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Affordable Analog OxygenMonitor forMaintaining Safe Oxygen Concentration in IndustrialEnvironments

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As industrial fields become more intertwined and complex, there is an increasing demand for a suitable & reliable method of monitoring the concentration of Oxygen in the surrounding work environment. It is often required that these Oxygen levels retain consistent values in order to protect the workforce and the material in use. This paper proposes an analog system which uses a combination of operational amplifiers in different configurations. They have been designed to convert the current signals generated by an Electrochemical sensor and compare these signals to a reference voltage set by the user. Features of the system include long battery life, affordability compared to other monitors on the market, analog signal precision and a wide variety of preset configurations and calibration methods to use in confined spaces. Multiple tests were performed using the device to monitor the concentration of Oxygen outdoors. The device's output is measured in volts using a voltmeter and converted to a concentration of Oxygen detected according to the formulas derived for the system. The results were then compared to the weather and humidity forecast data provided by internet sources and research done on the relationship between humidity and the concentration of Oxygen. This helped in fine tuning the circuit, fix previous issues with the prototype and implement more features. The system proposed was presented to and certified by Oman Chromite Company (SAOG) for use in their opencast and underground mines.

Introduction

When working in harsh industrial environments such as mining sites, oil extraction plains, power plants and manufacturing facilities. There is always a risk of oxygen contamination or deprivation. This happens either because of the process of oxidation through burning materials, dealing with gaseous tanks or because of spending prolonged periods of time in confined spaces. Oxygen deprivation can lead to different types of medical conditions which may lead to unconsciousness or even death. Study suggests that even working in environments with barely enough oxygen for prolonged periods of time can indeed shorten the lifespan of the subject and increases the chance of sudden mortality. The increase of oxygen concentration beyond its natural point of approximately 21% also possesses its fair share of problems. Additionally, high concentrations of oxygen have many indirect side effects like paraesthesia and nausea, and isn't limited to its risk on humans. It also affects materials as a result of oxidization, which causes rust and increased probability of fire taking place since some materials become more flammable under these conditions.

Materials' flammability is determined by a number of factors, auto ignition temperature, which is the lowest temperature required for a material to ignite without an ignition source and flammability range. Which describes the range of concentration in volume percent of flammable gas; its parameters are the lower flammability limit and the upper flammability limit where they refer to the minimum and maximum fuel mixture in volume percentage respectively. For instance, a material with a relatively small flammability range would catch fire more easily with the increase in oxygen concentration which increases the flammability range.

An experiment done by the same association tests this hypnosis (AirProducts, 2019).

Figure 1. *Cotton shirt experiment (AirProducts, 2019)*

During the real time project involvement with Oman Chromite Company; a public share holding company in the mining sector that specializes in mining chromite and its derivatives. It was learnt that these chromite mining sessions are usually done in open-pit and underground mines, depending on multiple factors (OCC, 2018). Open-pit mining sites are usually below sea level at low altitudes. Due to increased pressure, there'll also be an increase in oxygen levels. The company is also looking to start working in underground mines.

These mines are usually enclosed from direct contact with the surface and use special types of ventilation techniques that makes working in these environments possible (Robertson & Self, 2016) The strong ventilation systems work at circulating air in and out of the mine to refresh with a new supply of oxygen for the workers. In these cases, monitoring oxygen is a critical part of this process, in order to determine the amount of air that will be pushed in and out of the working area (Cuffari, 2017).

Comparative Study

Arduino Based Environmental Air Monitoring System

In this paper, a student in the degree of Master of Science under the name Zhuo Li, discusses the available methods of aerial monitoring techniques and their shortcomings. The author of the thesis claims that these days with the increase of air polluting factors such as industrial fumes and the burning of different kinds of fuels that there are no devices available to the public that monitor multiple air parameters autonomously at the same time. They go on to explain that while advanced atmospheric parametric monitoring devices do exist, they usually provide limited information to the public when handled by industry leading weather forecast companies and higher ups (Li, 2017).

The writer points out multiple times that they do not disagree with these methods but would like to further build upon them. Zhuo proposes in their thesis a device that is able to measure different aerial parameters at the same time and capture these measurements. These measurements can later on be used for short and long term analysis. Li strengthens their argument by performing research on air pollution and its effects on people, animals and even the materials used in construction and industrial sites (Li, 2017).

The background of their study is picked up by diving into the parameters they are attempting to measure, what they are, their effects on the environment and which levels are they required to stay in. The author maintains their stance by going through the parameters one by one, starting with PM 2.5. Zhuo describes how there has been an increasing awareness of PM 2.5, which is a parameter that refers to the microscopic material suspended in air with a diameter of 2.5 micro meter or less, this is referred to as particle pollution (Li, 2017).

They assert that particle pollution is a result of power plants, industrial processes and wood fire. They add that this results in a number of health problems ranging from respiration to cardiac diseases. Finally, they use a table to communicate the relationship between its concentration, effects and the cautionary statements assigned for each. The same formula is used to discuss the rest of the parameters such as that for Oxygen, Carbon Dioxide, humidity, temperature and finally rain (Li, 2017).

As for electrochemical sensors, the thesis doesn’t go deep into the structure of electrochemical sensors or their working but settle on only explaining how they are going to be incorporated into the system. The paper proposes the use of analog electrochemical sensors, as the name suggests, these output the signal in analog form. Zhuo emphasizes the use of an ADC converter with the Arduino board to convert the received analog signal to a digital one in which the microcontroller is able to read. The specific type of oxygen sensor used in the proposed system is a KE-50 oxygen sensor with a 10 year life expectancy; the writer clears out their choice by explaining that this sensor isn’t influenced by the presence of other gas molecules. In addition to a measurement range of 0-100%, an accuracy of ±2% and an operating temperature of 5-40%, the author contends that this sensor is perfect for the purpose of their project. Zhuo claims that the oxygen sensor in use is basically a lead-oxygen battery; they later on explain the working of the sensor on a chemical and electrical level (Li, 2017).

In the fourth chapter begins by what is referred to as the “Twelve hours experiments”, they are a series of experiments performed each over a span of twelve hours to test the performance of the device. The literature starts with the experiments done for the temperature and humidity sensors implemented in the system. The paper emphasizes that the experiment was done from 9 AM to 9 PM on April 2nd and that the device was given time to adjust to the outdoor temperature. The results we collected and the readings were graphed versus time. The same experiments steps were performed for CO2, O2, PM 2.5 and rain parameters scoring varying results. According to the writer, the results collected from the CO2 experiment were far from accurate, they note that this is because of the amount of calibration a CO2 sensor needs which requires professional calibration equipment. Failure to calibrate the CO2 sensor results in readings that are far away from the normal, however if the user were to look only at the change in concentration this wouldn’t pose as a problem.

