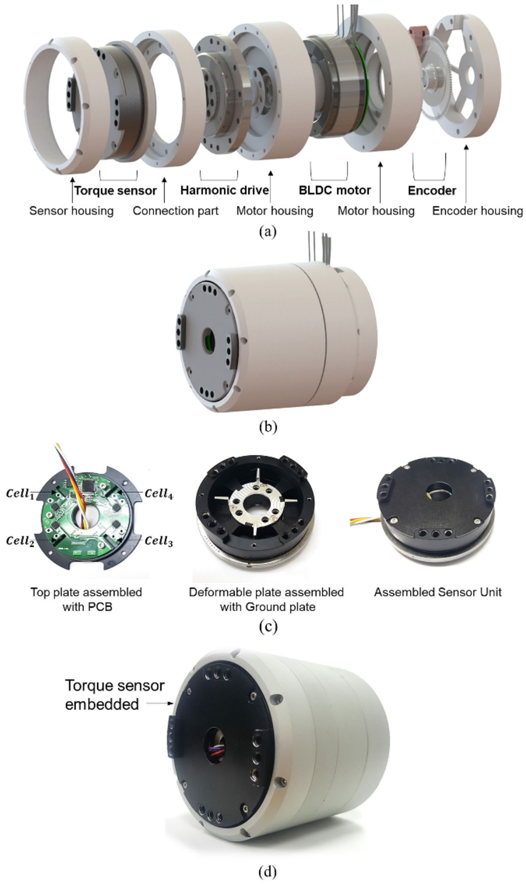
2. **Embedded torque sensors:**

   Embedded torque sensors are integrated directly within the system or component itself, provide accurate torque measurement without the need for external attachments. These sensors are securely mounted within the motor's housing or components, ensuring proper alignment and stability during operation. The sensor element, whether based on strain gauges, magnetoelastic materials, or other sensing technologies, is embedded within the motor's structure to accurately detect torque without interfering with the motor's performance.

   Use of Embbeded Torque Sensors



(a) Shaft Torque Sensor Applications: Catheter Torque Test



(b) Embedded Torque Sensors

2.1.1 Various Types of Torque Sensors and Manufacturing Companies

1. **FUTEK torque sensors**

   FUTEK's Hex Drive Rotary Torque Sensor offers a unique solution for torque auditing applications. The TRH300 Rotary Torque Sensor - Hex Drive is available in a wide capacity range and utilizes strain gauge technology.

   - Torque sensor type: Rotary
   - Torque Capacity: 2 N/m, 6 N/m, 12 N/m, 20 N/m
   - Max Operating Temp: 50.004 C

   FUTEK Shaft Rotary Torque Sensor

Figure 3: TRH300 Slip-Ring Hex-Drive Rotary Torque Sensor—FUTEK

2. **TE CONNECTIVITY torque sensors**
    - Tailored for diverse applications: torque measurement in non-rotating parts, process control equipment, robotics and effectors, laboratory and research settings, and test and measurement scenarios.
    - Compact yet robust contactless torque sensors designed for reliability in industrial and laboratory environments, featuring multiple mounting configurations.
    - Extensive range of rotary torque sensors equipped with stainless steel housings and mechanical stops, enhancing overload protection for various applications.
    - Static torque sensors crafted for measuring reaction torque, utilizing bonded foil strain gages to ensure excellent temperature stability. Measurement ranges extend up to 8,000 lbf-ft.
    - High-level outputs available, ensuring accurate and reliable torque data across a broad spectrum of operational requirements.

(a) TE CONNECTIVITY

(b) RFT80-6A02

3. **Robotous torque sensors**
Robotous 6-axis force torque sensor comes in all shapes and sizes to better suit the needs. The users can also get a custom-built model specifically designed for you that will fit your machine like a glove. This expert-approved 6-axis force torque sensor has indefinite applications of uses in diverse fields and industries, e.g. Medical, Engineering, Military, Pharmaceutical, etc. Robotous 6-axis force torque sensor is designed to work with most of the robot arms or other types of collaborative robots in the current market without any prior modification.

2.2 Industrial Applications

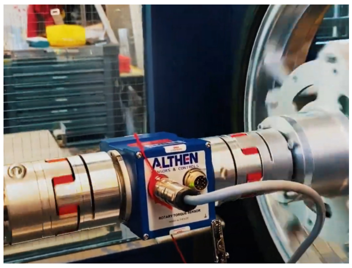
1. **Automotive Industry:**

   The automotive industry relies on rigorous testing across various components to ensure optimal performance and reliability. Engine testing assesses performance, tuning, and durability, while transmission testing monitors torque transfer efficiency and identifies gear issues. Drive train analysis evaluates component performance, distributes torque efficiently, and pinpoints sources of noise and vibration. Chassis dynamometer testing measures vehicle torque and power output for performance verification and emissions compliance.

   Torque sensor for Eco Runner Delft by althen Sensors and controlls

   - Torque sensors measure the rotational force (torque) applied to the drivetrain. By combining torque measurements with rotational speed (RPM), engineers can calculate the power output of the vehicle's motor or engine.
   - By comparing the power input (energy supplied to the motor) with the power output (measured using torque sensors), engineers can determine the efficiency of the motor and drivetrain. This helps in identifying losses and areas for improvement.
   - Real-time torque measurements allow for fine-tuning of the motor's performance. By analyzing torque data, engineers can optimize the vehicle's operation for different driving conditions, enhancing overall efficiency.
   - Torque sensors help in testing and validating different components like motors, gearboxes, and wheels. Ensuring each part operates efficiently contributes to the overall efficiency of the Eco Runner Delft vehicle.
   - Continuous monitoring of torque during vehicle operation provides valuable data for post-race analysis. This data helps in making informed decisions for future design improvements and optimizations.

(a) Eco Runner



(b) Torque Sensor

2. **Manufacturing and Automation Industry:**

   Torque Sensors in Screwdriving & Fastening Systems at stoeger automation

   - Utilize the DMS principle (strain gauge) for precise measurements.
   - Enhances durability by preventing wear and tear.
   - Positioned under the motor of hand-held or automatic screwdrivers to measure torque and rotation angle.
   - Maintains long-term reliability by operating without physical contact.
   - Allows for two sensors in series for increased reliability in critical applications.

   Torque sensors for Screw driving

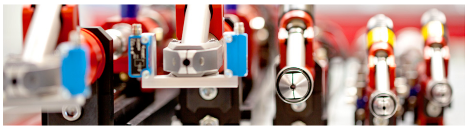


Figure 6: Screwdriving Fastening Systems

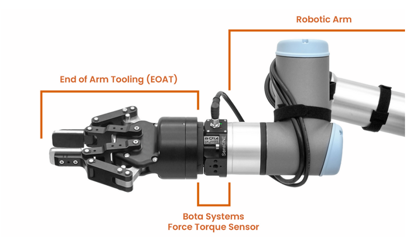
3. **Aerospace:**

   Torque sensors play a pivotal role in the rigorous efficiency testing of aircraft hydraulic systems before component installation. These sensors monitor the torque generated by hydraulic pumps, motors, and other critical components such as valves and cylinders. They ensure that each part meets stringent standards for mechanical efficiency, pressure, and flow capacity. Torque measurements also aid in fine-tuning load sensing capabilities and setting compensator pressures accurately. By detecting anomalies like leaks or improper assembly through torque data, engineers can preemptively address issues, ensuring optimal performance and reliability of the hydraulic systems in aviation operations.

4. **Industrial Robotics:**

   In industrial robotics, torque sensors are essential for ensuring precise and controlled movement of robotic arms and manipulators. They enable robots to perform delicate tasks with accuracy and efficiency, such as assembly, welding, painting, and material handling. Torque sensors provide feedback on the torque exerted by robotic actuators, allowing for real-time adjustments to maintain optimal performance and safety.

   You Tube SensONE 6-Axis Force Torque Sensor for Cobots



(a) Torque Sensors in a Robot Arm

(b) Pharmaceutical Bottle Capping

5. **Medical Devices:**

   Torque sensors are used in the manufacturing of prosthetic limbs, surgical instruments, dental equipment, and diagnostic devices.

   New torque sensor application by Original Equipment Manufacturers (OEMs) for pharmaceutical bottle capping

   - Approach: Digital rotary strain gauge sensors
   - Ensures caps are tightened within exact tolerances to maintain product integrity and compliance with regulations
   - Provides immediate feedback on torque values for each cap to ensure consistency and quality.
   - Supports high-speed capping (one bottle per second), crucial for meeting production targets.

   Torque sensors for pharmaceutical OEM

2.3 Various approches used in torque sensors

There are two common ways to measure the torque:

1. **Reaction Torque Sensors:**

   A reaction torque sensor measures the rotational force exerted on a stationary part by a rotating component during power delivery or absorption. It detects torque when the load source remains rigid while the drive source attempts to rotate.

2. **Rotary Torque Sensors:**

   Rotary torque sensors resemble reaction torque sensors in design and usage. Unlike reaction torque sensors, which measure torque on stationary parts, rotary torque sensors are aligned with the rotating element to directly capture the torque. Given that the shaft of a rotary torque sensor rotates fully, these sensors necessitate a method to transmit signals from the rotating element to a stationary surface.

2.3.1 Strain Gauge-Based Approach

This method involves the use of strain gauges attached to a material that deforms under the influence of torque. As the material experiences torque, its shape changes, causing strain in the attached gauges. The strain gauges then produce electrical signals proportional to the torque applied. This approach is widely used in the construction of torque sensors and offers good accuracy and sensitivity.

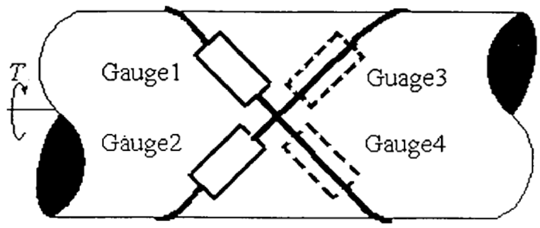


Figure 8: Strain Gauge Method

The following are the methodologies utilized for designing a rotary torque sensor based on strain gauges.

Advantages:

- High Accuracy
- Compact Size
- Capable of measuring rapid changes in torque

Disadvantages:

- Regular calibration is necessary to maintain accuracy
- Strain gauges can be affected by temperature changes, humidity, and other environmental factors
- Electrical Interference

