Department of Electronic and Telecommunication Engineering
University of Moratuwa

Design Methodology

Multi-turn Absolute Magnetic Encoder

Epa Y.L.A.	210156U
Epa Y.R.A.	210157A

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Contents

1 Need of the System

There is a significant demand for reliable, high-precision position tracking in various industries, particularly in automation and robotics. A multi-turn absolute magnetic encoder is a device that can meet this need by providing precise position tracking across multiple rotations, which is essential for many applications.

In the automation industry, for example, robotic arms need to know their exact position at all times to perform tasks accurately. Similarly, in the automotive industry, encoders are used in steering systems to ensure precise control. The demand for such applications is growing with the development of the robotics and automation industry.

Often it's necessary to use high precision multi turn absolute magnetic encoders in the industry due to the requirements, but, they are often quite expensive. Hence, there's a need for an affordable yet reliable, precise absolute magnetic encoder, particularly for the Sri Lankan industry.

2 Detailed Data Sheets of Existing Products (Abroad or Local)

Currently there are no local multi turn absolute magnetic encoder production companies in Sri Lanka. But in the world, we could identify several companies who offer a wide range of multi turn absolute magnetic encoders. Here we have presented three major multi turn absolute magnetic encoder products.

2.1 AS33-M42M Series - 42-Bit Full Magnetic Energy Harvesting Multi-Turn Absolute Encoder Module by Broadcom Inc.

- Product Specifications

- Single turn resolution - 18 bit max
- Multi turn resolution - 24 bit max
- Accuracy - $< 0.1^{\circ}$
- Operating temperature range - –40°C to 115°C
- Supply voltage - min : -0.3V max : 15V
- Output type
  - SSI (2 MHz)
  - BiSS-C (10 MHz)
  - RS-485 half-duplex (2.5/5.0/10 MB/s)

- Key Features

- Patented energy harvesting technology
- Total 42-bit resolution with 18-bit single-turn and 24-bit multi-turn
- Low angular accuracy error of $< 0.1^{\circ}$
- Overall encoder outer diameter of 33 mm and maximum height of 20 mm
- Programmable resolution
- Built-in temperature sensor

- Applications

- Small motors and linear actuators
- Robotic automation and engineering
- Drone and automated guide vehicles
- DC and AC servo motors
- Test and measurement equipment

- Product Image

Figure 1: *AS33-M42M Series Broadcom*

2.2 Battery Backup Multiturn True Absolute Rotary Encoder by Orbis

Orbis Battery Backup Multiturn Encoder is an absolute, through-hole rotary encoder with battery-powered multiturn counter that allows the encoder to count shaft rotations even when the main power supply is unavailable. Battery has to be connected externally and specifications are given for the selection of the battery.

- Product Specifications

- Overall resolution - 14 bit
- Accuracy ± 0.25°
- Operating temperature range - –40°C to 105° C
- Supply voltage 4.5V - 5.5V
- Output type - BiSS C communication interface

- Key Features

- Battery backup
- Total of 14 bit resolution
- Low angular accuracy error
- Overall encoder outer diameter of 45 mm
- Self calibration after installation

- Applications

- Six legged robots
- Automated guided vehicles
- Rotary and X/Y Positioning Tables

- Product Image

Figure 2: *Orbis Encoder*

2.3 Multi Turn Absolute Magnetic Encoder by EPC

There are several encoders in this series. We have presented on the model A36SB encoder specifically.

- Product Specifications

- Single turn resolution - 16 bit max
- Multi turn resolution - 43 bit max

- Accuracy ± 0.0878°
- Operating temperature range - –40°C to 85° C
- Supply voltage - min : 5V max : 32V
- Output type - SSI

- Key Features

- Energy harvesting technology
- Total 59-bit resolution with 16-bit single-turn and 43-bit multi-turn
- Low angular accuracy error
- Overall encoder outer diameter of 36 mm
- Meets CE/EMC standards for immunity and emissions

- Applications

- Wind turbines and medical scanners
- Robotic automation and engineering
- Drone and automated guide vehicles
- DC and AC servo motors
- Automated guided vehicles
- Rotary and X/Y Positioning Tables

- Product Image

Figure 3: *EPC Encoder*

3 Stakeholder Map

Stakeholder map helps us to identify the people who have an influence in our project. Below is the stakeholder map for our project in making a multi turn absolute magnetic encoder. The arev grouped according to the interest and impact they can have.