The paper shares a lot of parallels with this project, ranging from the goal of the thesis, its approach and the underlying principles behind the working of both proposed circuits. The main difference between both approaches is the electrical theory used in the analysis of signals. The circuit by Zhou relies on digital electrical theory where the signals come in discrete values, whereas analog theory used in this circuit is more flexible and defined at any given point in time. Both approaches have their advantages, while digital signal processing usually gives much more accurate outputs, it sacrifices the accuracy of the original readings in order to maintain a constant ratio between the readings. Analog signal processing on the other hand is more accurate in translating the sensory inputs to voltage signals but this comes with the disadvantage of having a harder time representing these readings in a comprehensible manner.

As discussed before, the proposed system by Li is intended to monitor six different sensory equipment each requiring its own implementation environment and set parameters while also having different working principles. This scatters the focus of the project over all the desired parameters which results in a general loss of vision. This project on the other hand has a single main objective. Which is monitoring the oxygen concentration in the surrounding environment. This allows this project to focus more on individual aspects of the system which results in farther vision and better stability.

Before getting into the electrical theory and aspects of the proposed system, one must first brainstorm and establish their ideas, and then try to implement that system afterwards. This starts with measuring the actual concentration of oxygen in the air, then transforming this result into an electrical signal that can be worked with. The next step would require setting a reference point that the oxygen concentration signal is compared with, it canbe thought of as the determinant factor in this system. After the results are collected from both steps, a circuit must receive these results and perform comparisons, the comparison results would later be represented in some kind of visual and auditory feedback.

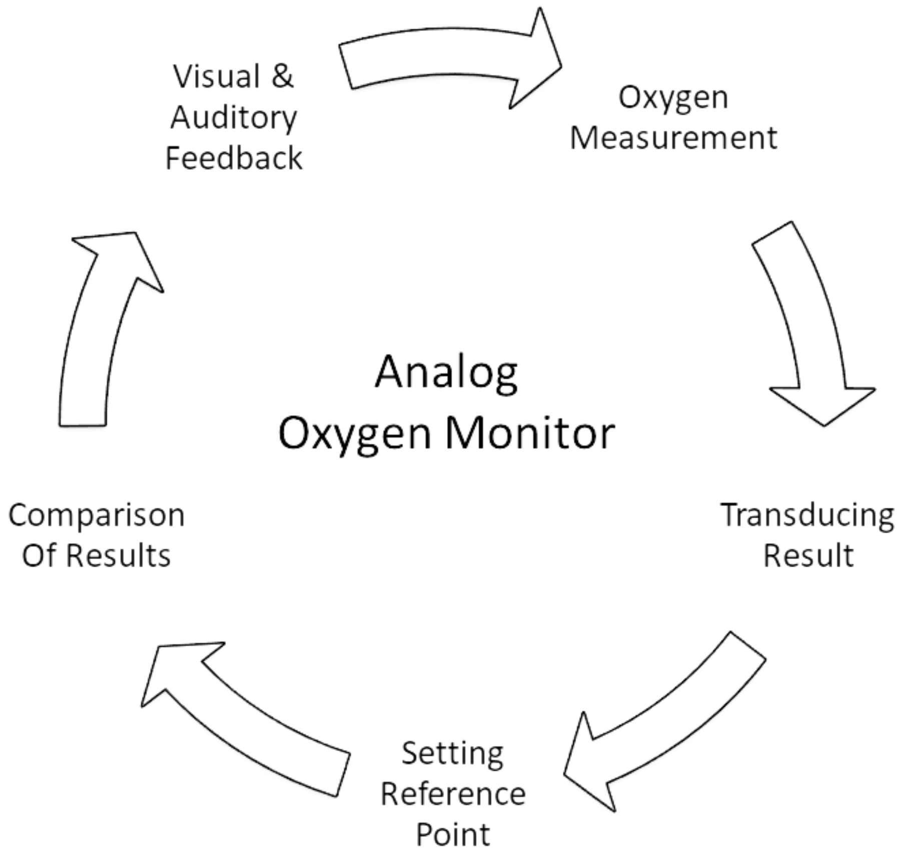

Figure 2. *System Design Process*

Starting with the first step in the process which is the oxygen measurement. A sensor could be used to translate the concentration of target gas in the air into electrical signals that can be processed by the system. The choice of sensor was an electrochemical based oxygen sensory component. During research, different kinds of oxygen sensors were found; these include but are not limited to electrochemical, catalytic, solid-state, non-dispersive infrared and photo-ionization sensors. The table below shows a comparison between these different types of sensors (Bakker & Telting-Diaz, 2002).

Type	Linearity	Consumption	Maintenance	Response	Expectancy
Electrochemical	At room temp	Very low	Low	<50 s	1-2 Years
Catalytic	400 °C – 600 °C	Large	High	<15 s	< 3 Years
Solid-state	Varies	Large	Low	20 s – 90 s	+10 Years
Infrared	Non-linear	Small	Very low	< 20s	3 - 5 Years
Photo-ionization	Relative	Medium	Medium	< 3s	Depends

Figure 3. *Comparison between sensors*

Electrochemical sensors use both electronic and chemical fundamentals in order to measure the parameters of selective gaseous elements in the environment. Their sensitivity and selectivity helped distinguish them over other sensing techniques. These sensors based on an electrochemical principle derived Faraday's law of electrolysis by Michael Faraday, which states that "The mass of a substance altered at an electrode during electrolysis is directly proportional to the quantity of electricity transferred at that electrode" (Bhattacharyya, 2015).

Electrochemical sensors use this principle to measure the concentration of the target gas using the dependent current generated from the sensor; this relationship is either linear or logarithmic depending on the sensor type and manufacturer.

Equation 1. Faraday's law (Bhattacharyya, 2015)

There are six essential components of an electrochemical sensor that most low concentration gas sensors use, the structure in order is: Capillary diffusion barrier, hydrophobic membrane, sensing electrode, reference electrode, counter electrode and finally the electrolyte (Bakker & Telting-Diaz, 2002).

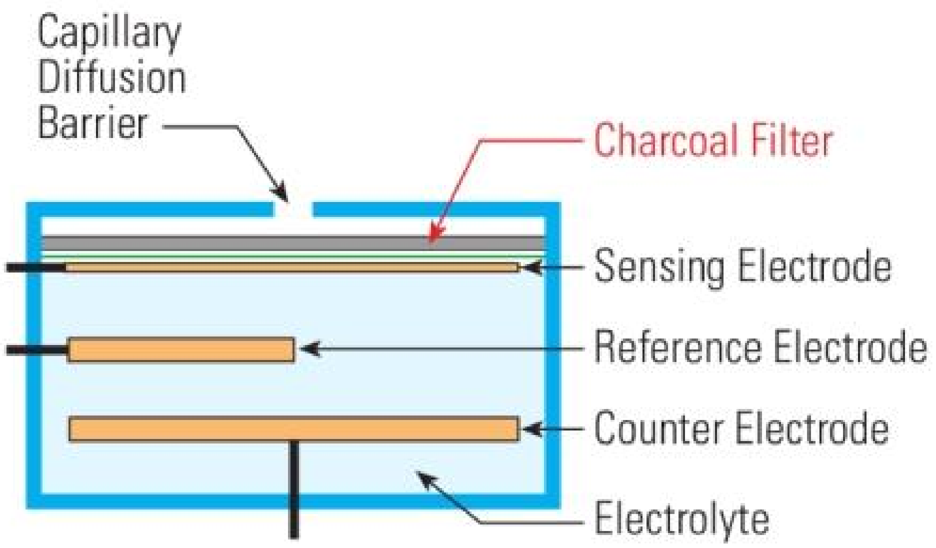

Figure 4. *Electrochemical sensor internal structure (Bakker & Telting-Diaz, 2002)*

Beginning with the capillary diffusion barrier; this is a type of mechanical protection included in some electrochemical sensors under the capillary family of electrochemical sensors. It acts as a membrane that filters out unwanted material from entering the inner sensor structure, protecting the internal mechanism of the sensor. Directly underneath the capillary barrier is the hydrophobic membrane, this is a special type of membrane that implements a diffusion mechanism similar to that found in organic cells. This mechanism allows only the target gas to pass through the barrier while keeping the liquid electrolyte found in the sensor from leaking out.