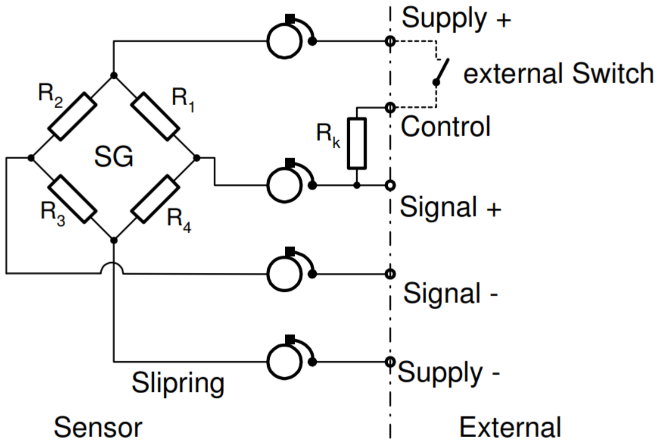


Figure 9: Slip Ring Method

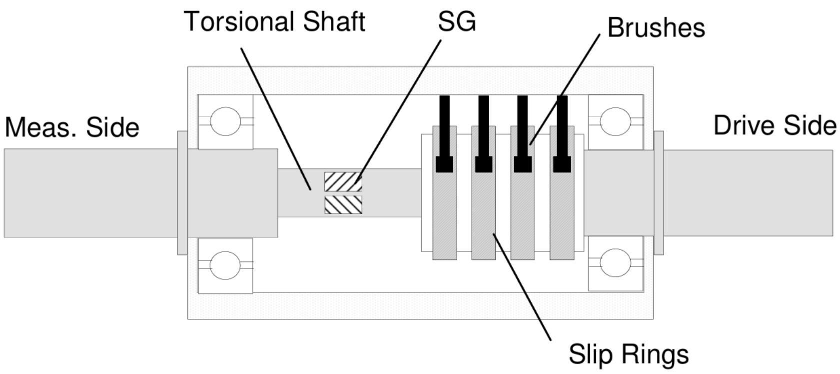


Figure 10: Slip Rings attached on the shaft

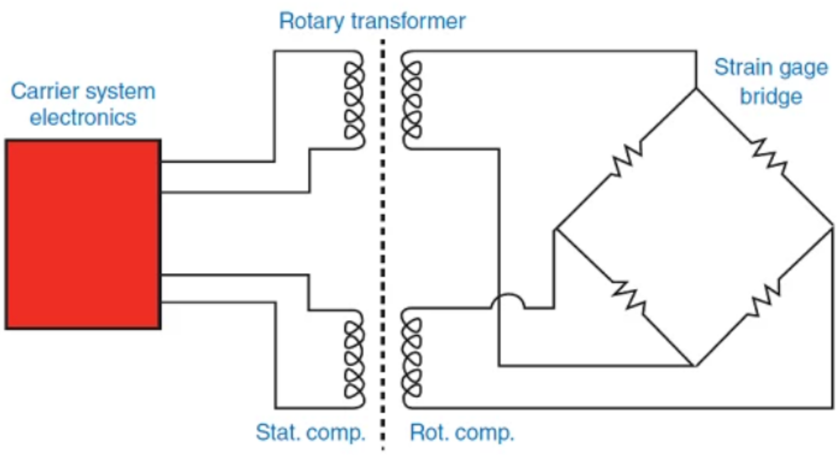


Figure 11: Rotary Transformer Method

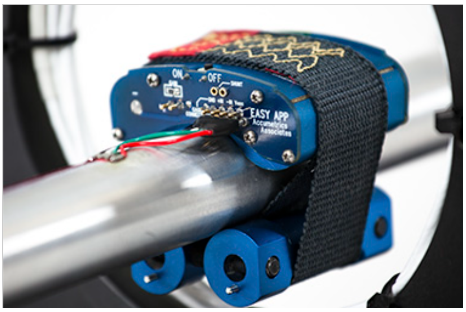
1. **Slip Ring Method:** The slip ring method involves connecting the strain gauge bridge to four silver slip rings mounted on the rotating shaft. Silver graphite brushes provide electrical contact with the slip rings, allowing for the transmission of both excitation voltage and signal output. This method enables the use of either AC or DC excitation for the strain gauge bridge.

2. **Rotary Transformer Method:** In the rotary transformer method, rotating transformers are used to transmit excitation voltage to the strain gauge bridge and transfer the signal output to the non-rotating part of the transducer. This approach replaces the need for slip rings by using two transformers, eliminating the requirement for direct contact between the rotating and stationary elements of the transducer.

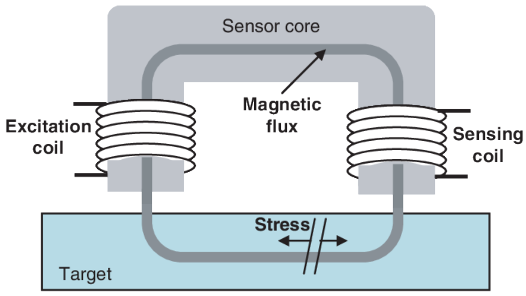
3. **Digital Telemetry Method:**

   The digital telemetry method utilizes a wireless approach with no physical contact points. It consists of a transmitter module integrated into the torque sensor, which amplifies, digitizes, and modulates the sensor signal onto a radio frequency carrier wave. This signal is then picked up by a receiver module via a caliper coupling, and the digital measurement data is recovered by a signal processing module.

   You Tube Battery Powered Telemetry System



(a) Digital Telemetry Method



(b) Magnetostrictive Torque Sensor Method

2.3.2 Magnetic-Field-Based Approach

Torque sensors using magnetic-field-based approaches often employ magnetoelastic or magnetostrictive principles. In magnetoelastic torque sensors, a ferrous core undergoes deformation when subjected to torque, altering its magnetic properties. This change is detected by magnetic sensors. Magnetostrictive torque sensors operate based on the magnetostrictive effect, where certain materials change shape in response to a magnetic field.

Advantages:

- Non-Contact Measurement
- High Durability

Disadvantages:

- Sensitivity to Magnetic Interference
- Temperature Sensitivity
- Magnetic field torque sensors can have a limited range of measurement
- Magnetic sensors can experience drift in their readings over time due to changes in the magnetic properties of materials

2.3.3 Optical Encoder-Based Approach

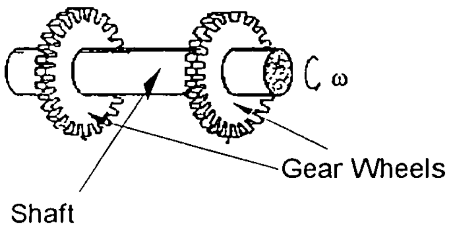
Optical encoders utilize light patterns to measure the displacement or rotation of a shaft, providing information about the applied torque. By analyzing the changes in light patterns as the shaft twists, the encoder can determine the torque. This approach is known for its precision and reliability, making it suitable for applications where accuracy is critical. However, optical encoders may be sensitive to environmental conditions such as dust or vibrations.

Advantages:

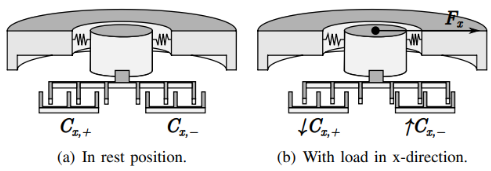
- Capable of operating at high speeds
- Non-Contact Measurement

Disadvantages::

- Optical encoders can be affected by extreme temperatures. High temperatures can degrade the optical components
- Misalignment due to mechanical stress, installation errors, or wear and tear can lead to inaccurate torque measurements.
- Optical encoders rely on light passing through or reflecting off a coded disk, making them highly susceptible to dust, dirt, oil, and other contaminants



(a) Optical Encoder Method



(b) Capacitive Method

2.3.4 Capacitive Torque Sensor Approach

Capacitive torque sensors operate based on changes in capacitance caused by the application of torque. In a capacitive torque sensor, there are typically two plates separated by a small gap. When torque is applied, it causes one of the plates to rotate relative to the other, changing the gap between them. This change in the gap between the plates alters the capacitance of the sensor. The capacitance is inversely proportional to the distance between the plates.

Torque sensors play a pivotal role in diverse applications across various industries, providing crucial data on rotational forces and enabling enhanced precision, safety, and control. Here are some applications of torque sensors.

Advantages:

- High Sensitivity
- Non-Contact Measurement

Disadvantages:

- Sensitivity to Environmental Factors
- Limited Overload Capacity
- High Cost
- Over time, capacitive sensors may experience drift in their output

3 Identification of Stake Holders

The stakeholder plan for our torque sensor project is designed to systematically identify, engage, and manage the various entities that have an interest in the development, implementation, and operation of the torque sensor. Primary stakeholders, such as the Design and Development Team, Manufacturing Team, Maintenance and Support Team, and End-users (Operators), are recognized for their critical roles.

Owners of factories and companies that rely on machinery, such as those producing cars or food, would be interested in acquiring our torque sensor. Our torque sensor is designed to enhance the performance of machinery, offering a significant advantage to companies that rely on precise control of rotational forces.

Secondary stakeholders, including Regulatory Authorities (Government) and Suppliers, are acknowledged for their influence on the project. Our primary suppliers are closely linked to the production of sensors and microcontrollers. These key partners play a vital role in providing the essential components needed for our torque sensor. By collaborating with suppliers specialized in sensor technology and microcontroller manufacturing, we can ensure the reliability and quality of our final torque sensor products.

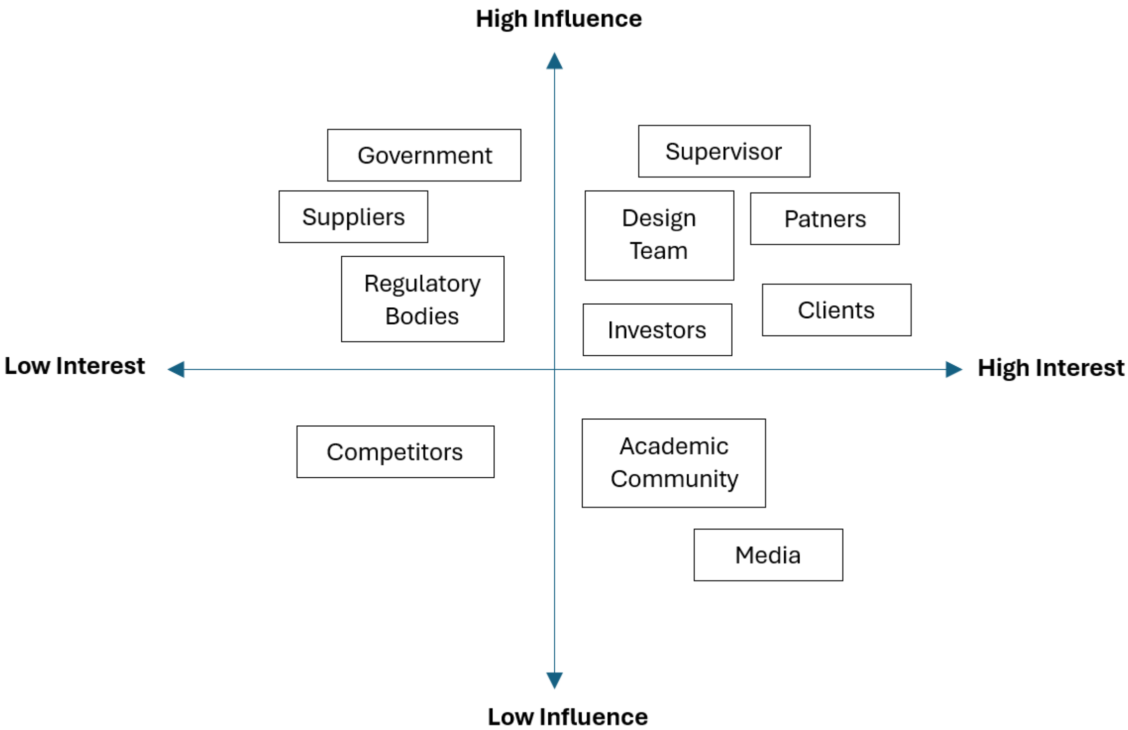


Figure 14: Stakeholder Map

4 Observe Users

User observation serves as a vital methodology in understanding the intricacies of product interaction and usage patterns. By directly observing how users engage with a product or service, valuable insights are gained into their behaviors, preferences, and pain points. This method allows for a deeper understanding of user needs. By observing users, and existing products in the market we identified the characteristics of existing torque sensors and pinpointed areas for further improvement. During our user observation, several key points emerged.

1. **Accuracy and Precision:** Precision in torque measurements is especially critical for users in car manufacturing and aerospace industries due to the importance of safety.

    - Improperly tightened bolts or fasteners due to inaccurate torque readings can lead to mechanical failures.

    The popular existing market products have accuracy values of approximately 0.3%, 0.5%.

2. **Size and Weight:** Having compact and lightweight torque sensors is essential, particularly for applications in robotics and portable devices.

    - Bulky sensors can restrict the range of motion and flexibility of robotic arms.
    - Larger sensors may require more power to operate, leading to increased energy consumption.
    - Inside machines or small robotic workspaces, bulky sensors may not fit properly.

    We found that the existing market offers torque sensors that typically start from approximately 3 cm in length and weigh around 50 grams.

3. **Ease of Integration:** We learned that torque sensors need to be easily integrated into existing systems without causing disruptions. Having standardized mounting options and interfaces can simplify this process across different industries.

4. **Cost-effectiveness:** We discovered the importance of balancing quality with affordability. Enterprises are seeking dependable torque sensors that offer cost-effectiveness, particularly within sectors such as manufacturing and electronics. Every torque sensor we found was prohibitively expensive, with prices starting at approximately 100,000 LKR each. .

5 Need List

1. **Accuracy:** As sensitivity in torque measurement is crucial for ensuring the reliability and effectiveness of the sensor we need high precision and sensitive sensor material. So that our sensor can consistently provide accurate torque measurements across a wide range of operating conditions.

