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# Absolute Magnetic Encoder

## Precision Position Sensing for Modern Automation

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# A Problem in the World of Machines!

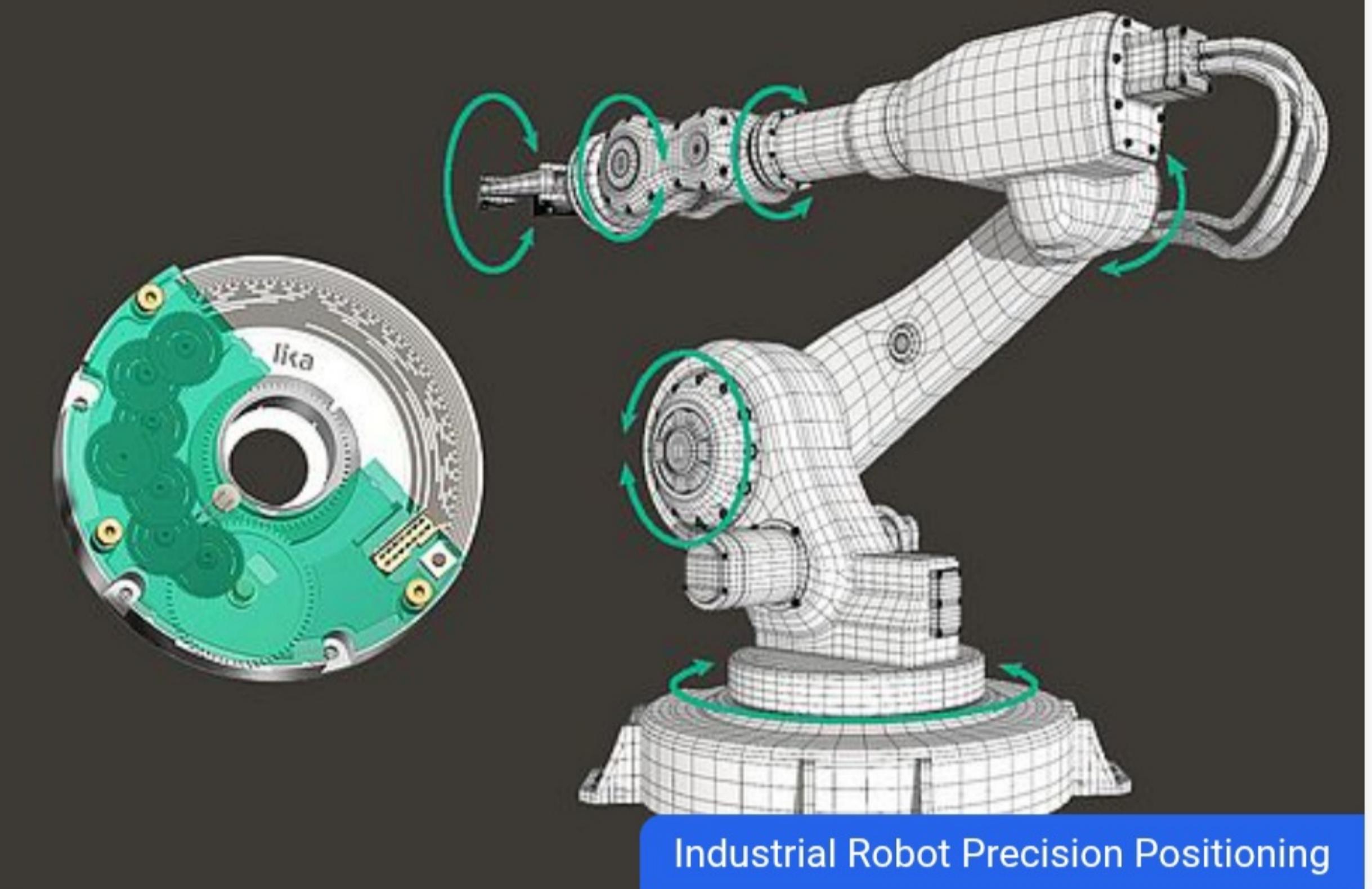
## The Questions:

- ➊ How does the robotic arm know the exact position of its motors?
- ➋ What if the power supply to this robotic arm is interrupted while it is performing a specific task?
- ➌ Will it restart the task from the beginning when the power supply is restored?
  
- 💡 These questions are real problems in precision systems, and the solution is what we'll discuss today: the absolute magnetic encoder.

In smart factories (Industry 4.0), machines must "see," "feel," and "understand" their position with precision:

- A system that doesn't know its location is an **Open-Loop** system – like driving a car with your eyes closed!
- The solution is **Feedback Control (Closed-Loop)**, which needs "eyes" to tell it where it is. These "eyes" are the Encoders.

## Encoders for robotics



Industrial Robot Precision Positioning

# What is an Encoder?

## Definition & Purpose:

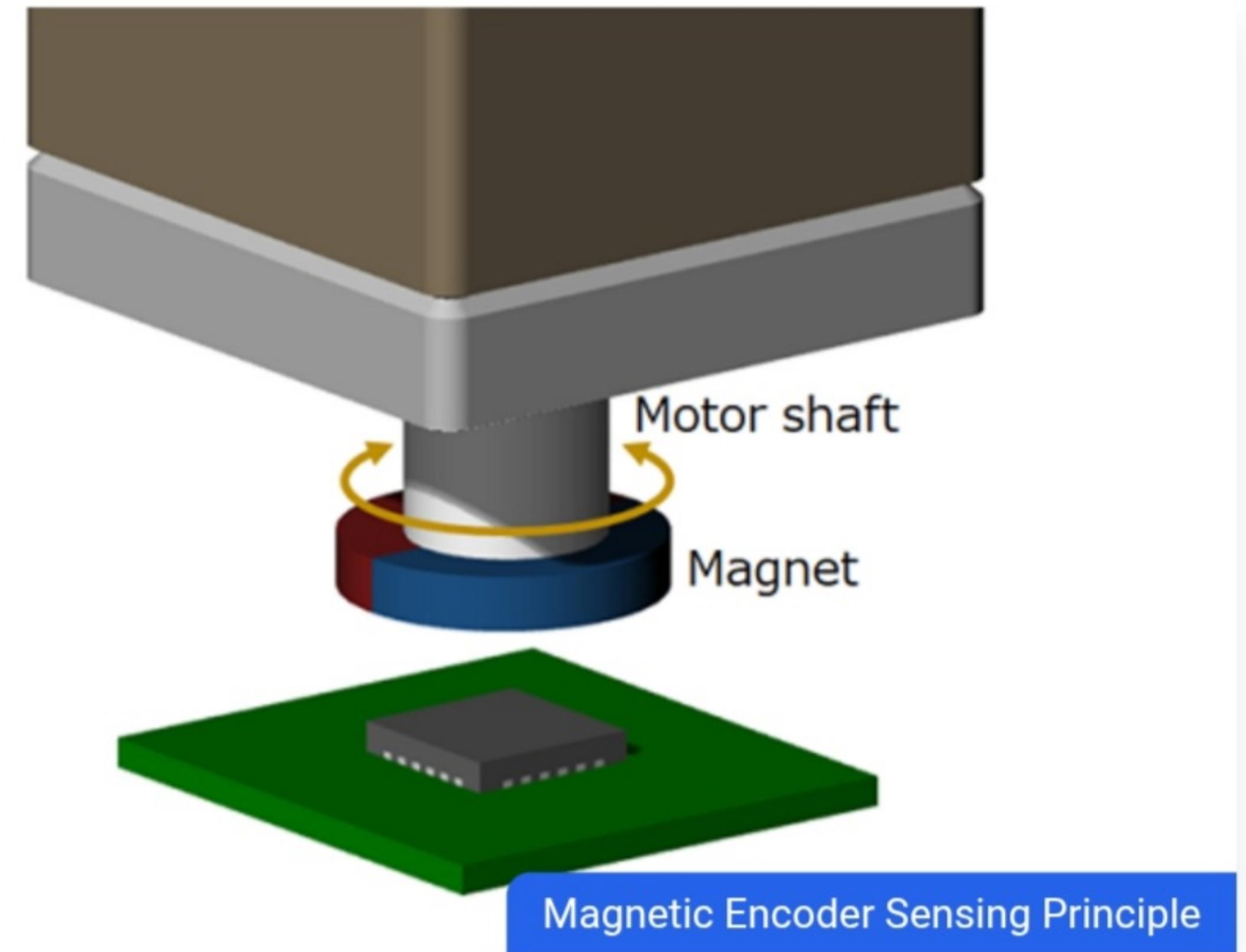
- ⚙️ **Definition:** An electromechanical sensor that converts mechanical motion (rotary or linear) into electrical signals.
- 🕒 **Measured quantities:** Position (absolute/relative), speed (RPM), and direction of movement.

