# Design and Implementation of a Current Sensor

FORMULA
UOTTAWA

Ahmad Arab

October 26, 2025

**Abstract**

The purpose of this report is to document the design and implementation of a current sensor for measuring electrical current in medium- to high power circuits. The objective is to develop a system capable of accurate, real time current measurement while keeping signal noise to a minimum. The report explores two main sensing approaches, shunt resistors and Hall effect sensors. The chosen design uses a Hall effect sensor due to its suitability for both AC and DC measurements. The implementation covers circuit design and analog-to-digital conversion for micro controller based data acquisition. Calibration and testing procedures are discussed to evaluate sensor linearity and sensitivity. The results demonstrate that the sensor achieves high accuracy and stability within defined operational limits, making it suitable for monitoring energy efficiency.

# Contents

# 1 Introduction

This report focuses on the design and implementation of a Hall-effect current sensor for measuring loads up to 50 A. The primary objectives are circuit design, calibration, data acquisition, and real-time wireless data transmission. The project is motivated by the need to quantify the electrical power generated by the stator of the GGR25's GSX-R600 engine to determine whether the onboard battery can operate indefinitely while the engine is running and supplied with fuel.

## 1.1 Objectives

1. Design a current sensing circuit capable of measuring up to 50 A accurately.
2. Implement a Hall-effect sensor to measure the amount of current flowing from the stator to the battery
3. Calibrate the sensor to minimize measurement error.
4. Develop a data acquisition system for real-time monitoring.
5. Integrate wireless transmission to display current and power data remotely.
6. Evaluate the system's accuracy and stability under engine operating conditions.

# 2 Theory

## 2.1 Principle of Current Measurement

An electric current flowing through a conductor produces a magnetic field around the conductor, this phenomenon is called electromagnetism and forms the basis of many current sensors. there are two main factors that dictate the strength of the magnetic field produced. The first is the amount of current since the magnetic field strength is directly proportional to the amount of current flowing through the conductor. The second factor is distance since the strength of the magnetic field decreases as the distance from the conductor increases.

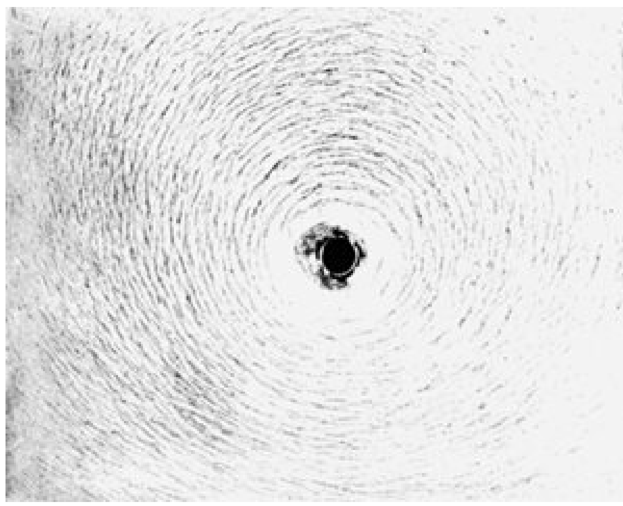

Figure 1: Iron filings around a current carrying wire

There are two main ways to measure the current flowing through a conductor, Shunt resistors and Hall effect sensors.

### 2.1.1 Shunt Resistors

Shunt resistors (or shunts) create a low resistance path for an electric current to allow it to pass through another point in the circuit and are useful for both direct and alternating current measurements [1]. Shunts are designed with an extremely low resistance value and when current flows through them they create a small voltage drop. The voltage drop is proportional to the current passing through the shunt and is later used to measure the current passing through the shunt. Shunts are made from low temperature coefficient materials such as Manganin (a copper-manganese-nickel alloy) to maintain resistance stability despite heating. Shunts use extremely low and precise resistance values of 1m$\Omega$ - 100m$\Omega$ with tolerance a of $\pm$0.1 to $\pm$1. Shunts are very robust with great mechanical strength, vibration resistance and corrosion resistance. Shunts have an exceptionally long service life as they are simple metal bars.