2. **Cost-Effectiveness:** As cost-effectiveness is also a key consideration for users we need simple mechanical system to transfer torque measurement and low cost sensing component to sense the torque. So that our sensor solution remains affordable, making it accessible to a wider range of users and applications.

3. **Range:** As We require a torque range of up to 100 Nm. Consequently, we need a mechanical system capable of withstanding and accurately measuring this level of torque. So that we find torque levels up top 100Nm.

4. **Sensitivity** As we require a torque measurement resolution of 0.004 Nm(smallest measurement), we need a sensing material with high sensitivity. So that we can ensure measuring torque with excellent precision and accuracy.

5. **Overload capacity** As we need a mechanical system capable of handling 300 Nm of torque. To achieve this, we need require robust materials for the mechanical components, so that torque sensor can measure high torque levels without damage.

6. **Dimension and Weight:** As we require a system that is compact and easy to manage. We need the circuitry and mechanical components to be small and simple, so that it allowing us to create a torque sensor that is user-friendly and easy to handle.

6 Stimulate Ideas

We generated new and creative concepts, through brainstorming and other techniques. Any model that can accurately measure the relative displacement or twist of a shaft can be used to measure torque. The fundamental principle is that the torque applied to a shaft causes it to twist, and this twist can be measured as a relative displacement between two points along the shaft. Here is the initial concept we developed.

An optical encoder torque sensor with two disk patterns enhances measurement accuracy and functionality by using two distinct optical encoder disks. The two disks are mounted on the shaft with a small angular offset. As torque is applied, the shaft twists slightly, causing a relative displacement between the disks. This displacement is proportional to the applied torque. Each disk modulates its respective light beam, and the photodetectors convert these modulated light signals into electrical signals. By comparing the signals from the two disks, the system can determine the relative displacement caused by the torque.

The capacitive method for torque sensing relies on variations in capacitance to measure torque. In this method, torque sensors consist of two sets of conductive plates, typically arranged in a stationary and a rotating part, separated by a non-conductive material. When torque is applied, causing deformation or rotation, the distance between these plates changes, altering the capacitance between them. This change in capacitance is directly proportional to the applied torque, allowing for accurate torque measurement.

We propose integrating a dielectric material with higher permittivity between the conductive plates to enhance sensitivity and precision in torque sensing. This simple yet effective improvement amplifies the capacitance changes induced by torque, enabling the sensor to detect and measure torque variations more accurately.

Additionally, we've discovered and devised strategies for transferring signals from a rotating shaft to a stationary printed circuit board (PCB)

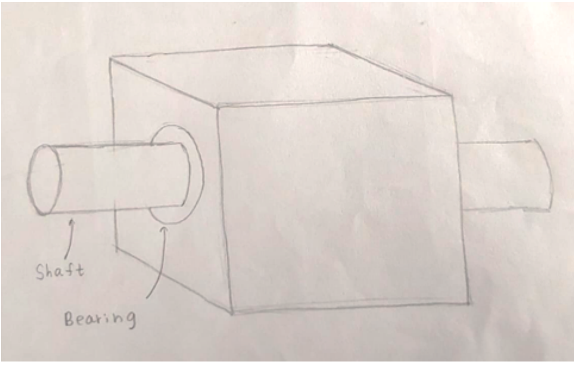
One of that strategy is use of digital telemetry to wirelessly transmit signals from torque sensors, enabling real-time data transfer without the need for physical connections. This approach typically involves integrating digital telemetry modules directly into torque sensors, allowing them to convert analog torque signals into digital data packets. These digital data packets are then wirelessly transmitted using radio frequency (RF) or other communication protocols to a receiver unit situated at a fixed location. The receiver unit captures the transmitted data, decodes it, and forwards it to a central processing unit or data logging system for further analysis.

7 Conceptual Designs

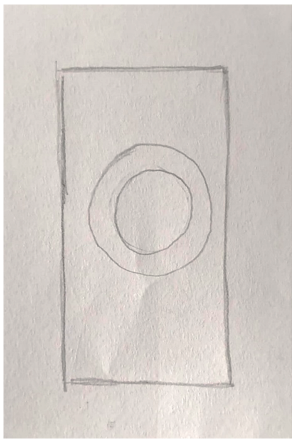
Considering both the user requirements we targeted and the ideas we developed, we have formulated the following conceptual designs.

7.1 Conceptual Design 1

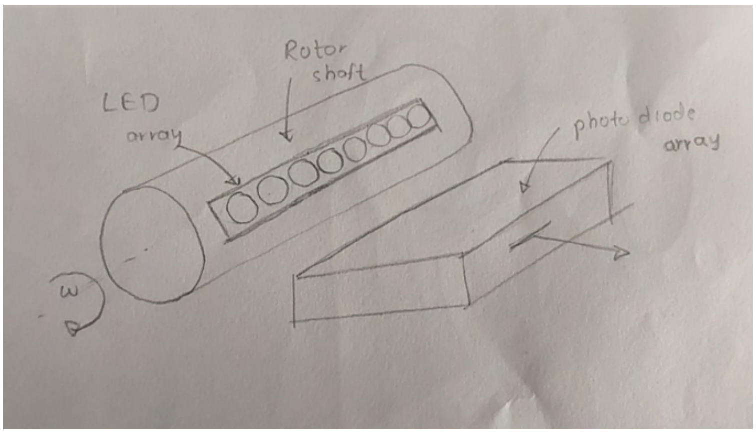
A rotary torque sensor employing strain gauges and slip rings operates by measuring the deformation experienced by the rotating shaft under torque. Strain gauges, arranged in a Wheatstone bridge configuration, detect this deformation by changing their electrical resistance, generating a proportional electrical signal. Slip rings enable the transfer of this signal from the rotating shaft to stationary components for processing. After amplification and conditioning, the signal provides an accurate measurement of the applied torque.



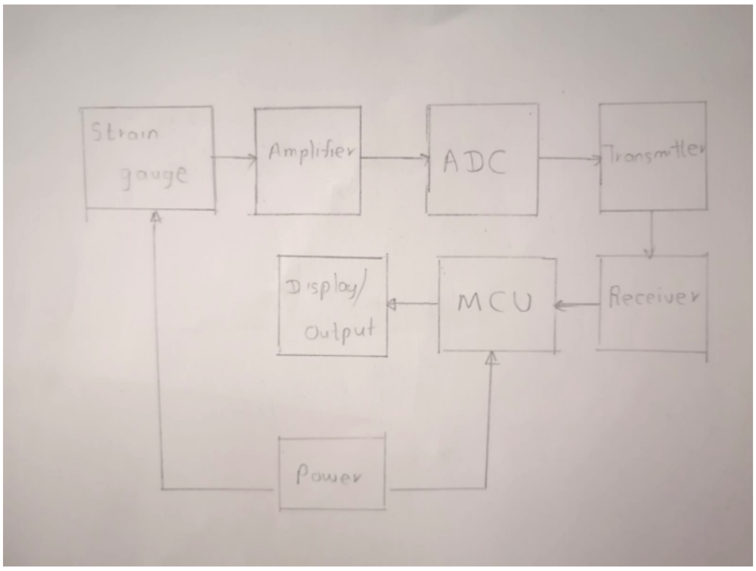
(a) Front View



(b) Side View



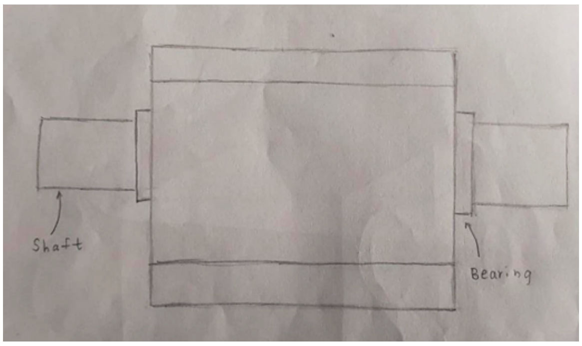
(c) Shaft Design



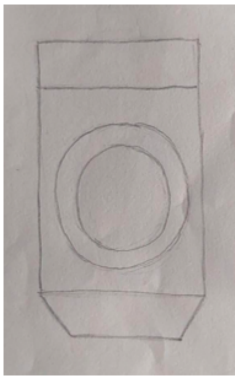
(d) Block Diagram

Figure 15: Conceptual Design 1

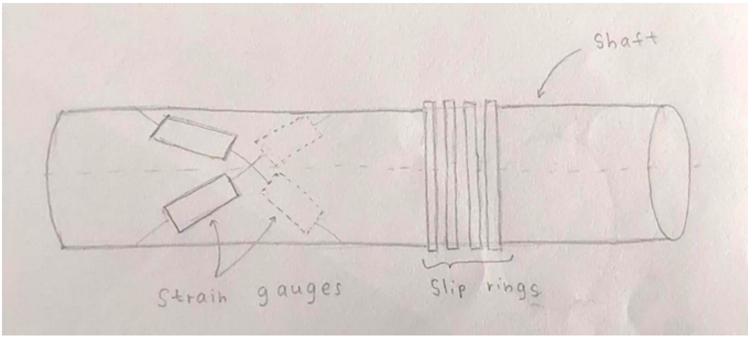
7.2 Conceptual Design 2



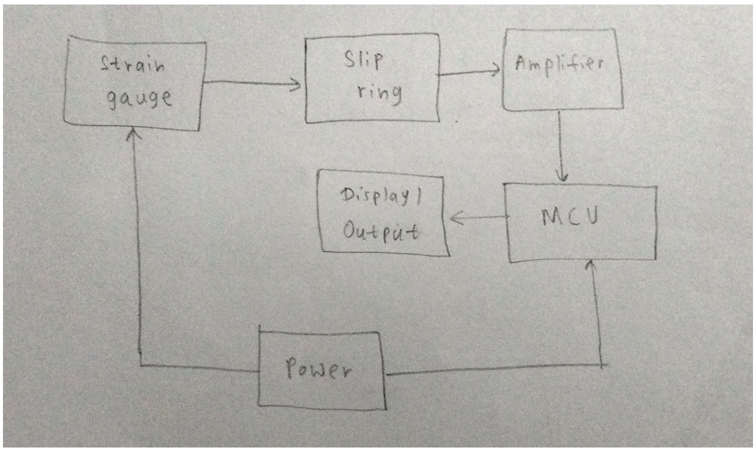
(a) Front View



(b) Side View



(c) Shaft Design

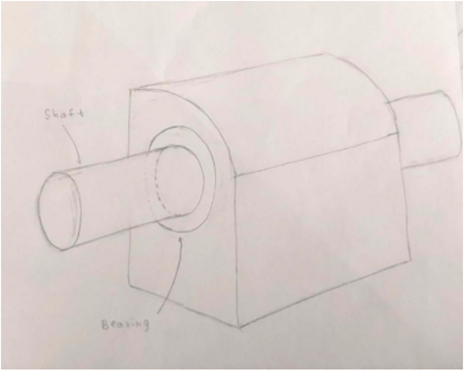


(d) Block Diagram

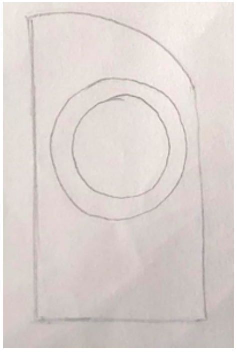
Figure 16: Conceptual Design 2

As torque is applied to the shaft, strain gauges detect the resulting deformation, altering their electrical resistance. This change is converted into an electrical signal that is then transmitted wirelessly using the transmitter. The receiver, located in the stationary part of the sensor system, captures the transmitted signal, allowing the extraction of torque-induced data without the need for physical contact between rotating and stationary components. After the signal is amplified, it provides a reliable measurement of the applied torque.

