

## RTD120D-EVK

Thermopile CO<sub>2</sub> Detector Evaluation Kit

The Thermopile CO<sub>2</sub> Detector EVK provides an easy way to evaluate the RTD120D Dual-Channel Thermopile in a CO<sub>2</sub> gas detector application.

A Renesas RA4W1 MCU on the main board reads both channels of the dual thermopile detector, and computes and displays the concentration of CO<sub>2</sub>. The EVK may be connected to a Windows PC via USB, making the CO<sub>2</sub> concentration and intermediate data available for plotting, logging, processing, exporting and analysis using the provided software or user-supplied software.

### Features

- User-friendly EVK expedites evaluation of the thermopile detector.
- Operates stand-alone or with a PC running CO<sub>2</sub> Detector Evaluation Software (on Windows®), or end-user supplied software that is able to communicate using text commands or via ModBus over USB, using Windows®, Linux or MacOS
- Evaluation Software is available on the Renesas website at [www.renesas.com/rtd120d-evk](http://www.renesas.com/rtd120d-evk).

### Kit Contents

- CO<sub>2</sub> Detector EVK Board
- Detachable LCD Module
- USB to Micro-USB Cable
- Shorting jumpers (2)
- Quickstart Guide

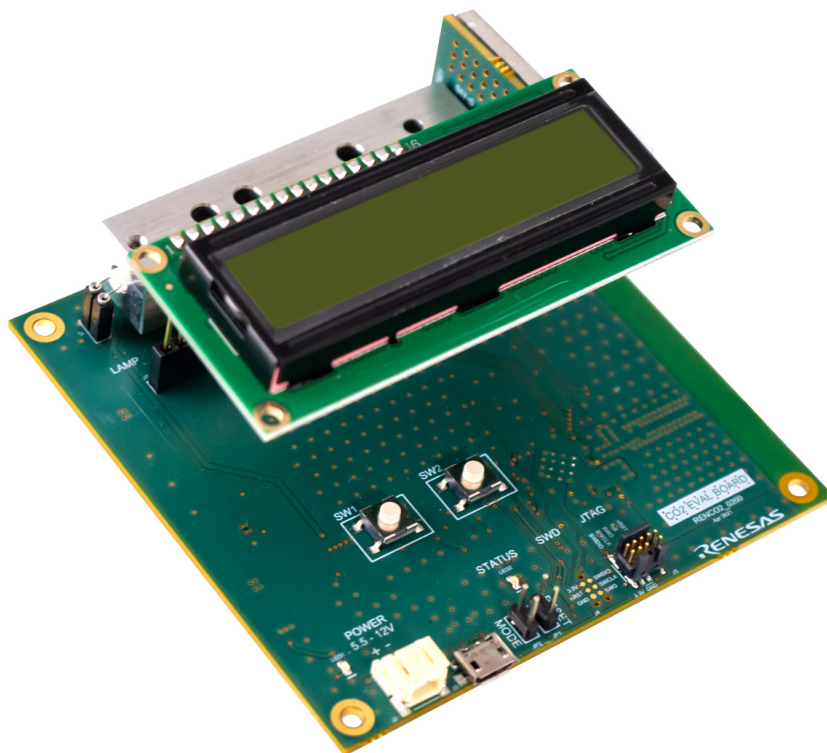


Figure 1. CO<sub>2</sub> Detector Board with LCD Module

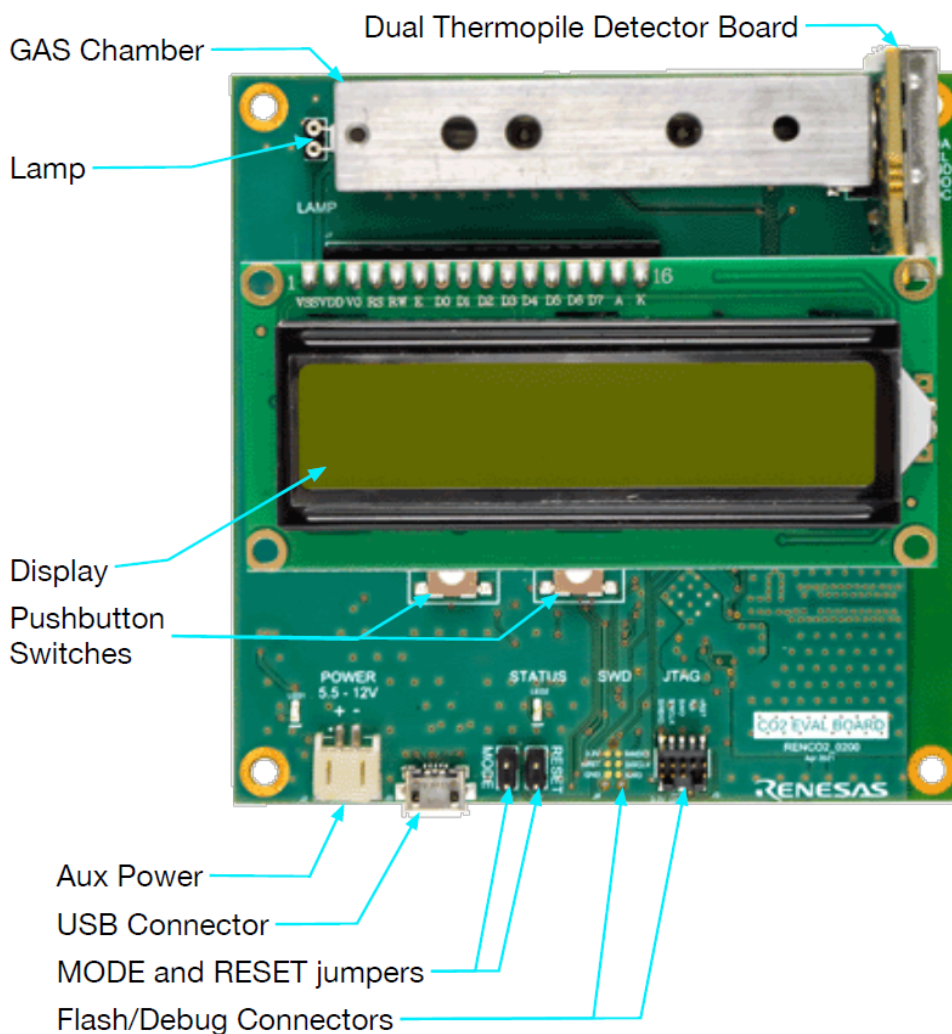
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## 1. Introduction

The EVK for CO<sub>2</sub> Detector is designed for evaluation of the Renesas' RTD120D dual thermopile in a CO<sub>2</sub> gas sensing application, such as to detect the ambient CO<sub>2</sub> concentration. It has a NDIR (Non-dispersive Infrared) thermopile-based gas sensing circuit and the concentration of CO<sub>2</sub> gas is measured based on the intensity of the NDIR radiation.

It can be used as an application example to illustrate how the thermopile, in combination with other Renesas components can be used to implement a CO<sub>2</sub> detection and concentration measurement system. In [Figure 2](#) below is an annotated top view of the EVK.



**Figure 2. Annotated View**

Operating stand-alone, an on-board 2-line character based LCD module is used to display the results of CO<sub>2</sub> concentration measurement, as well as barometric pressure, relative humidity and ambient temperature. The display is also used in conjunction with two push-buttons on the board to allow various menu functions to be performed, including calibrating the CO<sub>2</sub> detection process using gases with precisely known CO<sub>2</sub> concentrations.