Figure 2: Standard shunt resistor

There are two ways to connect a shunt to a circuit: Low-side or high-side. Low-side shunts are connected to the current return after it has passed through the load, this type of circuit is easy to implement due to its simplicity and the analog to digital converter only and the operational amplifier only see a few millivolts above ground so the circuitry is safer. A small voltage relative to ground also reduces noise coupling however, this makes it more susceptible to potential ground noise as the loads local ground is no longer at zero volts. A typical low-side shunt to ADC circuit involves an op-amp, a low pass RC filter. The op-amp amplifies the voltage difference of the shunt to fit within the ADC range and an RC filter to remove noise before reaching the ADC, the result is a clean amplified voltage difference that could be used to measure current.

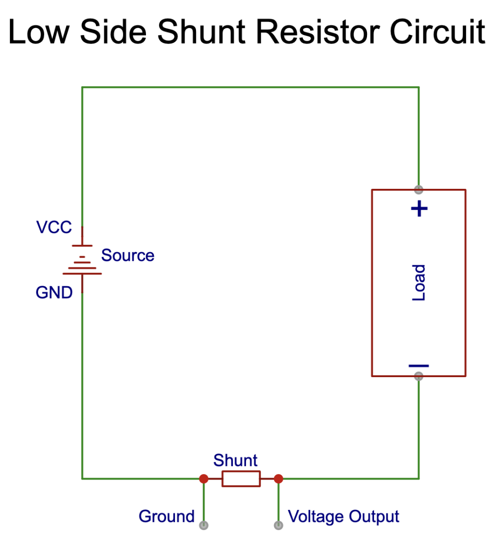


Figure 3: Typical low-side shunt resistor circuit before amplification

In a high-side shunt circuit, the shunt is connected to the circuit before it passes through the load, this creates a diffirential voltage depending on the load current which is then amplified to create an analog voltage signal. High-side shunt circuits are widely used in battery chargers and for over-current protection.

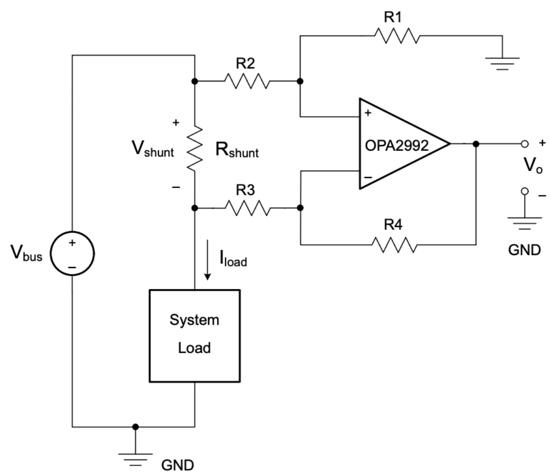


Figure 4: Typical high-side shunt resistor circuit
[2]

An advantage to high-side current sensing is that is can detect a load short to ground while low-side shunts cannot. When there is load short ground a high-side shunt is still included in the circuit however low-side shunts get excluded. The red line in figure 5 indicates the short path. Notice how the high-side shunt remains part of the circuit and is able to detect a current surge from a ground short condition, whereas the low-side shunt is excluded from the circuit.

