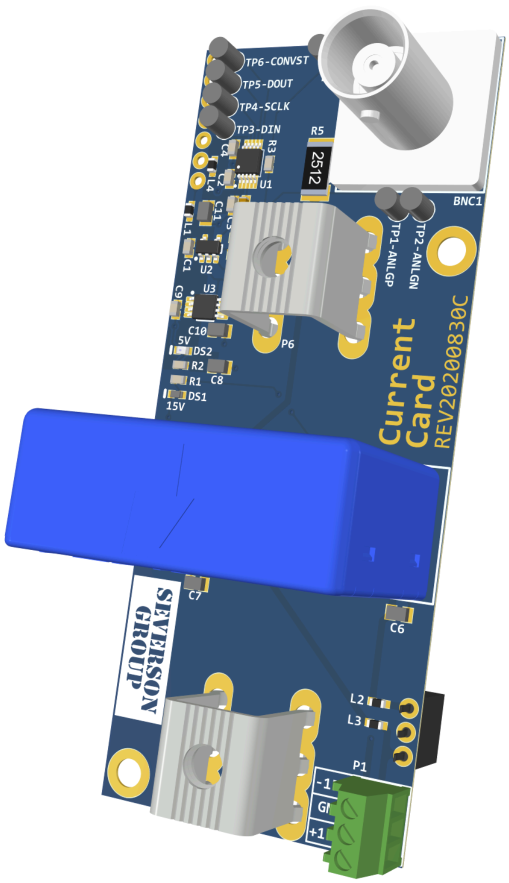
Current

This document describes the design considerations and implementation details for the current card. A block diagram is presented and each component is discussed in detail. Specifications of each component are provided based on the datasheet.

Relevant Hardware Versions

REV C



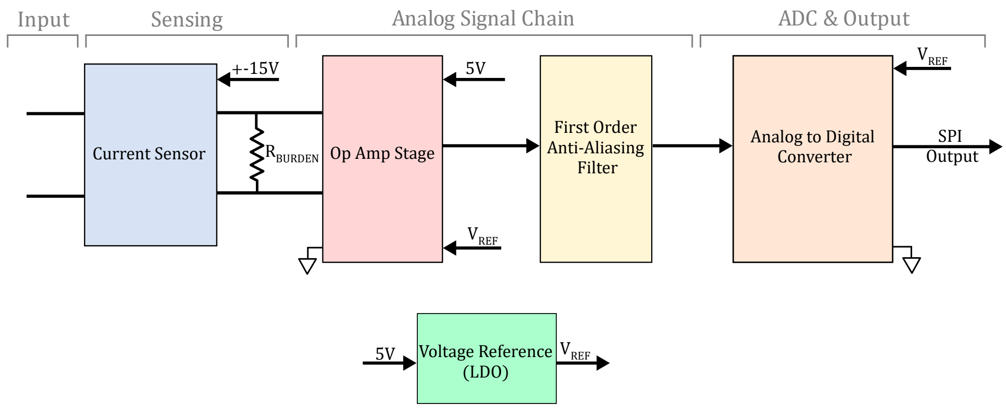
Design Requirements and Considerations

The current measurement card was designed to the following specifications:

1. Current measurement range
2. Noise immunity
3. Quick adjustment of the sensing range
4. High sensor bandwidth
5. SPI output to interface with the sensor motherboard

Block Diagram

The high level block diagram of the current sensor card is shown below:



Current Sensor

The LEM LA 55-P and LA 100-P current sensors with an open aperture and PC pins are introduced in this article. The open aperture was selected because it allows the measurement range to be easily scaled down by adding turns to the primary conductor. These sensors provide an excellent bandwidth of 200 kHz and a low-impedance current output, which is inherently more immune to noise than a high-impedance voltage output. The following section describes how to determine the burden resistor and current sensor gain for the LA 55-P and LA 100-P sensors.

LA 55-P

The LA 55-P is a closed loop compensated hall effect transducer that has measurement range of +/-55A (rms), an accuracy of +/-0.65%, and linearity of <0.15%.