## Role in Mechatronics:

- ⟳ Key feedback element enabling closed-loop control, ensuring accuracy and repeatability in automated systems.

## Applications:

- Robotic arm joint position sensing
- CNC machine tool axis positioning
- Motor shaft position and speed control
- Automated production line monitoring



# Encoder Types & Classification

## Classifications of Encoders

### Based on Sensing Technique:

- Rotary Encoder: Measures angular movement (rotation)
- Linear Encoder: Measures linear movement (in a straight line)

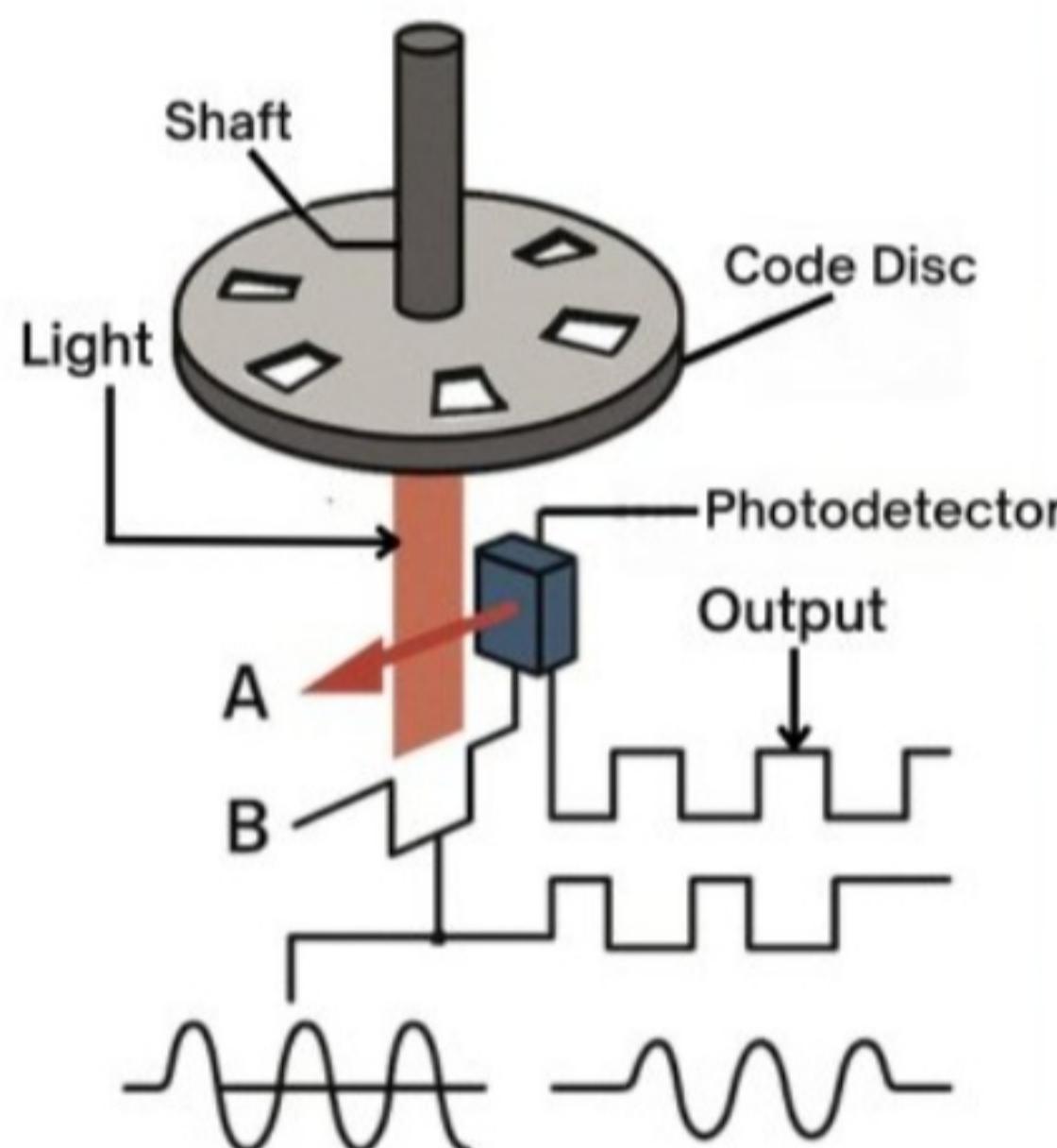
### Based on Measuring Type:

- Absolute Encoder: Provides unique digital code for each position. Knows position immediately on power-up.
- Incremental Encoder: Outputs pulses as it moves. Requires homing to find reference position.

