Sensors Laboratory – Experiment 3

An Electronic Compass Using Hall Effect Sensors

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1 Circuit Design & Simulation

1.1 Circuit Diagram

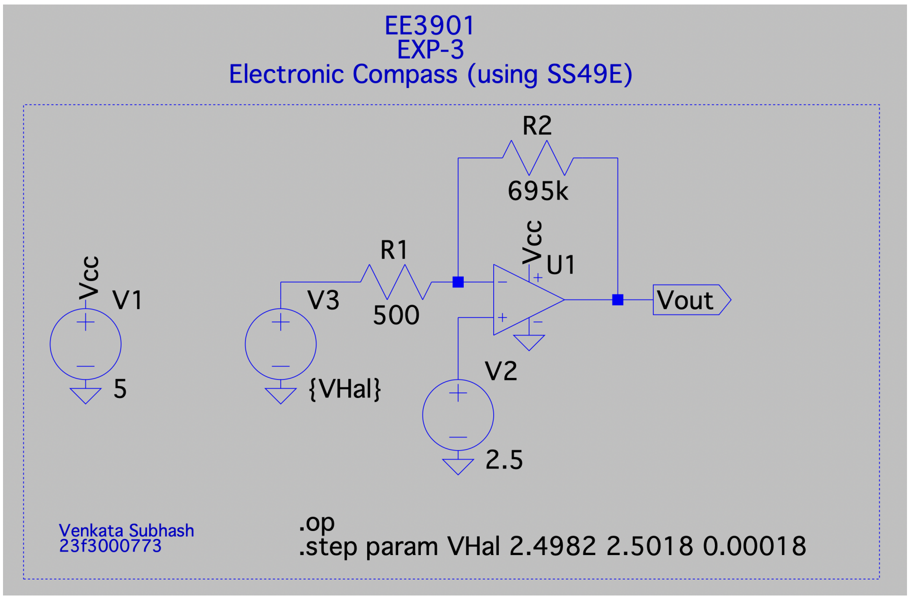


Figure 1: Simulated circuit of the Hall sensor with difference amplifier

- The sensitivity of the sensor is 1.8 mV per 100 μT.
- The op-amp is powered by a 5V supply, with a common-mode voltage of 2.5 V.
- We require the op-amp to saturate at 300 μT.
- Therefore, we need an output swing of 2.5 V for an input change of $1.8 \times 3 = 5.4$ mV.

$$\Rightarrow \text{Gain} = \frac{2500}{5.4} \approx 463$$

- Hence, the required gain equation becomes:

$$1 + \frac{R_2}{R_1} \approx 463$$

- However, in the simulation, I am using $R_2 = 695\,\text{k}\Omega$ to demonstrate saturation at a lower magnetic field of 100 μT.

1.2 List of Components

- Hall Effect Sensor (SS49E)
- Op-Amp (MCP6004)
- Resistors: 1kΩ, 500kΩ (for setting amplifier gain)
- Power Supply: 5V DC

1.3 Simulation Setup

- The Hall sensor was modeled as a voltage source producing an output centered at VDD/2 (2.5V for a 5V supply).
- A `.step param` command was used in LTSpice to vary the magnetic field from -100 µT to +100 µT.
- The sensitivity of the Hall sensor (SS49E) is 1.8 mV/G, where 1 G = 100 μT. Since we are asked to simulate the effect for magnetic fields ranging from -100 μT to $+100$ μT in steps of 10 μT, we will vary the Hall voltage (V_{Hal}) from $2.5 - 0.0018$ V to $2.5 + 0.0018$ V in steps of 0.18 mV.