After passing through both the capillary barrier and the hydrophobic membrane, the target gas interacts with the sensing electrode, which in turn triggers an oxidation or reduction mechanism based on the type of the sensor. The sensing electrode is a catalyzed material made from a noble metal, this metals reaction with the target gas results in either emission of electrons or intake of electrons depending on the chemical reaction performed, these electrons are later carried on to the reference electrode by the liquid electrolyte implemented inside the cell. This structure is very similar to a structure of a typical chemical battery but doesn’t generate as much voltage; this is why electrochemical sensors are sometimes referred to as amperometric gas sensors or micro fuel cells.

Electrochemical sensors, while ideal in some areas, do have their disadvantages. All electrochemical sensors share the same narrow temperature range. Another common factor that holds back electrochemical sensors is their relatively short lifespan. This life expectancy is affected by the concentration of the target gas that causes decay of both the electrode and the electrolyte used in the sensor (Bhattacharyya, 2015).

ME2-O2-Φ20 is the model number of the specific type of oxygen sensor used in this circuit; it is the second model of a series of electrochemical oxygen sensors developed by Winsen. This electrochemical sensor uses the oxidation process of target gas on a working electrode inside an electrolyte cell, which in turn produces current as a result of the chemical reaction. This relationship is linear and directly proportional with the oxygen concentration at the working electrode (Winsen, 2014). Features of this oxygen sensor include low power consumption and high precision, sensitivity, selectivity and stability. All electrochemical sensors require some time to warm up before typical operation; the recommended waiting time is around 10 minutes. This would give the electrochemical sensor enough time to stabilize.

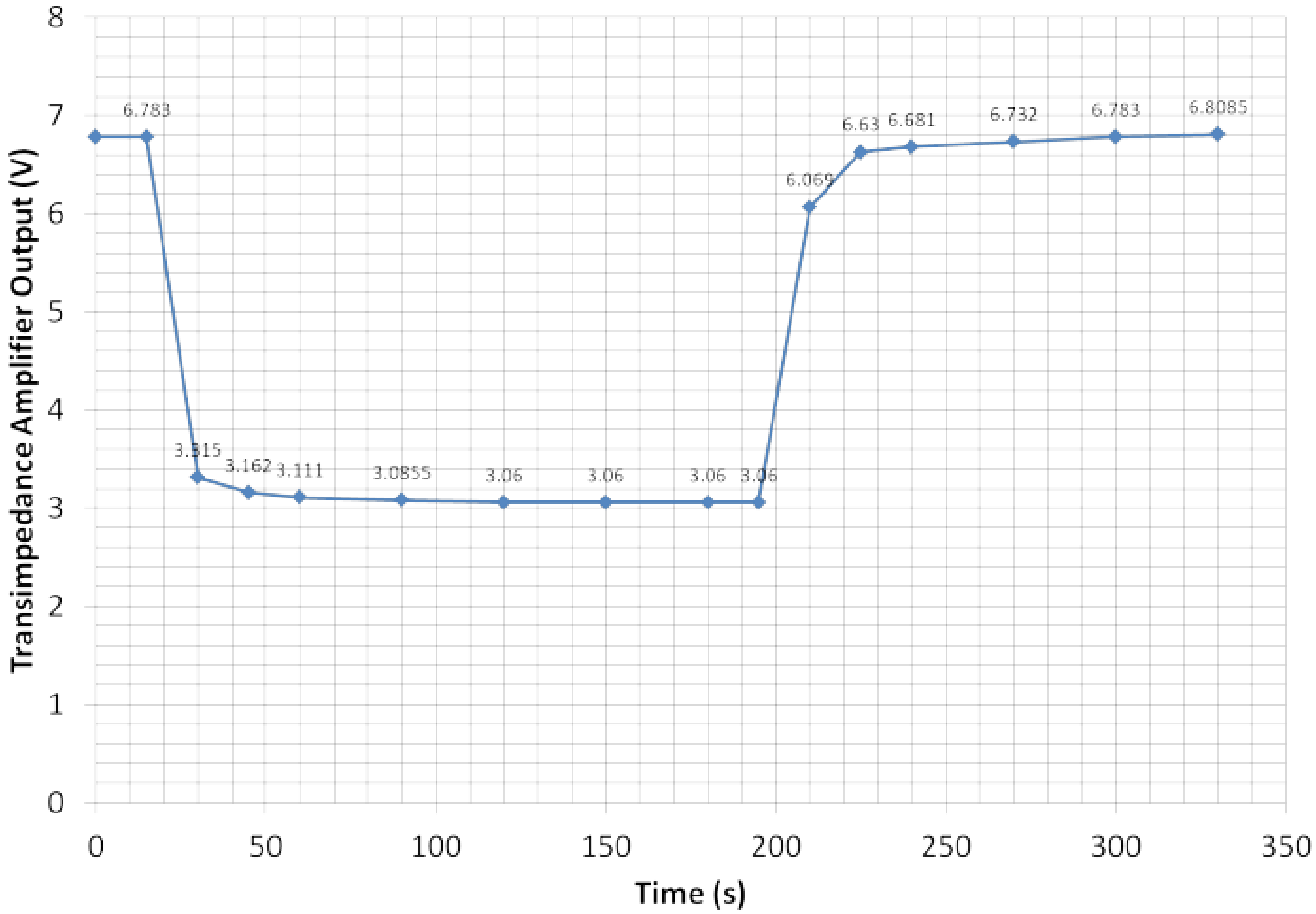

Figure 5. *Sensor response time*

The next step in designing the system would be to find a way to convert the low current signals received from the sensor to more readable ones. For this purpose, a transimpedance amplifier was used. The transimpedance amplifier starts with a resistor in parallel with the inverting and non-inverting terminals of operational amplifier with a value of 10 kΩ. No thought process went behind this choice aside from the fact that this load resistance value was recommended by sensor's datasheet (Winsen, 2014). A respective formula is used to calculate the value of the gain resistance for the amplifier.