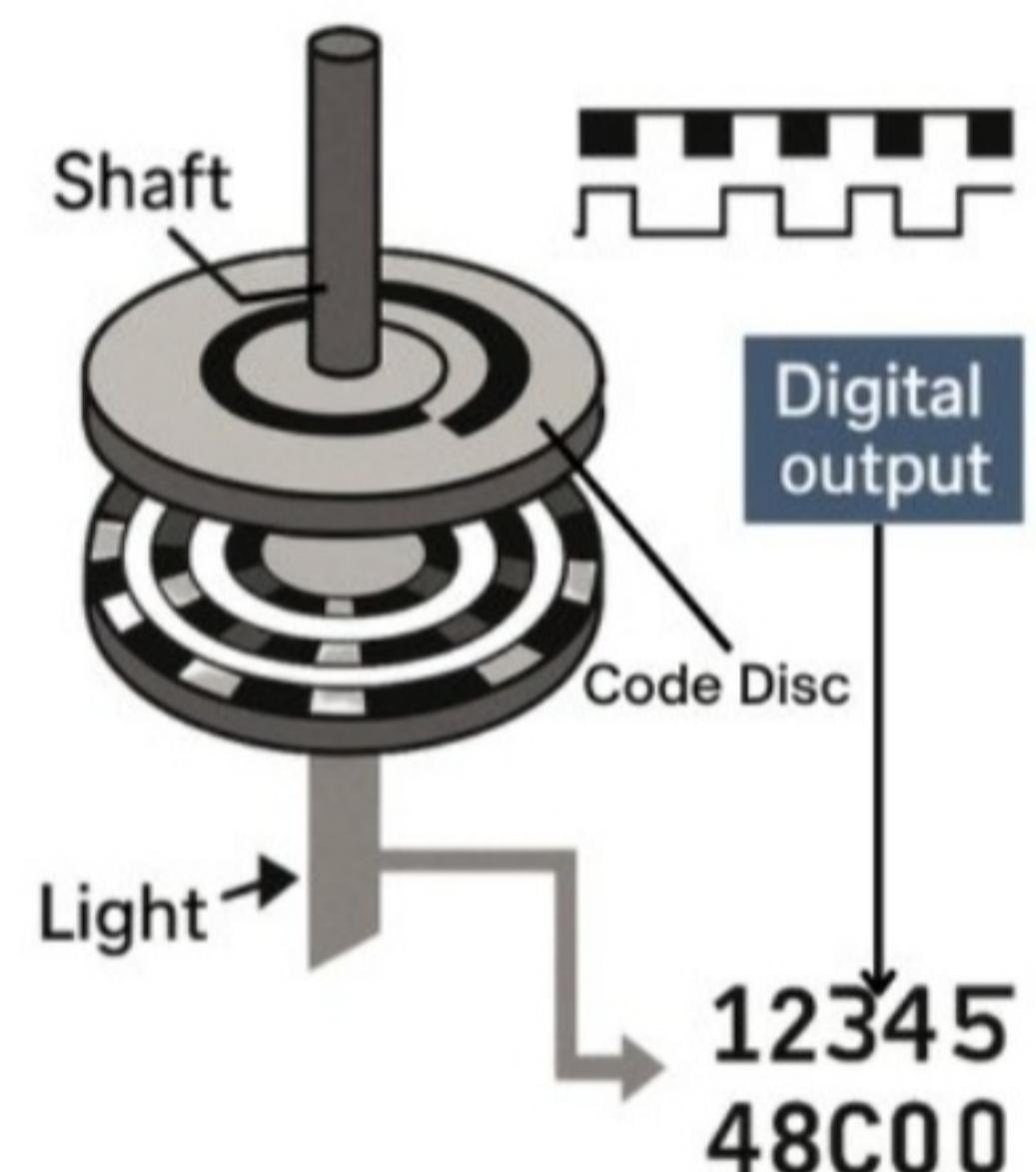
### Based on Technology:

- Optical: High resolution
- Mechanical: Low cost
- Capacitive: Balanced
- Magnetic: Robust
- Inductive: Durable
- Laser: Highest precision

## INCREMENTAL ROTARY ENCODER



## ABSOLUTE ROTARY ENCODER



Absolute vs Incremental Encoders

# Encoder Technologies Comparison

Selecting the right encoder technology depends on your application requirements. This comparison helps identify the best fit for your needs:

Technology	Accuracy / Resolution	Environmental Resistance	Approx. Cost (USD)	Ease of Integration	Power Loss Behavior
Optical	★★★ Very High	★ Low (Susceptible to dust, fog, oil, vibrations)	50 - 500	Moderate (Alignment sensitive)	Incremental: Position lost Absolute: Position retained
Magnetic	★★ Medium to High	★★★ Very High (Resists dust, moisture, vibration, oils)	40 - 400	Easy (Robust mounting)	Incremental: Position lost Absolute: Position retained
Mechanical	★ Low	★ Low (Contacts prone to wear & tear)	5 - 30	Very Easy (Simple wiring)	Position always lost
Inductive	★★★ High	★★★ Very High (Excellent for harsh environments)	100 - 600	Moderate	Incremental: Position lost Absolute: Position retained
Capacitive	★★★ High	★★ High (Resists dust, condensation)	20 - 100	Easy (Compact, digital programmability)	Incremental: Position lost Absolute: Position retained
Laser	★★★★ Extremely High	★ Low (Requires clean, stable lab conditions)	500 - 5,000	Difficult (Precise calibration needed)	Varies (Typically position lost)

## Key Insight

For IoT and industrial applications requiring reliability in harsh environments, **magnetic encoders** offer the best balance of accuracy, durability, and cost-effectiveness, especially in their absolute configuration.

# Hall Effect: The Beating Heart

## The Physical Principle Behind Magnetic Sensing

The Hall Effect is the phenomenon that enables magnetic encoders to function. Discovered by Edwin Hall in 1879, it describes how voltage is generated when a current-carrying conductor is placed in a magnetic field.

**How it works:** When a current flows through a conductor in a magnetic field, the magnetic force deflects moving charge carriers, creating a measurable voltage perpendicular to both the current and field.

### The Hall Voltage Formula:

$$V_H = (I \cdot B) / (n \cdot e \cdot d)$$

I = Current through the sensor (A)

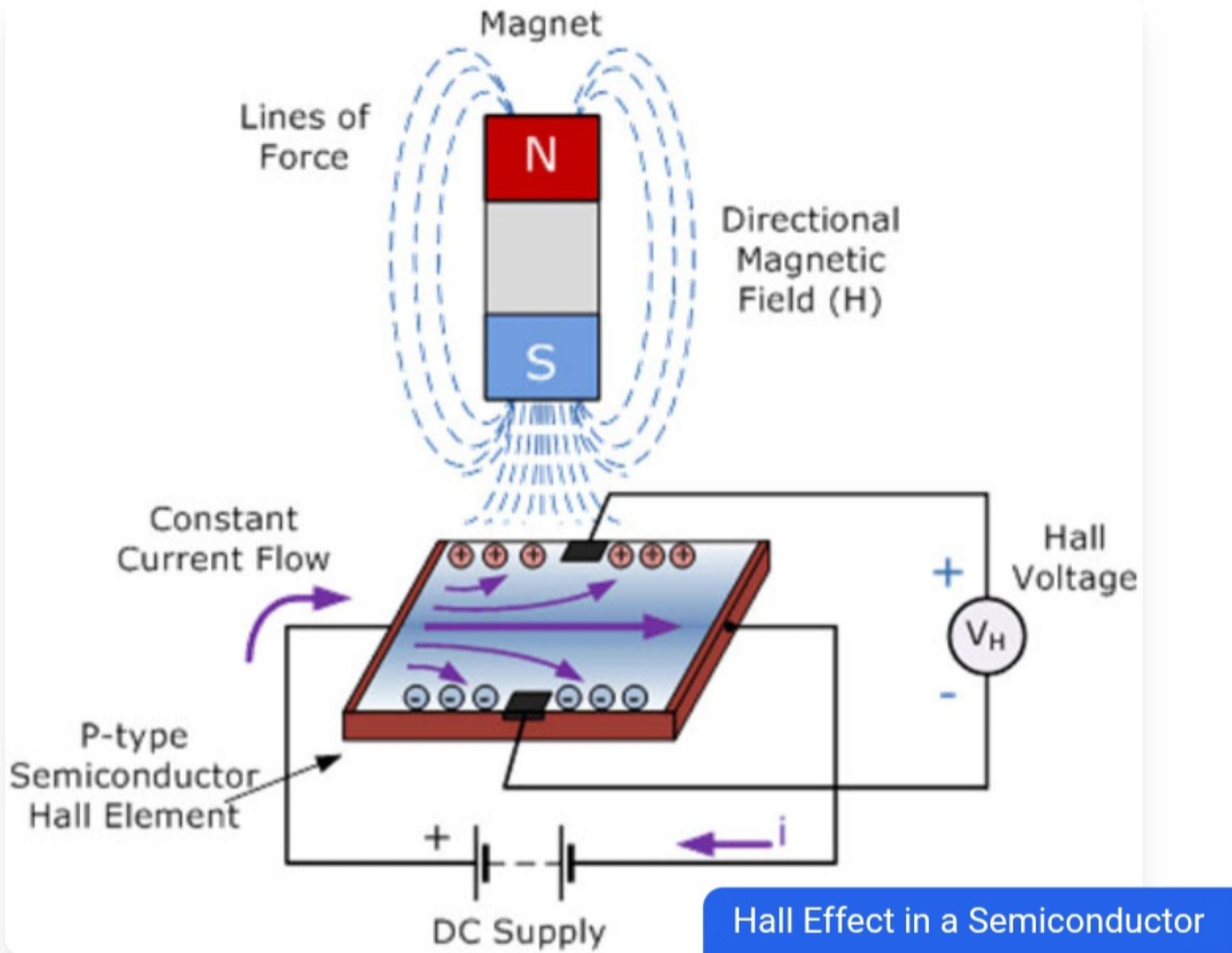
B = Magnetic flux density (T)