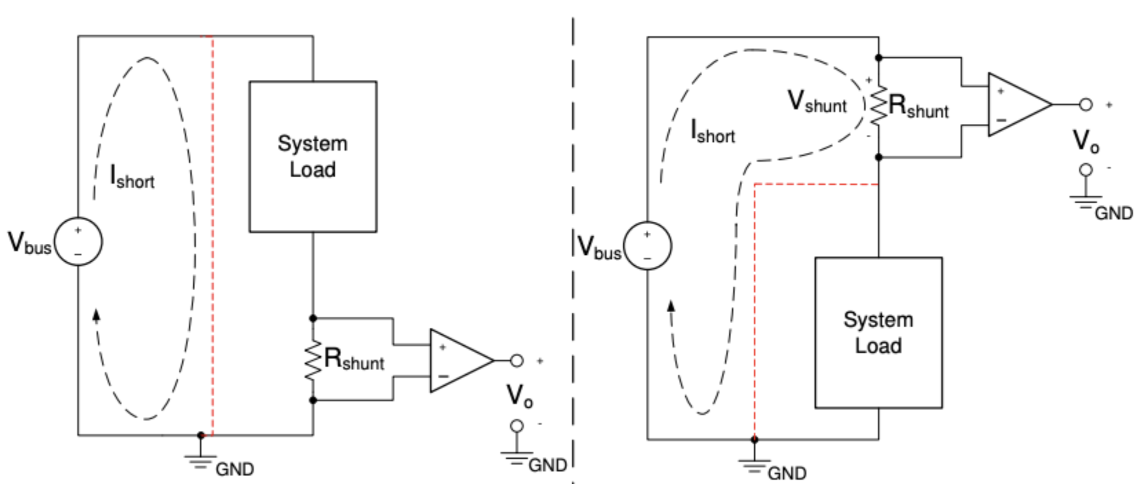


Figure 5: Ground short with a low-side (left) VS high-side shunt circuit (right)
[2]

### 2.1.2 Hall Effect Sensors

Hall effect sensors take advantage of the magnetic field produced by a current carrying wire (as shown in figure 1) to measure the current flowing through a live wire. In this approach, the sensor circuit is electrically isolated from the circuit of interest. In a hall effect sensor a thin semiconductor called the hall element plate is placed near the conductor. As the magnetic field deflects charge carriers in the sensor it creates a small voltage across it called the Hall voltage which is proportional to the magnetic field strength, electronics then amplify the hall voltage and convert it into an output signal. A hall effect sensor can measure AC and DC current in a non-intrusive manner [3].

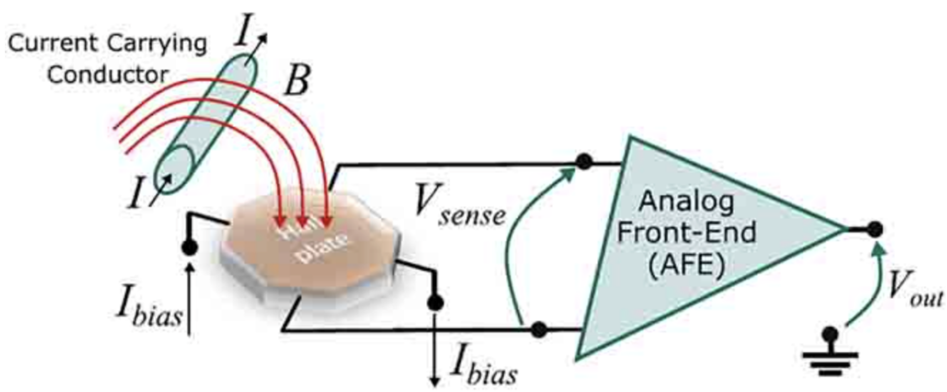


Figure 6: Published in: IEEE Sensors Journal ( Volume: 22, Issue: 11, 01 June 2022)

### 2.1.3 Reasoning for using hall effect sensors

The Hall effect sensor detects the magnetic field generated by current flow, enabling current measurement without direct electrical contact. This eliminates the need for shunt resistors, which cause voltage drops, power losses, and possible signal interference. The Hall effect method provides electrical isolation and a non-intrusive means of measurement, making it suitable for analyzing the GGR25's stator performance. Consequently, the The Hall effect sensor detects the magnetic field generated by current flow, enabling current measurement without direct electrical contact. This eliminates the need for shunt resistors, which cause voltage drops, power losses, and possible signal interference. The Hall effect method provides electrical isolation and a non-intrusive means of measurement, making it suitable for analyzing the GGR25's stator performance. Consequently, the ACS37010LLZATR-050B3 Hall effect sensor was selected for this application. Hall effect current sensor was selected.

## 2.2 Signal Conditioning

The ACS37010LLZATR-050B3 features a built in operational amplifier eliminating the need for an external amplifier. For stability, a 100nF decoupling capacitor was placed between the sensor's VDD and ground to act as a high frequency low pass filter suppressing voltage spikes and high-frequency noise that could affect the ESP32's ADC performance [4]. A ground copper pour was also implemented to reduce bounce-back and minimize ground impedance.

