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Bachelor's Thesis

Designing a Circuit for Alphasense NO2-B43F Sensor

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Abstract

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I confirm that this Master's Thesis is my own work and I have documented all sources and material used.

Munich, October 3, 2018

Place, Date

Signature

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Chapter 1

Introduction

As the world population increases by millions every year, the environmental damage we cause increases dramatically. In densely populated areas -and especially in larger cities- air pollution is a major problem, which does not only have financial consequences but also affects the quality of our lives in many ways. Since air pollution today constitutes a significant problem, there are more than many researches and studies regarding this issue: " . . . the total damage costs of air pollution [is estimated] to be US$ 3.0 trillion in 2010, or 5.6% of Gross World Product (GWP). These losses are equivalent to US$ 430 for every person on the planet."[1] is from just one of the numerous studies made on financial damage caused by air pollution.

To be able to assess this problem correctly and take suitable measures to minimize the harm of air pollution, one should first be capable of finding out the cause accurately. Only after an accurate diagnosis can there be a suitable solution and thus a significant outcome. When it comes to air pollution, the best way to detect the cause is to make density measurements of air pollutants with electrochemical sensors sensitive to specific gases in various locations. However there are some requirements that must be fulfilled: "To adequately characterize air quality (AQ), measurements must be fast (real-time), scalable, and reliable (with known accuracy, precision, and stability over time)."[2] The more accurate and fast the sensors get, the more expensive the gas measurement station will be. Since it is important to make measurements in multiple locations to create a pool of air pollutant density data and thus getting a better understanding of the environmental damage, a collective of stations are needed, which increases the total cost dramatically.

The goal of this bachelor thesis is to design and build a low-cost circuit suited for Alphasense NO2-B43F sensor, which is sensitive to $\mathrm{NO_2}$ concentration in the air. In addition to that documenting the steps and the final project well also plays a very important part, since it enables to create the same sensor station more efficiently, which means with less time and resources spent.

Chapter 2

Preparation

2.1 Initial Researches

Some research on the working principle of Alphasense NO_2 electrochemical sensor had to be made prior to the initialization of the mechanical and electronical sections of this project. The paper /////// on previous experiments conducted in Boston, United States of America was very helpful to get a first idea about how I could start building my project designed for NO_2 density measurements. In another paper about a research conducted in Zurich, Switzerland, /// Previously mentioned researches did not provide much direct information about the circuit itself and were realistically not essential for me to realize my project, as my goal was to build a functioning circuit, to get meaningful data from it and to document the entire process of my project well. However, the researchs and the papers I read gave me even more motivation about how topical air pollution is and thus how important it is to try to build a low-cost air pollutant density measuring station and to collect useful environmental data.

2.2 Getting a Better Understanding

I had to read the application notes on the Alphasense Webpage to get a better understanding of the inner structure as well as the pinout of the sensor and for this purpose I began to study the /////////////// (kaynak) (inner structure). As I started to understand which electrode of the sensor was responsible for which purpose, I began to get an idea of how I could build my own circuit, which would be able to supply enough current to the sensor and output voltage, linearly proportional to the concentration of the air pollutant, which in other words is the ppb level of NO_2 in the air.

Afterwards I started to read //////////////////(designing a circuit), which gave me a starting point for the circuit. In diagram ////// from //// you can see a circuit design for a three-electrode sensor. I was actaully working with the sensor NO2-B43F, which is a four-electrode sensor, but this circuit schematic was nonetheless a good point to start building and testing the circuit.

Chapter 3

Putting Into Practice

3.1 Design of the Circuit

In order to understand the circuit fully, we must first study the structure and the pinout of the NO2-B43F sensor. There are 4 electrodes of the electrochemical sensor: Working electrode, reference electrode, counter electrode and auxilliary electrode. The reference electrode holds the potential of the working electrode stable at a certain level, which is equal to the potential of the reference electrode itself. This potential must be fixed to ensure a stable outcome from the sensor and the circuit. The counter electrode must be able to supply enough current to the working electrode, so that the current through the counter and working electrode can be translated and amplified to create the output voltage.

The A4 and B4 sensors have two sensing electrodes: The working electrode and the auxiliary electrode. The main purpose of the working electrode is to react to the NO_2 in the air and thus create a current flow proportional to the gas concentration. In other words the working electrode responds to gas concentration whereas the auxiliary electrode does not respond to gas. The idea is to be able to correct for zero drifts using the auxiliary electrode output. It is thus recommended that at the beginning both electrode outputs are recorded (Working electrode and auxiliary electrode) rather than applying a correction directly.

The circuit in general comprises of operational amplifiers, a couple of capacitors to reduce noise from the sensor and various resistors to get the desired gain from the operational amplifiers.In Figure ////// the detailed circuit schematic is given. On the left hand side of the circuit the NO2-B43F sensor is connected via 3 electrodes to the circuit. This schematic is for 3 electrode sensors like previously mentioned, so the auxilliary electrode is left out. The power connections of the operational amplifiers are also not shown, however they must be provided a regulated and high enough voltage to encompass the maxima of the output voltage. In addition to that the power supply must be rated with high enough current to be able to supply the required current drawn by the counter electrode and the operational amplifiers themselves.

