Lead Acid Battery Charging Current Measurement
ELEN4006: Measurement and Systems

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Abstract: The purpose of this document is to provide the design of a smart transducer in an explosive environment. The system designed is for measuring the charging current of the Lead acid battery in coal mines. The system was modelled using transfer functions and then evaluated based on its performance, static response and dynamic response. It had a bandwidth of more than 1 kHz as required. The design of the system adhere to the standards such that the system is intrinsically safe.

Key words: smart transducer, Hall current Sensor

1. INTRODUCTION

This report aims at the design of a "smart" instrumentation measurement system with a bandwidth of at least 1 kHz to be used in an explosive environment/atmospheres. The measurement system is to follow the *Bentley* method.

A discussion on charging batteries in coal mines is presented along with the requirements of the designed system. Following this is a clear analysis of the components of the design. The system is then evaluated based on its performance, static response and dynamic response.

2. BACKGROUND

This section explores some of the currently used measurement system for controlling the charging current of a battery in coal mines. The explosive environment is also categorized based on the standards (SANS).

2.1 Existing solutions

The current existing solutions make use of current transformers, this in not an efficient way of measuring current since the measuring system need to be en-co-operated in the measured system and can result in errors.

2.2 Environment

The explosive environment chosen is the battery charging bays in Underground coal mines. The SANS 10108 classifies any location in underground mines other than coal mines where, under normal operating conditions, there is a continuous presence of flammable gas (concentration of 0,5 % volume fraction, or more), in the air, as a hazardous location in terms of the relevant national legislation.

Lead acid batteries are frequently used in large-scale uninterrupted power supply (UPS) installations. When a lead acid cell is on charge, hydrogen and oxygen are released from the cell and could form an explosive gas atmosphere. A gas mixture with a hydrogen concentration of between 4 % (volume fraction) and 75 % (volume fraction), is explosive, and burning is enhanced by oxygen enrichment [1].

The volume of gas produced will be considerably greater under boost charge, particularly as the battery nears full charge. The hydrogen emission rate and hydrogen concentration can be calculated as shown.

To ensure that the hydrogen concentration in battery rooms and cabinets or cubicles is always within acceptable limits, one can calculate the minimum ventilation requirements, which are dependent on the rate of evolution of hydrogen from the cells, particularly in the event of overcharging. The Hydrogen evolution under overcharge operation can be calculated (see Appendix A), and the number of air changes needed per hour to keep the hydrogen concentration below the recommended maximum can be determined. However, since prevention is better than cure, in this design, the system is to measure the charging current such that it does not go over the battery maximum charging current. This helps prevent the battery from overcharging and thus releasing the explosive gasses to the atmosphere.

3. DESIGN METHODOLOGY

The structure of the measurement system consist of several subsystems. According to the Bentley method, the system must consist of a sensing element, signal conditioning element, signal processing element and data presentation element [2]. The measurement system is designed to measure battery charging currents. Following the model, a block diagram was developed, see Figure 1.

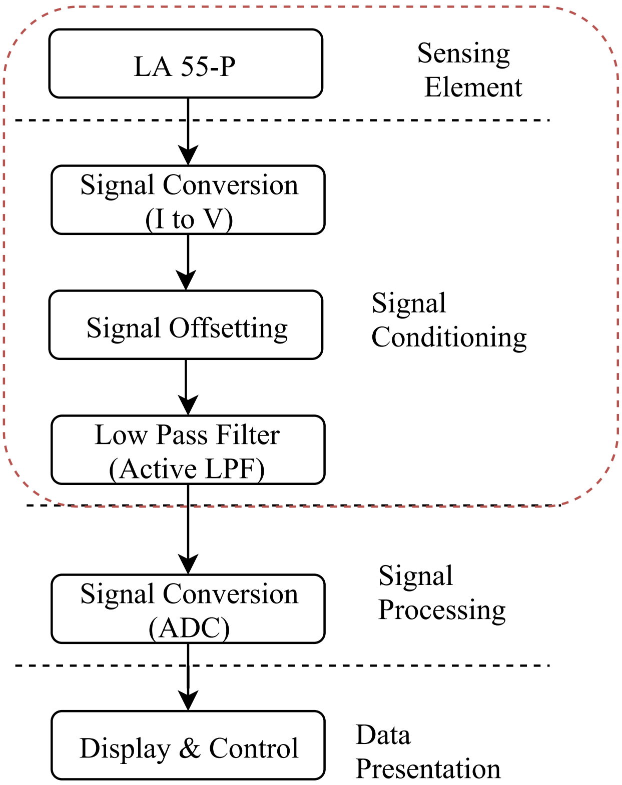

Figure 1 : Design model

The system consists of a LA55P current transducer, a signal conditioning system, signal processing and Data presentation. For the scope of this report, the main focus will be on the sensing element and the signal conditioning. The signal processing and data presentation are discussed but were not simulated. The details of the subsystems are to be discussed.