According to the datasheet, the sensor is able to measure the oxygen concentration from 0% all the way to 25%. These oxygen concentrations are represented by the respective currents of zero amps and 145 uA. And so, the mean of this output is:

LM324 has a ratio of 15:13 with the output, calculating the mean of the op-amps output:

Calculating the feedback resistance for when the current is 72.5 uA at a 3.9V output. This will provide the best possible range for the transimpedance amplifier.

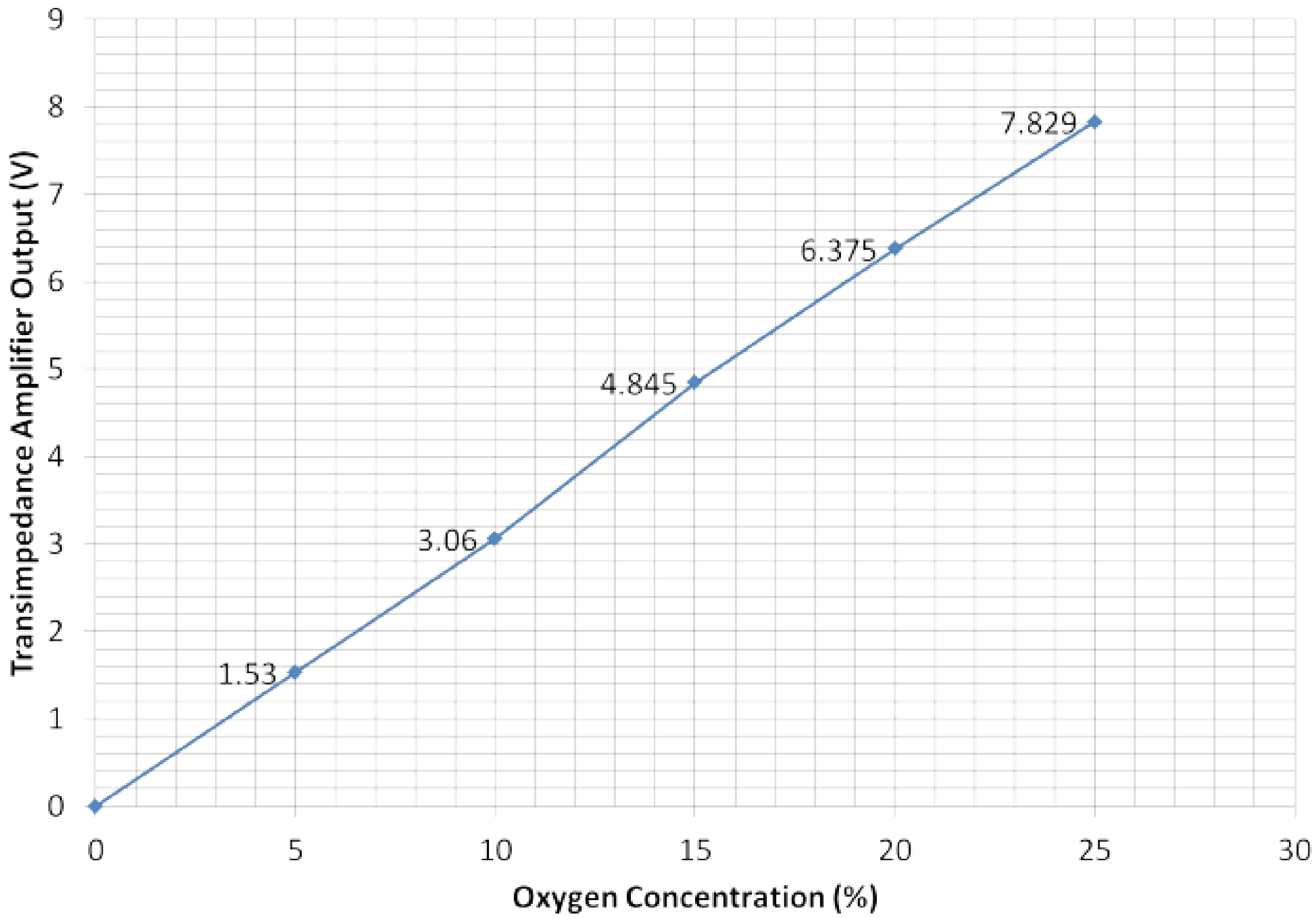

Figure 6. *Oxygen concentration vs. Amplifier voltage graph*

The above graph assumes a feedback resistance of 51 kΩ as seen in the project prototype, increasing the feedback resistance would increase the transimpedance amplifier range but would result in very oxygen concentration signal to be clamped by the operational amplifiers max output. The same is true for choosing a very small feedback resistance. In order to monitor the change in oxygen concentration in the system, a comparator can be used to compare the voltage signals of the oxygen concentration and its reference point. The system requires three comparators, one for monitoring the drop in oxygen, a comparator for the increase in oxygen and for operating the siren. As you might recall, an operational amplifier was used to construct the system's transimpedance amplifier. If the comparators were designed with op-amps as well, it's possible to use a op-amp package in the circuit to simplify it. This is the reason behind the choice of the LM324, which provides a number of op-amps operating under the same supply voltage.

There is a debate over the use of operational amplifiers as comparators. The reason behind the argument is because op-amps usually have lower performance than that of conventional comparators, which are made with this operation mode in mind. Another concern is the voltage swings of some op-amps such as the LM324 used in the circuit. However, since this system is analog, and with the oxygen sensor having a relatively slow response time, an operational amplifier can be used as a comparator with little to no negative effects on the circuit.