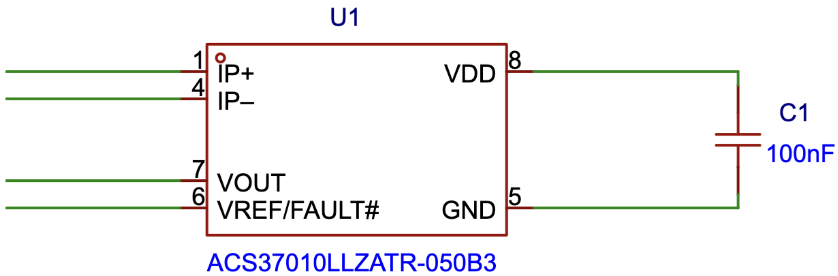


Figure 7: Decoupling Capacitor placed between GND and VDD

# 3 Design and Implementation

The selected packaging approach uses a Printed Circuit Board (PCB). This design minimizes wiring errors and electrical noise. The sensor's analog output connects to an ESP-32 analog-to-digital converter (ADC) pin, where it is digitized to measure the current flow through a wire. The PCB integrates a 15 V voltage divider and a 12 V-to-5 V buck converter to regulate voltage levels for both the sensor and the ESP-32. The PCB occupies an area of 70 x 65 mm and is intended to house an on-board ESP-32 and an OLED screen for diagnostic and trouble shooting purposes.

