KEMET
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Application Notes

SMD Pyroelectric Infrared CO$_2$ Gas Sensing Evaluation Kit USEQGSK3000000 Basic Calibration

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DOCUMENT HISTORY

Version	Date	Change Ref.	Change Details
01	15 JUN 2020	N/A	First Release
02	19 NOV 2020	N/A	Logo Change and Reformatting

1   INTRODUCTION

This document covers a simplified and approximate calibration procedure that can be used to provide the most basic possible calibration of the CO$_2$ Gas Sensing Evaluation Kit USEQGSK3000000. It is worth noting that the procedure can be followed for any other KEMET sensor being used for gas detection, but this guide will use USEQ*S sensors and CO$_2$ for the procedure.

<u>Please note that the results achieved by following this approach are suitable for indicative demonstration only, and do not constitute a precise calibration regime often required in applications.</u>

This guide implements the calibration procedure documented in the Application Notes *NDIR − Determination of Linearization Coefficients.pdf* using only 3 data points. A further simplified method of using 2 points only is also proposed. This makes it useful for first contact with the kit. For higher accuracy and range, known gas concentrations covering a larger number of points of the desired operating range should be used.

2   REQUIRED EQUIPMENT

To be able to follow this guide you will need to have access to the following items.

1. A CO$_2$ gas sensing evaluation kit USEQGSK3000000
2. The KEMET gas demo software v2.0.1197.0 or newer
3. The application notes *NDIR − Determination of Linearization Coefficients.pdf*
4. The excel file *NDIR Gas Coefficients.xlsx*
5. A source of pure nitrogen gas (optionally not required, see Appendix 1)
6. A person that can exhale steadily (approximately 48000 ppm CO$_2$)
7. The atmosphere (approximately 400 ppm CO$_2$)

Items 2 to 4 are supplied with the purchase of a CO$_2$ Gas Sensing Evaluation Kit USEQGSK3000000.

It is worth reading the document *NDIR − Determination of Linearization Coefficients.pdf* prior to moving on as it will help you understand why you must acquire the data points for determining the coefficients from the modified Beer Lambert law.

3   3 DATA POINTS − CO$_2$ CONCENTRATION

In order to create a model that is not just a straight line the minimum number of data points required is 3. The concentrations used in this document are assumed based on data readily available on the internet. In order to improve the accuracy of the data points a secondary CO$_2$ sensor can be used.

The largest value of concentration of CO$_2$ readily available to the average person is simply the exhaled concentration. The midpoint being used in this procedure is the ambient CO$_2$ of the atmosphere. This will change over the course of a day in an office, so it is worth doing it in a larger uncrowded space if possible. The last data point is harder to achieve as it requires a nitrogen gas source. The gas is flowed into a container with a relatively good seal, but not airtight, as the demo kit is placed in the box and the pressure caused by the nitrogen will force other gases out of the box. Since nitrogen does not absorb IR in the absorption region of CO$_2$ this gives approximately the same reading as a vacuum would provide and is hence considered the zero concentration point.

This guide will show you how to get the 3 data points. Once these have been acquired you can then use the documents *NDIR − Determination of Linearization Coefficients.pdf* and *NDIR Gas Coefficients.xlsx* to acquire the coefficients.

3.1   Signal Strength − RMS per Emitter Period

For this procedure the signal being used is the RMS per emitter period. This means that each data point in the graphs shown represents the RMS value for a single emitter period. This is opposed to the rolling

RMS that provides an RMS value for every data point provided by the sensor. The latter is faster responding; however, it is also less stable.

3.2 Nitrogen Chamber

To acquire a zero concentration point a very simple nitrogen chamber is required to be made. A set up similar to the picture below can be made.