n = Charge carrier density ( $m^{-3}$ )

e = Elementary charge ( $1.602 \times 10^{-19} C$ )

d = Thickness of the sensing layer (m)

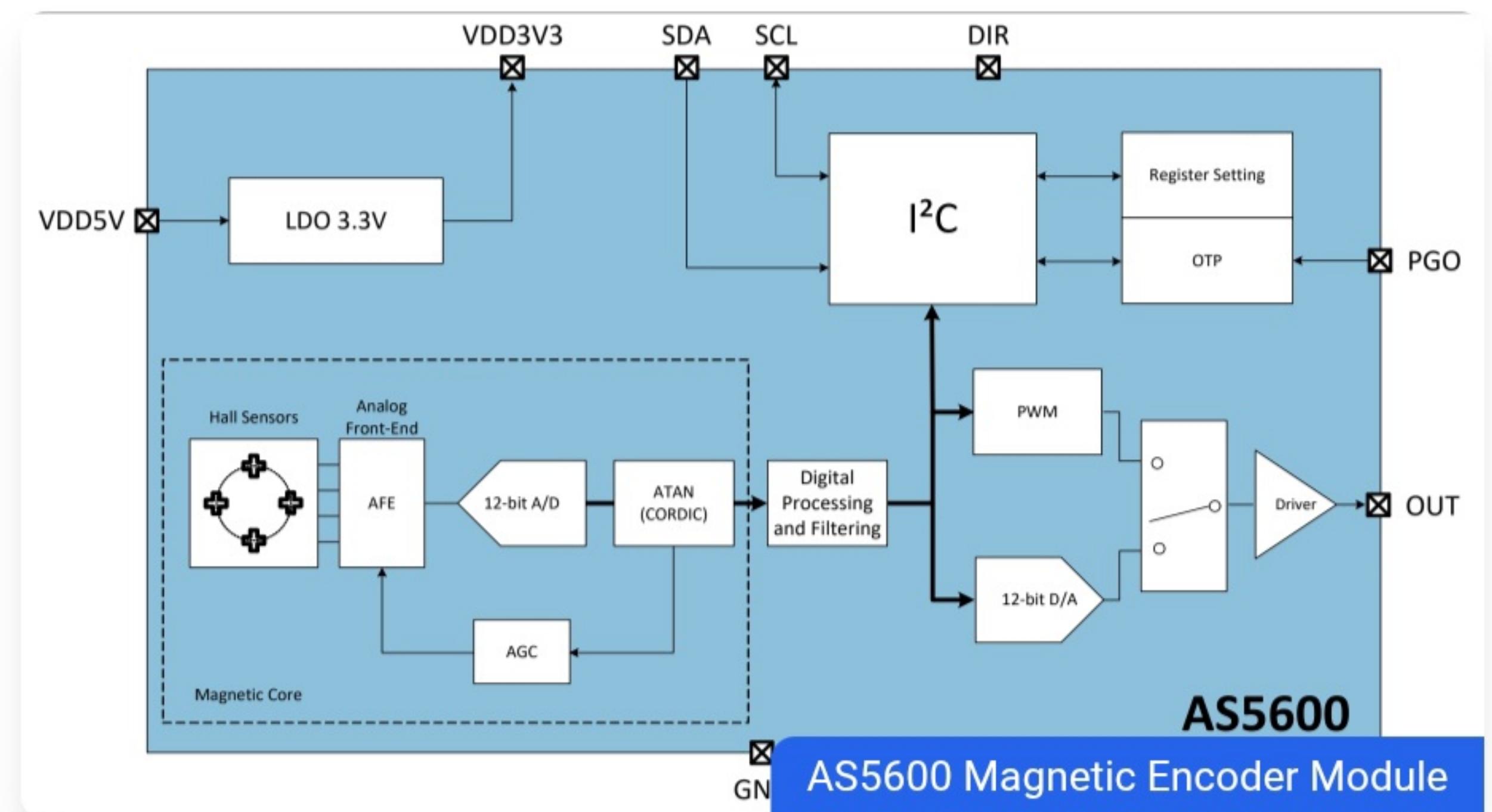
**?** In magnetic encoders, an array of Hall-effect sensors detects the rotating magnetic field from a permanent magnet, translating field variations into precise position data.



# The AS5600 Magnetic Encoder: Technical Overview

## Technical Specifications & Features:

- Definition:** An absolute magnetic rotary position encoder that measures the angle of a diametrically magnetized on-axis magnet.
- Contactless Design:** No mechanical wear, extended lifespan, immune to environmental contaminants.
- Resolution:** 12-bit (4096 positions), allowing precise angular measurement of  $0.088^\circ$  per step.



## Output Interfaces:

- Analog Output:** Voltage output linear and ratiometric to supply voltage VDD (0 to VDD).
- PWM Output:** PWM signal with duty cycle proportional to the absolute angle.
- I<sup>2</sup>C Interface:** For reading raw or processed digital angle data and device configuration.