1.4 Simulation Results

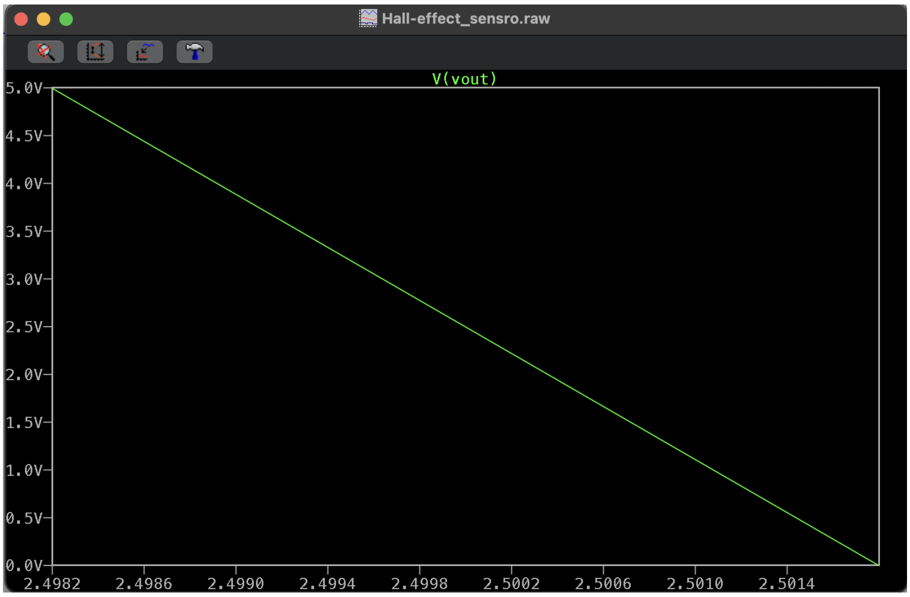


Figure 2: Amplifier response

2 Hardware Implementation

2.1 Breadboard Setup

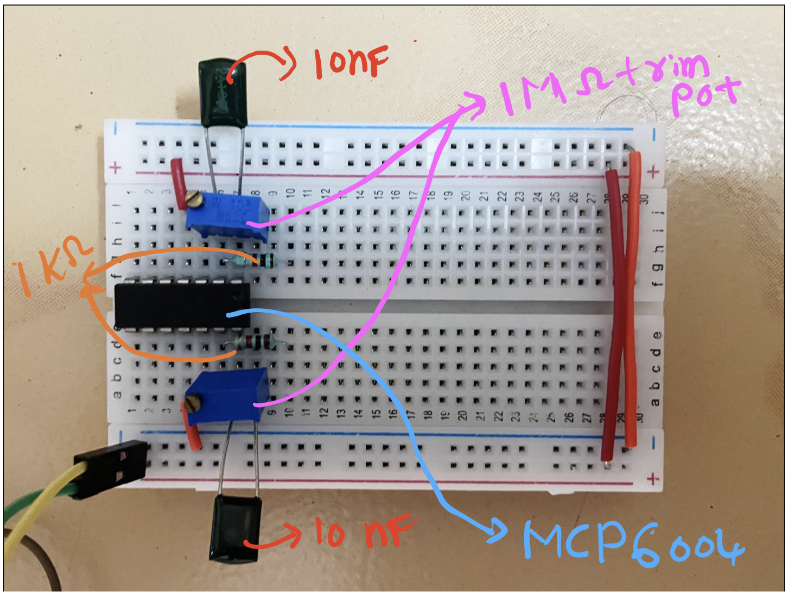


Figure 3: Breadboard with amplifier circuit

2.2 Mounting of Hall ICs

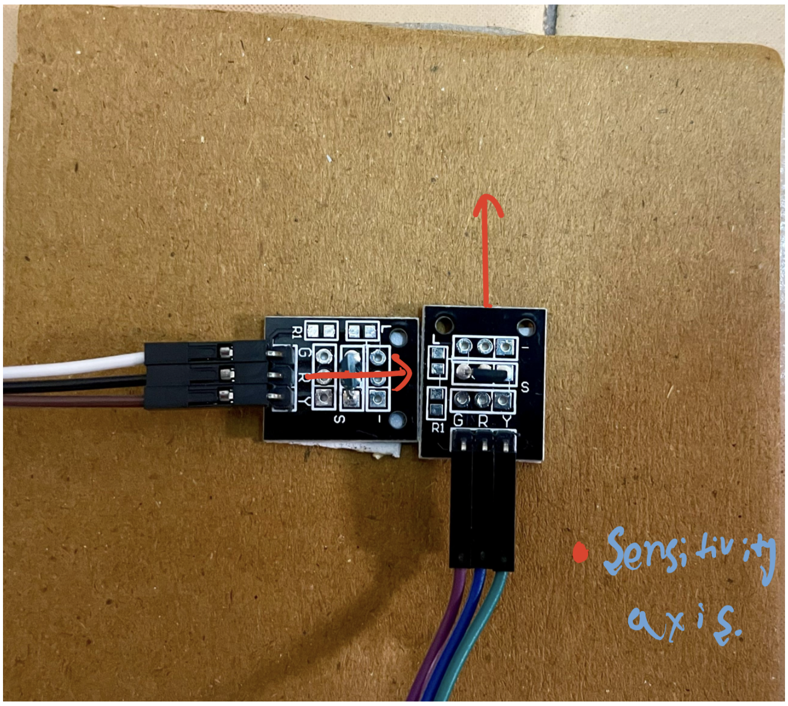


Figure 4: Cardboard with Hall-effect Sensors mounted

- Two SS49 Hall sensors were mounted at 90° angles on a non-magnetic cardboard strip.
- The sensitive axes of the sensors were aligned to measure orthogonal components of the horizontal magnetic field.

2.3 Circuit Wiring

- The Hall sensor's output was connected to the inverting terminal of the op-amp.

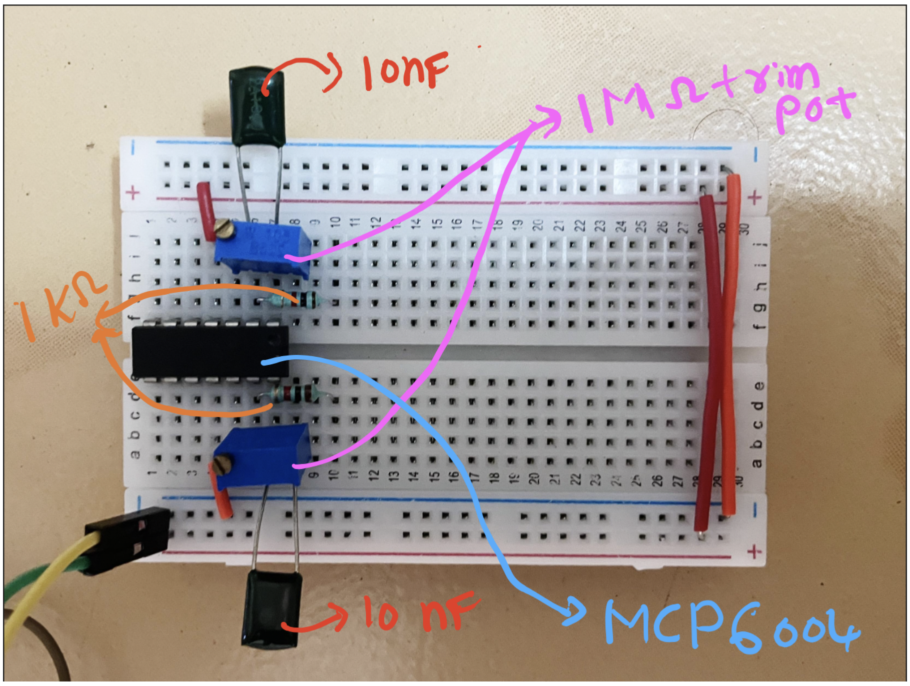


Figure 5: Breadboard with amplifier circuit

- The non-inverting terminal receives a DC offset generated using Channels A and B of the ADALM1000. This method was chosen to precisely control the bias voltage, as the high gain of the op-amp makes trim-pot tuning prone to error. Using the ADALM1000 provides finer resolution and stability for biasing.
- The feedback loop included a gain resistor and a parallel capacitor for low-pass filtering (10 nF) (band-limiting capacitor).

2.4 Measurement Procedure and Noise Filtration

The measurements were carried out using the ALICE software. I operated the ADALM1000 in **Split I/O mode**, which allows simultaneous voltage sourcing and measurement through the same channel. This mode is particularly useful in my setup, as I needed to generate and monitor two independent voltages to bias the inputs of the difference amplifier.

Snapshots of the output waveforms, captured using ALICE, are provided below. These include cases both with and without the filtering capacitor, for comparison and reference.

I have used 10 nF capacitor in series with Feedback resistor (trimpot in this case) for filtering the noise.