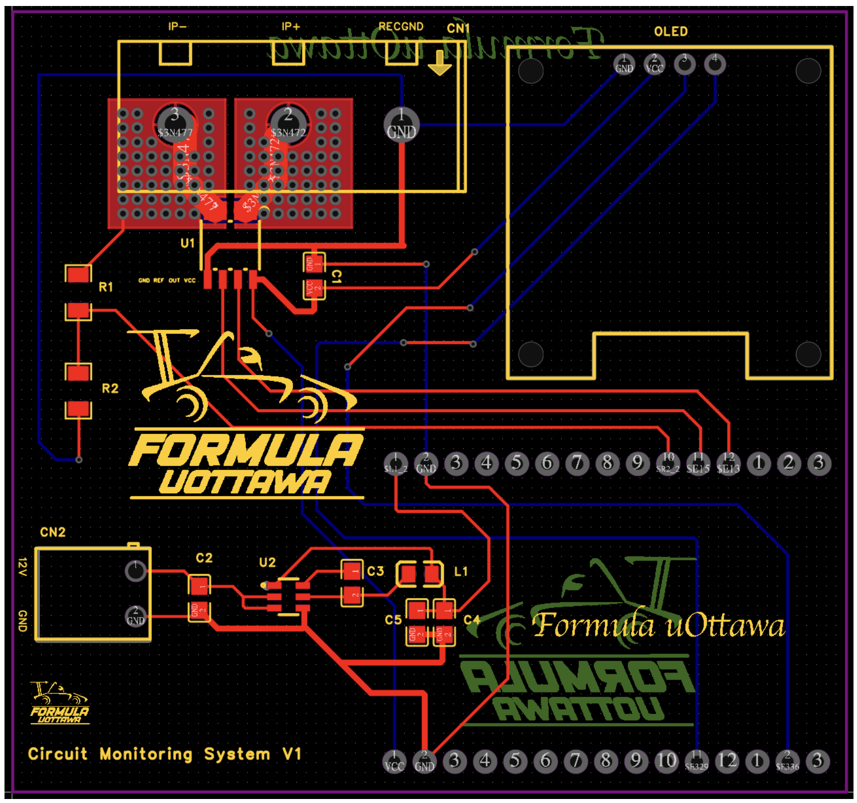


Figure 8: Current sensor PCB without ground pour

## 3.1 Wiring of the ACS37010

The ACS37010 has a total of 6 pins, 2 of which (IP+ & IP-) act as bus-bars to allow low-impedance current flow near the hall element to get a signal while the rest (GND, VCC, VOUT, VREF) are used to power the sensor and send an analog signal to the ESP-32. The two bus-bar pins are electrically isolated from the rest of the circuitry. The current flowing through IP+ and IP- pins is expected to be from 20-40 amps, a standard 1 oz copper trace would not be sufficient under this load and would likely run hot with an $I^2R$ loss in excess of 1 watt. To combat this, a copper pour with area 110 mm$^2$ was added on both the top and bottom copper layer, these copper pours were stitched with vias to minimize impedance and maximize the cooling effect, with this addition the $I^2R$ loss is estimated to be around 0.2-0.5 watts which is a manageable given the surface area of the copper pours.

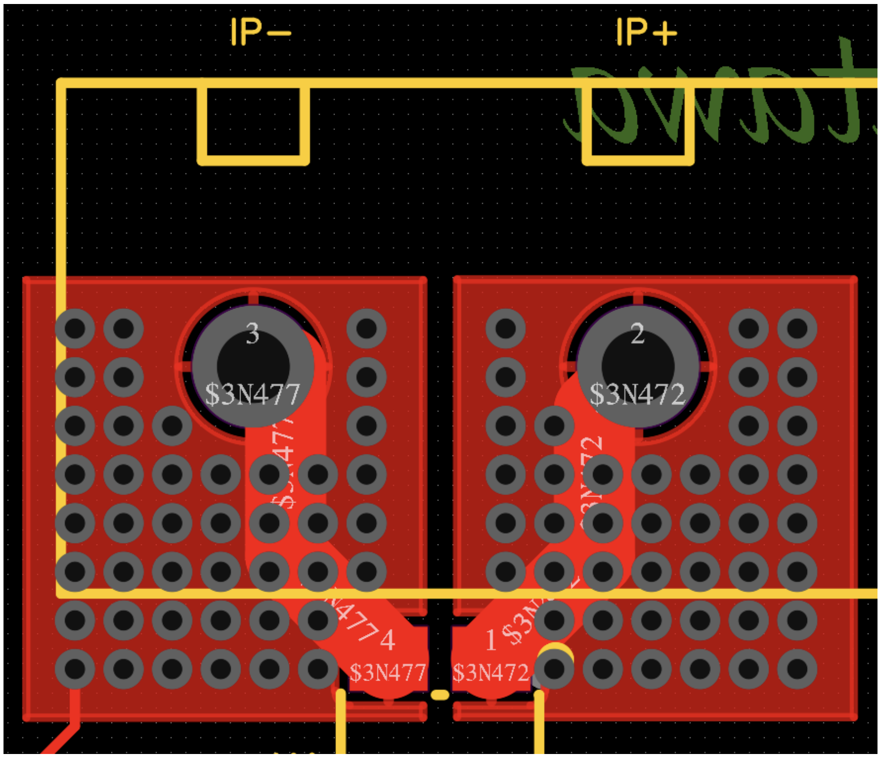

Figure 9: Copper Pours for IP+ and IP- pins on the ACS307010

## 3.2 Voltage Divider

A 15V to 3.3v voltage divider was implemented to get the difference in potential energy between the rectified AC output and ground. The voltage divider rule was used to calculated the ratio of R2 to R1:

$$V_{out} = V_{in}\left(\frac{R2}{R1 + R2}\right) \tag{1}$$

$$\frac{V_{out}}{V_{in}} = \left(\frac{R2}{R1 + R2}\right) \tag{2}$$

$$\frac{3.3V}{15V} = \left(\frac{R2}{R1 + R2}\right) \tag{3}$$

$$0.22 = \left(\frac{R2}{R1 + R2}\right) \tag{4}$$

From this, the chosen resistor values for R1 and R2 were 82KΩ and 22KΩ respectively, these are standard values and are easy to source and yield a final voltage division of

$$\frac{22K\Omega}{82K\Omega + 22K\Omega} \approx 0.21 \tag{5}$$

The Output of the voltage divider is digitized through the ESP-32 ADC and could be multiplied by $\frac{82K\Omega+22K\Omega}{22K\Omega} \approx 4.7$ to get the true voltage.