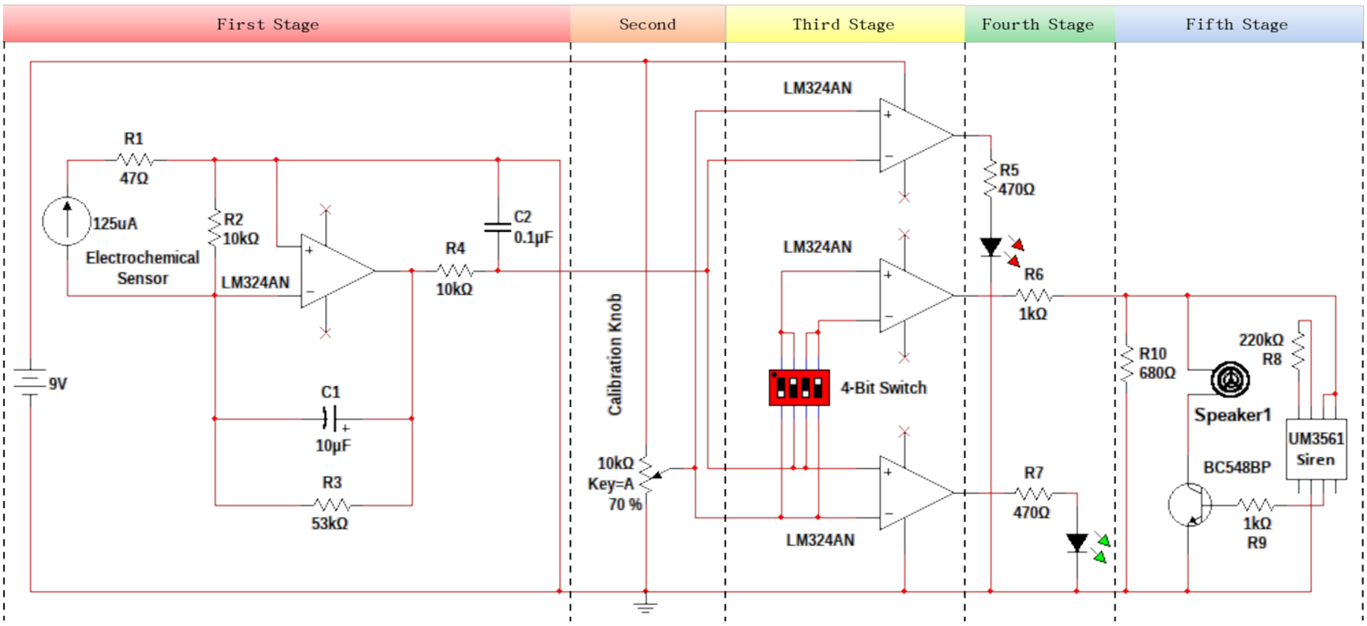

Figure 7. *Circuit Schematic*

The circuit starts operating at the electrochemical sensor. As explained before, an electrochemical sensor functions as a chemical battery that changes its supply voltage based on the oxygen concentration in the surrounding gas. And thus it is represented with a current source. For now, the current signal is assumed to be 130 µA, which is the typical current signal in an environment with approximately 21% concentration of oxygen. R1 is the internal impedance of the electrochemical cell, this is only used in schematics so that it gets accounted into calculations, however during hardware implementation, this resistance would not be used since the electrochemical sensor itself will provide that impedance. R2 is the load resistance attached to the electrochemical sensor, this resistance is required by the datasheet of the ME2-O2 sensor to limit the amount of current going through the sensor, preventing any current overload. These three components form the electrochemical sensor's loop, which feeds the next part of the stage with sufficient voltage.

The first stage in the circuit includes a transimpedance amplifier as well. For this TIA, an LM324 operational amplifier was used as the amplification component in the circuit, R3 is the feedback resistance. The most defining characteristic of transimpedance amplifiers is that the resulting gain equals that of the feedback resistance with no held-backs. Which in turn suggests that the current applied at the summing point of the op-amp is thus multiplied by the value of the feedback resistance, resulting in a huge boost in the output voltage. The capacitor C1 is the feedback capacitor. While not essential, it helps a lot in improving the circuit's stability. The output of the transimpedance circuit then goes through a low pass filter built using a resistor and a capacitor, R4 & C2 in series. This ensures the amount of noise generated by the amplifier is minimized, improving the monitoring accuracy.

The second stage of the circuit consists of the calibration knob; it is implemented using a potentiometer. In this configuration, two out of the three pins in a potentiometer are connected in parallel with the supply voltage, while the output of the potentiometer is connected to the comparators' inputs. The output of the potentiometer changes when its resistance is changed, where the output voltage increases with the increase in resistance towards ground and decreases with its decrease. This plays two important roles in the circuit. The potentiometer sets the reference voltage for the third stage of comparators; it also works as a way to calibrate the circuit to match the desired oxygen concentration to be detected.

The third stage in the system is the heart of the circuit, all of the circuit operations concerning the oxygen concentration and monitoring it are done here. It is the most complicated part of the circuit at first site as well. There are seven terminals in this part of the circuit, two of these terminals are the supply and ground terminals. The five remaining consist of two input terminals and three output terminals. The input terminals are provided with voltages generated from the previous two stages discussed before. In the first stage, the output voltage represented the oxygen concentration detected while the second stage provided the reference voltage required for comparison. These voltages are shared across the input terminals of the two operational amplifiers and one dip switch. The first operational amplifier is the comparator responsible for detecting the drop in oxygen beyond the reference voltage; this is done by supplying its positive terminal with the reference voltage and its negative terminal with the oxygen concentration signal. As a result, when the oxygen signal becomes lower than that of the reference voltage, the comparator will output a high signal which turns on its respective LED. The third comparator is the one responsible for detecting the increase of oxygen, by supplying its negative input with the reference voltage and its positive input with the oxygen signal, the comparator would output a high signal once the oxygen signal exceeds the reference voltage, turning on the LED, indicating an increase in oxygen.

The purpose of this dip switch is to control the behavior of the siren comparator, by altering the arrangement of the dip switch, we change how the comparator responds to the received voltages. This lets the user choose whether the siren would alarm with the increase of oxygen or with its decrease, allowing for flexible operation of the system. The dip switch configurations are provided in the table below.

Oxygen State	HIGH	LOW
Binary	1 0 1 0	0 1 0 1

Table 1. *DIP Swtich binary configuration*

The fourth stage contains the visual feedback of the circuit and the siren comparator. Two LEDs are used to indicate oxygen states for their respective comparators, red for low concentration and green for high concentration. The siren comparator receives voltage signals through its input terminals determined by the dip switch. A binary configuration of “1 0 1 0” supplies the positive terminal of the siren comparator with the oxygen concentration signal while the negative input is supplied with the reference voltage, this lets the comparator output a HIGH signal when the oxygen concentration signal surpasses the reference voltage, in other words when the oxygen concentration is high. During a “0 1 0 1” binary configuration, the states of the op-amp terminals are reversed, with the negative terminal receiving the oxygen concentration signal and the positive one receiving the reference voltage, allowing the comparator to output HIGH when the oxygen concentration drops below the reference voltage.

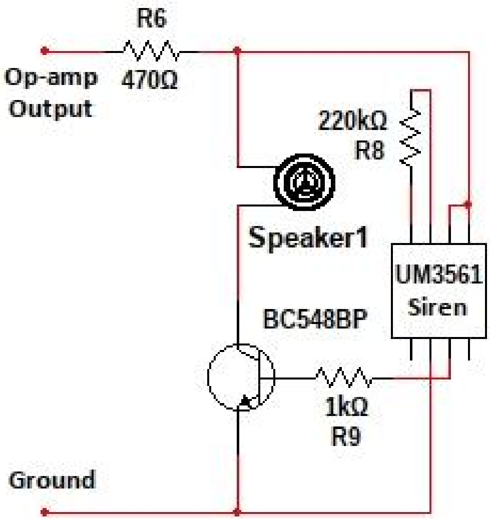

Figure 8. *Siren circuit schematic*

The fifth and final stage in the system contains the siren circuit; this circuit is used to generate oscillations by the UM3561 IC that simulates a siren sound through a speaker. R6 is used to drop the voltage across the IC to a suitable operation value; the configuration used for the siren is predetermined by the IC's datasheet. R8 controls the frequency of oscillations which in turn controls the siren speed, while R9 is used to bias a transistor in amplifier configuration to operate the speaker. For better understanding of the sirens operation, refer back to the hardware requirements section of this chapter.