4. SENSING MODULE

The sensing element is composed of a LA 55-P current transducer. The LA 55-P was chosen because it has an Excellent accuracy with a very good linearity. It is very sensitive and it is quite suitable to measure battery currents. Some of its specifications can be viewed in Table 1.

Table 1 : LA 55-P Electrical and Dynamic Data.

Property	Value
Primary nominal r.m.s. current	50 A
Primary current, measuring range	0 .. 70 A
Conversion ratio	1 : 1000
Secondary nominal r.m.s. current	50 mA
Supply voltage ($\pm 5\%$)	$\pm 12..15V$
Response time @ 90 % of IP max	<1 μs
Frequency bandwidth (- 1 dB)	DC .. 200 kHz
Ambient operating temperature	- 25 .. + 85 °C

The LA 55-P has 50 A nominal primary current rms (P_{NI}), and 50 mA nominal secondary current (S_{NI}). It is clear from the specifications that the sensor outputs current. Since microcontroller is not appropriate to measure current, a current to voltage converter circuit is designed. making use of the frequency bandwidth from the sensor's data sheet, the following transfer function (Equation 1) was derived:

$$H_1(s) = \frac{1.256 \times 10^6}{s + 1.256 \times 10^6} \tag{1}$$

This transfer function was used to model the current sensor.

5. SIGNAL CONDITIONING

In this section, the signal received from the current sensor is conditioned such that it can be fed to the next system, the signal processing system. As mentioned earlier, the current sensor give current on the output [3]. First the signal will be converted to voltage, then conditioned. This part of the circuit consist of resistors, capacitors and op-amps. The resistors are rated safe and the op-amp is also a good choice but then forces the whole system to be enclosed.

5.1 Signal conversion and offset

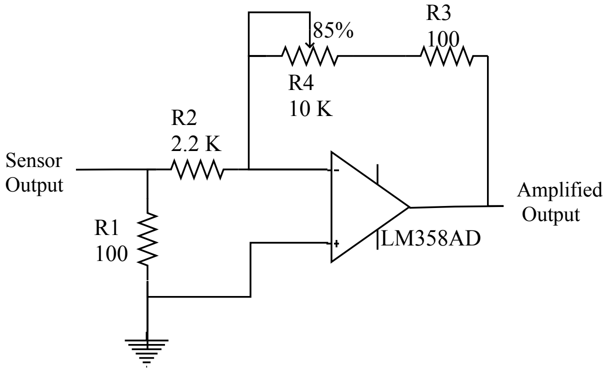

Figure 2 : Circuit for converting I to V and to amplify it.

In this circuit, current flowing from the current sensor will cause a voltage drop on 100 Ω resistor (R_1). The voltage is then amplified and inverted. After the amplification, the signal is fed into the second inverting op-amp (this can be seen in Appendix C, Figure 7).

In second op-amp, voltage is applied by a variable resistance to positive input pin of the op-amp. This voltage is used to cause an offset to the amplified signal. In this way it is made possible to measure negative current. This is done because it is not possible to measure negative voltage with a microcontroller[4]. Relationship between the measured battery current passing through the primary of LA 55-P and op-amp output voltage are seen in the next section.

$$H_2(s) = \frac{1.455 \times 10^7}{s + 1.257 \times 10^6} \qquad (2)$$

The transfer function in Equation 2, is used to simulate the behaviour of the amplifying and signal offsetting circuit.

5.2 Signal filtering

The filtering circuit filters any high frequency noise in the signal before it is fed to the ADC. The circuit can be seen in Figure 3.