# From Magnetic Field to Angle: Signal Processing

## How the Encoder Calculates the Angle:

### 1. Signal Generation

As the magnet rotates, Hall sensors on the die sample the magnetic field along a circular path, producing two signals:

- A sine wave (proportional to  $B\sin(\theta)$ )
- A cosine wave (proportional to  $B\cos(\theta)$ )

### 2. Signal Processing Chain

These raw signals undergo a sophisticated processing sequence:

- **Amplification:** Strengthening the signal
- **AGC:** Automatic gain control adjusts for varying magnetic field strengths
- **ADC:** 12-bit analog-to-digital conversion

### 3. Angle Calculation (CORDIC Algorithm)

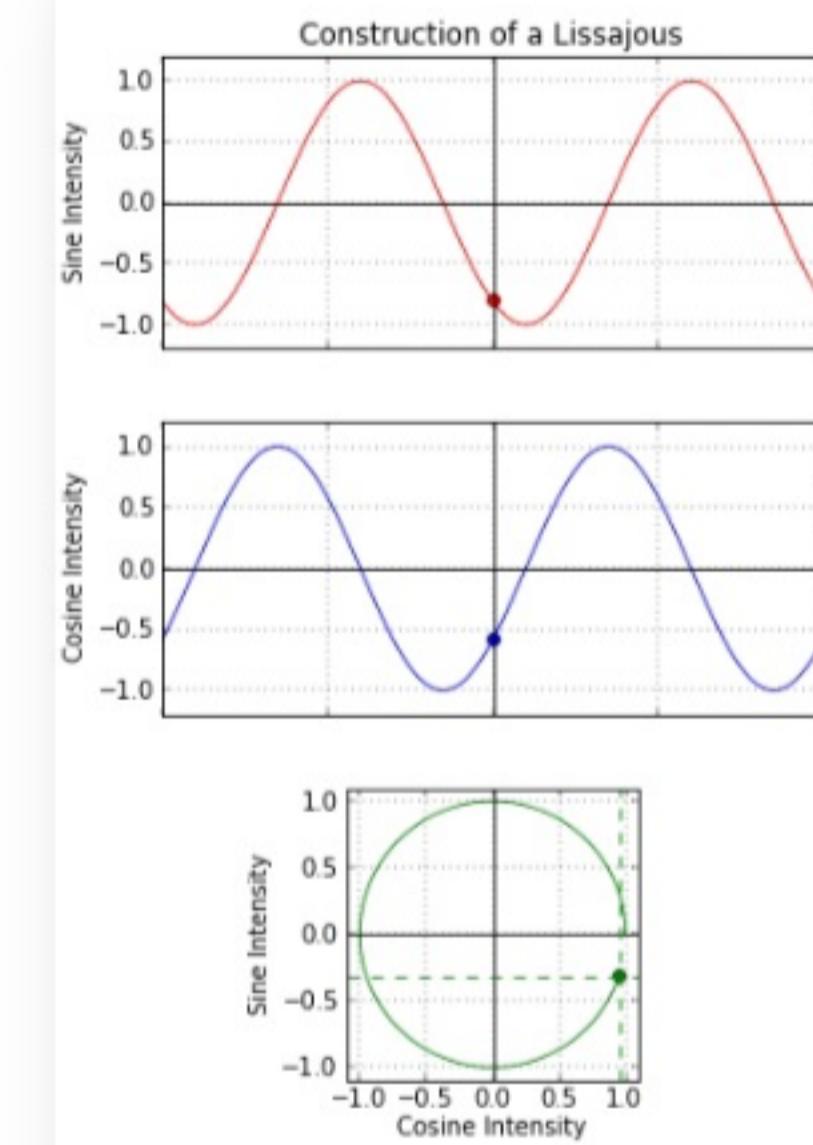
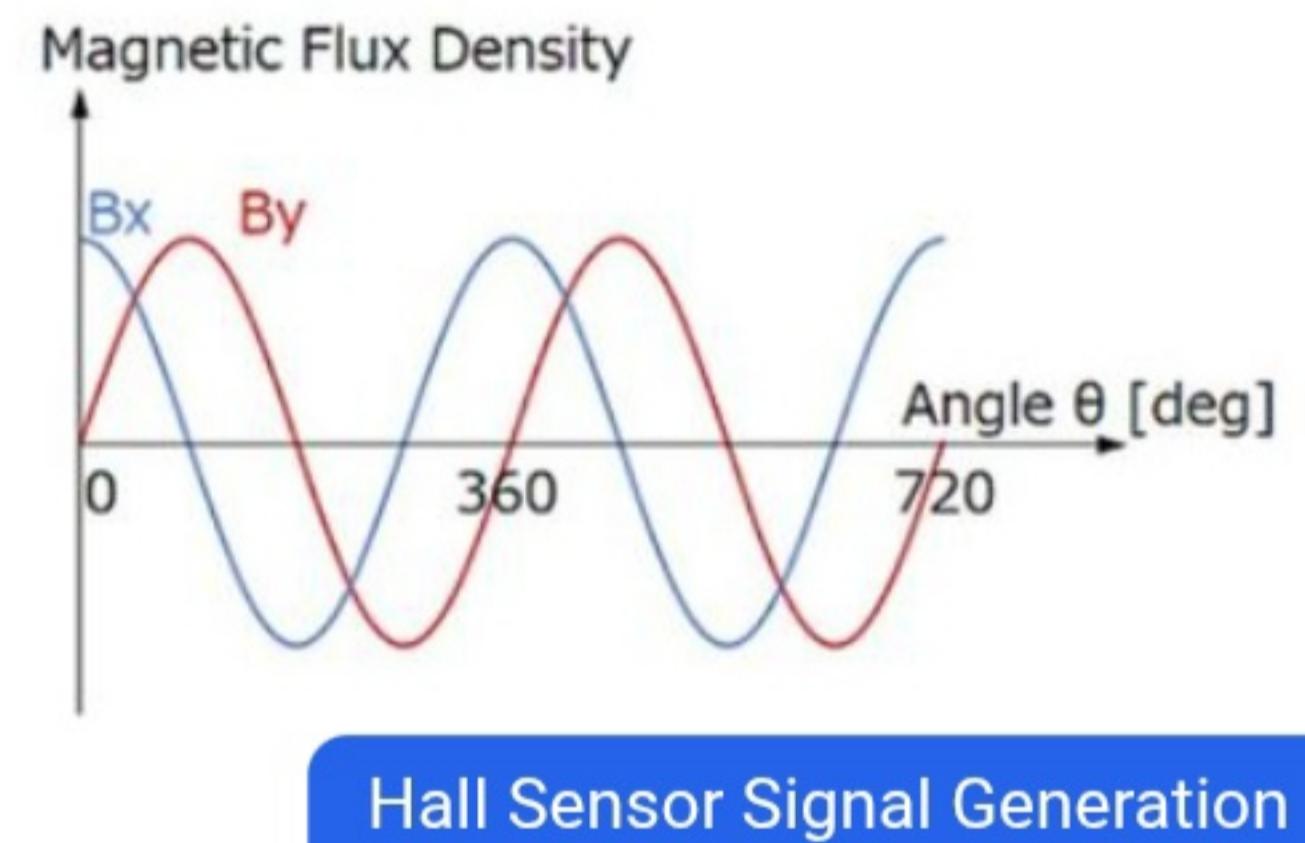
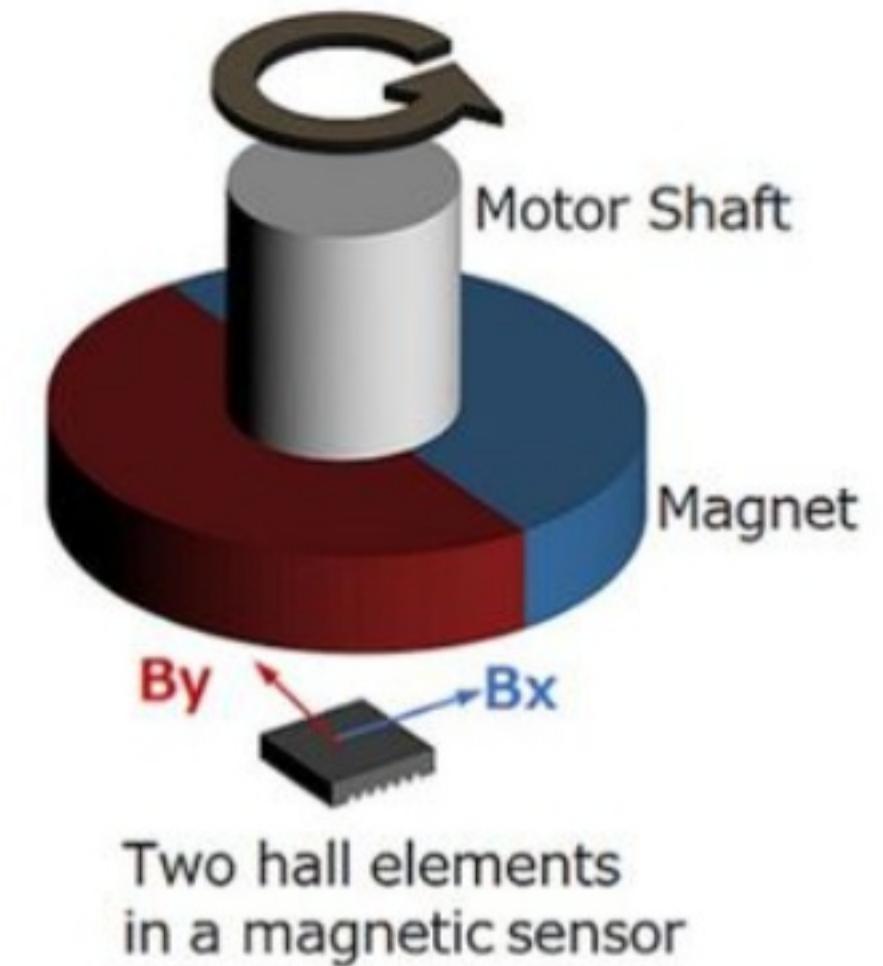
The angle is calculated using the arctangent function:

$$\theta = \arctan(\text{sine}/\text{cosine})$$

CORDIC (Coordinate Rotation Digital Computer) is an efficient algorithm implemented in hardware to calculate this function without complex multiplication.

### 4. Resolution

With 12-bit resolution, the AS5600 divides a complete rotation ( $360^\circ$ ) into 4,096 distinct positions, giving an angular resolution of  $0.088^\circ$  per step.

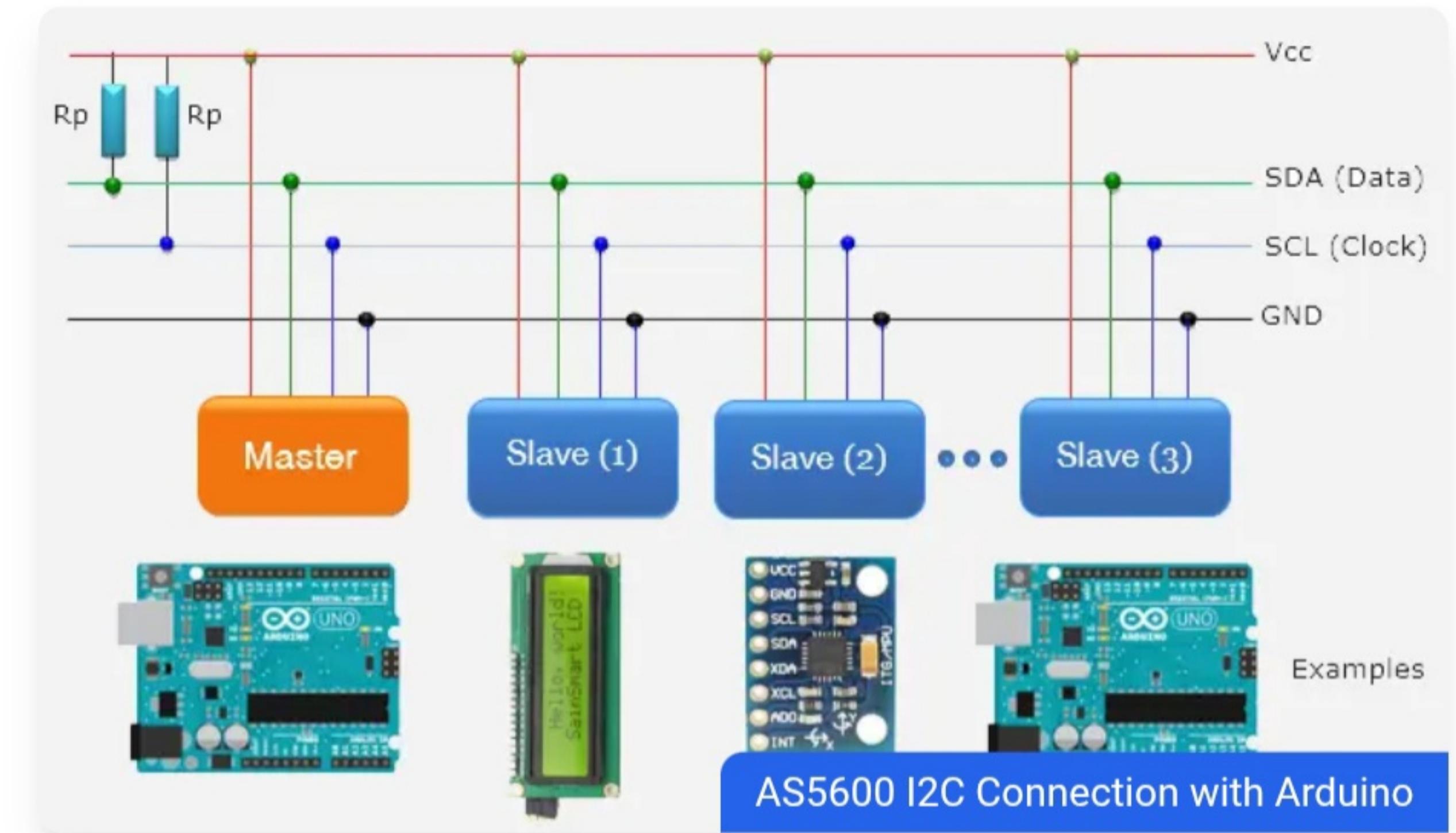


Lissajous Figure (Sine vs Cosine)

# I2C Protocol: Communication in IoT Systems

## The Language of Micro-IoT Communication:

- ⌚ **I2C (Inter-Integrated Circuit)**: A two-wire serial communication protocol that allows multiple devices to connect with minimal wiring
- ⌚ **Efficiency**: Only requires two main wires - SDA (Serial Data) for data transfer and SCL (Serial Clock) for synchronization
- ⌚ **Addressable**: Each device on the bus has a unique address (AS5600: 0x36), enabling dozens of sensors on the same two wires



## AS5600 I2C Communication Steps:

1. **Start Condition**: Master initiates communication
2. **Address**: Master sends AS5600 address (0x36) with read bit
3. **Acknowledge**: AS5600 responds with ACK signal
4. **Data Transfer**: AS5600 sends two bytes (16 bits) of angle data
5. **Stop Condition**: Master terminates the session

**Why I2C is Perfect for IoT:** If we used UART to connect four sensors, we would need four pairs of wires. With I2C, all four can share the same two wires, saving pins and simplifying circuits!

