# SENSOR_LAB_3

★ Name – MD TOUSIF ANSARI

★ Roll No – 23F3000577

## An Electronic Compass Using Hall Effect Sensors

An electronic compass utilizes Hall Effect sensors to detect the Earth's magnetic field and determine direction electronically, offering significant advantages over traditional mechanical compasses. By measuring the field strength along two perpendicular axes using Hall Effect ICs, such as the SS49, and amplifying these signals, the compass can accurately calculate heading angles through simple signal processing.

This hands-on experiment demonstrates the principles of the Hall Effect in practical navigation systems, as used in modern devices from smartphones to robotics. Through careful circuit design, simulation, and calibration, the study enables a deeper understanding of sensor-based electronic compasses and highlights the importance of precision and signal conditioning in accurate directional sensing.

# Components Used

→ SS49e hall Sensor – 2

→ Adalm1000 kit – Power supply

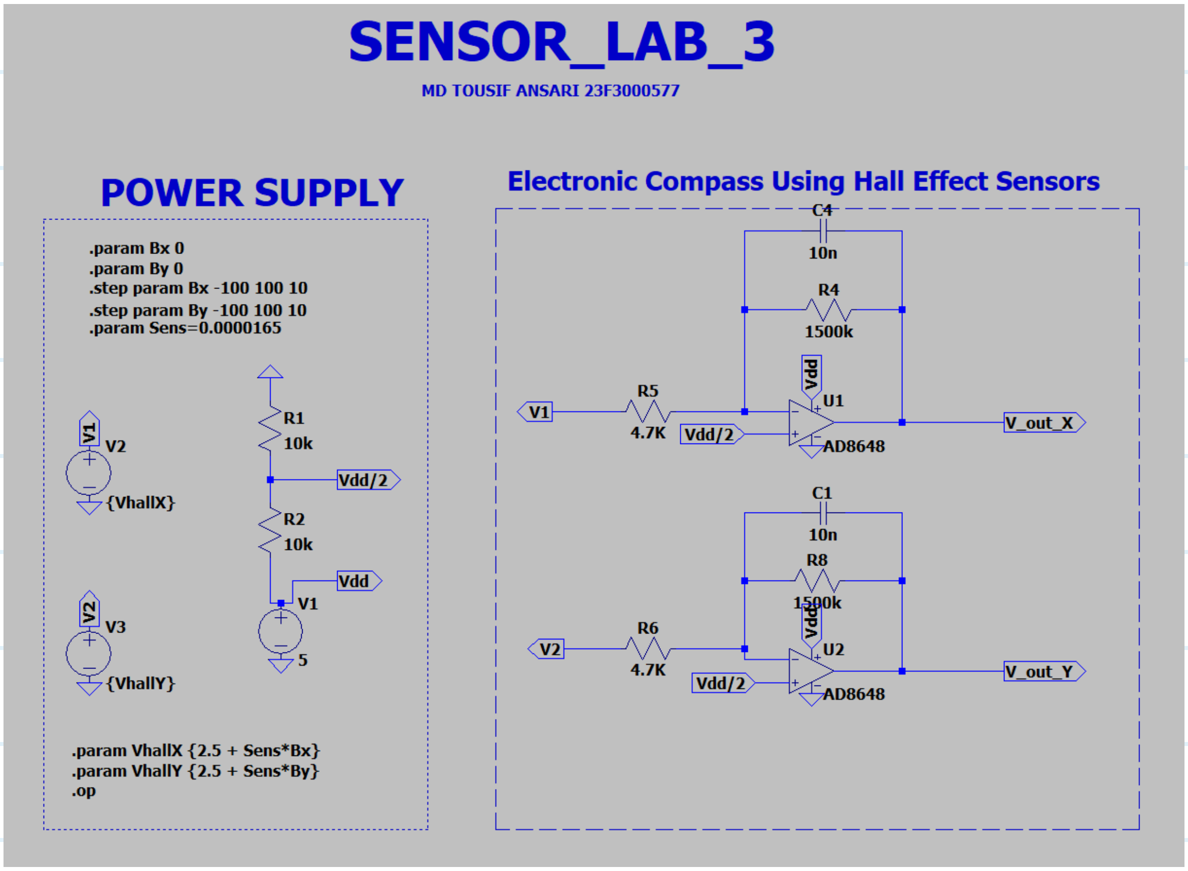
→ Resistors – 1.5 MΩ x 2 ; 4.7k x 2

→ Capacitor – 10 nF x 2

→ mCP6004-IC – 1

# Circuit design and Simulation

## • Simulation



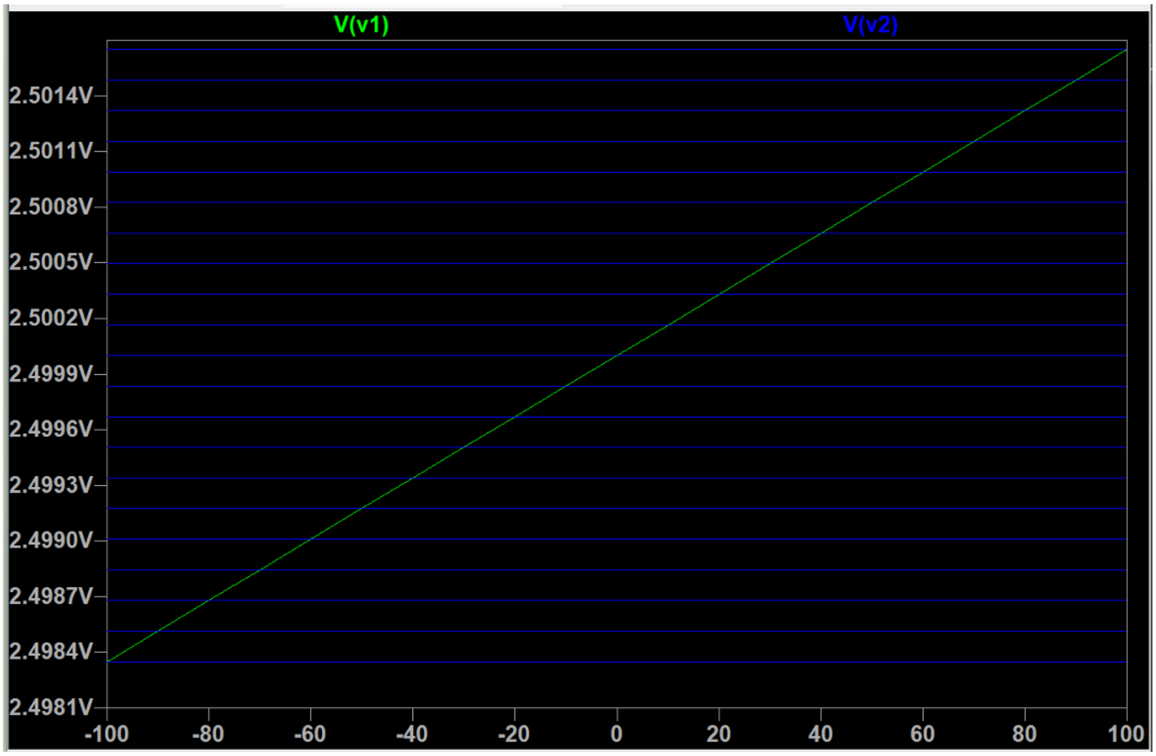

• Opamp gain of 320 and filter of 10 Hz using 10nF capacitor and 1.5 MΩ Resistor [ Via Calculation ]

## • Hall IC emulation :

→ SS49E hall sensor gives 2.5 V (output) when no magnetic field Present.

Sensor response to an external field is small, so for a magnetic field of −100 uT to 100 uT we have used the voltage supply for simulation (.step param as seen in the image), based on my calculations I got the following voltage range.