Here we have identified several stakeholders.

- Competitors
  Competitors are one such stakeholder. Competitors affect the relevance and technology of our project outcome. Some of the competitors are,
  - Pepperel+Fuchs
  - Broadcom
  - EPC
  - Heidenhain
  - Kuebler
  - RLC

  who are leading manufacturers in industrial encoders.

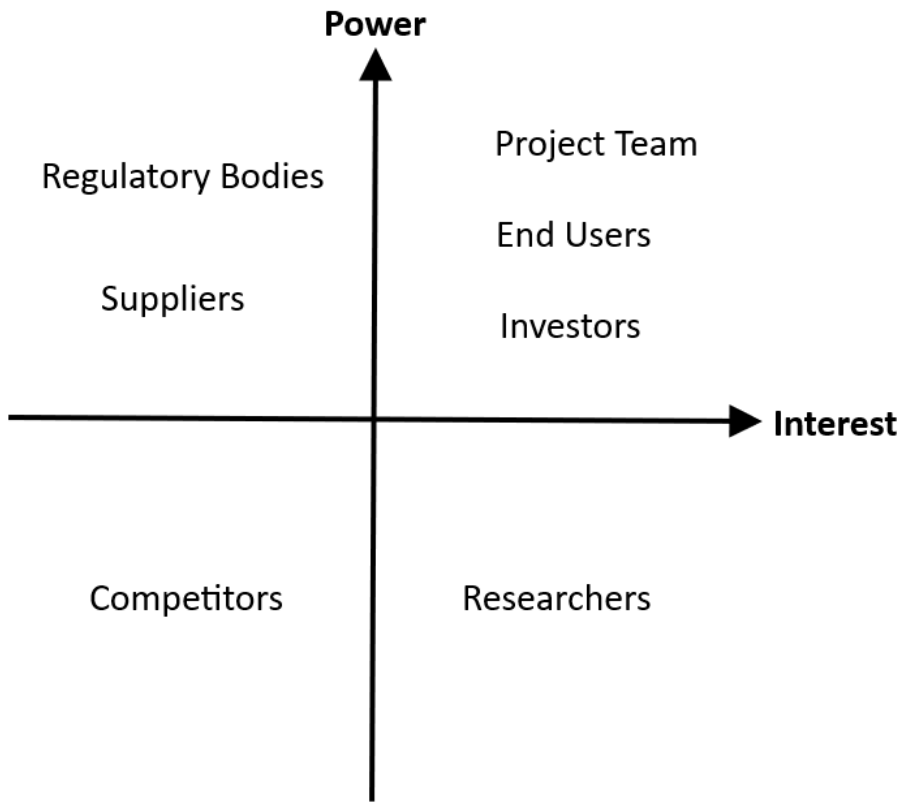

Figure 4: *Stakeholder map*

4 Users

Multi turn absolute magnetic encoders are widely used in the industry in many applications such as robotic arms, CNC machines, conveyor systems etc. Following are some real world users of these type of encoders.

- Comau
  - This is an Italian company that provides industrial automation solutions and systems, advanced robotics and digital solutions. They integrates multi-turn absolute magnetic encoders into their products, particularly in their robotic welding systems.
  - These systems require precise control over robot movement and positioning during welding operations.
  - The ECI 1118 absolute rotary encoder with the EnDat2.2 digital interface by Heidenhain is commonly used in their advanced C5G control and 3D SmartLaser laser welding systems.
    - Encoders by Heidenhain
    - Advanced C5G control implemented by Comau
- Strausak AG
  - This is a company specializing in precision machining and tool grinding solutions, incorporating multi-turn absolute magnetic encoders into their products.
  - Their robotics for operator-free grinding and re-sharpening of tools utilizing gripper arms use EQI 1100 rotary encoders in every axis of the arm, which continuously provide feedback on its position, ensuring accurate tool placement and consistent grinding results.
    - EQI 1100 rotary encoders
- KUKA LBR Med

Figure 5: *Comau SMARTLaser*

Figure 6: *EQI 1100 HEIDENHAIN rotary encoders inside Strausak AG robot arm*

– This is a collaborative robot specifically designed for medical applications. It uses encoder signals to ensure precise control for the safety of the user.