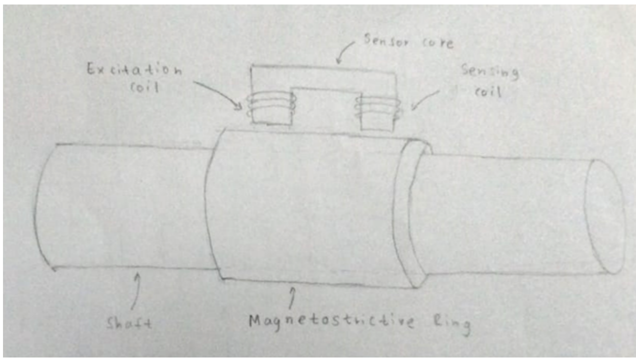
7.3 Conceptual Design 3



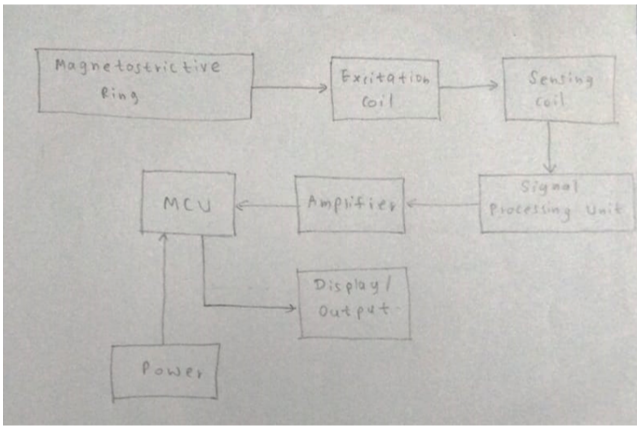
(a) Front View



(b) Side View



(c) Shaft Design



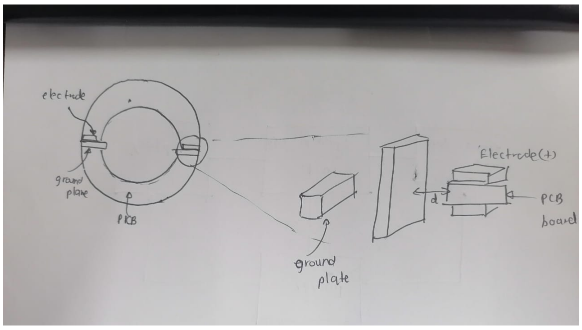
(d) Block Diagram

Figure 17: Conceptual Design 3

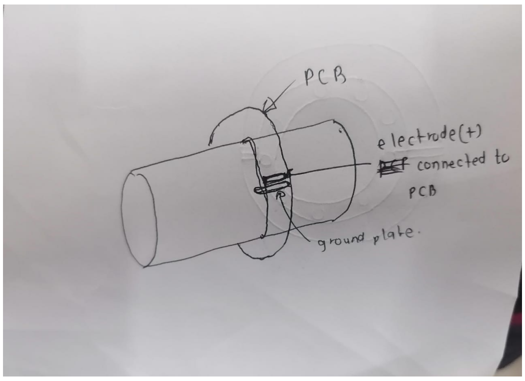
Torque applied to the shaft induces mechanical stress, altering the magnetic properties of a magnetostrictive material attached to the shaft. An excitation coil generates a magnetic field which interacts with the magnetostrictive material, producing torsional waves. These waves propagate along the material and are detected by a sensing coil. The position of the torsional wave, as detected by the sensing coil, correlates with the amount of torque applied to the shaft.

7.4 Conceptual Design 4

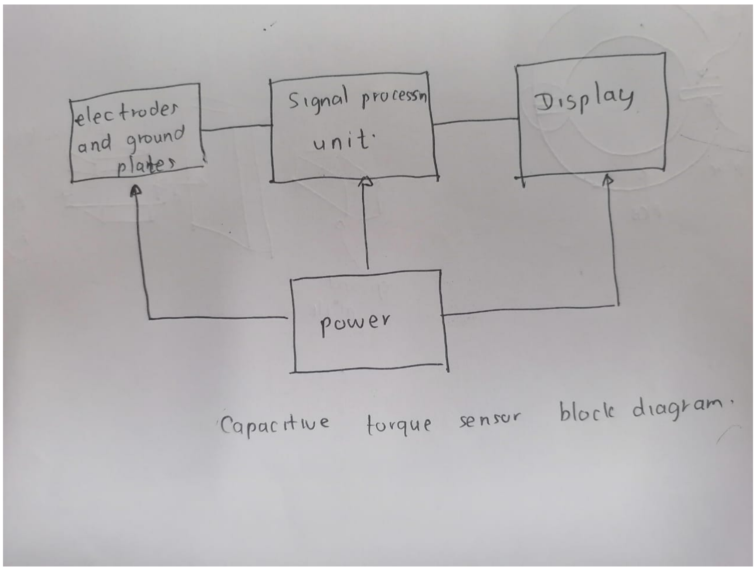
Capacitive torque sensors represent a significant advancement in torque measurement technology. Unlike traditional resistance-based sensors, which rely on strain gauges attached to flexure hinges, capacitive torque sensors measure capacitance between two closely spaced electrodes.



(a) Enclosure Design



(b) Shaft Design



(c) Block diagram

Figure 18: Conceptual Design 4

Torque applied to the shaft induces mechanical deformation or displacement, altering the distance or overlap between two closely spaced electrodes. This change in distance or overlap affects the capacitance of the system. An excitation voltage is applied across the electrodes, creating an electric field between them. As torque-induced deformation alters the spacing between the electrodes, the capacitance of the system changes accordingly. This variation in capacitance is detected and measured using appropriate circuitry. By calibrating the sensor's response to changes in capacitance, the applied torque can be accurately determined. Thus, the amount of torque applied to the shaft can be inferred from the corresponding change in capacitance

8 Evaluation of the Designs

8.1 Evaluation Criteria

8.1.1 Enclosure

1. **Functionality**: Does the design function as intended?
2. **Aesthetics**: Is the design visually appealing and pleasing?
3. **Ergonomics**: Does the design consider human factors and optimize usability?
4. **Durability**: Does the product have an appropriate lifespan?
5. **Scalability**: Can the design be scaled up or down to accommodate different product variations?

8.1.2 Functional Block Diagram

1. **Functionality**: Does the circuit design function as intended?
2. **User experience**: How intuitive and user-friendly is the interaction?
3. **Cost**: Evaluate the overall cost effectiveness for the provided functionality
4. **Performance :** Does the design ensure reliable and efficient functioning? Are there any potential bottlenecks?
5. **Simplicity**: Is the design easy for designers to grasp and work with?
6. **Accuracy:** How precise and consistent are the measurements provided by the design?
7. **Future proofing**: To what extent does the design allow for easy replacement or upgrade of individual components?
8. **Power Efficiency**: How effectively does the device manage power consumption?
9. **Manufacturing Efficiency**: How well does the design optimize the manufacturing process in terms of production time, cost, and resources?

8.2 Evaluation

8.2.1 Enclosure

Criteria	Design 1	Design 2	Design 3	Design 4
Functionality	9	9	9	8
Aesthetics	8	9	9	8
Ergonomics	9	9	9	9
Durability	8	8	8	8
Scalability	9	9	9	9
Total	43	44	44	42

8.2.2 Functional Block Diagram

Functional Block diagram	Design 1	Design 2	Design 3	Design 4
Functionality	7	8	6	8
User Experience	9	9	9	9
Cost	8	8	8	7
Performance	7	8	7	8
Simplicity	8	9	8	7
Accuracy	7	8	7	7
Future Proofing	8	7	8	8
Power Efficiency	8	7	9	9
Manufacturing Efficiency	8	9	8	8
Total	70	73	70	71

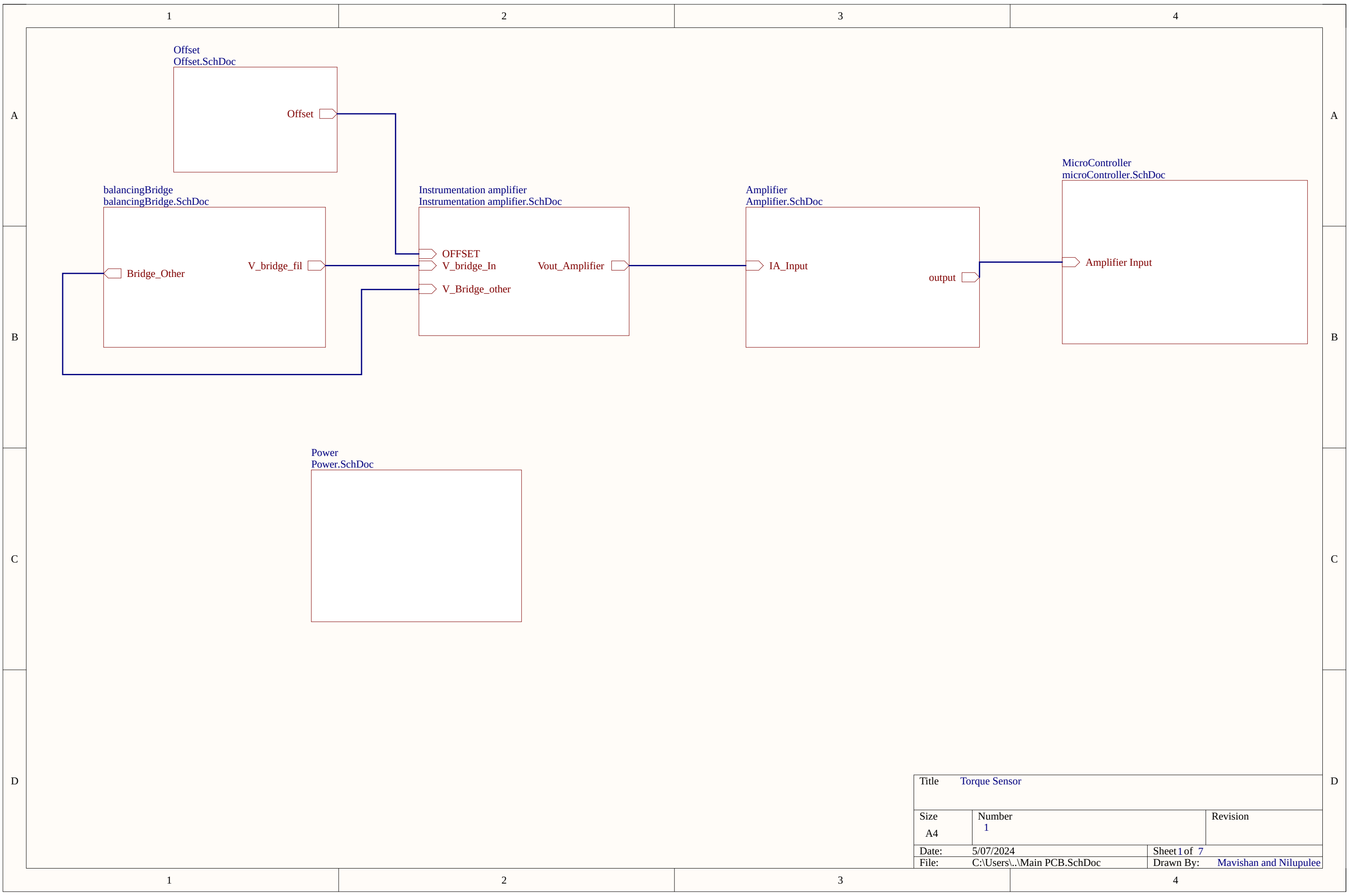
We selected the the slip ring-based strain gauge method primarily due to the following reasons:

1. **High Accuracy and Precision:** Strain gauge-based torque sensors are indeed known for their high accuracy and precision. The principle of strain gauges changing resistance in response to torque allows for precise measurement.