Voltage – {2.4984 to 2.5014}



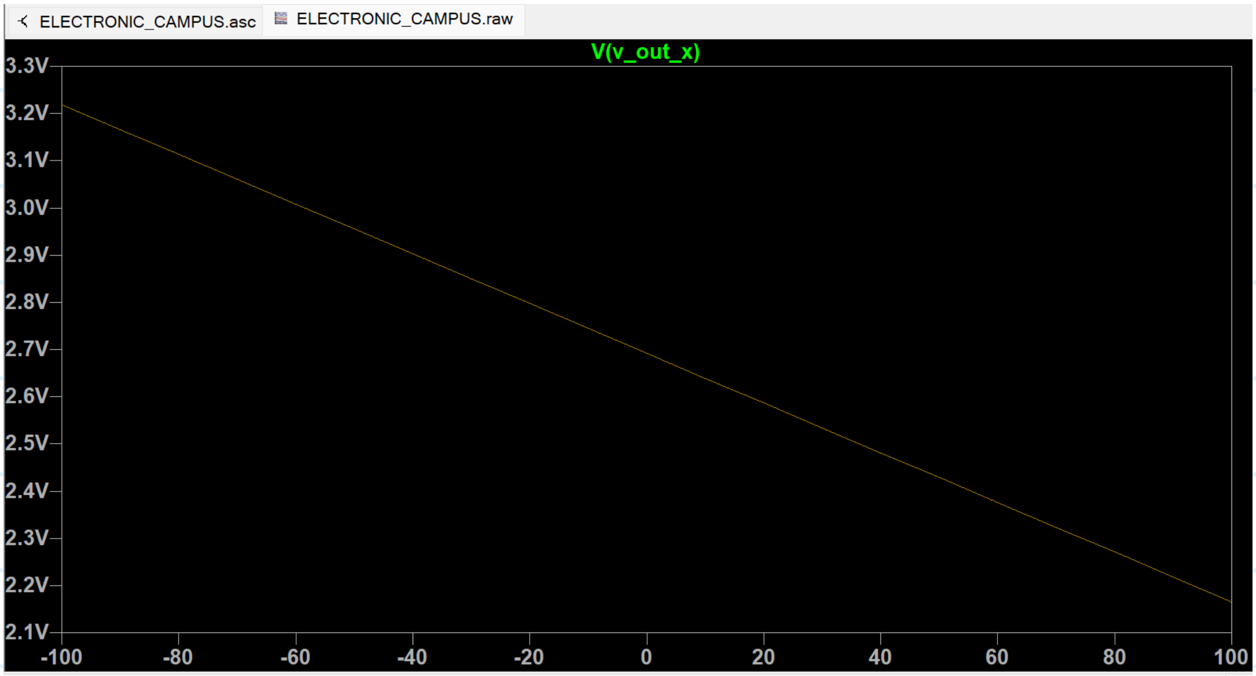

Magnetic field(-100 to 100)

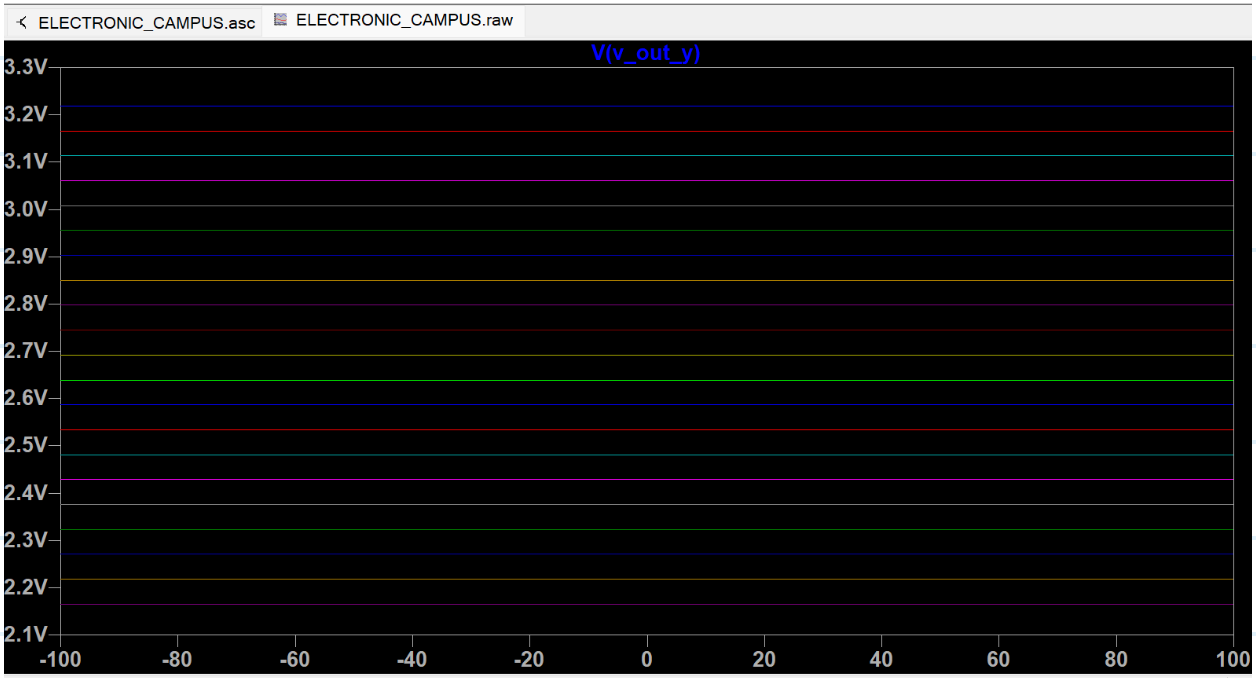
→ We are using the Amplifier with a gain of 320 {why? – See Calculation part} as the output of hall sensor is so small to be used. For this purpose we are using the diffrence amplifier.

→ One input of the diffrence amplifier is connected to Vdd/2 and the other to hall IC's output.

- Capacitor(10nF) added across the feedback(1.5Mohm) resistor to limit the bandwidth to less than 10 Hz.
- The gain (320) is set such that the output is just below the Op-amp saturation level for a 300uT magnetic field variation

## • Output



## Working of Hall Effect Sensor Compass:

### SS49E Linear Hall-effect Sensor

### How Does a Hall Sensor (like SS49E) Work?

### Hall Effect Principle

When current flows through a thin semiconductor plate and a magnetic field is applied perpendicular to the plate, a voltage (Hall voltage) develops at right angles to both the current and the magnetic field.

### SS49E Functionality

- The SS49E operates by supplying power (typically 3V to 6.5V) across its Vcc and GND pins.
- When a magnetic field (from a permanent magnet or electromagnet) is brought near the sensor, it produces an **analog output voltage** at its output pin.
- The output voltage is directly proportional to the **strength and polarity** of the magnetic field.
  - For example, without a magnetic field ("zero Gauss"), the sensor outputs about **2.5V** (at 5V supply).
  - As a south pole approaches the branded side, the output goes above 2.5V; as a north pole approaches, it drops below 2.5V.
- Sensitivity is about **1.8mV per Gauss** (at 25°C).