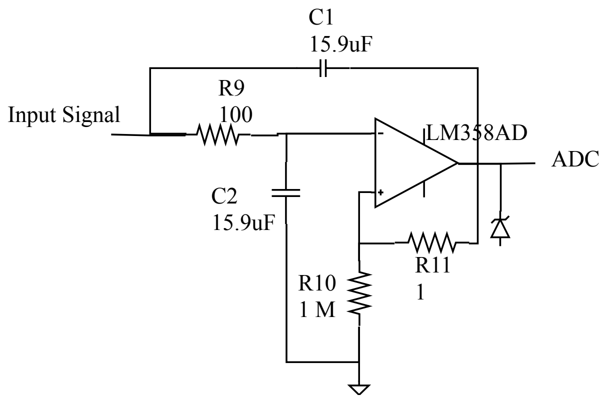

Figure 3 : Filter Circuit.

From the circuit elements in Figure 3, the following transfer function was derived:

$$H_3(s) = \frac{3.956 \times 10^9}{s^2 + 2.516 \times 10^5 s + 3.956 \times 10^9} \qquad (3)$$

This transfer function was used to model the filter during simulations.

SANS60079-11

6. SIGNAL PROCESSING, COMMUNICATION AND CONTROL

This takes the output of the conditioning element and converts it into a form more suitable for presentation. The presentation then presents the measured value in a form which can be easily recognised by the operator. As part of communication, a signal can be sent to the ventilation control system.

This part of the system is taken care off by the PIC micro-controller. The control sequence is summarized by the flow diagram depicted in Figure 4. The program embedded in microcontroller performs measure (ADC), control, display, and communication tasks.

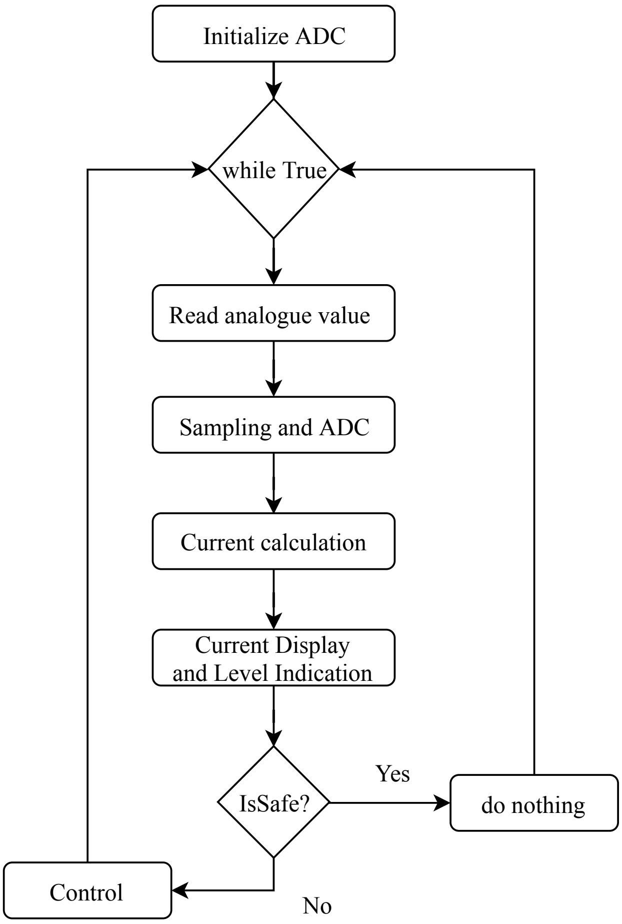

Figure 4 : Micro-controller operation flow diagram.

6.1 Analogue to Digital Conversion

One of the most important requirements of an analog-to-digital conversion is the resolution a 10-bit ADC converter breaks the voltage into 1024 parts. This conversion can calculate the voltage accurately up to $5/1024 \approx 4.8\ mV$. The other important requirement of the ADC conversion is the sampling rate, which identifies how fast the analog-to-digital converter can receive readings. The PIC microcontroller can go as high as 100k samples/Sec.

6.2 Signal Communication and Signal Control

This section of the system is not part of the scope. However, this part of the circuit deals with displaying the measure signal on an LCD, lighting up an LED to indicate safety status and sending signals to other control systems that are dependent on this system.

7. POWER SUPPLY

Power supplies are an essential item in any electrical circuit. Where the power is supplied to intrinsically safe circuits located in hazardous areas, the output of the power supply should be intrinsically safe.