# AS5600 Features & Interfaces

## Multiple Interface Options

### >Analog Output

A voltage output linear and ratiometric to the supply voltage VDD (0 to VDD). Ideal for replacing traditional potentiometers with a contactless solution.

### % PWM Output

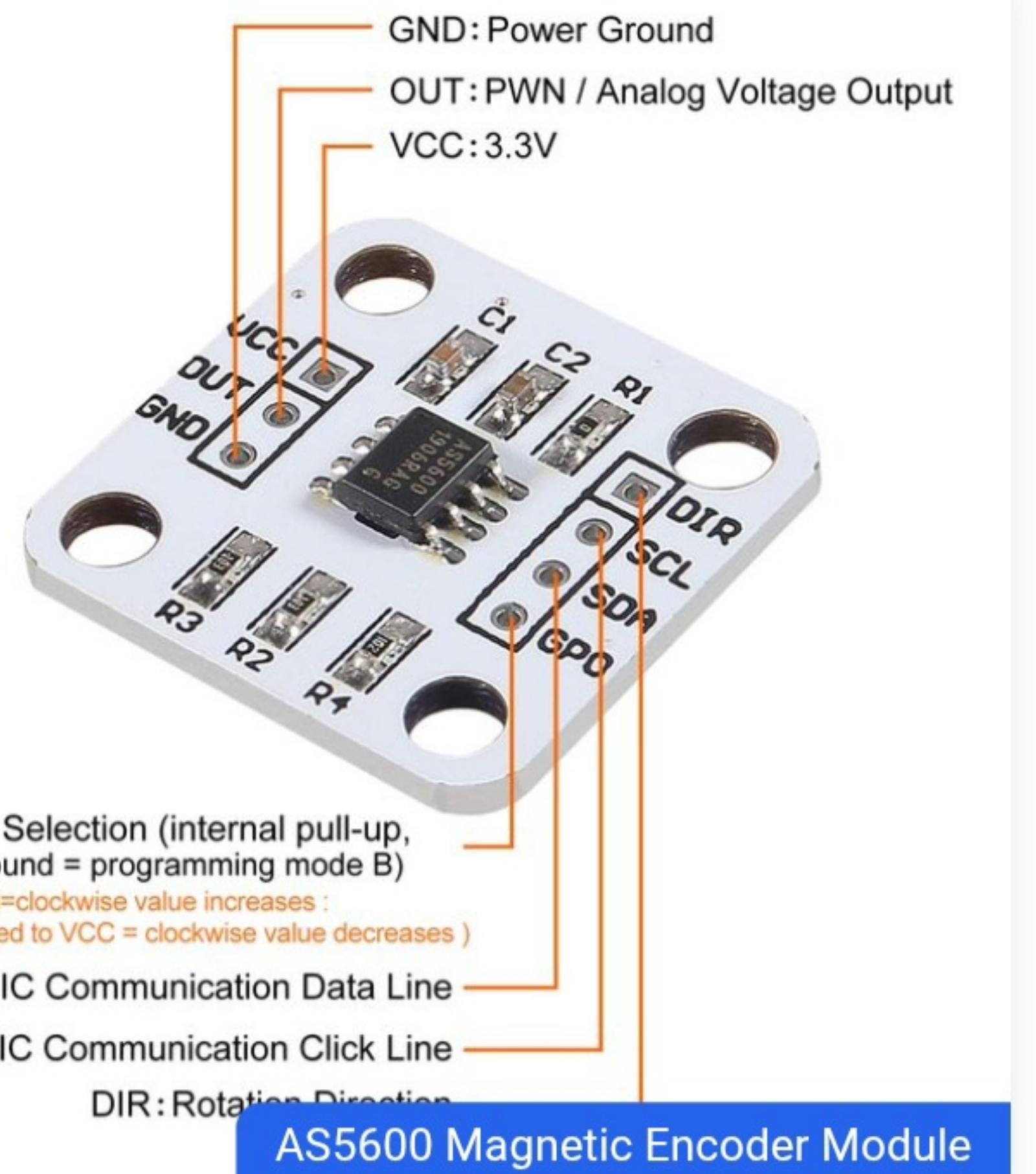
Pulse Width Modulation signal with duty cycle proportional to the absolute angle. Excellent for microcontrollers with PWM input capabilities.

### I<sup>2</sup>C Interface

Digital communication for reading raw or processed angle data and for comprehensive device configuration. Address: 0x36.

## Key Programmable Features

- **Angular Range Programming:** Define custom zero angle (ZPOS) and maximum angle (MPOS/MANG) for applications needing less than 360°
- **Non-Volatile Memory (OTP):** Permanently store settings using burn commands
- **System Monitoring:** Read magnetic field magnitude and AGC value for diagnostics
- **Digital Filters:** Programmable filters for optimizing response time and noise



# Wiring the AS5600: I<sup>2</sup>C Interface Method

## I<sup>2</sup>C Digital Interface (Primary Method)

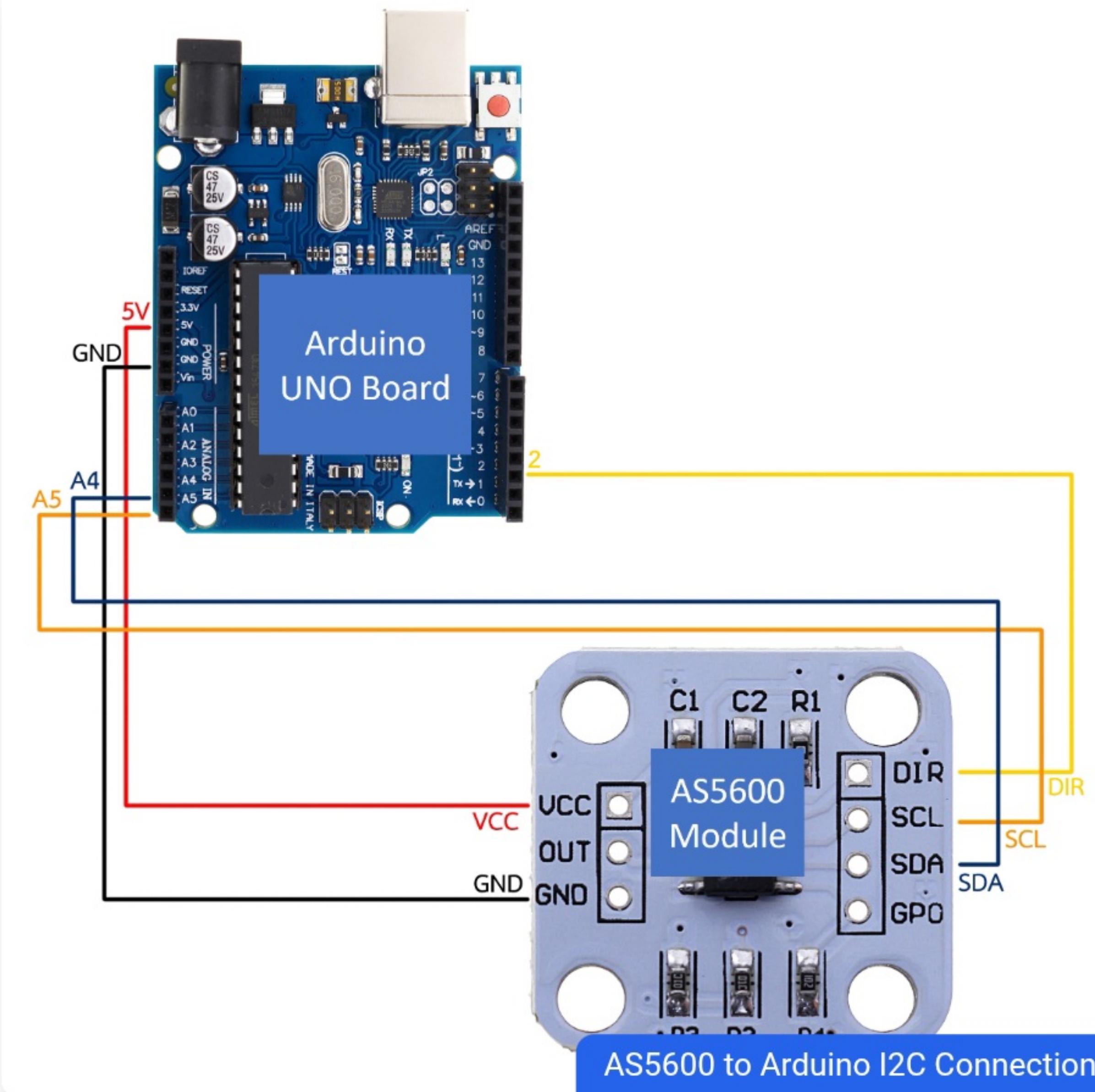
This is the most versatile connection method, allowing full access to the 12-bit digital angle data and configuration settings.