### Applications

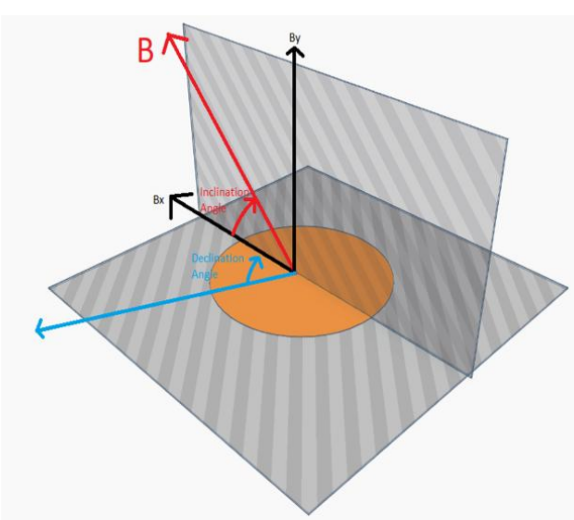
- Magnetic field detection
- Motor and current sensing
- Proximity and position sensing
- Linear position encoding
- Ferrous metal detection

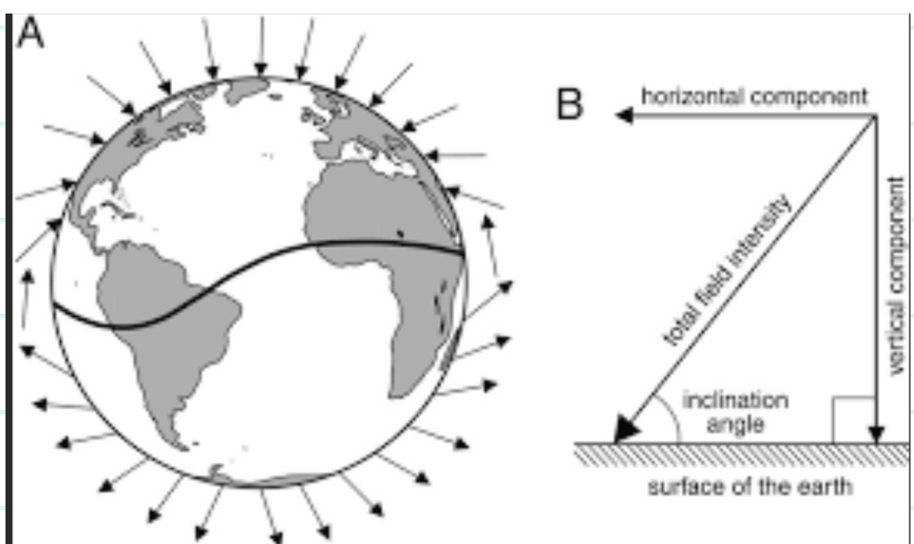
## Key Characteristics

- **Type:** Linear, analog Hall-effect sensor
- **Operating voltage:** 2.7V to 6.5V
- **Output voltage:** Proportional to magnetic field (typically 2.5V at zero field on 5V supply)
- **Sensitivity:** ~1.8mV/Gauss
- **Low noise:** No external filtering needed
- **Temperature stability:** Enhanced with thin-film resistors
- **Operating temperature range:** -40°C to 100°C
- **Current draw:** Typically 4–6mA
- **Output range:** 0.86V to 4.21V (for -1,500G to +1,500G field)

## Working Details

- A magnetic field perpendicular to the sensor’s surface will cause the output voltage to shift above or below this center point depending on the field's polarity and strength. Raw output due to Earth's field is small.
- The SS49E will increase or decrease its output voltage from nominal based on the magnetic field encountered.
- **North pole** near the sensor: output voltage decreases from 2.5V.
- **South pole** near the sensor: output voltage increases from 2.5V.
- Placing two Hall sensors orthogonally on a flat plane lets us capture two-dimensional components of the Earth's magnetic field. By taking the arctangent of Vx and Vy, compass heading can be determined.



# # Calculations

<u>Sensitivity of SS49e</u>: 1.8 mV/G (millivolts per Gauss)

<u>MCP6004</u>: rail-to-rail inputs/outputs, **GBW = 1 MHz**, input offset ≈ **±4.5 mV (max)**, input bias ≈ **~1 pA**, supply 1.8–5.5 V — good for single-supply 5 V operation. **Maximum single-stage gain** to keep peaks just below saturation (conservative) ≈ **452**.