  * KUKA LBR Med Details

Figure 7: *KUKA LBR Med*

5 Market Segment

The industrial automation segment encompasses various industries and applications where automated systems and machinery are used to streamline production processes, improve efficiency, and ensure consistent quality.

5.1 Industrial Automation

In the automation industry, multi-turn absolute magnetic encoders are used in robotic arms and other automated machinery. These devices require precise position tracking to perform tasks accurately and efficiently.

- Key Specifications Considered

- Precise position sensing solutions to facilitate accurate control and monitoring of automated machinery
- Durable and reliable encoder systems capable of withstanding harsh operating conditions

- Emphasis on real-time data acquisition and feedback for optimizing manufacturing processes and enhancing productivity

- Applications

- Robotic arms and manipulators
- CNC machining centers
- Automated material handling systems
- Packaging and labeling machines

5.2 Automotive Industry

The automotive segment includes manufacturers and suppliers involved in the design, production, and maintenance of vehicles and automotive components.

- Key Specifications Considered

- High-precision position sensing solutions in vehicle subsystems such as steering, throttle, and transmission systems
- Compact and lightweight encoder systems suitable for integration into automotive applications
- Focus on reliability and durability to withstand the rigors of automotive environments

- Applications

- Electric power steering systems
- Drive-by-wire throttle control systems
- Automatic transmission systems
- Vehicle chassis and suspension control

5.3 Consumer Electronics Industry

The consumer electronics industry comprises companies engaged in the design, manufacturing, and sale of electronic devices for personal and household use. This segment encompasses a wide range of products, including smartphones, tablets, laptops, gaming consoles, wearables, and home appliances.

- Key Specifications Considered

- Often require compact and lightweight components to optimize portability
- Seamless functionality and intuitive interfaces in electronic devices
- cost-effective encoders that balance performance and affordability