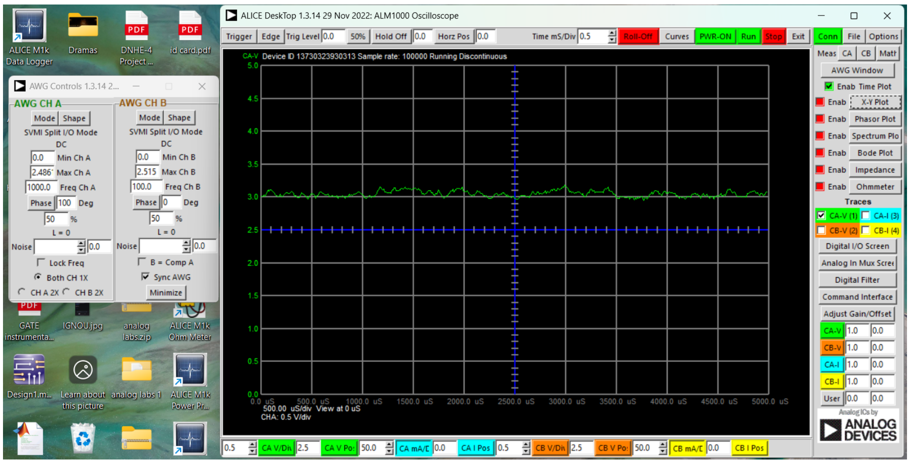


Figure 6: Output without filtering

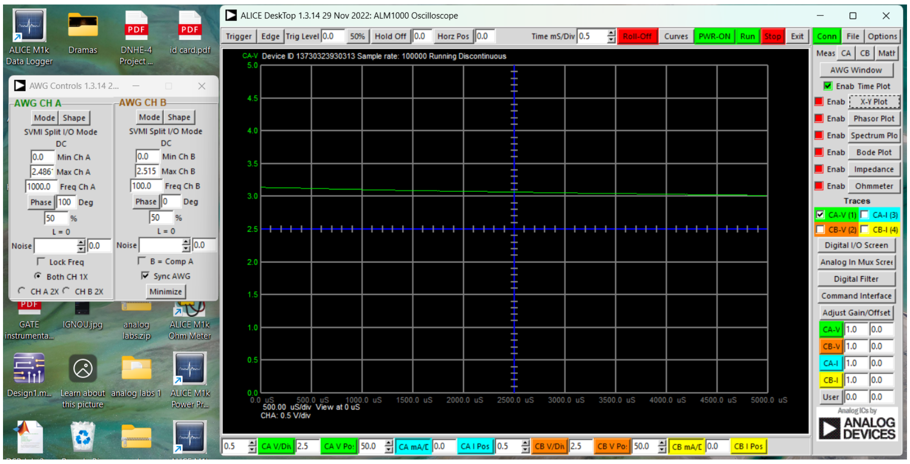


Figure 7: Output with filtering

3 Testing and Data Recording

3.1 Data Collection Method

(a) Image 1

(b) Image 2

(c) Image 3

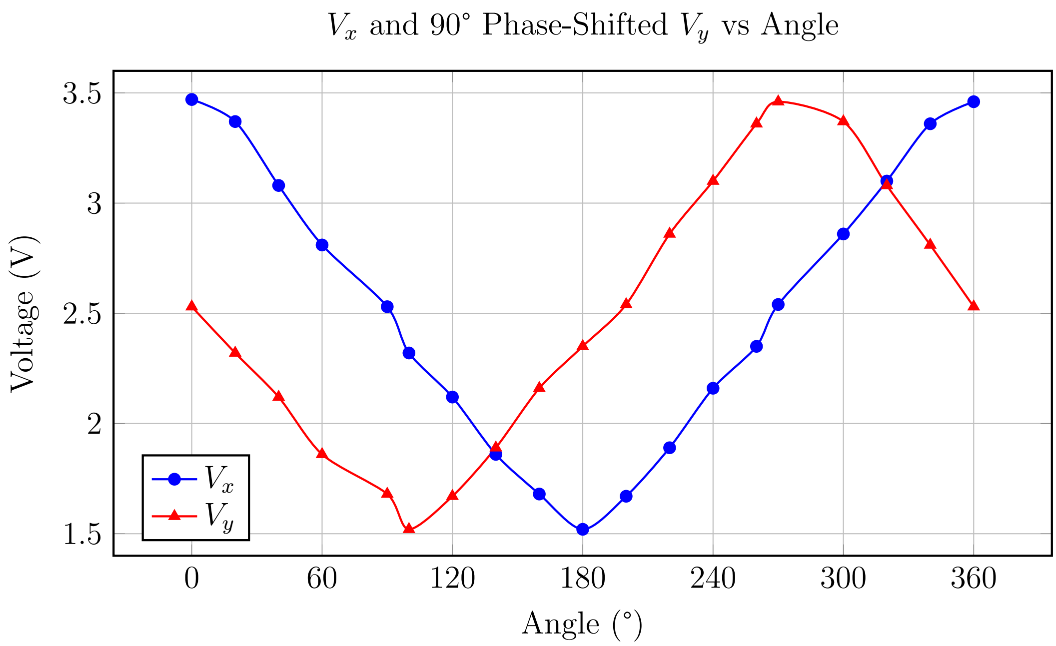
Figure 8: Arrangement of the three portrait images.