- 1 Gauss (G) = 100 µT. So **300 µT = 3 G.**
- Using SS49E sensitivity $S = 1.8\ \mathrm{mV/G}$ (typical):

$$\Delta V_{sensor} = S \times 3\ \mathrm{G} = 1.8\ \mathrm{mV/G} \times 3 = 5.4\ \mathrm{mV}$$

So, the Hall output moves about **±5.4 mV** around 2.5 V for ±300 µT .

To set the gain such that the output change is just below op-amp saturation for a 300 µT swing

(Aim target output swing about **±1.8 V)**

We can change target output swing to get different voltage value.

Gain required:

$$G = \frac{V_{out\_peak}}{\Delta V_{sensor}} \approx \frac{1.8\ \mathrm{V}}{5.4\ \mathrm{mV}} \approx 333$$

So pick **G ≈ 330** (round number).

So based on the gain the R and Rf values are R=4.7kohm and Rf= 1.5Mohm

<u>BANDWIDTH-</u>

$$f_c = \frac{1}{2\pi R_f C} \quad \Rightarrow \quad C = \frac{1}{2\pi R_f f_c}$$

---

C= 10nF, Rf= 1.5Mohm

# Hardware Implementation

offset voltage

MCP6004

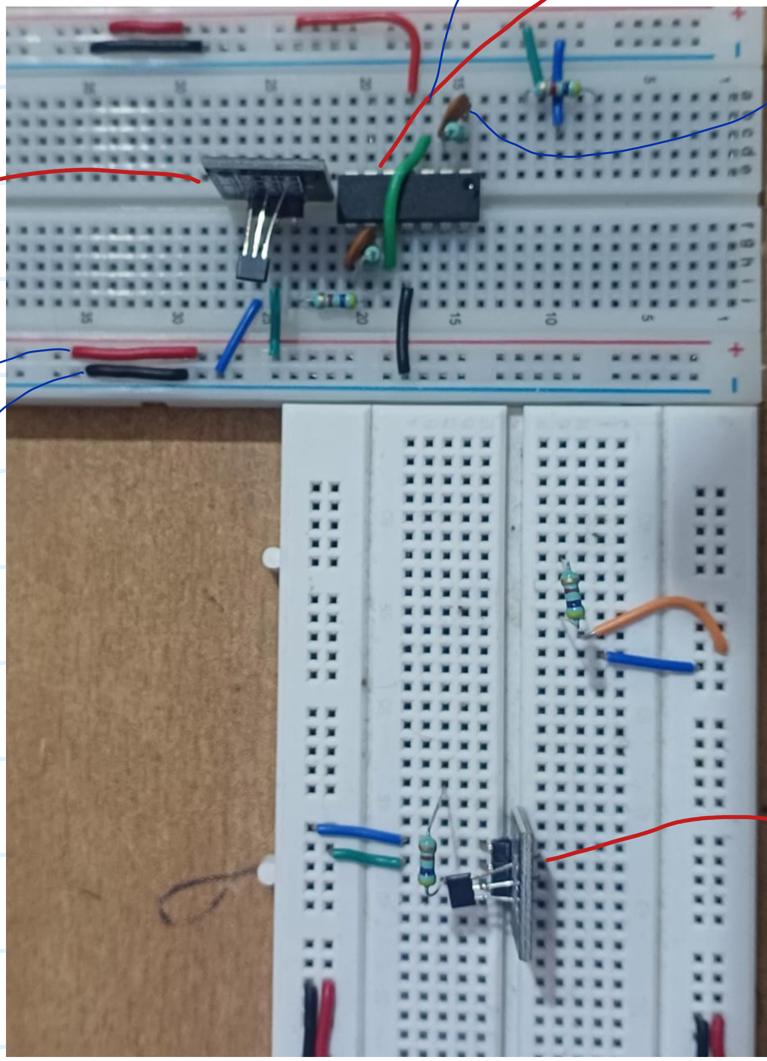
capacitor

Hall Ic(1)
(ss49e)