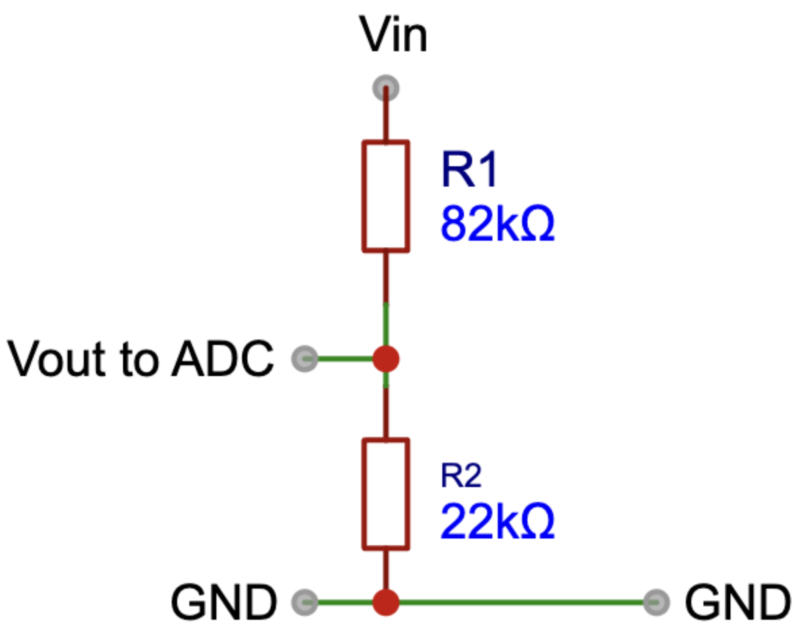


Figure 10: Schematic of the Voltage Divider used in the circuit

## 3.3 Buck Converter

A 12-5V buck converter was added, which removes the need for an external 5V battery and instead uses the 12V car battery. this decreases the overall weight and cost of the sensor package. The AP63205WU 5V switching regulator was used due to its ease of implementation, as not much external circuitry was needed since it already integrates high and low side MOSFETS [5].

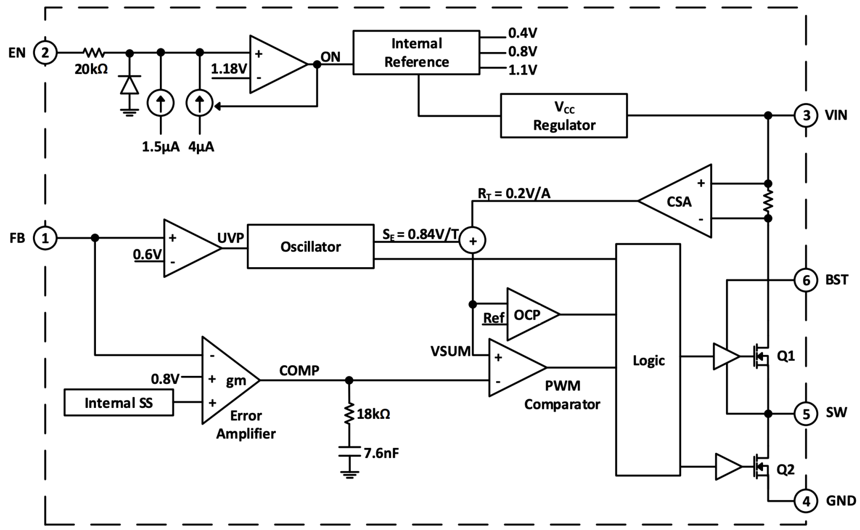


Figure 11: AP63205WU Functional Block Diagram

On the PCB, the buck is powered via a screw terminal that takes in the battery positive and negative connections. The regulated 5V output is fed to the ESP-32 VIN pin, which expects a 5V input. The VIN pin bucks the voltage down to 3.3V and distributes it through the 3V3 pin to the rest of the components on the PCB