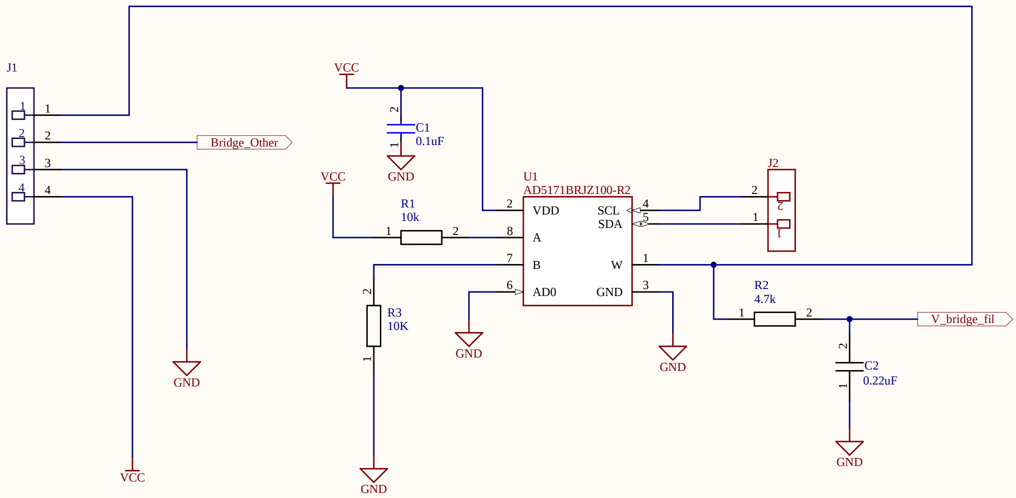
2. **Cost-Effectiveness:** Strain gauge-based torque sensors tend to be more cost-effective compared to alternative methods like magnetostrictive or capacitive techniques. This is because the materials and manufacturing processes for strain gauges are often simpler and less expensive. Additionally, strain gauge sensors require fewer components and less complex electronics, contributing to their cost-effectiveness.

3. **Simplicity of Design and Installation:** Strain gauge-based torque sensors typically have a simpler design and installation process compared to alternative methods.

9 Schematic and PCB Design



Offset
Offset.SchDoc
Offset
balancingBridge
balancingBridge.SchDoc
Bridge_Other
V_bridge_fil
Instrumentation amplifier
Instrumentation amplifier.SchDoc
OFFSET
V_bridge_In
V_Bridge_other
Vout_Amplifier
Amplifier
Amplifier.SchDoc
IA_Input
output
MicroController
microController.SchDoc
Amplifier Input
Power
Power.SchDoc
Title Torque Sensor
Size A4
Number 1
Revision
Date: 5/07/2024
Sheet 1 of 7
File: C:\Users\..\Main PCB.SchDoc
Drawn By: Mavishan and Nilupulee



Title	Balancing bridge		
Size A4	Number 2		Revision
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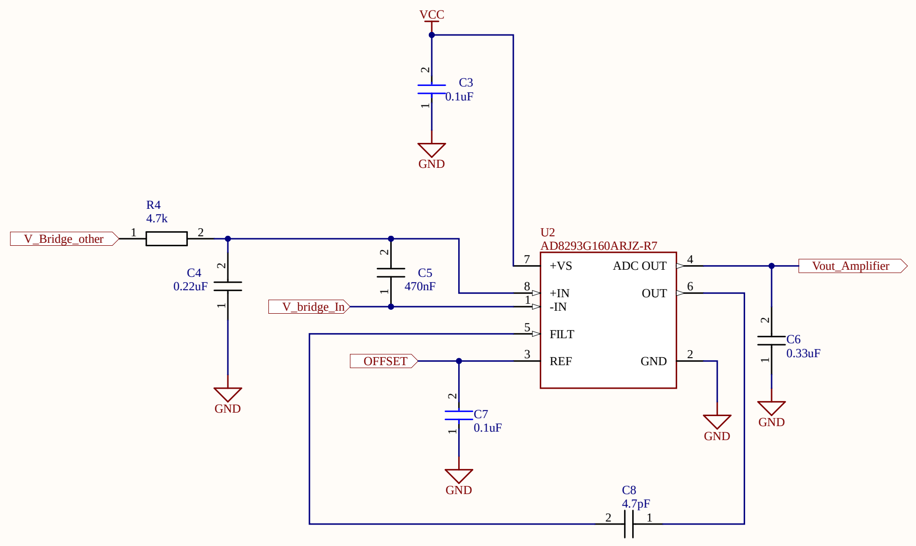
File:	C:\Users\..\balancingBridge.SchDoc	Drawn By:	Mavishan and Nilupulee



Title	Instrumentation Amplifier		
Size A4	Number 3		Revision
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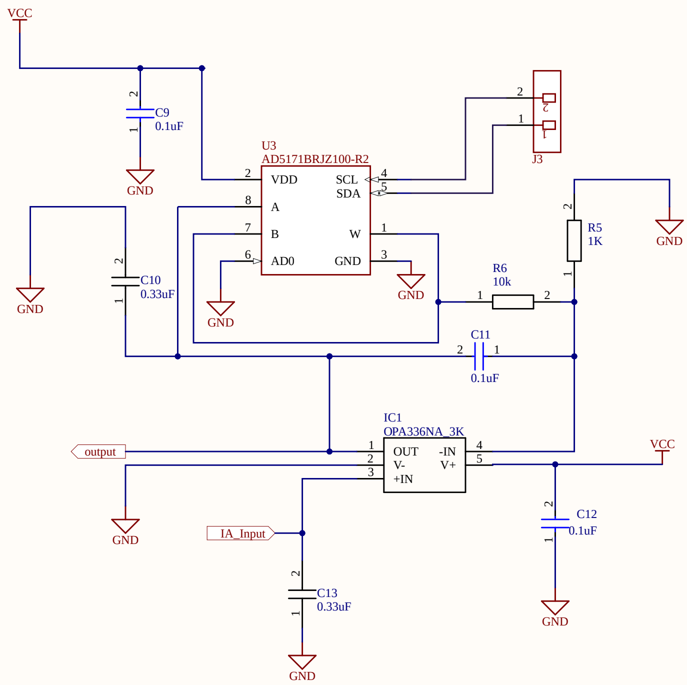
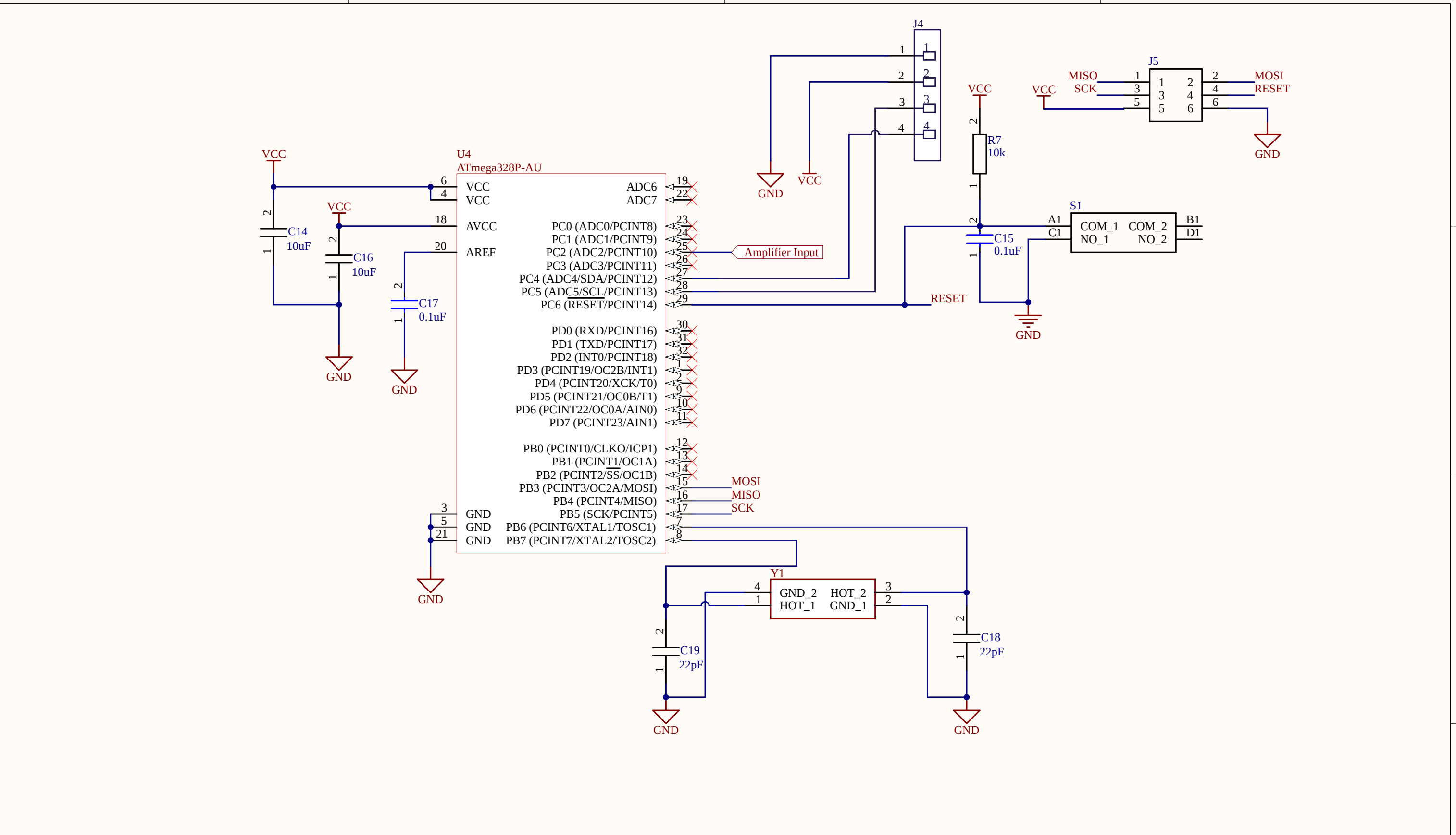
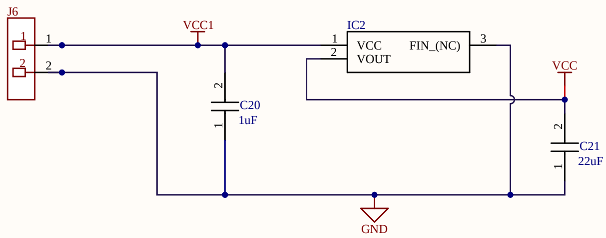
File:	C:\Users\..\Instrumentation amplifier.SchDoc	Drawn By:	Mavishan and Nilupulee



Title	Amplifier		
Size A4	Number 4		Revision
Date:	5/07/2024	Sheet 4 of 7	
File:	C:\Users\..\Amplifier.SchDoc	Drawn By:	Mavishan and Nilupulee



Title	Microcontroller
Size	A4
Number	5
Revision	
Date:	5/07/2024
Sheet	5 of 7
File:	C:\Users\..\microController.SchDoc
Drawn By:	Mavishan and Nilupulee



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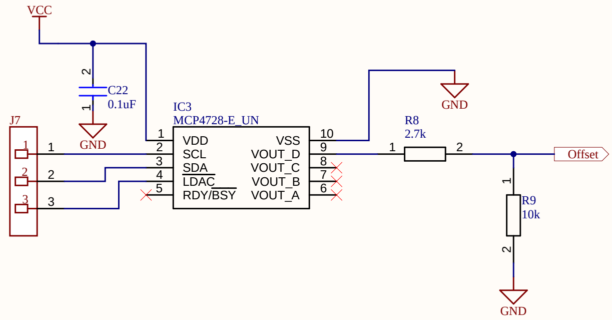
File:	C:\Users\..\Power.SchDoc	Drawn By:	Mavishan and Nilupulee