The SANS 60079-11 The transformer together with its associated devices shall maintain a safe electrical isolation between the power supply and the intrinsically safe circuit even if any one of the output windings is short-circuited and all other output windings are subjected to their maximum rated electrical load. The maximum output voltage V_{out} shall be in the range 14 V to 17,5 V under the conditions specified in this standard for the respective level of protection. The maximum unprotected internal capacitance and inductance shall be not greater than 5 nF and 10 H, respectively. The output circuit from the power supply may be connected to earth.
For the purpose of this design, the power supply is not designed. However, the designed or used model must be able to operate within the standards. It must agree with the FISCO. The power supply must have a Voltage of 15, and a permissible current of 531mA.

8. SIMULATION RESULTS

The simulations where performed using the transfer functions presented earlier using *Matlab*. The following specifications where extracted from the results presented in Appecndix B-C.

Table 2 : Current transducer Electrical and Dynamic Specs.

Property	Value
Primary current, measuring range	0 .. ± 54 A
Conversion ratio	5:108
Supply voltage (± 5 %)	± 12 .. 15 V
Response time @ 90 % of IP max	0.133 ms
Freq bandwidth (- 3 dB)	DC.. 2.5 kHz
Ambient operating Temperature	- 25 .. + 85 °C

A detailed plot of the dynamic response of the system can be seen in Appendix C, Figure 11.

9. DISCUSSION

The Simulations were made and the results can be observed from Appendix C, Figure 11.

Looking at Figures 5 and 6 from Appendix B, it can be seen that the sensor behaves like a low pass filter but with a high bandwidth (200kHz). The sensor shows a very fast rise time of $1.75\mu s$.

From Figure 8 in Appendix C, It is obvious that for 54 mA case, circuit output voltage is at approximately 5V level and there is a linear relationship between output voltage and the measured battery current. In the current stage, the negative current produces a negative voltage. Looking at Figure 10, by the time the signal reaches the end of the filter the signal is scaled between 0-5V and offset-ted such that there are no negative voltages. This signal is then fed to the analog input of the microcontroller.

These circuits are composed of very simple voltage dividing, filter, and protect circuits (Figure 9). The voltage dividing circuit is employed to adjust the ADC input level. High frequency components (noises) are destroyed with filter circuit. The protection circuit is formed of 5V zener diode and it guaranties that ADC input voltage level is not over than 5V level.

9.1 Social Impact

The employment of the use of smart transducers is vital since they can help prevent life threatening situations. The mine is a dangerous place and therefore prevention is better than cure. The use of standards is important since it makes sure that the measurement system does help prevent hazardous situations than to create them.

10. FUTURE RECOMMENDATIONS

The system needs a self calibration program that is dependent on the external factors like temperature and etc.

11. CONCLUSION

The system was designed using the Bentley method and following the standards. The final system had bandwidth of 2.5 kHz and a response time of about 0.133 ms. The system ment the bandwidth requirement.

ACKNOWLEDGEMENT

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Appendices

A Hydrogen Evolution Calculation

$$V = N \times I \times 0,00045 \tag{4}$$

where:

$$V\ is\ the\ volume,\ in\ cubic\ metres\ (m^3), at\ standard\ atmospheric\ pressure\ of\ hydrogen,\ liberated\ per\ hour.$$
$$N\ is\ the\ number\ of\ cells\ in\ the\ battery.$$
$$I\ is\ the\ overcharge\ current,\ in\ amperes\ (A).$$
$$0,00045\ is\ the\ constant\ value,\ in\ cubic\ metres\ per\ ampere\ (m3/A).$$

The volume of hydrogen obtained can be expressed as a percentage of the total volume of the room or cabinet or cubicle, and this can be used to calculate the number of air changes per hour necessary to keep the hydrogen concentration below the recommended maximum of a volume fraction of 0,8 %.