Bonding Pad		Sound Effect
SEL 1	SEL 2	
No Connection	No Connection	Police Siren
V_{DD}	No Connection	Fire engine siren
V_{SS}	No Connection	Ambulance siren
"–" don't care	V_{DD}	Machine gun

Figure 9. *UM3561 Configurations (Spiratronics, 2019)*

System Simulation

Quite Universal Circuit Simulator or Qucs for short is another circuit simulation and schematic software, it is an open source software under the GNU General Public License 'GPL' (Brinson & Kuznetsov, 2019). The main advantage of Qucs is the much more accurate simulation results. Qucs is very strict when it comes to the circuit parameters matching their electrical rules, decreasing the margin of error that could occur during simulation (Brinson & Kuznetsov, 2017). In addition to its accuracy, simulations in Qucs are relatively faster than those under Multisim, since Qucs's code is much more clean and straight forward, with a lack of a visual feedback and a live simulation. The circuit was built in Qucs using the provided components, with the LM324 op-amp being absent from the component selection. While this is a clear weakness of Qucs, it does provide a way to edit the parameters of the default op-amps, where the user can set maximum output voltage, voltage swings and slew rate. Two simulation configurations were performed for the circuit, DC Simulation and a Parameter Sweep.

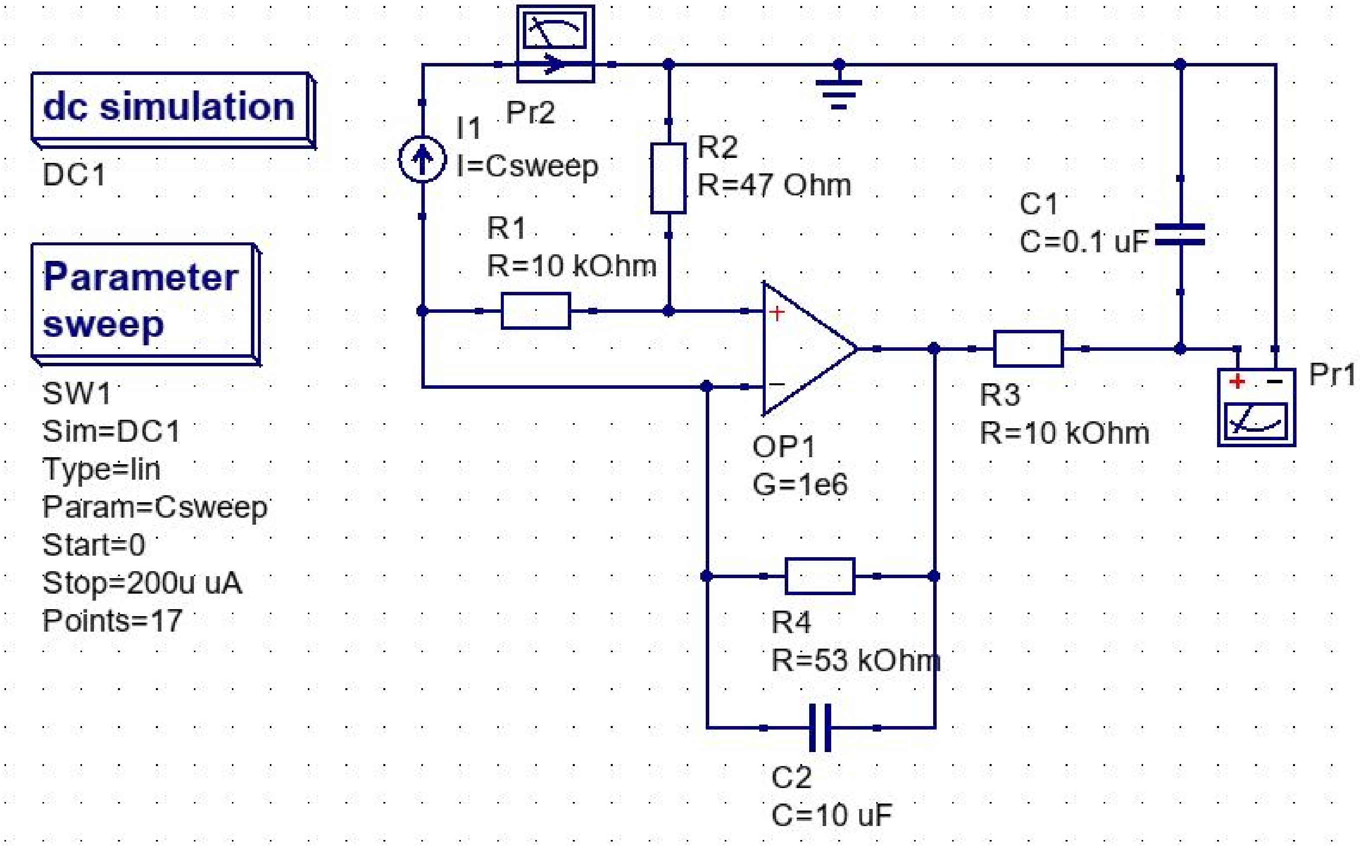

Figure 10. *Simulation of transimpedance amplifier*

A parameter sweep is used to define a sweep in a value, in this case, simulating the amplifier's output at different current intensities provided by the sensor. The datasheet of the sensor specifies a current intensity from zero to 150 uA depending on the oxygen concentration. A parameter sweep was set for the current source, instructing it to vary the current intensity from zero to 200 uA in 20 steps. A value of 200 uA was chosen in order to test the output range of the op-amp as well.