- Applications

- 3D printers
- Drones

6 Conceptual Designs and Functional Block Diagrams

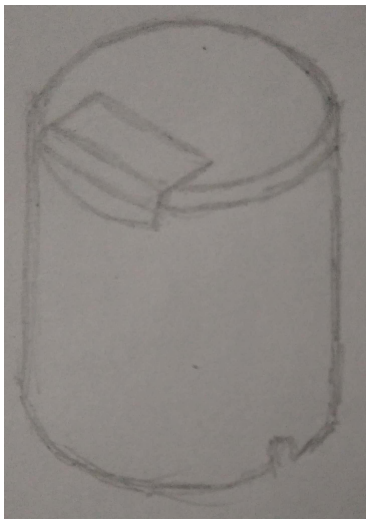

Figure 8: *Conceptual Design 1*

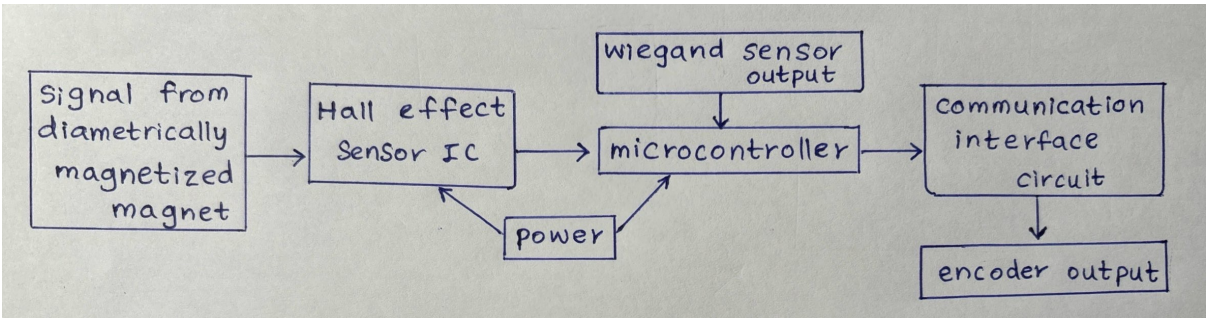

Figure 9: *Functional Block Diagram for Conceptual Design 1*

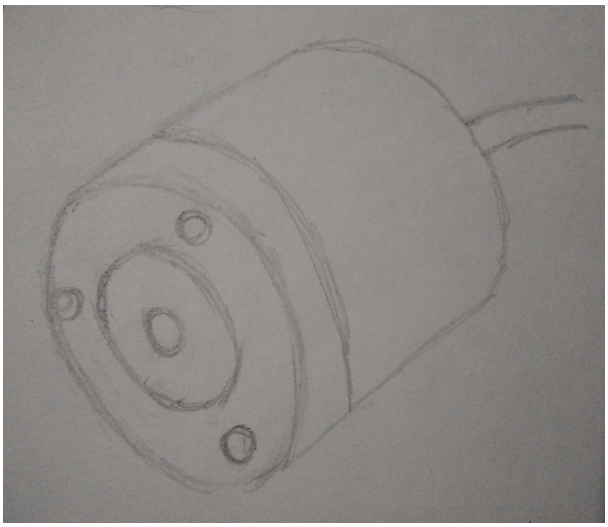

Figure 10: *Conceptual Design 2*

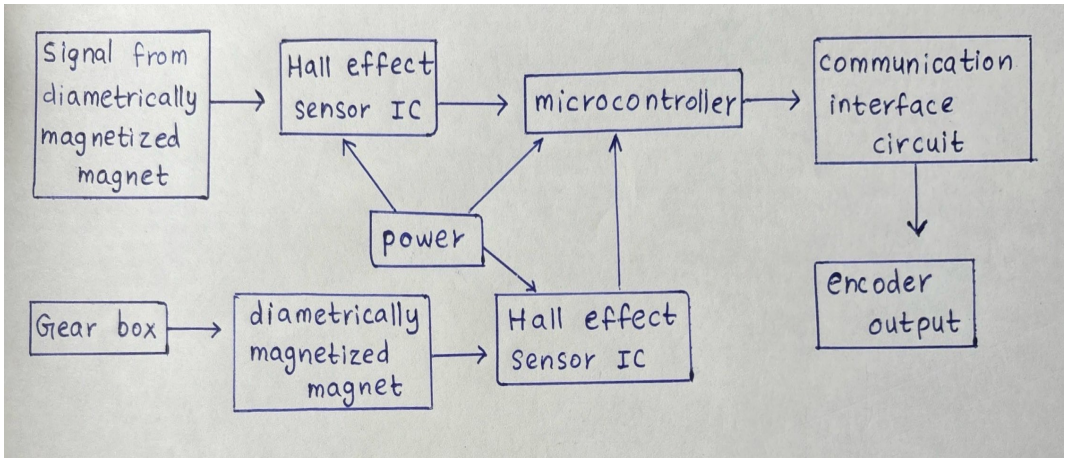

Figure 11: *Functional Block Diagram for Conceptual Design 2*

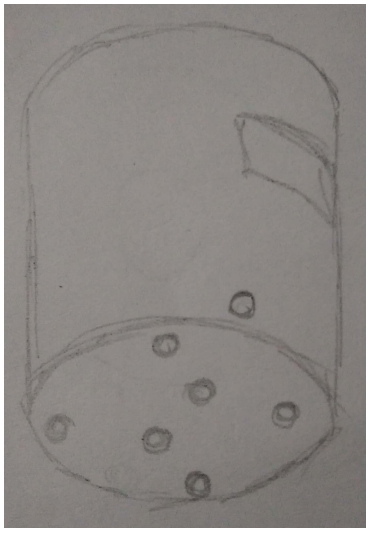

Figure 12: *Conceptual Design 3*

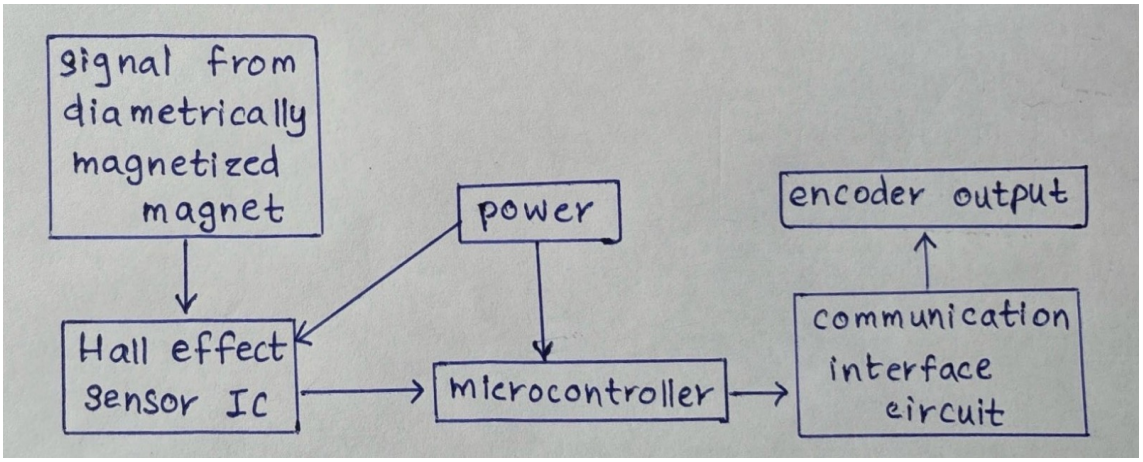

Figure 13: *Functional Block Diagram for Conceptual Design 3*

7 Complete Comparison of the Conceptual Designs

	Conceptual design 1	Conceptual design 2	Conceptual design 3
Newly added features	Multi turn capability using wiegand sensor which doesn't require power to operate	Multi turn capability using Gear box and two hall effect sensor ICs	Multi turn counting using the microcontroller and one hall effect sensor
Removed features	Removed the necessity to give internal power for the circuitry to function during power outages	removed the need for wiegand sensor	removed extra sensors and circuitry to address the multi turn capability
Enclosure design criteria comparison:			
1. Functionality	9	9	9
2. Size and weight	9	5	8
3. Ergonomic	8	7	8
4. Heat dissipation	8	6	8
5. Mounting and alignment	8	6	8
6. Simplicity	7	6	8
Functional block design criteria comparison:			
1. Functionality	8	9	8
2. Requirements	7	9	7
3. Power consumption	9	8	8
4. Future proofing	6	6	8
5. Cost	6	4	9
6. Manufacturing feasibility	5	4	8
Total	90	79	97

8 Evaluation Criteria for the Conceptual Designs

Enclosure Design Criteria:

1. Functionality: How well does the design support internal functionality?