Hall Ic at 90°

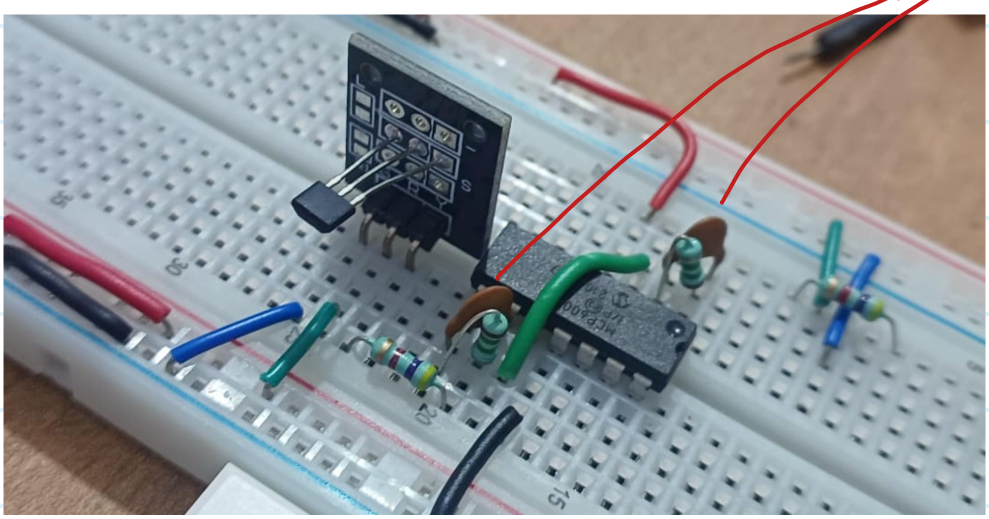
+5V

gnd



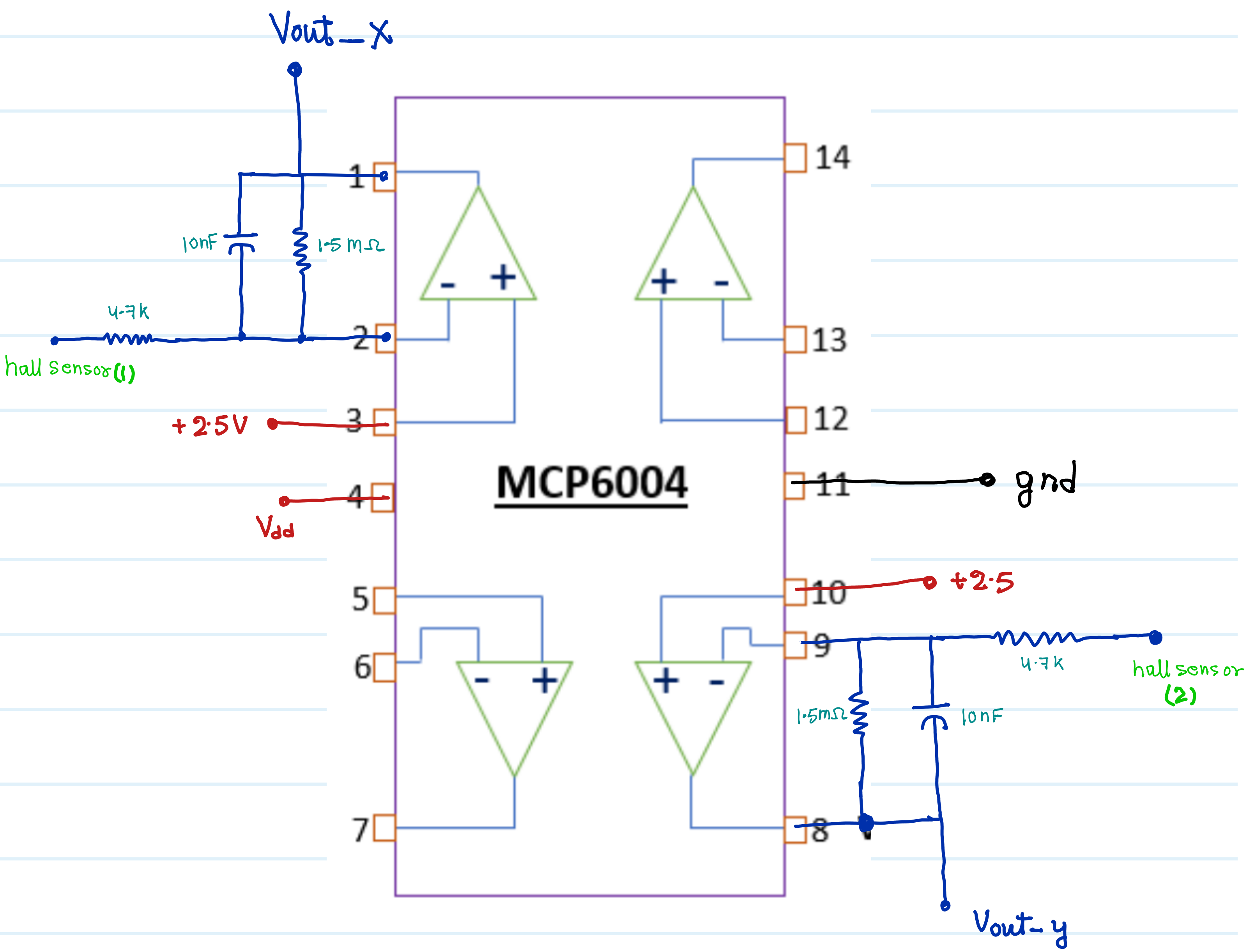
Hall Ic(2)
(ss49e)