B Sensing Element

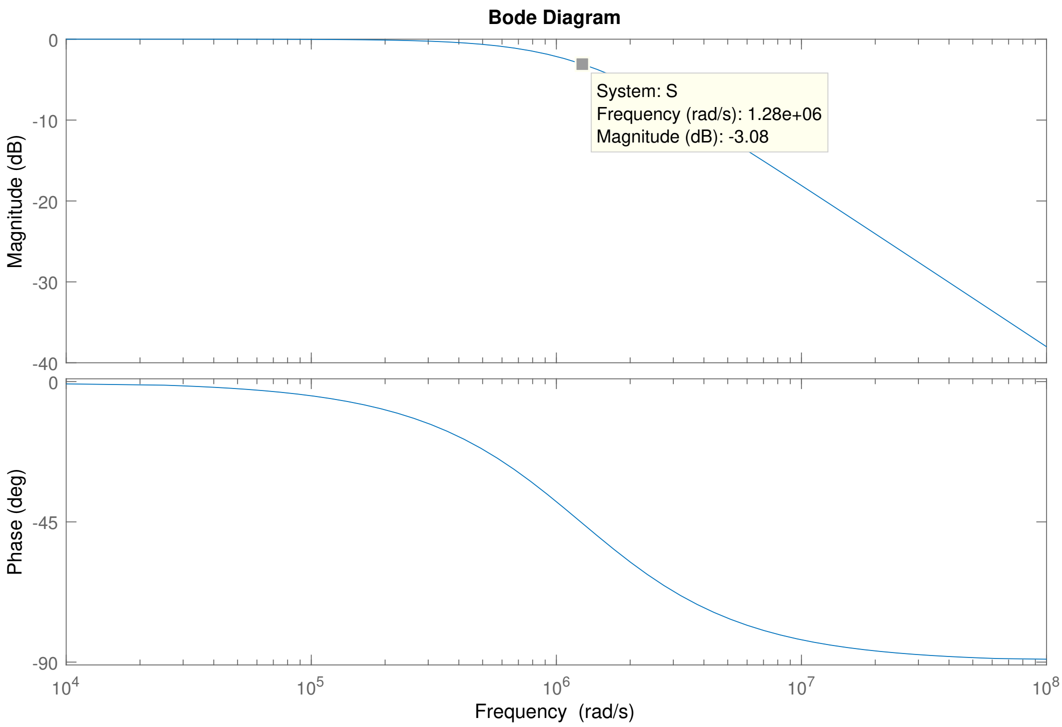

Figure 5 : Sensor Bode plot

Figure 5 shows the bode plot of the current sensor. And Figure 6 shows the step response of the current sensor.

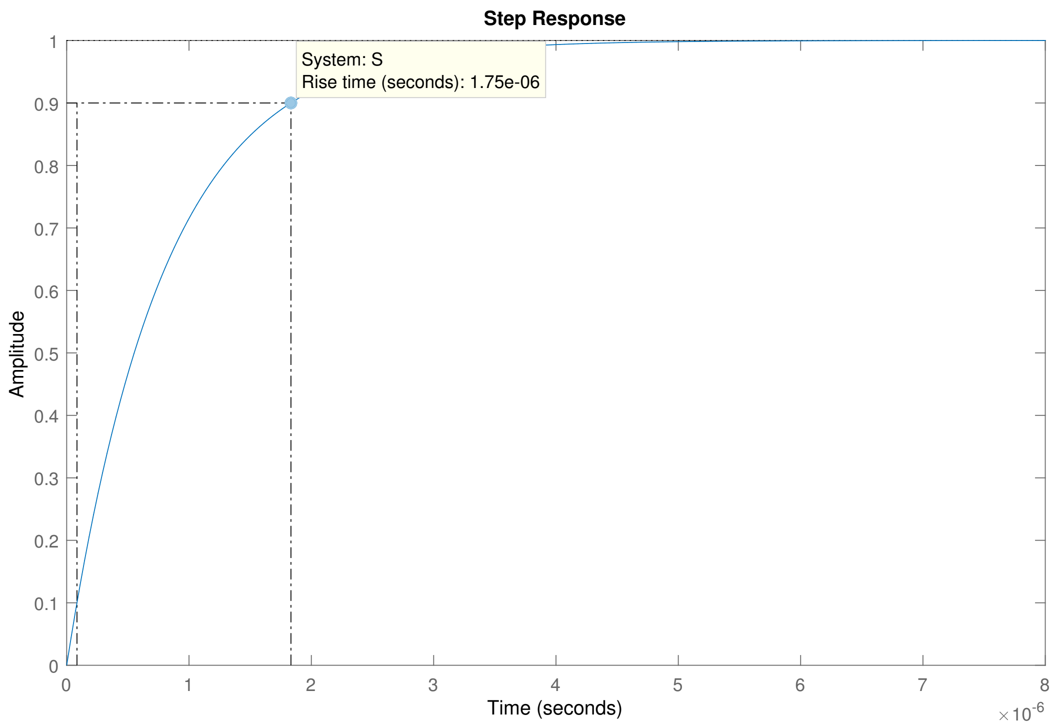

Figure 6 : Sensor Step Response

C Signal Conditioning

Equation 5 represent the Transfer function of the overal system depicted in Figure 9.