2. Size and weight: How compact and lightweight is the enclosure for easy integration?

3. Ergonomics: How well does the enclosure design allow for easy handling installation and maintenance?

4. Heat dissipation: How much heat is generated and how well it has been managed?

5. Mounting and alignment: How easy is it to mount and align the encoder with the shaft, and how well does the enclosure maintain its alignment?

6. Simplicity

Functional Block Diagram Criteria:

1. Functionality: How well the circuit design meets functional requirements such as resolution, accuracy, and speed?

2. Requirements: How well does the components (magnet, hall effect sensors, etc) meet the requirements for accuracy and resolution?

3. Power consumption: How efficiently does the design manage power consumption?

4. Future proofing: To what extent does the design allow for easy replacement or upgrade of individual components?

5. Cost: Overall cost effectiveness for the provided functionality

6. Manufacturing feasibility: Feasibility of manufacturing the design

9 Selected Design

From the above three designs, we have selected the final design. There are several reasons for this.

Design 1 included a wiegand sensor which isn't available to purchase at small quantities. Even though we tried to find out an alternative part for that, we got no success.

Design 2 utilizes a gear box which isn't practical because of the size. Also it will make the encoder complex and ultimately limit the number of multi turns which the encoder can count. Durability and the weight of the encoder is also affected because of this.

The third design is the option we can go for in this situation. A battery backup is used in this design to power the encoder every time and it's charged when the main supply is available.