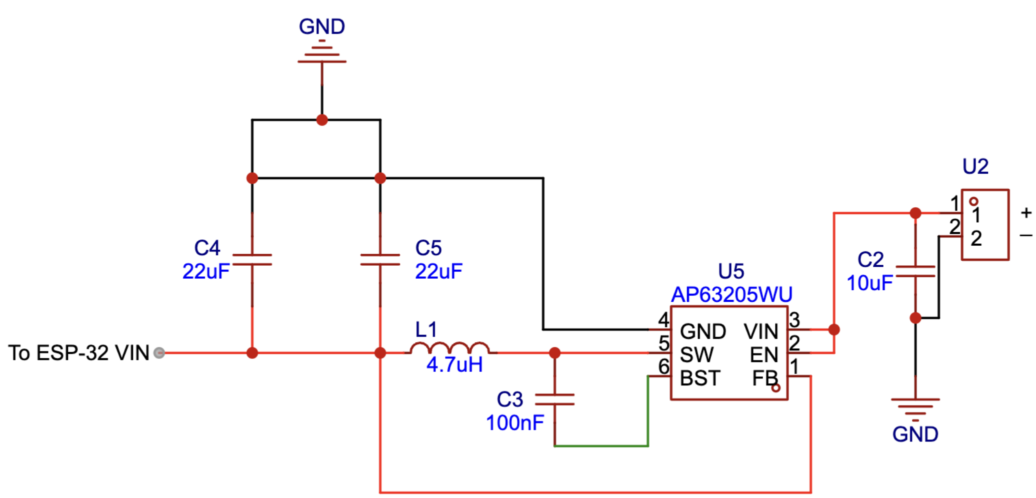


Figure 12: AP63205WU Buck Converter Circuit

## 3.4 Prototyping

for prototyping purposes, the PCB mill at the uOttawa maker space was used, this was mainly done to verify component placement and packaging before production. The initial PCB size was 90 x 90 mm; however, this was later reduced to the 70 x 65 mm PCB that was sent for production.