Title	Offset		
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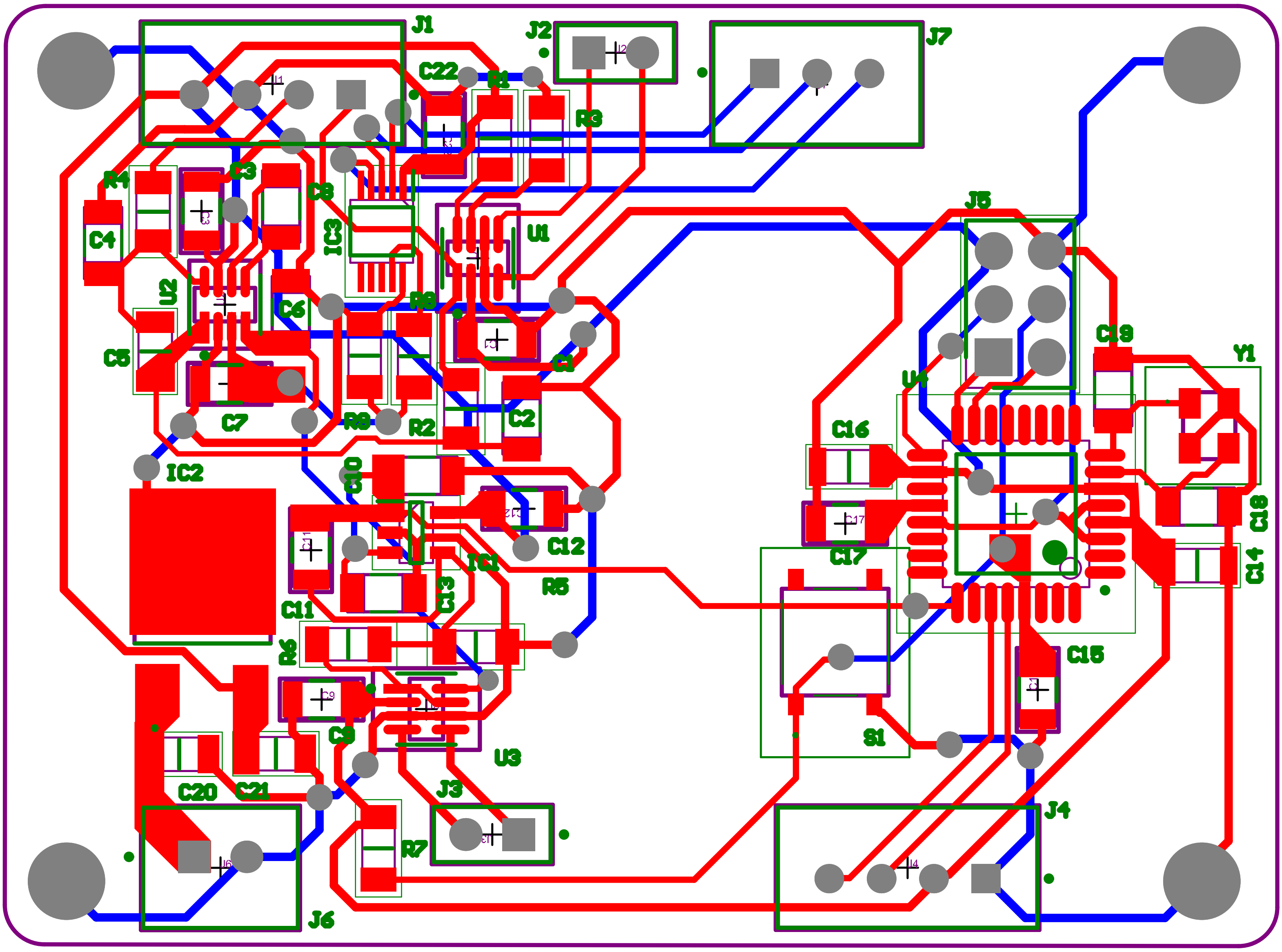
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J2
J7
C22
R1
R3
R4
C3
C8
IC3
U1
C4
U2
C6
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C1
C7
R8
R2
C2
IC2
C10
C12
IC1
R5
C11
C13
R6
C9
U3
C20
C21
J3
R7
J6
J5
C19
Y1
U4
C16
C17
C18
C14
C15
S1
J4

Comment	Description	Designator	Footprint	LibRef	Quantity
0.1uF	CAP CER 0.1UF 25V C0G/NP0 1206	C1, C3, C7, C9, C11, C12, C15, C17, C22	FP-C1206C-EB-MFG	CMP-1037-04186-2	9
12063C224JAT2A	Capacitor	C2, C4	CAPC3216X94N	12063C224JAT2A	2
12065C474JAT2A	Capacitor	C5	CAPC3216X152N	12065C474JAT2A	1
12063C334MAT2A	Capacitor	C6, C10, C13	CAPC3216X127N	12063C334MAT2A	3
12063A4R7DAT2A	Capacitor	C8	CAPC3216X94N	12063A4R7DAT2A	1
CGA5L1X7R1C106K160AC	Capacitor	C14, C16	CAPC3216X190N	CGA5L1X7R1C106K160AC	2
12063A220JAT2A	Capacitor	C18, C19	CAPC3216X94N	12063A220JAT2A	2
12063C105MAT2A	Capacitor	C20	CAPC3216X178N	12063C105MAT2A	1
12063D226MAT2A	Capacitor	C21	CAPC3216X229N	12063D226MAT2A	1
OPA336NA_3K	Integrated Circuit	IC1	SOT95P280X145-5N	OPA336NA_3K	1
BD450M5FP-CE2	Integrated Circuit	IC2	ROHM_TO-252-3	BD450M5FP-CE2	1
MCP4728-E_UN	Integrated Circuit	IC3	SOP50P490X110-10N	MCP4728-E_UN	1
B4B-XH-A(LF)(SN)	CONN HEADER VERT 4POS 2.5MM	J1, J4	FP-B4B-XH-A_LF_SN-MFG	CMP-17439-000250-1	2
M20-9990246	CONN HEADER VERT 2POS 2.54MM	J2, J3	FP-M20-9990246-MFG	CMP-15831-000009-1	2
87914-0606	Connector	J5	HDRV6W69P254_2X3_762X498X859P	87914-0606	1
B2B-XH-A(LF)(SN)	CONN HEADER VERT 2POS 2.5MM	J6	FP-B2B-XH-A_LF_SN-MFG	CMP-2000-05888-3	1
B3B-XH-A(LF)(SN)	CONN HEADER VERT 3POS 2.5MM	J7	FP-B3B-XH-A_LF_SN-MFG	CMP-17439-000014-3	1
ERA-8AEB103V	Resistor	R1, R3, R6, R7, R9	RESC3216X70N	ERA-8AEB103V	5
CHP1206AFX-4701ELF	Resistor	R2, R4	RESC3116X65N	CHP1206AFX-4701ELF	2
ERA8AEB102V	Resistor	R5	RESC3216X70N	ERA8AEB102V	1
ERA-8AEB272V	Resistor	R8	RESC3216X70N	ERA-8AEB272V	1
TS-1187A-B-A-B	Switch	S1	TS1187ABAB	TS-1187A-B-A-B	1
AD5171BRJZ100-R2	AD5171BRJZ100-R2 Digital Potentiometer 64POS 100kOhm Single Automotive 8-Pin SOT-23 T/R	U1, U3	FP-RJ-8-IPC_A	CMP-00026-00446399-1	2
AD8293G160ARJZ-R7	IC INST AMP 1 CIRCUIT SOT23-8	U2	FP-RJ-8-IPC_B	CMP-09116-000116-1	1
ATmega328P-AU	8-bit AVR Microcontroller, 32KB Flash, 1KB EEPROM, 2KB SRAM, 32-pin TQFP, Industrial Grade (-40°C to 85°C)	U4	32A_M	CMP-0095-00269-2	1
CX3225SA40000D0PTWCC	Crystal or Oscillator	Y1	CX3225SA40000D0PTWCC	CX3225SA40000D0PTWCC	1

In our project, we employed various techniques in PCB (Printed Circuit Board) design to optimize performance and reliability. we encountered challenges with the incoming signal from the Wheatstone bridge (strain gauge setup), which necessitated the use of multi-stage amplification (two stages). To ensure minimal noise addition during amplification, meticulous attention was paid to PCB layout design, particularly in routing signal traces and grounding.

In order to maintain precise control over signal routing and minimize the risk of unintended coupling or interference, polygon pours were deliberately avoided. Instead, individual signal traces were routed without the use of large copper pours, allowing for greater isolation and control over signal paths.

In our design approach, we prioritized the placement of decoupling capacitors in close proximity to components requiring them. The close proximity of decoupling capacitors to their respective components ensures that they can effectively filter out high-frequency noise and transient disturbances, optimizing the performance and reliability of the amplification stages.

In addition, we used varying trace widths to efficiently route signals and power lines, enhancing performance and reliability throughout our system. This approach allowed us to accommodate high currents, minimize voltage drops, and optimize signal integrity, ensuring robust operation under varying load conditions. To further enhance power distribution efficiency, solid copper regions were utilized to connect power components and distribute power across the PCB. These solid regions offered low impedance paths, minimizing voltage drops and enabling uniform distribution of power to critical components.

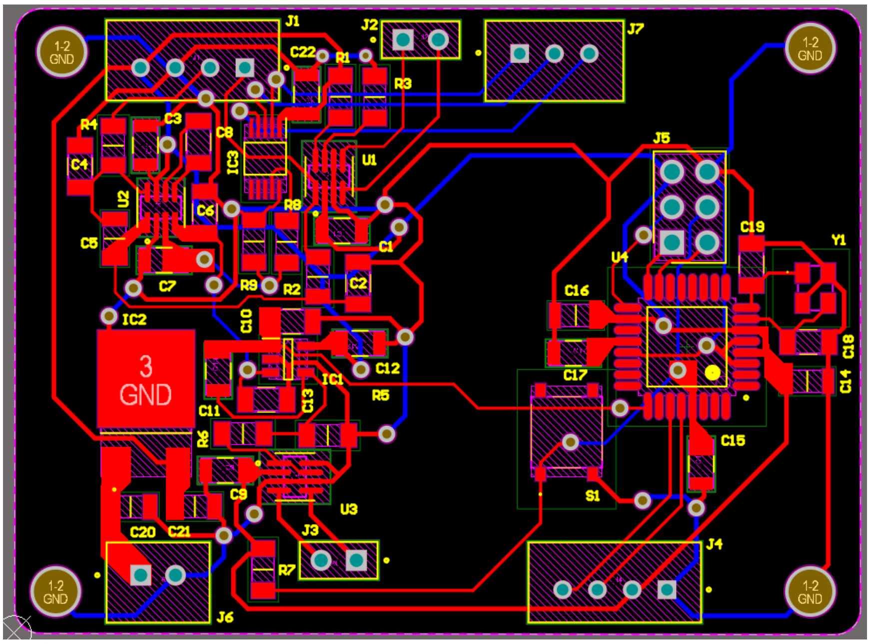


Figure 19: PCB Layout

output of 35mA
of
opAmp
500mA
40mA.

Component	Max current	width (mm)
AD5171	8mA	—
AD623	1.5mA	—
OPA336N	36mA	—
Almega	0.2A	0.03
display	20mA	0.001
Power (V_{cc})	500mA	0.1mm

Trace width calculation.

$$A = \left\{ \frac{I}{(k \times T_{Rise}^{b})} \right\}^{1/c}$$

$$W = \frac{A}{\text{thickness} \times 1.378}$$

IPC-2221 standards.

$k = 0.048$

$b = 0.44$

$c = 0.725$

$T = 25°C$ $\quad T_{rise} = 10°C$

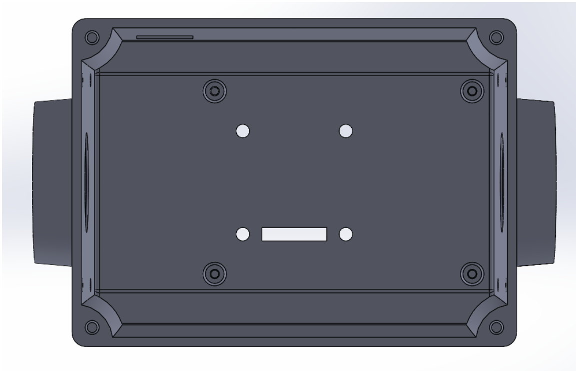
thickness = 1 OZ

∴ we will choose prefered with 0.381mm
To power routing - we choosed 0.4mm
and from battery to power regulator
we will chose polygon shapes to
increase area.