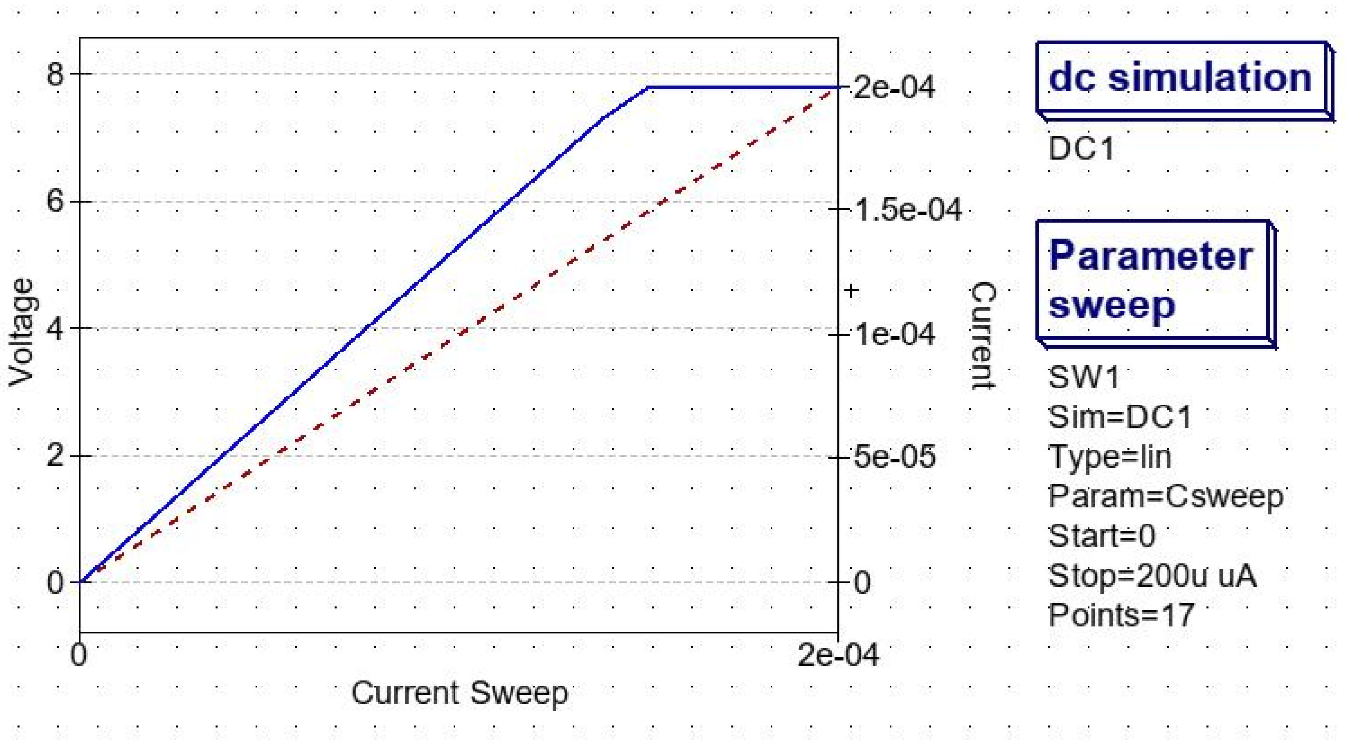

Figure 11. *Simulated sensor current sweep*

The Cartesian graph returned the requested readings. In the graph above, the blue continuous line represents the output voltage of the op-amp with the left Y-axis defining its value. The current intensity of the sensor is represented with the dotted red line defined by the right Y-axis.The current of the sensor raises from zero to 200 uA as mentioned before. The left Y-axis uses an E-notation formatting for numbers with long decimals, such as the very low value of current used in the circuit. As you can clearly see, the voltage at the output increases with the current in a directly proportional behavior, until the value of current reaches approximately 150 uA, which in turn stops the voltage from changing that locks at around 7.8 V.

The low pass filter integrated in the circuit is tested next. The simulation was carried using different simulation parameters. This time an AC Simulation and a Transient Simulation. The AC simulation varies the frequency of any AC voltage source in the circuit according to predetermined values, while the transient simulation performs a simulation for different circuit parameters vs. time. The AC simulation was configured to sweep the frequency from zero to 1 kHz. The simulation was initiated and a Cartesian chart was used to visualize the results.

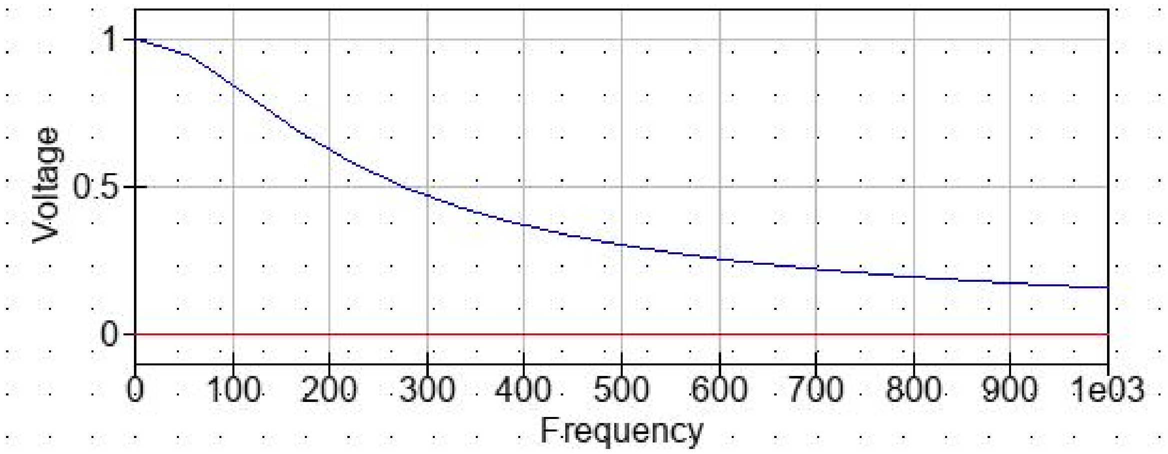

Figure 12. *Simulated LPF response*

It was covered in brief previously that operational amplifiers not being very suitable comparators. The counter argument to this however is that this circuit does not rely on very fast voltage sweeps like those found in digital circuits. Nor is the accurate output voltage a requirement in an analog based circuit that doesn't depend on discrete voltage levels.