Bandwidth limiting capacitor



# # Pin diagram

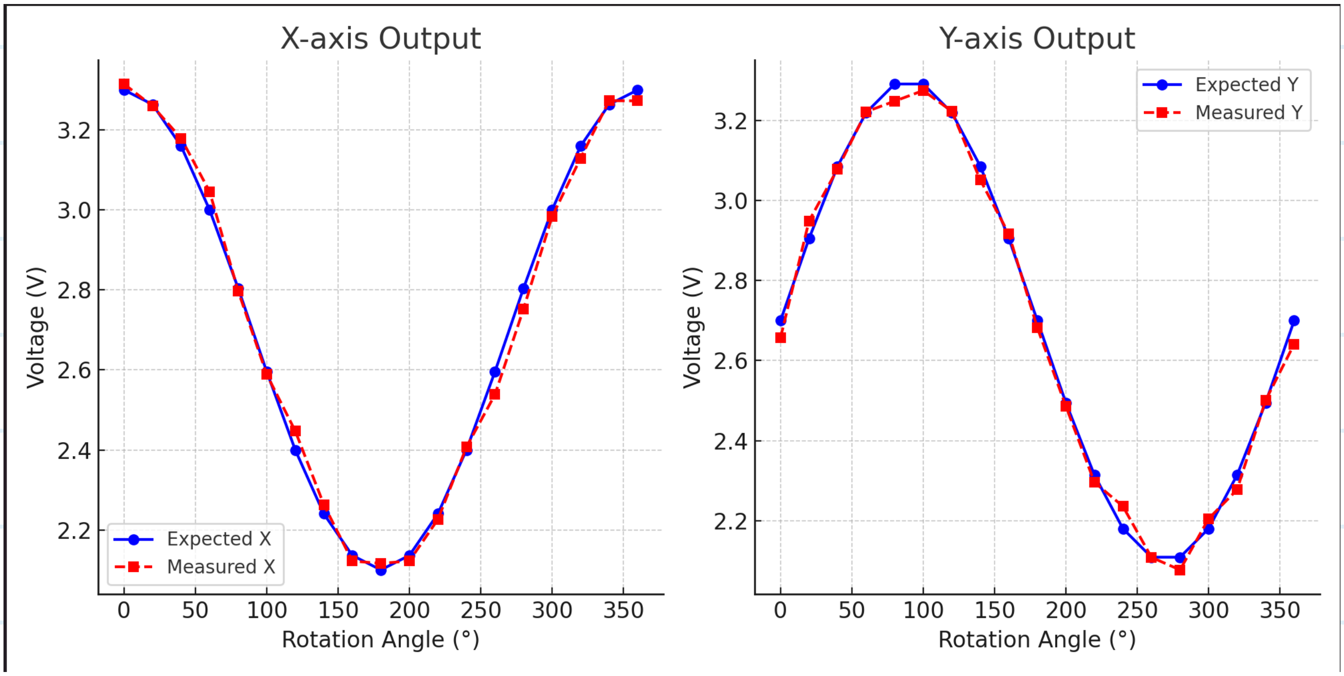
(Wiring of difference Amplifier)