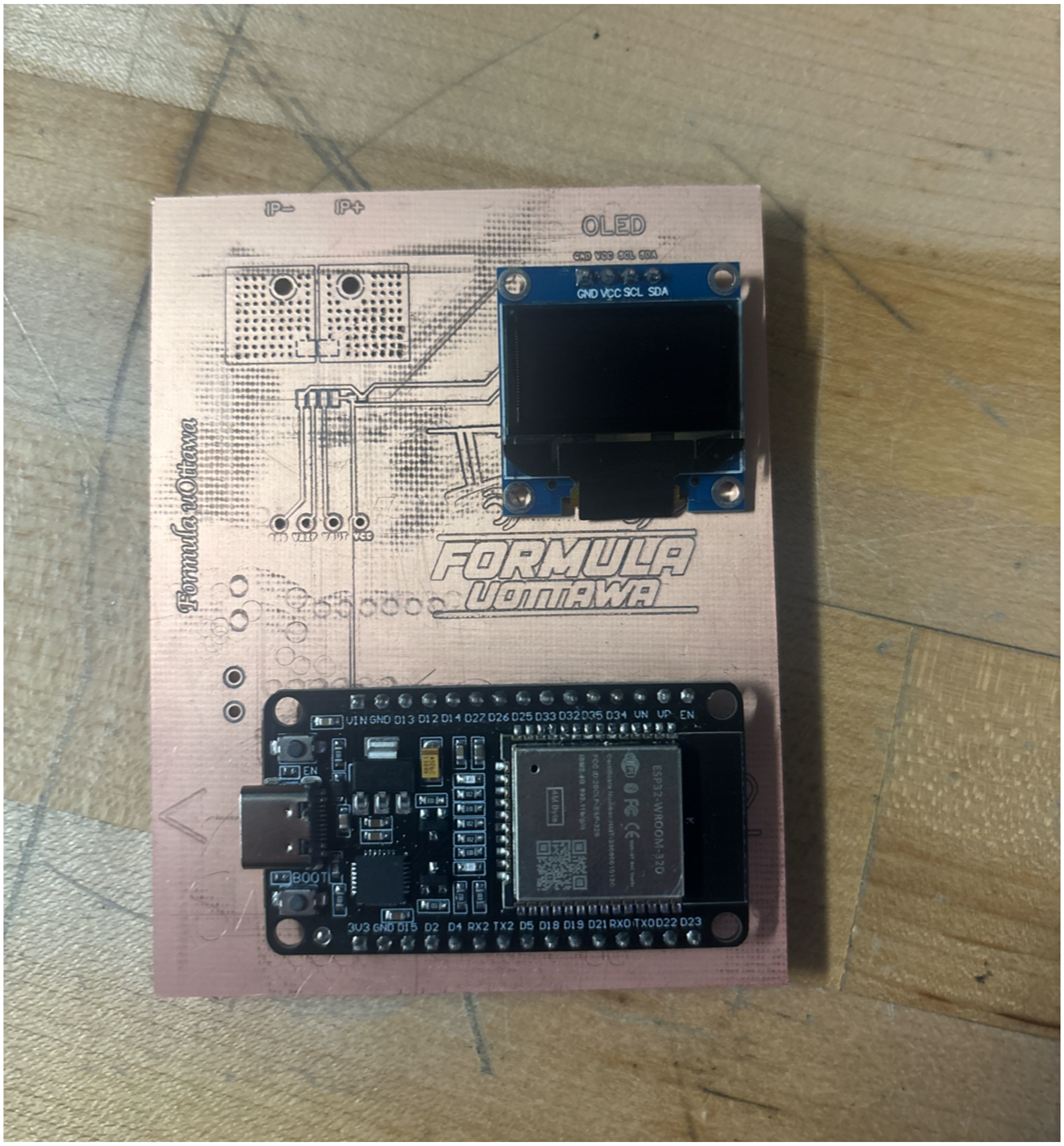


Figure 13: Current sensor PCB prototype

# 4 Testing and Results

While the data sheet for the ACS37010 current sensor does not explicitly provide a formula for the conversion of the Vout and Vref to current values, the following relationship could be derived using the ACS37010LLZATR-050B3 performance characteristic table on page 11 and the relationship between sensitivity, Vout, and current on page 22 [6].

$$Sens = \frac{V_{OUT(ip1)} - V_{OUT(ip2)}}{IP_1 - IP_2} \tag{6}$$

$$Given\ that, \quad Sens = \frac{\Delta V_{OUT}}{\Delta I} \quad and \quad (V_{OUT})(I_2) = V_{REF} \tag{7}$$

$$I = \frac{V_{OUT}(I) - V_{REF}}{Sens} \tag{8}$$

# 5 Conclusion

# References


[1] Physics—LibreTexts, "Electrical measuring instruments." https://phys.libretexts.org/Bookshelves/University_Physics/University_Physics_(OpenStax)/University_Physics_II_-_Thermodynamics_Electricity_and_Magnetism_(OpenStax)/10%3A_Direct-Current_Circuits/10.05%3A_Electrical_Measuring_Instruments, 2016. [Accessed: October 25th, 2025].

[2] R. C. Tim Claycomb, Marc Liu, "Using an op amp for high-side current sensing." https://www.ti.com/lit/ab/sboa347a/sboa347a.pdf?ts=1761716700248&ref_url=https%253A%252F%252Fduckduckgo.com%252F, 2021. [Accessed: October 29th, 2025].

[3] M. Crescentini, S. F. Syeda, and G. P. Gibiino, "Hall-effect current sensors: Principles of operation and implementation techniques," *IEEE Sensors Journal*, vol. 22, no. 11, pp. 10137–10151, 2022.

[4] Renesas, "Choosing and using bypass capacitors." https://www.renesas.com/en/document/apn/an1325-choosing-and-using-bypass-capacitors, 2011. [Accessed: November 2nd, 2025].

[5] Diodes—Incorporated, "Ap63200/ap63201/ap63203/ap63205." https://www.lcsc.com/datasheet/C2071056.pdf, N/A. [Accessed: November 2nd, 2025].

[6] A. Microsystems, "Ap63200/ap63201/ap63203/ap63205." https://www.allegromicro.com/-/media/files/datasheets/acs37010-datasheet.pdf?sc_lang=en, 2023. [Accessed: October 24th, 2025].