$$H(s) = \frac{1.807 \times 10^{23}}{s^4 + 1.633 \times 10^6 s^3 + 5.094 \times 10^{11} s^2 + 4.517 \times 10^{16} + 6.243 \times 10^{20}} \quad (5)$$

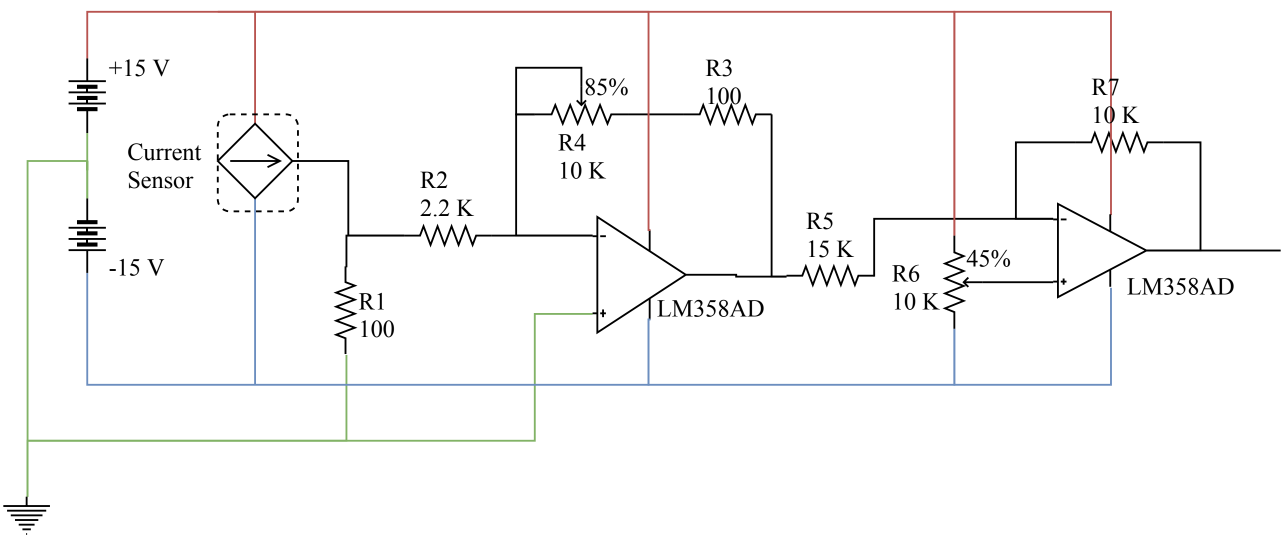

Figure 7 : Amplifying and offsetting Circuit.

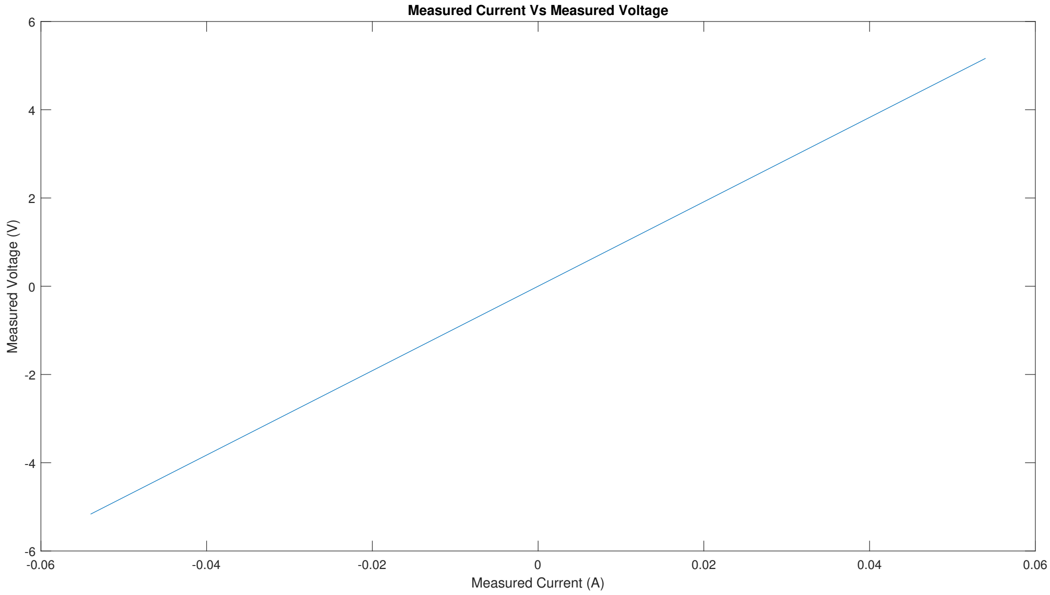

Figure 8 : Measured current vs Measured voltage.