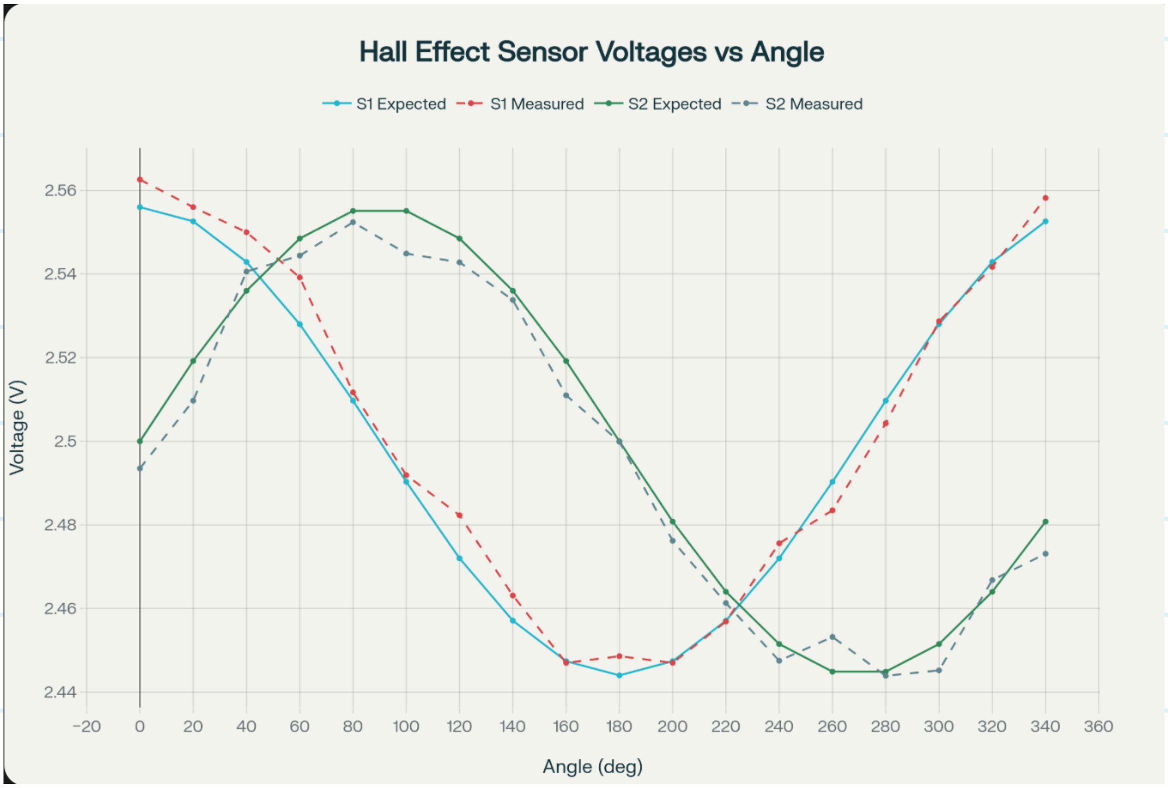

- Opamp - gain = 320.
- 10 Hz Feed back Filter used.

# # Testing and data Recording

- Voltage vs Angle Plot (after opamp amplification)




- Hall Sensor Output



# Reason for deviation from expected values and Potential Source of error.

- **Sensor Non-linearity:** Hall sensors have slight deviations from linear response under varying magnetic field strengths, especially near limits, causing measurement errors.
- **Temperature Drift:** Sensor offset voltage and sensitivity change with temperature, leading to shifts in output and reduced accuracy without compensation.
- **Mechanical Misalignment:** Imperfect 90° placement or incorrect orientation relative to Earth's magnetic field causes systematic voltage and heading errors.
- **Amplifier Offset and Gain Variations:** Differences in gain or DC offset between sensor channels distort sinusoidal voltage patterns necessary for accurate direction calculation.
- **External Magnetic Interference:** Nearby magnetic sources (electronics, ferrous materials) can introduce stray fields altering sensor readings unpredictably.
- **Electrical Noise:** Environmental electromagnetic noise and circuit noise get amplified along with the signal, impacting precision.
- **ADC Resolution and Quantization:** Limited resolution of the data acquisition system can cause rounding errors, especially with low signal swings.
- **Sensor-to-Sensor Manufacturing Variability:** Each sensor has unique offset and sensitivity characteristics requiring calibration to minimize biases.
- **Calibration Limitations:** Insufficient or incomplete calibration (e.g., limited points, no temperature correction) limits accuracy and repeatability.
- **Stray Magnetic Fields and Shielding Issues:** Improper shielding or proximity to stray fields causes offset and sensitivity errors affecting readings.

# Possible improvements

## Possible Improvements

1. **Better Sensor Alignment**
   - Use precision mechanical fixtures and digital inclinometers to ensure the two Hall sensors are exactly orthogonal (90° apart) and coplanar.
   - Minimize sensor tilt and offset by rigidly mounting sensors on a non-magnetic, vibration-resistant material.
   - Implement software compensation algorithms to correct for minor misalignments detected during calibration.
2. **Improved Calibration**
   - Employ multi-point calibration over the entire 360° rotation to accurately center the sensor outputs and normalize scale factors.
   - Use ellipse fitting and compensation techniques to correct soft iron distortions (non-circular sensor output patterns).
   - Automatically update calibration parameters periodically or when environmental conditions change to handle sensor drift and magnetic interferences.
3. **Advanced Signal Processing Techniques**
   - Implement digital filtering such as low-pass or Kalman filters to reduce sensor noise and improve signal stability.
   - Integrate sensor fusion algorithms (e.g., combining accelerometer data with magnetometer signals) for tilt compensation and more accurate heading calculation.
   - Use adaptive gain control in the amplifier stages to maintain optimum dynamic range under varying magnetic field strengths.

4. **Hardware Enhancements**

- Use low-offset, low-drift precision operational amplifiers in the conditioning circuit.
- Add temperature sensors and compensation circuitry to correct for temperature-induced variations.
- Design a PCB for a more compact, noise-resistant build rather than a breadboard implementation.

# Conclusion

### Key Observations and Learning Outcomes

- The Hall effect sensors, when properly arranged and conditioned, can effectively measure the Earth's horizontal magnetic field components and provide reliable heading information.
- Signal conditioning circuits with appropriate gain and filtering are critical to amplifying the small sensor signals to measurable and noise-free levels.
- Calibration is essential to correct sensor offsets, scale mismatches, and environmental magnetic distortions to achieve accurate heading measurements.
- Software processing, including angle calculation and filtering, drastically enhances the usability and precision of the compass readings.
- Practical challenges such as sensor misalignment, magnetic interference, and temperature effects must be understood and addressed in both hardware and software design.
- Through this experiment, one gains hands-on experience in sensor physics, analog circuit design, simulation, embedded programming, and systematic testing and calibration methodologies.
- The overall project underlines the interplay between hardware precision, signal integrity, and software correction needed to achieve a robust electronic compass system.