If you do not have access to a source of nitrogen the value of the signals can be estimated by following Appendix 1.
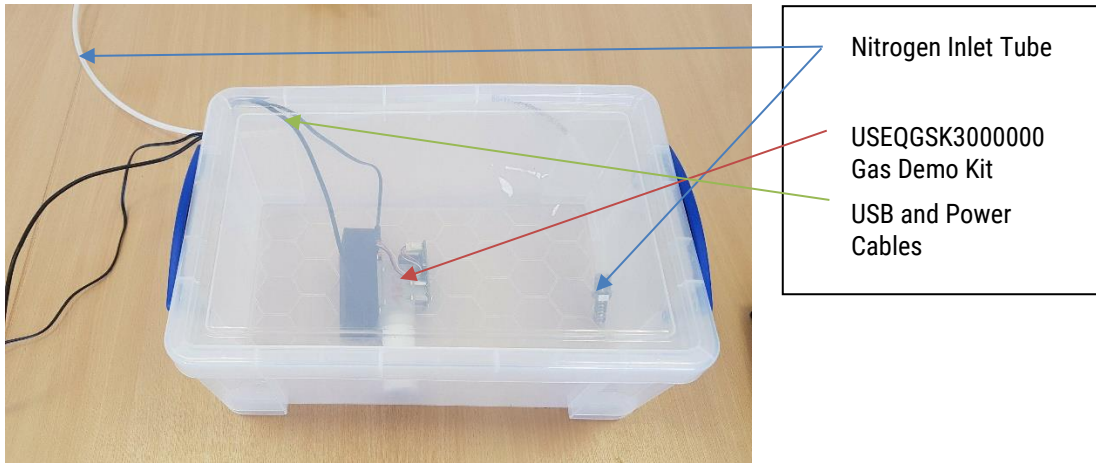

Figure 1 − USEQGSK3000000 Gas Demo Kit in Nitrogen Filled Container

Once the nitrogen is turned on the positive pressure inside in the box will cause a flow of air to the outside of the box. Over time the box will contain almost entirely nitrogen. This works faster if the box is well sealed but not quite airtight as you want to limit the entrances to the box. This can be observed by watching the RMS output on the USEQGSK3000000 gas demo kit. Once the value of the RMS stops changing the box contains almost no CO_2. This can be observed either live in the GUI or by leaving the kit writing a csv file for a period of time, the time period depending on the box size and the pressure of nitrogen.

An example of a csv file record for the RMS per emitter period values is shown below.
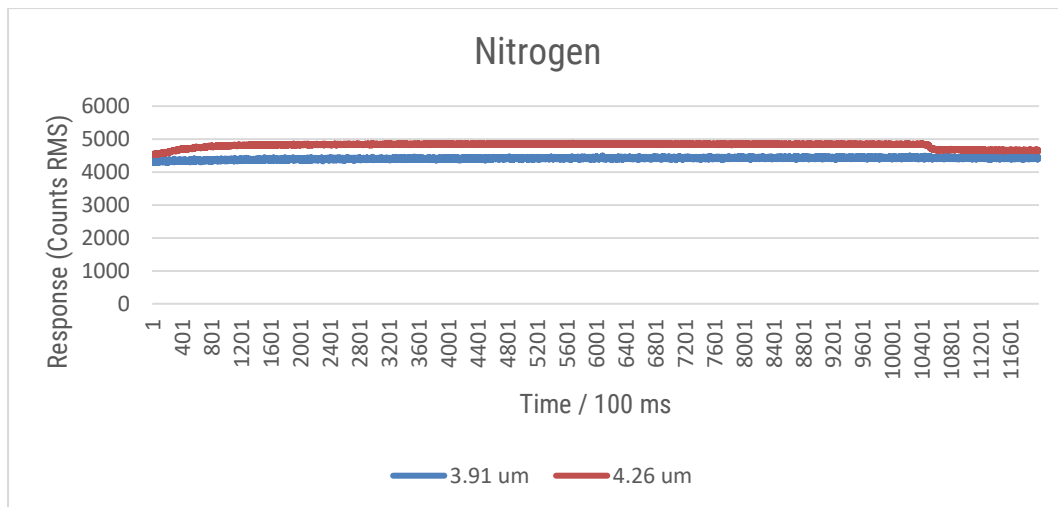

Figure 2 − Response to Introduction of Nitrogen into the Environment

The above graph shows the effect of turning on the nitrogen just after starting to record a csv file. Initially the CO_2 levels are such that the IR signal reaching the sensor is lessened by the absorption of the atmospheric levels of CO_2 present.

The above information is believed to be correct but does not purport to be all inclusive and must be used only as a guide.

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Once the box begins to fill with nitrogen the CO_2 sensor RMS value increases as there is less absorption in 4.26 μm region. This value can be seen to increase, then level out as the concentration of CO_2 begins to settle once the box is filled with nitrogen. The drop near the end is where the box was opened and the signal returns to the value associated with atmospheric levels of CO_2. The 3.91 μm signal remains constant through this period as is desired from a reference sensor.