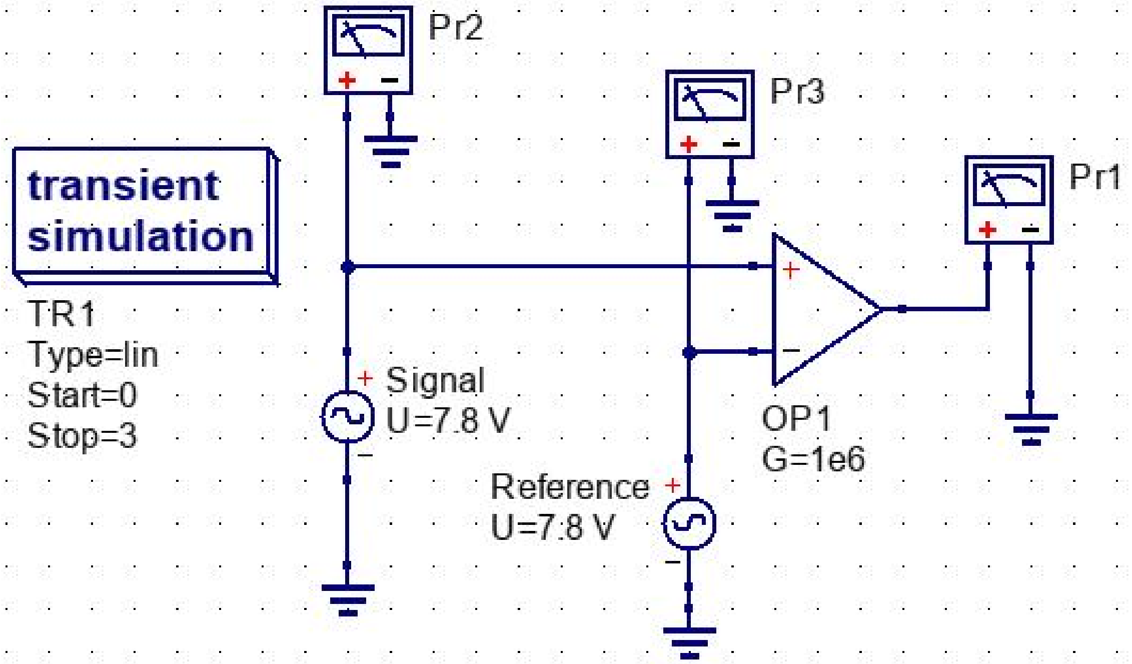

Figure 13. *Simulation of LM324 in comparator configuration*

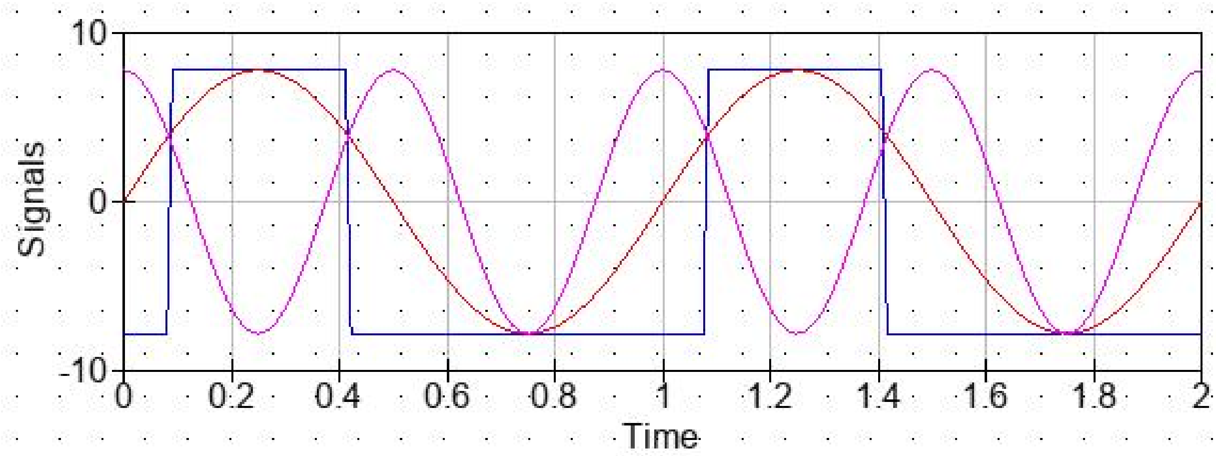

Figure 14. *Simulated LM324 Comparator output*

The Cartesian graph returns the above results. The sensor signal, reference and output voltages are represented by the red, pink and blue lines respectively. The comparator in this scenario is set to output high when the voltage of the sensor signal is higher than the reference signal and lower when the opposite is true. The output of the op-amp what 7.8 V at max as expected with accurate comparison of input voltages. The only fallback is the op-amp's slew rate which results in pulses with delayed voltage increases and drops.

The tests were performed on the 21st of June '19, in Muscat, Oman. During that period, humidity of the air increases after sunset. This is a huge advantage to test the sensitivity of the sensor which is affected by humid weather that causes the oxygen pressure distribution to change because of the water molecules in the surrounding environment. The tests were done from 7 PM to 7 AM on a new 9V battery. This will allows for testing the system's power consumption as well. The battery used was an Energizer Pile Alkaline, with an initial voltage of around 9.6 V. And 9.56 V when connected to the circuit.

The prototype was placed outside at 6:45 PM for preparation, the system was turned on and after 10 minutes returned an oxygen signal of 6.54 V, this indicated an oxygen concentration of around 20.71%. The oxygen concentration is expected to drop because of the humidity, so a reference voltage was applied using a potentiometer at 6.5 V. This provides the sensor with a small amount of range to fluctuate without triggering the siren. Then the siren was set to sound an alarm with the decrease of oxygen concentration as explained before. The output of the transimpedance amplifier was to be measured every 2 hours, in order to determine if the circuit is functioning as intended. The first measurement at 9 PM returned an oxygen signal of 6.53 V, a reference voltage of 6.5 V, and a battery voltage of around 9.47 V.

Evidently, at exactly 10:12 PM, the circuit sounded an alarm indicating the drop in oxygen. At that time, the voltmeter reading returned 6.48 V. To make sure the circuit was working correctly, the reference voltage was measured as well, which was a stable 6.5 V as set previously. The reference voltage was once again lowered to 6.45 V and the circuit was left outside.

The results acquired are represented in the table below:

Time	Battery	Reference	Output	%O2
7 PM	9.56 V	6.5 V	6.54 V	20.71 %
9 PM	9.47 V	6.5 V	6.53 V	20.68 %
10:12 PM	ALARM	6.45 V	6.48 V	20.52 %

11 PM	9.13 V	6.39 V	6.52 V	20.65 %
1 AM	9.09 V	6.45 V	6.61 V	20.93 %
3 AM	9.08 V	6.45 V	6.58 V	20.84 %
4:23 AM	ALARM	6.65 V	6.68 V	21.15 %
5 AM	9.03 V	6.72 V	6.69 V	21.18 %
7 AM	8.82 V	6.72 V	6.67 V	21.12 %

Table 2. *Prototype technical results*

Time	Humidity	Temperature	Concentration
7 PM	83 %	34/32 °C	20.71 %
9 PM	85%	34/33 °C	20.68 %
10:12 PM	89%	33/33 °C	20.52 %
11 PM	91%	32/32 °C	20.65 %
1 AM	89 %	34/31 °C	20.93 %
3 AM	86 %	33/33 °C	20.84 %
4:23 AM	83 %	33/33 °C	21.15 %
5 AM	79 %	34/33 °C	21.18 %
7 AM	77 %	34/32 °C	21.12 %

Table 3. *Prototype results vs. Temperature*

Conclusions

During the technical experiment, results were acquired concerning oxygen levels in Muscat on the 26th of June 2019. The idea was to measure oxygen concentration in the air and compare it to humidity values provided by weather stations. The principle was that the concentration of oxygen decreases in humid environments due to the presence of water molecules in the air which effects the pressure of oxygen leading to a decrease in its concentration. The results were very similar to those acquired in previous research done in areas concerning the same parameters. The goal of that experiment however wasn't to measure the oxygen concentration in Oman per say, but to determine whether the system designed satisfied design calculations and expectations.

One of the system's limitations is its inability to show the exact percentage of oxygen concentration without the aid of a digital voltmeter. It is also worth mentioning that the sensor's range of detection is limited to a maximum oxygen concentration of 25%, anything higher can potentially damage the sensor and the circuit itself. Moreover, the circuit must be turned off before the DIP switch configuration is changed, either that or after disconnecting the sensor using the provided switch. The circuit does not disconnect the sensor automatically after it is turned off, which can result in decreased sensor life in case the user has forgotten to disconnect it. Furthermore, the circuit must be recalibrated from time to time when working on a battery in order to complement the drop of voltage with constant use. Lastly, the sensor is highly sensitive and effected by heat, dust and humidity. This limits the sensor's possible usage scenarios.

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