10 Final Draft of Specifications

10.1 Technical Specifications

- Single turn resolution - 12 bit
- Multi turn resolution - 16 bit
- Accuracy - $< 0.08^{\circ}$
- Operating temperature range - do be tested
- Supply voltage - min : -0.3V max : 6.1V
- Output type - SPI

10.2 Key Features

- Multi turn capability
- Magnetic hall effect sensing
- Absolute turn count even after power failure
- Low power consumption
- Lightweight, compact

10.3 Physical Specifications

- Dimensions
  - Height - 3.8 cm
  - Length - 4.4 cm

  - Width - 4.4 cm
- Weight - to be measured

11 Structure Diagram

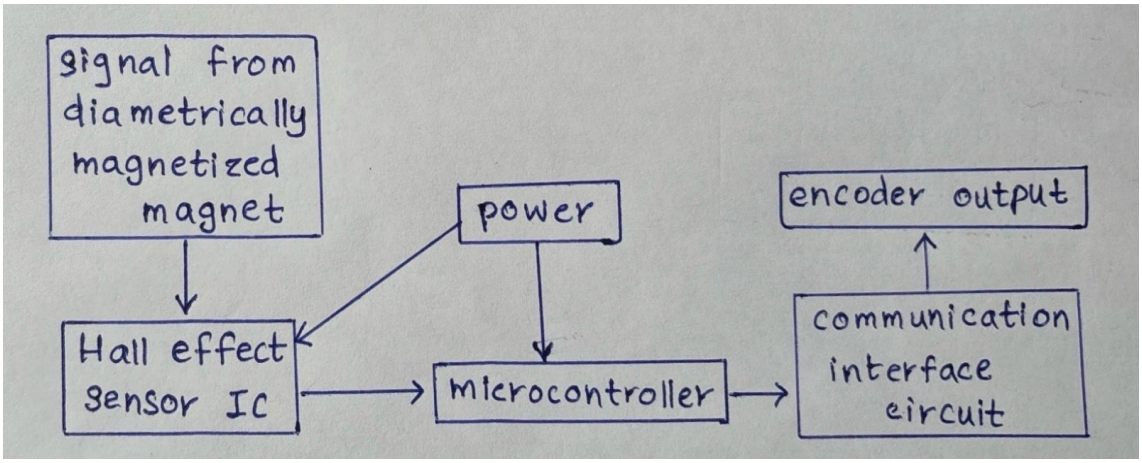

Figure 14: *Functional Block Diagram for Conceptual Design 3*

12 Rough Sketch of the System

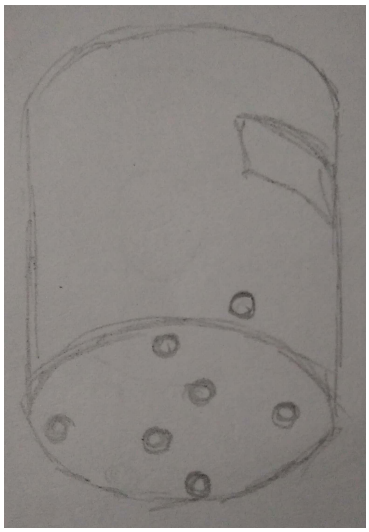

Figure 15: *Conceptual Design 3*

We have decided to use this conceptual design after considering three main other designs. The key main advantages of this design approaches are,

- Compactness (no gear boxes)
- Simple approach (no additional circuitry to do multi turn counting)
- Low power consumption
- No upper limit for multi turn count except with the memory available of the microcontroller

13 Standards Available

13.1 Performance Standards

- ISO 9001

This standard sets out the criteria for a quality management system and is based on a number of quality management principles including a strong customer focus, the involvement of top management, a process approach, and continual improvement.

13.2 Environmental Standards

- IP Code (Ingress Protection Code)

  This standard rates the degree of protection provided by mechanical casings and electrical enclosures against intrusion, dust, accidental contact, and water.

- RoHS (Restriction of Hazardous Substances):

  This EU directive restricts the use of certain hazardous substances in electrical and electronic equipment.

14 References

[1] AS33-M42M series: 42-bit full magnetic energy harvesting ..., https://docs.broadcom.com/doc/AS33-M42M-Series-42-bit-Magnetic-Energy-Harvesting-MT-Absolute-Encoder-Module (accessed May 7, 2024).

[2] ORBIS TM battery backup multiturn (BBM) absolute rotary encoder, https://www.rls.si/eng/fileuploader/download/download/?d=1&file=custom/upload/BRD08_01_BBM.pdf (accessed May 7, 2024).

[3] MODEL A36SB - ABSOLUTE SHAFT ENCODER, https://www.encoder.com/hubfs/products/Model_A36SB/datasheet_model-a36sb.pdf?hsLang=en (accessed May 7, 2024).