The value to be used from the above graph should be an average of the values from the period of stable signal when the box is filled with nitrogen.

The value used in this guide is

Test Conditions	CO₂ Concentration	3.91 μm Average RMS Value	4.26 μm Average RMS Value
Nitrogen Box	0 %	4,422.919	4,849.687
Atmospheric	0.04 %		
Exhaled	4.8 %		

3.3 Atmospheric

This value can be taken simply by leaving the gas demo running for a long period of time. Then taking the average of the RMS per period over this time. It is worth mentioning again that doing this in an office or enclosed space will result in a higher than atmospheric concentration. This can be avoided by recording the data in an empty office or before everyone turns up.

Also make sure that the kit is protected from large temperature changes. Leaving it at a window with the wind blowing in will reduce the effects of CO_2 build up but will introduce possible thermal effects from cold wind causing sensor instability. For the graph below the sensor system was put inside the same box used for the nitrogen data point but containing only atmospheric CO_2 levels. This avoids any thermal effects from air flow occurring.
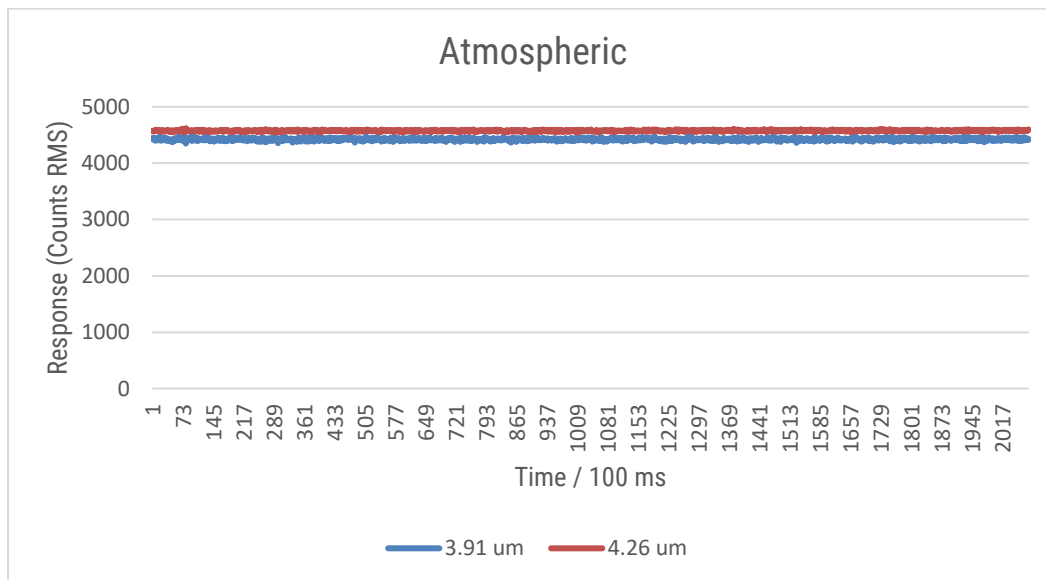

Figure 3 – Readings in Stable Atmospheric Environment

The graph above shows the RMS values from the gas demo kit being in a box with atmospheric levels of CO_2 to provide a stable environment for the sensor.

The table of values can be updated.

Test Conditions	CO₂ Concentration	3.91 µm Average RMS Value	4.26 µm Average RMS Value
Nitrogen Box	0 %	4,422.919	4,849.687
Atmospheric	0.04 %	4,422.889	4,575.519
Exhaled	4.8 %		

3.4 Exhaled Air

The exhaled CO_2 is the most difficult to achieve an accurate value for as it requires getting an average off the portions of the graph that correspond to exhaled CO_2. This is inaccurate due to the varying levels of CO_2 during this period as well as the fact that the kit cannot be kept in a stable environment.