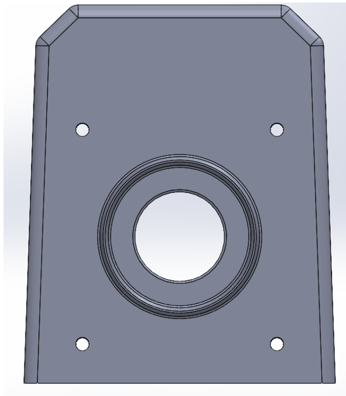
Figure 20: Trace Width Calculation

10 Solidworks Design

10.1 Top Part



(a) Bottom View



(b) Side View

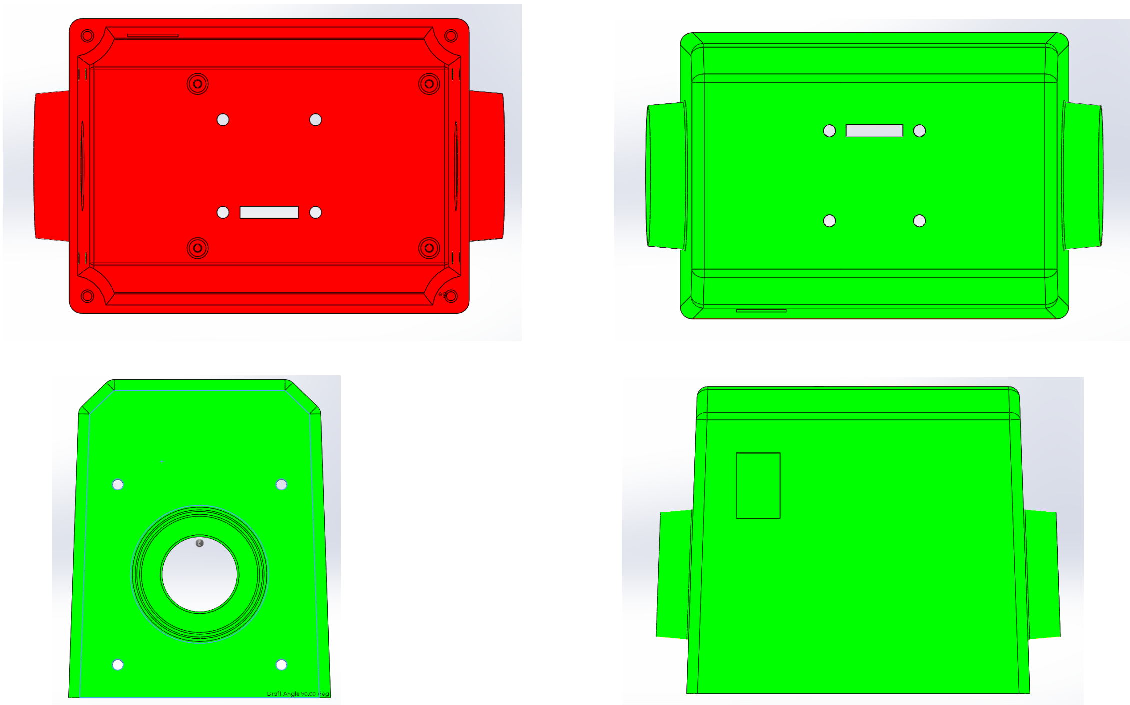


Figure 21: Different Views and Draft Analysis

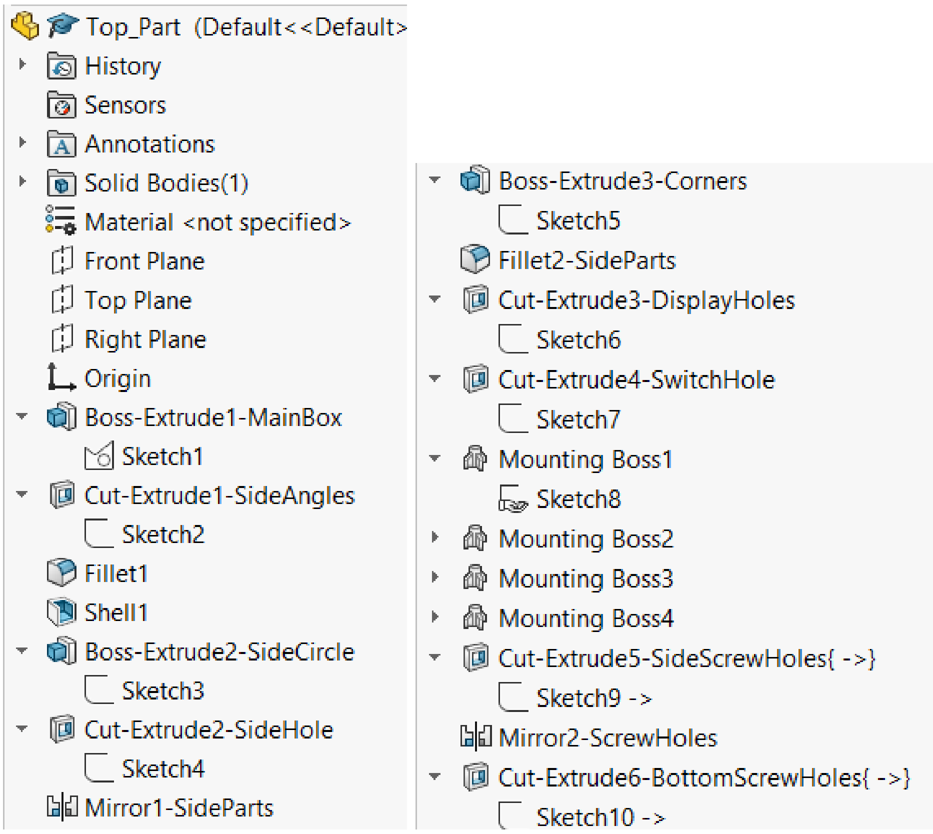
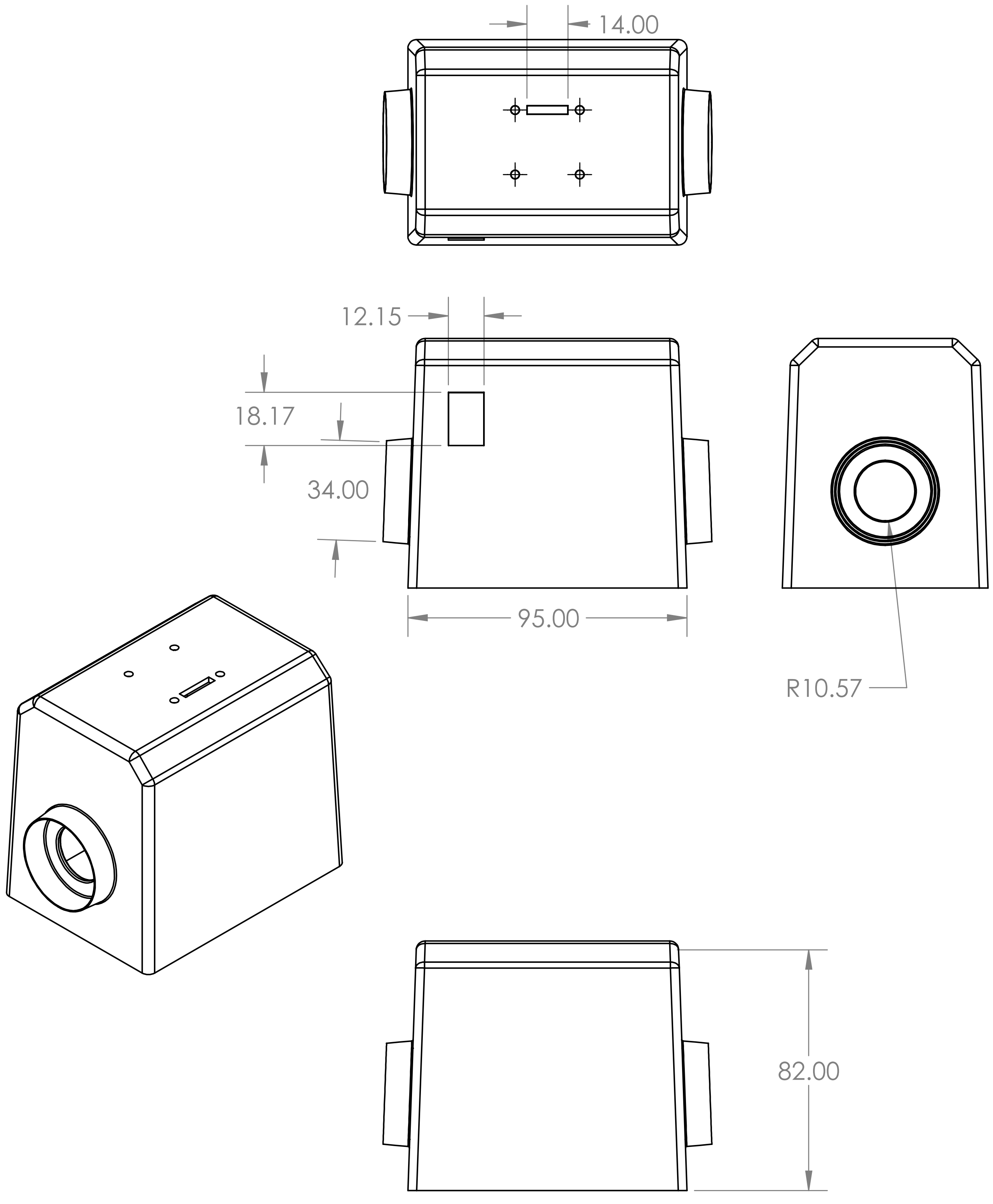


Figure 22: Model Tree



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SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

DWG NO.

Top_Part

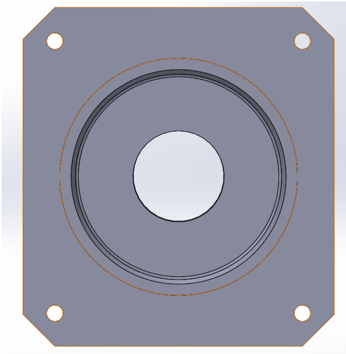
A4

WEIGHT:

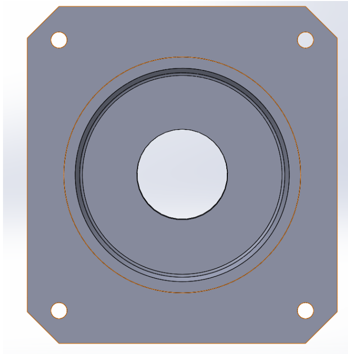
SCALE:1:2

SHEET 1 OF 1

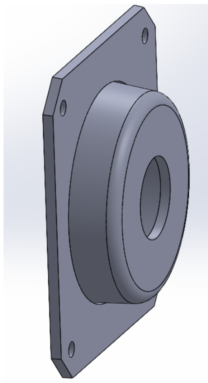
10.2 Side Part



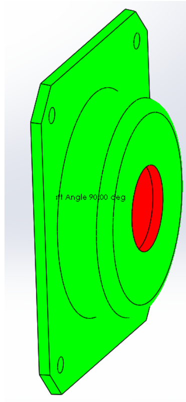
(a) Front View



(b) Bottom View



(c) Dimetric View



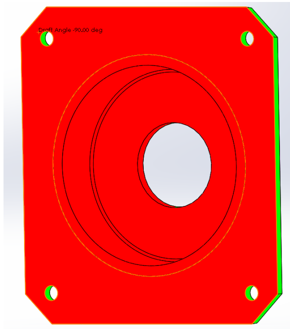


Figure 23: Different Views and Draft Analysis

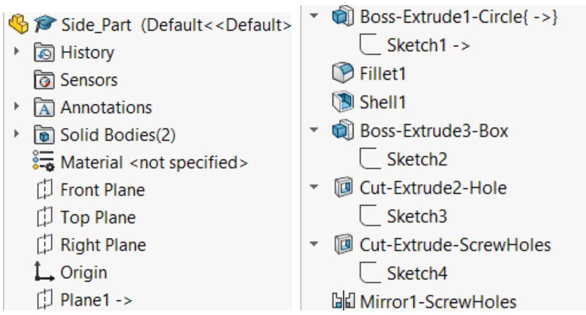
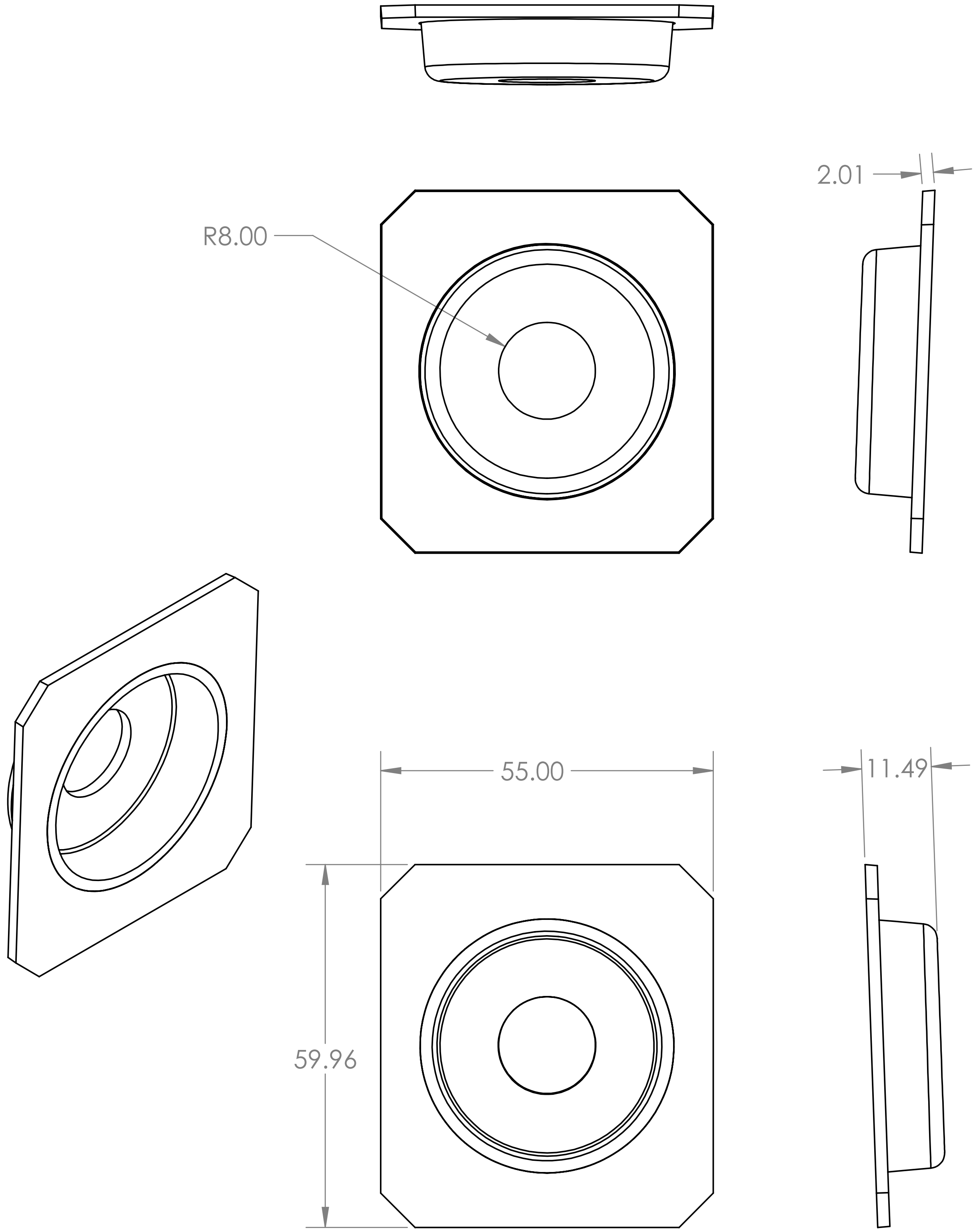


Figure 24: Model Tree



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:			DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
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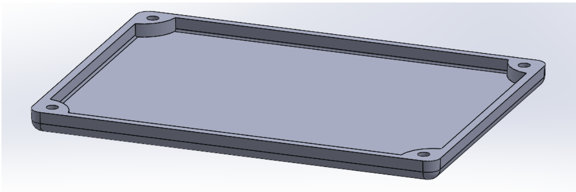
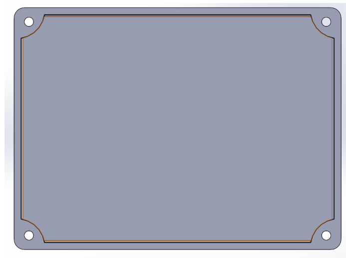
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL:	DWG NO. Side_Part	A4
				WEIGHT:	SCALE:1:1	SHEET 1 OF 1

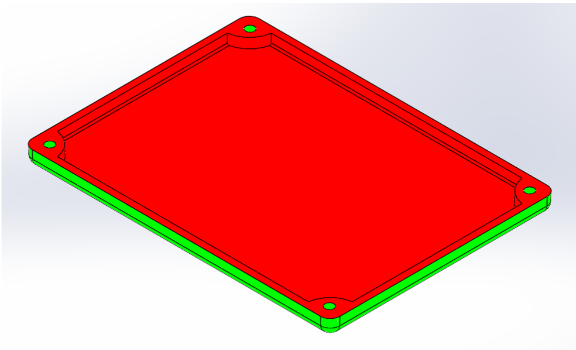
10.3 Bottom Part



(a) Dimetric View



(b) Bottom View



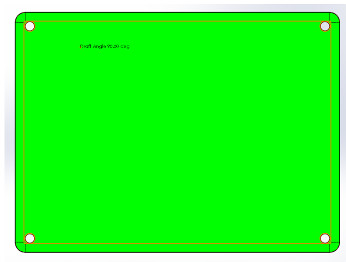


Figure 25: Different Views and Draft Analysis

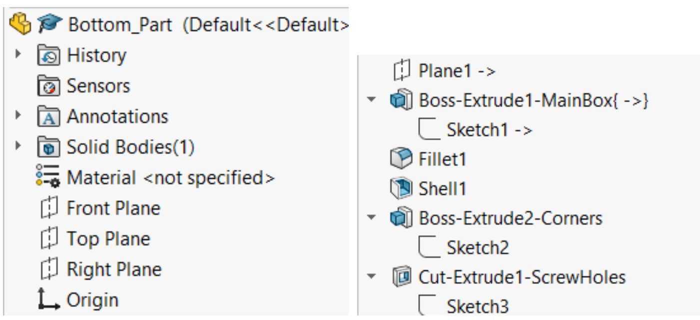
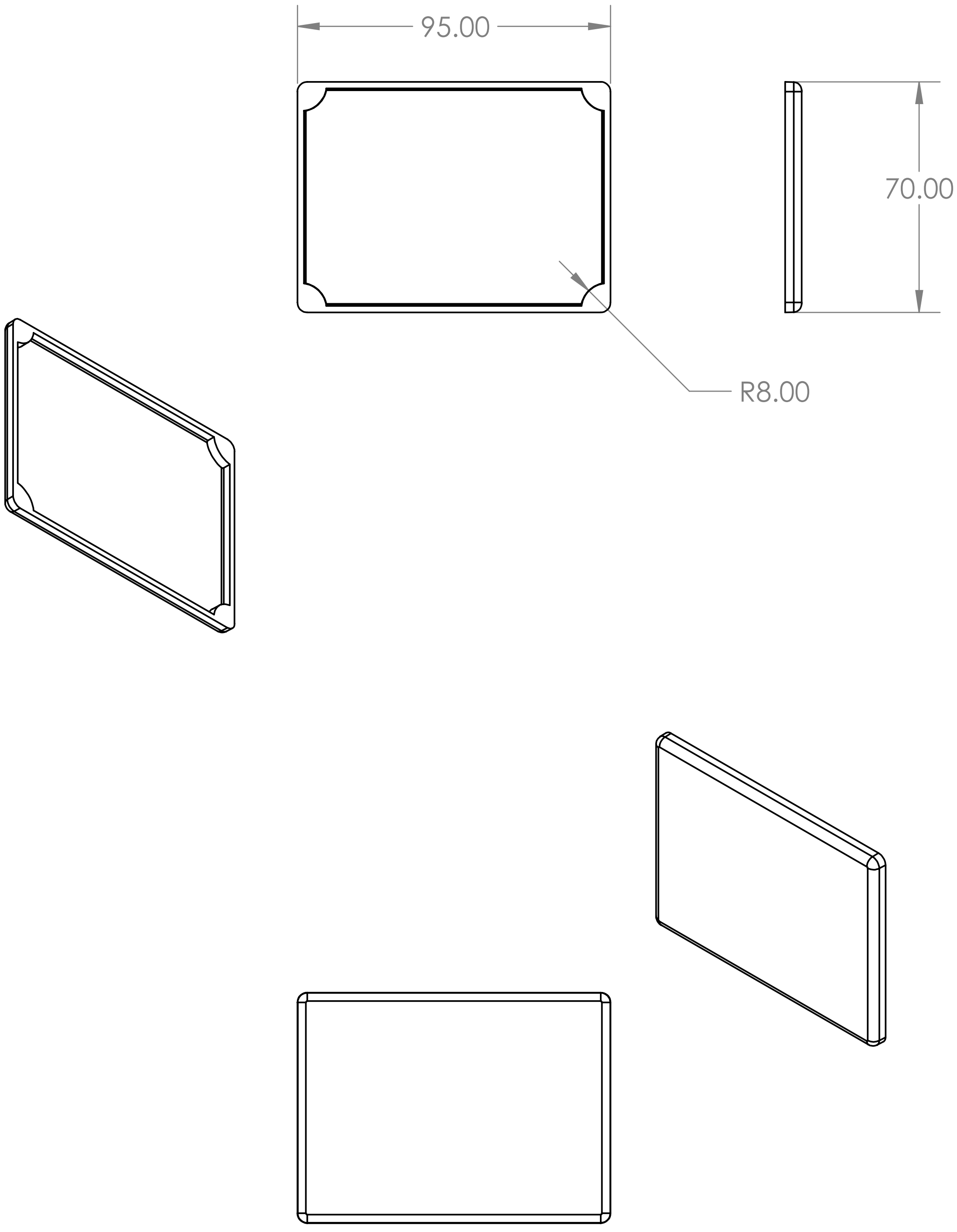


Figure 26: Model Tree



UNLESS OTHERWISE SPECIFIED:
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TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND
BREAK SHARP
EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

WEIGHT:

DWG NO.

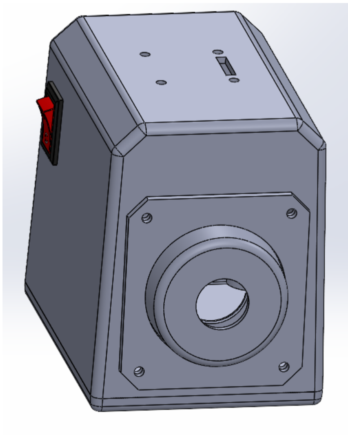
Bottom_Part

A4

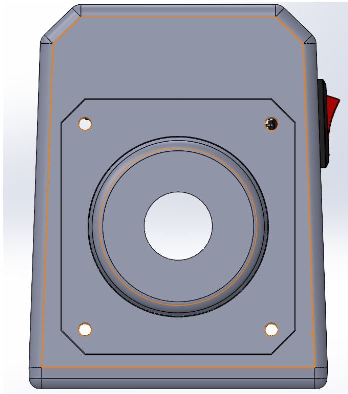
SCALE:1:2

SHEET 1 OF 1

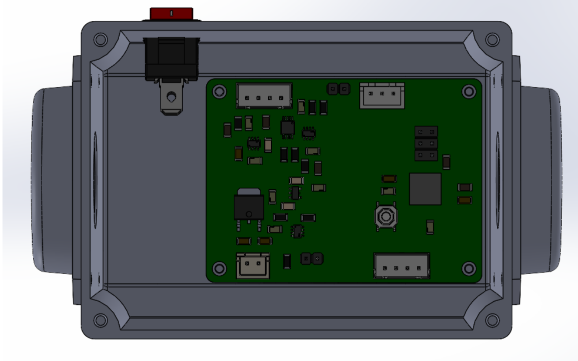
10.4 Assembly



(a) Isometric View



(b) Side View



(c) Inside the Assembly

Figure 27: Different Views of the Assembly

The report was reviewed by:

(D.E.O Jayathilaka)

(210216F: H.M.G.N.I. Herath)

(H.M.D.P. Herath)

210669U. H.M.V. Vidumini