The graph in Figure 8 show the relationship between the measured current and the corresponding voltage.

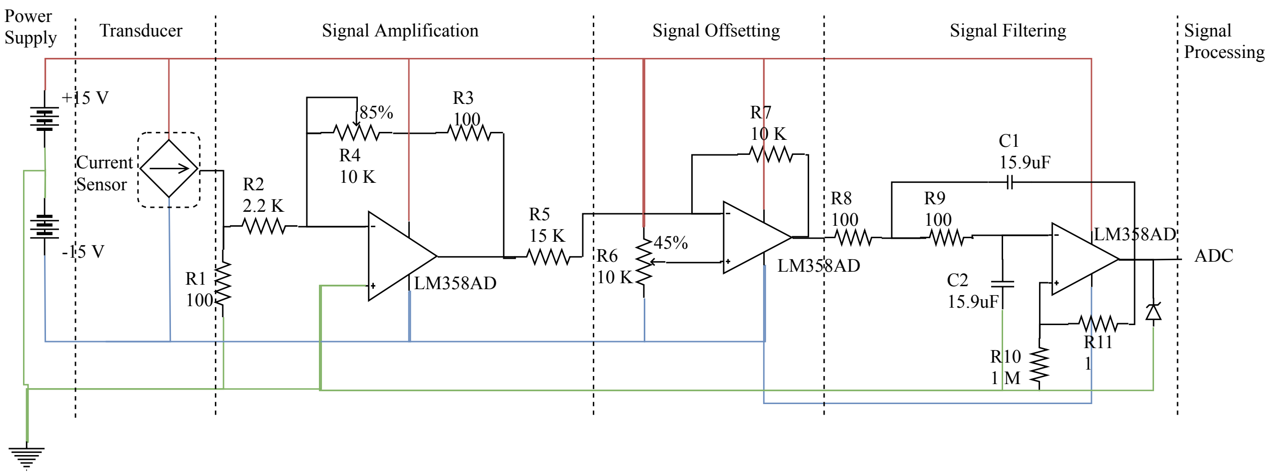

Figure 9 : Full system circuit.

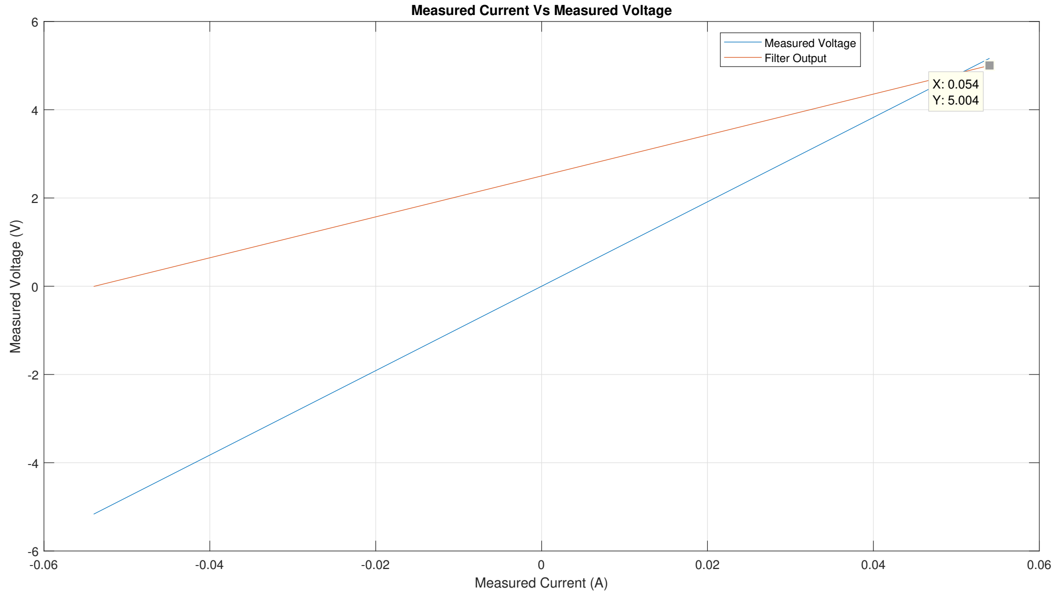

Figure 10 : Measured Current Vs Filtered output.