AS5600 → Arduino Uno/Nano

- 1 (VDD5V) → 5V
- 4 (GND) → GND
- 6 (SDA) → A4 (SDA)
- 7 (SCL) → A5 (SCL)
- 8 (DIR) → GND (CW) or 5V (CCW)

### Key Requirements:

- ❗ Crucial: 4.7kΩ pull-up resistors are required on both SDA and SCL lines. Connect between each line and 5V.
- ⚙️ The **DIR** pin controls rotation direction interpretation: GND for clockwise increase, 5V for counter-clockwise.
- ▼ For stable operation, add a 100nF decoupling capacitor between VDD and GND pins.



AS5600 to Arduino I<sup>2</sup>C Connection

### I<sup>2</sup>C Communication Details:

- Fixed I<sup>2</sup>C address: 0x36
- 12-bit angle data accessible via register reads
- Access to configuration registers for custom setup
- Supports standard (100kHz) and fast (400kHz) modes
- Angle data available in 12-bit (0xFFFF) and 16-bit formats

# Arduino Example: Reading the Angle

## Simple AS5600 Angle Reading

```
1 // Include the library for AS5600
2 #include "AS5600.h"
3 // Create an object to control the encoder
4 AS5600L as5600;
5
6 void setup() {
7   Serial.begin(9600); // Start serial communication
8   Wire.begin(); // Initialize I2C protocol
9   as5600.begin(); // Initialize the encoder
10  Serial.println("AS5600 Angle Reader Example");
11}
12
13 void loop() {
14  // Read the raw angle (0-4095)
15  int rawAngle = as5600.readAngle();
16
17  // Convert to degrees (0-360)
18  float degrees = rawAngle * 360.0 / 4096.0;
19
20  // Print the values
21  Serial.print("Raw: ");
22  Serial.print(rawAngle);
23  Serial.print("\tDegrees: ");
24  Serial.println(degrees);
25
26  delay(100); // Wait 100ms
27}
```

## Code Explanation

### Library Setup (Lines 2-4)

Include the AS5600 library and create an instance of the encoder object for communication.

### Initialization (Lines 6-11)

In the setup function, we initialize the Serial monitor, the I2C bus (Wire), and the encoder itself.

### Reading Angle Data (Lines 15-18)

The encoder provides 12-bit resolution (0-4095) representing 360°. We convert this raw value to degrees by multiplying by 360/4096.

### Serial Output (Lines 21-24)

We display both the raw value and the calculated angle in degrees on the Serial Monitor.

### AS5600 to Arduino Connection

AS5600:

- VDD5V → Arduino 5V
- GND → Arduino GND
- SDA → Arduino A4 (SDA)
- SCL → Arduino A5 (SCL)
- DIR → GND (clockwise) or 5V (counterclockwise)

Remember: Add 4.7kΩ pull-up resistors to both SDA and SCL lines.

# Practical Applications & Benefits

## Real-World Applications:

### Industrial Robotics

Precise arm positioning even after power interruptions, enabling continuous operation without recalibration.

### CNC Machines & Automation

Accurate tool positioning and workpiece orientation tracking in manufacturing processes.

### Smart Factory Systems (Industry 4.0)

Real-time position feedback for intelligent manufacturing networks and predictive maintenance.

### IoT Devices & Connected Sensors

Power-efficient position tracking in battery-operated devices and remote monitoring systems.

### Automotive Steering Systems

Precise angle measurement for electric power steering and drive-by-wire systems with absolute position awareness.

### Medical Equipment

High-reliability position sensing in surgical robots, patient beds, and diagnostic equipment requiring fail-safe operation.



Industrial Robotic Systems Using Encoders

### Key Advantages:

- ✓ **Instant Position Knowledge:** No homing procedures after power-up
- ✓ **Environmental Robustness:** Resistant to dust, moisture, vibrations
- ✓ **Compact Integration:** Small form factor for tight spaces
- ✓ **Contactless Operation:** No mechanical wear, extended lifespan
- ✓ **Cost-Effective:** Lower maintenance costs compared to optical encoders

# Conclusion and Future Outlook

## ✓ Key Benefits Summary

### Position Reliability

Absolute magnetic encoders maintain position data even after power loss, eliminating the need for homing procedures.

### Environmental Robustness

Operates reliably in challenging conditions with dust, moisture, vibration, and temperature variations, unlike optical alternatives.

### Integration Simplicity

Modern chips like AS5600 provide multiple interfaces ( $\text{I}^2\text{C}$ , PWM, analog) for flexible integration with diverse control systems.

### Cost-Effectiveness

Balanced price-to-performance ratio compared to other technologies, with reasonable 12-bit resolution (4096 positions) sufficient for most applications.

## Future Trends

### Higher Resolution Sensors

Development of 16-bit and beyond magnetic sensing technology will enable sub-0.01° accuracy for ultra-precise applications.

### Integrated Connectivity

Direct wireless protocols (BLE, Wi-Fi) built into encoders for IoT-ready operation without additional gateway devices.

### Hybrid Sensing Solutions

Fusion of magnetic with other sensing technologies (inertial, optical) to create redundant, higher reliability positioning systems.

### AI-Enhanced Diagnostics

Intelligent self-monitoring systems that can predict failures and compensate for environmental variations using machine learning algorithms.

## ■ Significance in Industry 4.0

Absolute magnetic encoders are foundational components enabling smart factories and advanced automation. Their immediate position awareness after power-up ensures continuous operation, minimizes downtime, and guarantees precision in critical systems. As we move toward more autonomous industrial processes, these encoders will continue to be essential building blocks for reliable, efficient, and intelligent machines.