Nevertheless it is the best that can be achieved without specialist gas canisters with known concentrations of gas.
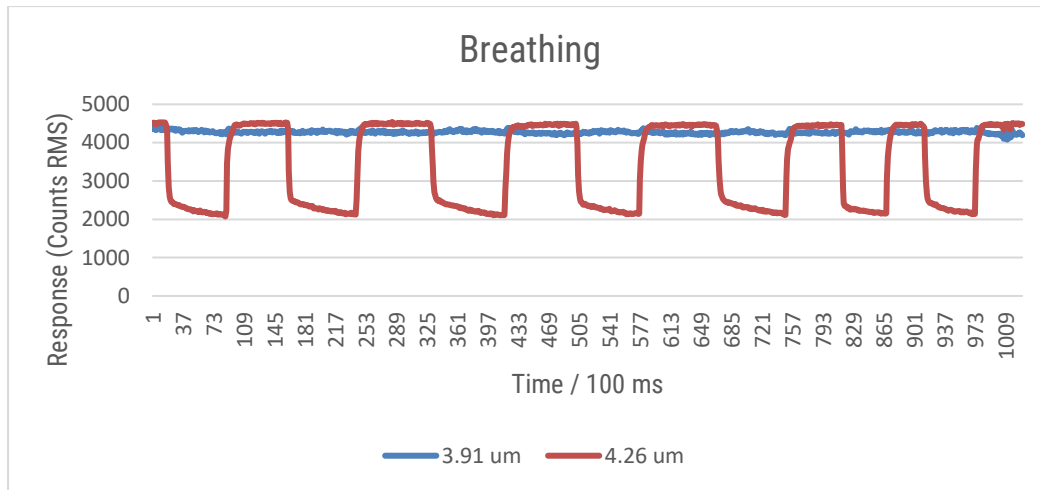

Figure 4 − Response to Breathing

From the graph above the required information to be extracted is the average RMS value of the troughs created during the exhalation periods. This is done by taking the average value of each trough and getting the average of all the troughs.

This value will then correspond to the mid-range possible value of end tidal CO_2, approximately 4.8%.

The above procedure would greatly benefit from the use of a secondary CO_2 measurement system to give the exact concentrations of exhaled CO_2 as the concentrations can vary from person to person. However as a rough and ready way to show a calibrated system that does not have to pass any criteria within a certain margin of error the calibration is suitable.

Test conditions	CO₂ Concentration	3.91 µm Average RMS Value	4.26 µm Average RMS Value
Nitrogen Box	0 %	4,422.919	4,849.687
Atmospheric	0.04 %	4,422.889	4,575.519
Exhaled	4.8 %	4,287.697	2,240.175

It should be noticed that the reference sensor does in fact vary when the gas is being exhaled. This is due to the additional water vapour in the path of the IR. This is an optical effect that the reference sensor can compensate for. The optical effect is seen on both sensors and the effect is roughly proportional to each sensor's output.

4   MODIFIED BEER LAMBERT COEFFICIENTS

The values from the previous section have been obtained in order to determine the coefficients a, b and c from the modified Beer Lambert law shown below.

$$x\% = \sqrt[c]{\frac{\ln(1 - \frac{ABS}{a})}{-b}}$$

Where ABS is absorption defined as 1 minus the transmission as below

$$ABS = 1 - T$$

$$ABS = 1 - \frac{I}{I_0}$$

For further information please consult the document *NDIR – Determination of Linearization Coefficients.pdf* along with the associated excel file *NDIR Gas Coefficients.xlsx*.

5   A CALIBRATED DEMO KIT

Now that the coefficients have been determined using the experimental data and the equation solver of excel the coefficient values can be used in the demo kit software to plot the concentrations in real time and save the values to a csv file.

KEMET gas demo software version v2.0.1997.0 onwards provides a **Gas concentration view** from the drop-down options menu.

Please refer to the CO₂ Gas Sensing Evaluation Kit User Guide for instructions on how to use these values in the software.

6   APPENDIX 1

If there is no nitrogen source available to give the signal strengths for zero concentration then you can estimate that value by using a simplified version of the modified beer lambert law.

The simplified version of the beer lambert law is acquired by setting all of the coefficients to 1 and setting the two expressions of ABS equal to each other.

1. $ABS = a(1 - e^{-bx^c})$
2. $ABS = 1 - \frac{I}{I_0}$

Let a = b = c = 1 in equation 1

$$ABS = 1 - e^{-x}$$

And set the right-hand side of this equal to the right-hand side of equation 2.

$$1 - e^{-x} = 1 - \frac{I}{I_0}$$

Then solving for I_0 yields

$$I_0 = \frac{I}{e^{-x}}$$

This equation will provide a rough indication of the value of I_0 by substituting the values for atmospheric concentration and the corresponding value for I, where

$$I = \frac{gas\ sensor\ signal\ strength}{reference\ sensor\ signal\ strength}$$

And I_0 is the above equation for zero concentration of gas.