The graph in Figure 10 show the relationship between the input current to the system and the voltage at the output of the cicuirt dipicted in Figure 9.

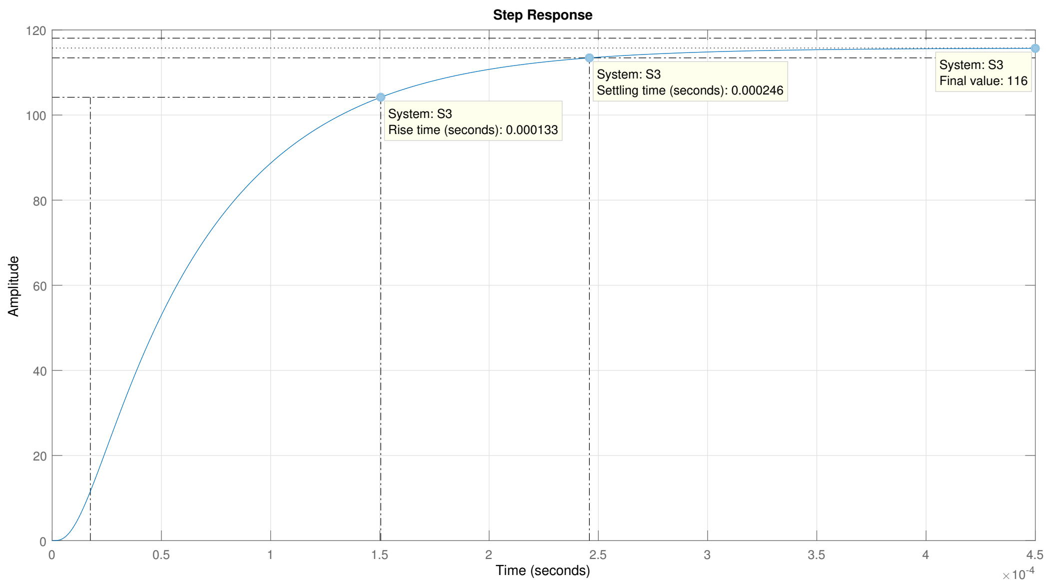

Figure 11 : Final System Step response.

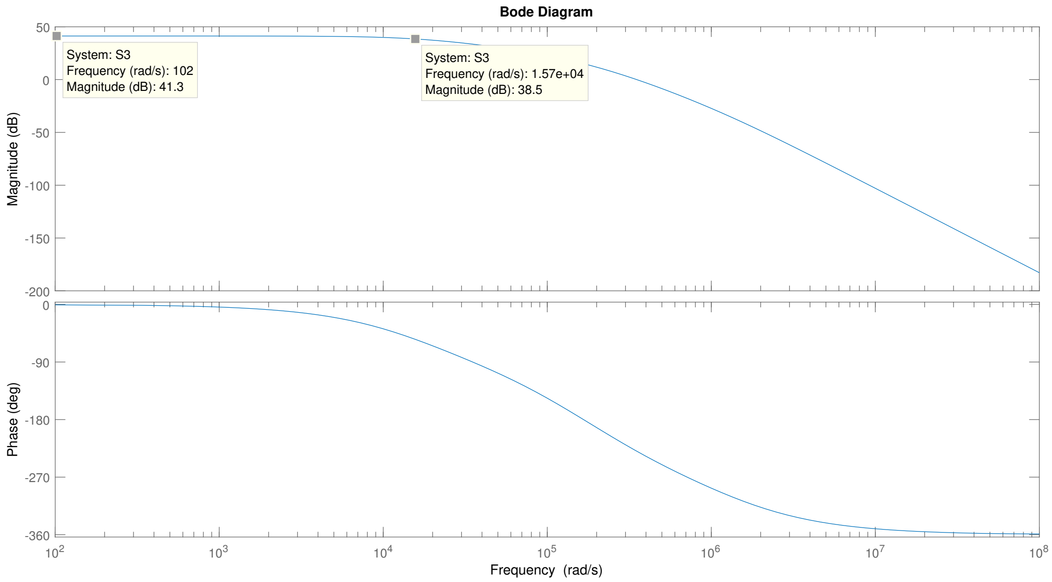

Figure 12 : Final system Bode diagram.