Burden Resistor (R_{BURDEN})

A burden resistor (`R5`) is used to convert the current output of the sensor to a voltage. For a sensing range of 70A, the burden resistance, R_{BURDEN} was calculated using the following equation

$V_{BURDEN} = (N_1/N_2)\ I_{PRIMARY}\ R_{BURDEN}$

R_{BURDEN} = (10 V/70 A)*(1000/1) = 143Ω

The LA 55-P datasheet specifies the burden resistor value must be between 135Ω and 155Ω so a 150Ω resistor was selected.

Current Sensor Gain

The LA 55P has a conversion ratio of N_1:N_2 = 1:1000, where N_1 is the primary turns (the number of turns the user passes through the sensor's window) and N_2 is the secondary turns. With the chosen R_{BURDEN} and N_1 = 1, the current sense circuitry has a current-voltage gain of 1/7 [V/A].

To use the sensor in a lower current range, the user can increase the number of primary turns without the need to modify any other parts of the circuit. As an example, to sense currents in the range of +/- 7 A, N_1 = 10 can be used.

LA 100-P

The LA 100-P is a closed loop compensated hall effect transducer that has measurement range of +/-150A (rms), an accuracy of +/-0.45%, and linearity of <0.15%.

> **Note**
>
> The LA 100 series has three variants, LA 100-P, LA 100-P/SP13, and LA 100-TP, that users must be careful about when ordering. The sensor gains of each of these variants are different, which has implications for the choice of the burden resistor. The rest of this document is specific to the LA 100-P variant.

Burden Resistor (R_{BURDEN})

For a sensing range of 150A, the burden resistance, R_{BURDEN} was calculated using the following equation

R_{BURDEN} = (2 V/150 A)*(2000/1) = 26.7Ω

The LA 100-P datasheet specifies the burden resistor value must be between 0Ω and 33Ω so a 28Ω resistor was selected.

Current Sensor Gain

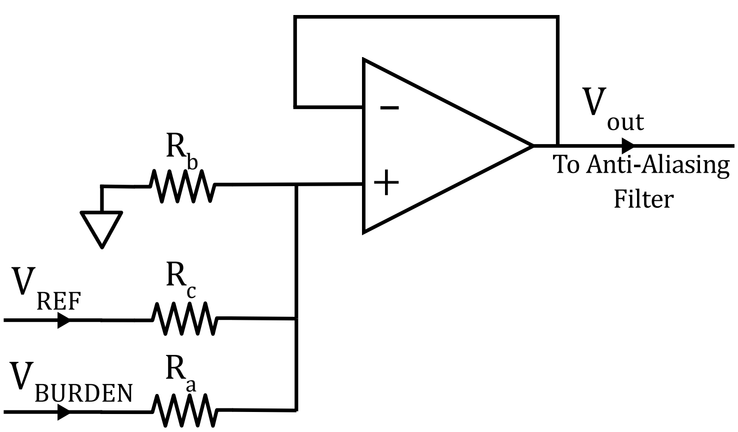
The LA 100-P has a conversion ratio of N_1:N_2 = 1:2000. With the chosen R_{BURDEN} and N_1 = 1, the current sense circuitry has a current - voltage gain of 1/75 [V/A].

Voltage Reference (LDO)

The voltage reference, V_{REF} is needed for the ADC. As 5V is readily available, and the LDO will have a minimum drop out voltage, V_{REF} = 4.5V was chosen (beginning with board revision C). The LDO selected was `REF5045` from Texas Instruments, which can take a 5V input and provide a 4.5V reference output. This has an accuracy of 0.1% and low noise of 3µVpp/V.

Op Amp Stage

A non-inverting level translation circuit is implemented using Op Amps as shown here:



This circuit is used to translate the voltage across the burden resistor, which is bipolar (voltage span includes both positive and negative voltages), to the ADC input range of 0-V_{REF}.