- The sensor assembly was rotated in 20° steps.
- At each angle, output voltages from both sensors (X and Y) were recorded using ADALM1000.
- These voltages were used to compute heading angle using the arctangent function.

3.2 Sample Data Table

Sensor Voltages (V_x and 90°-Shifted V_y)

Angle (°)	V_x **(V)**	V_y **(V)**
0	3.47	2.53
20	3.37	2.32
40	3.08	2.12
60	2.81	1.86
90	2.53	1.68
100	2.32	1.52
120	2.12	1.67
140	1.86	1.89
160	1.68	2.16
180	1.52	2.35
200	1.67	2.54
220	1.89	2.86
240	2.16	3.10
260	2.35	3.36
270	2.54	3.46
300	2.86	3.37
320	3.10	3.08
340	3.36	2.81
360	3.46	2.53



3.3 Discussion of Errors

- Small angular errors were observed due to:
  - Misalignment in mounting.
  - Noise in analog signal (fixed by a filtering capacitor)
  - Magnetic interference from nearby electronics.

Angle (°)	Measured V_x	Ideal V_x	Error V_x	Measured V_y	Ideal V_y	Error V_y
0	3.47	3.50	-0.03	2.53	2.50	0.03
20	3.37	3.44	-0.07	2.32	2.84	-0.52
40	3.08	3.27	-0.19	2.12	3.14	-1.02
60	2.81	3.00	-0.19	1.86	3.37	-1.51
90	2.53	2.67	-0.14	1.68	3.48	-1.80
100	2.32	2.33	-0.01	1.52	3.48	-1.96
120	2.12	2.00	0.12	1.67	3.37	-1.70
140	1.86	1.73	0.13	1.89	3.14	-1.25
160	1.68	1.56	0.12	2.16	2.84	-0.68
180	1.52	1.50	0.02	2.35	2.50	-0.15
200	1.67	1.56	0.11	2.54	2.16	0.38
220	1.89	1.73	0.16	2.86	1.86	1.00
240	2.16	2.00	0.16	3.10	1.63	1.47
260	2.35	2.33	0.02	3.36	1.52	1.84
270	2.54	2.67	-0.13	3.46	1.50	1.96
300	2.86	3.00	-0.14	3.37	1.86	1.51
320	3.10	3.27	-0.17	3.08	2.16	0.92
340	3.36	3.44	-0.08	2.81	2.84	-0.03
360	3.46	3.50	-0.04	2.53	2.50	0.03

Table 1: Measured and Ideal V_x, V_y with Errors (All Voltages in Volts)

4 Discussion & Conclusion

4.1 Performance Analysis

– The compass could detect direction across 360° with reasonable accuracy.

– Noise reduction techniques improved stability.

4.2 Improvements Suggested

– Use 3-axis digital magnetometer (e.g., HMC5883L) for better accuracy.

– Calibrate output using a known reference direction and using a magnetometer for proper calibration.

– Implement digital filtering (e.g., moving average).

– Implementing a way to stream the data in real time and process the data.

4.3 Key Learnings

– Understood Hall sensor response and practical interfacing.

– Gained an intuitive feel about electronic compass.

– Observed impact of sensor orientation and ambient interference.