The circuit consists of 2 stages of amplifiers. The first stage is the control circuit, whose main objective is to supply the counter electrode with enough current so that the current required by the working electrode is met. The potential at the reference electrode, namely the reference voltage is connected to the inverting input of the operational amplifier. It is important that near to zero current is drawn from the reference electrode, so an op amp with minimal input bias current is recommended. **alinti** Since the current control part of the circuit can already supply the counter electrode with enough current, the next step is to build the sensing part of the circuit, namely the current measuring stage. In this stage, the current through the counter and working electrode flows through the sensing resistor R_{Load}, which in return creates a voltage on the inverting input of the second operational amplifier IC1. As it is mentioned before this current through R_{Load} is linearly proportional to the gas concentration in the air. As a reminder our main goal is to measure the amplitude of this current created by the working electrode, which gives us information about the concentration of NO_2. That is where IC1 comes into play. The voltage difference between the inputs of IC1 is amplified (multiplied) by a very large number and is created on the output of IC1. However this high voltage is fed back to the inverting input over the resistor R4, which increases the voltage on the inverting input and thus reduces the voltage difference between the inputs of the operational amplifier. As a result the output voltage is reduced and so is the influence of the output on the inverting input voltage. This pendulum saturates at a specific voltage level, which is equal to the input voltage multiplied by a constant determined by the resistors R_{Load} and R4. This constant i.e. the gain of the amplifier is equal to **formÃ$\frac{1}{4}$l**.

In conclusion the control stage supplies the required current by the counter electrode to the sensor, which is created by the potential difference between the counter and working electrodes. The current then flows through the sensing resistor R_{Load} creating a voltage on the inverting input of IC1. This input voltage is then multiplied by the gain and in the end creates the output voltage.

3.2

The circuit mainly consists of 3 operational amplifiers, a couple of capacitors to reduce noise from the power supply and various resistors to get the required output voltage to input voltage ratio from each operational amplifier. The circuit and the purpose of its components will be explained in detail in the following section.

Chapter 4

Challenges

4.1 Mechanical and optical challenges

After preparing an orders list according to the previously mentioned circuit design taken from Alphasense **dokuman** and receiving these components, my first challenge was very clear: Transforming the surface-mount device (SMD) parts into through-hole components. The operational amplifiers used in the circuit (LT6011) were only available to order in SMD form. Since I needed the SMD components to verify the circuit design, I could not simply design a printed circuit board and solder the components on the board without testing the circuit design with a breadboard first. Otherwise everything would be inalterable and the tiniest change in circuit schematic would lead to a whole new circuit design and thus a printed circuit board from scratch. That is why I started to build an adapter for making the SMD modules breadboard compatible.

For this purpose I used a perfboard and male sockets. I first split the male sockets into two 4-pin male sockets, since the LT6011 ICs have an 8-pin structure, namely 4 pins on both sides. Afterwards I soldered these sockets parallel to each other with reasonable distance so that there is enough room for the IC to fit between the two sockets. Here it is quite important to first solder the sockets on the side of the perfboard with copper rings around the holes while the longer side of the sockets lays on this side. The IC will be fixed on the other side of the perfboard because the distance between any two pins of the IC is much smaller than the distance between two holes of the perfboard. Therefore I placed the IC between the sockets and anchored it on the perfboard by gluing it with hot glue. This makes it easier to make the connections between the sockets and the IC itself, since it stays fixed during soldering.

4.2 Critical parameters

It is of utmost importance to pay attention to the resistor values in the circuit schematic and the resistors used in the actual circuit. A little difference in these values creates a large spread between the desired output voltage and the actual output, since most of the resistors in this circuit design plays a role in determining the gain of the operational amplifiers. An inaccuracy in resistor value changes the gain of the operational amplifier and consequently the output voltage gets multiplied with that error. If the resistor inaccuracy is in earlier stages of the circuit, the error at the output side gets even higher since the error gets amplified by the second operational amplifier in the last amplifying stage. It is recommended to check the resistors' values preferably with a multimeter before mounting it on the circuit, even if the circuit is being built on a breadboard. There are a lot of resistors in this circuit design and it can be really complicated to detect where the problem lies after the circuit is completed. For this reason it is quite important to check every part individually before putting them into the circuit.

In my case I built the circuit exatly how it was depicted on the circuit schematic and

Chapter 5

Outlook

5.1 Possible Future Enhancements

Directly measuring the output voltage gives us in theory the raw data of the NO_2 concentration, since the output voltage increases or decreases linearly as the ppb level of NO_2 changes. **grafik**, however the data will depend on electromagnetic noise and environmental elements -especially from humidity and temperature- and thus be somewhat inconsistent. The raw data obtained directly from the circuit must be calibrated against such noises in order to get a better approximation of real concentration values. This can be achieved through altering the circuit and making it more resistent to electromagnetic noise. There are two possible ways of dealing with such noises: Passive and active filtering. The former is achieved by adding passive elements like resistors, capacitors and inductors. After detecting the peak frequency of the noise contained in the raw signal (possibly with the help of an oscilloscope by applying Fourier Transformation on the signal and acquiring the frequency spectrum of the signal) it can be eliminated by adding high and low-pass filters. The latter option requires an outside power source, hence the name "active", which makes it a more expensive option than the former, however this can amplify the desired frequency while surpressing the noise, which makes the signal-to-noise ratio larger. Both options can be useful and serve our purpose of noise cancellation.

Data calibration against humidity and temperature could be achieved by integrating a humidity and temperature sensor into the circuit board and measuring their effect on the output voltage and then subtracting these elements from the raw data itself.

APPENDIX

Appendix A

Some Appendix

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Appendix B

Source Code

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Bibliography

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[2] Eben S. Cross. Use of electrochemical sensors for measurement of air pollution: correcting interference response and validating measurements. Technical report, Massachusetts Institute of Technology, Cambridge, MA 02139, USA, 2017.