The output voltage for this circuit can be solved as:

$$V_{\text{out}} = \frac{R_{\text{a}}R_{\text{b}}}{R_{\text{a}}R_{\text{b}} + R_{\text{a}}R_{\text{c}} + R_{\text{b}}R_{\text{c}}}V_{\text{REF}} + \frac{R_{\text{b}}R_{\text{c}}}{R_{\text{a}}R_{\text{b}} + R_{\text{a}}R_{\text{c}} + R_{\text{b}}R_{\text{c}}}V_{\text{BURDEN}}$$

A more precise expression for V_{BURDEN} can be derived as:

$$V_{\text{BURDEN}} = \frac{R_{\text{a}}R_{\text{BURDEN}}}{R_{\text{a}} + R_{\text{BURDEN}}}\left(\frac{N_1}{N_2}\right)I_{\text{PRIMARY}} + \frac{R_{\text{BURDEN}}}{R_{\text{a}} + R_{\text{BURDEN}}}V_{\text{out}}$$

The resistor values can be calculated from solving these expressions analytically. However, the algebra gets quite complicated. Instead, these values were computed using the TI analog engineer's calculator.

The final design is implemented so that $I_{\text{PRIMARY}} = -70A$ results in $V_{\text{out}} \approx 0V$ and $I_{\text{PRIMARY}} = 70A$ results in $V_{\text{out}} \approx 5V$.

Attention

As the op-amp output voltage approaches the supply rails, it tends to distort and behave nonlinearly. It is recommended to limit the output voltage to stay within 0.2V to 4.5V for best performance. The user is advised to consider their required current measurement range with the final voltage expressions to select an appropriate number of primary turns.

First Order Anti-Aliasing Filter

A first order RC filter is implemented on the output of the op amp circuit. The cutoff frequency was set at 48kHz and the following equations was used for the computation:

$$f_c = \frac{1}{2\pi RC}$$

Note: The cutoff frequency can easily be changed by swapping out `R3`.

Analog to Digital Converter

A single-ended ADC was selected. The ADC used is the Texas Instruments ADS8860. It is a pseudo-differential input, SPI output, SAR ADC. The maximum data throughput for a single chip is 1 MSPS but decreases by a factor of N for N devices in the daisy-chain. The input voltage range is 0-V_{REF}. The positive input pin of the ADC `AINP` is connected to the output of the low pass filter, and the negative input pin `AINN` is connected to `GND`.

Relationship Between Input and ADC voltage

From the equations provided in the Op Amp Stage section, the general relationship between the measured current I_{PRIMARY} and the input voltage of ADC V_{ADC} can be calculated, and the relationship for each revision of the current sensor board is provided below:

General Expression

$$I_{\text{PRIMARY}} = \frac{N_2}{N_1}\left[\frac{(R_aR_b + R_aR_c + R_bR_c)(R_a + R_{\text{BURDEN}}) - R_bR_cR_{\text{BURDEN}}}{R_aR_bR_cR_{\text{BURDEN}}}\right]\left[V_{\text{ADC}} - \frac{\quad}{(R_aR_b + \cdots}\right.$$

Revision A, B

In this design, N_1:N_2 = 1:1000, V_{REF} = 5V, R_{BURDEN} = 150Ω, R_{a} = 10kΩ, R_{b} = 8.45kΩ, R_{c} = 4.64kΩ, resulting in:

$$I_{\text{PRIMARY}} = 29.2579 \times (V_{\text{ADC, RevA,B}} - 2.4922) \qquad [\text{A}]$$

Revision C

In this design, N_1:N_2 = 1:1000, V_{REF} = 4.5V, R_{BURDEN} = 150Ω, R_{a} = 10kΩ, R_{b} = 10.7kΩ, R_{c} = 4.12kΩ, resulting in:

$$I_{\text{PRIMARY}} = 29.4146 \times (V_{\text{ADC, RevC}} - 2.5126) \qquad [\text{A}]$$

Connectors

- There are two screw terminals `P5` and `P6` to connect the conductor in which the current is to be measured
- A screw terminal block `P1` is used to connect the +-15V supply for the current sensor
- A BNC terminal is available to directly measure the output across the burden resistor R_{BURDEN}

Footprints

A user may want to change some of the passive components based on the range required and the RC filter cutoff frequency desired. The footprints of passive components that may need to be replaced i.e, the burden resistor (`R5`), the resistors in the Op Amp stage, and the RC filter components is provided here for quick reference. Note that these footprints are imperial codes and **not metric codes**.

Component	Footprint
R3	0603
R4	0603
R5	2512
R6	0603
R8	0603
C5	0603

Datasheets

- Current Sensor (LA 55-P)
- Current Sensor (LA 100-P)
- Op Amp
- Voltage Reference (LDO)
- Analog to Digital Converter