The available CO<sub>2</sub> Detector Evaluation Software allows Windows®-based operating systems to communicate with the EVK for CO<sub>2</sub> Detector via a USB connection on the user's computer. The software and additional related documentation is available on the Renesas website. The software communicates using the ModBus™ protocol, over a USB serial connection transport. It can be used to connect to the board for data acquisition and processing.

The software uses *DAQFactory* (by AzeoTech) data acquisition and processing platform to monitor and process real-time data streaming from the EVK board.

As an alternate way of communicating with the board, terminal commands can be used to interrogate and stream data from the board and to perform various functions.

The EVK uses a Renesas RA4W1 microcontroller (MCU) to perform data acquisition and sequencing, execute a CO<sub>2</sub> detection algorithm on the acquired data, and handle USB communications with a host computer for advanced operation such as monitoring raw and processed data from the board, and exporting data to other tools for further processing. The MCU uses I2C to communicate with a multi-channel A/D converter on the detector board for thermopile detector and thermistor temperature readings, and various other sensors on the main board.

The main board has devices mounted on both sides. On the top side is a ventilated gas chamber used to measure the CO<sub>2</sub> concentration using a lamp at one end and a dual thermopile at the other end. Also on the top side is a detachable LCD module which, along with two pushbuttons, provides a stand-alone menu driven user interface to perform basic functions.

A USB (B-micro) connector is used as the preferred method of powering the board and for communications with a host computer. There is also an auxiliary power connector (not needed for normal operation), two jumper headers to facilitate firmware updates (updating the application software that comes pre-loaded on the EVK), and a programming/debug interface using two different connector options. The programming/debug interface can be used to support developing custom firmware to run on the EVK, using Renesas Flexible Software Package (FSP) and the Renesas e2studio Eclipse-based IDE.

The bottom of the board has the RA4W1 microcontroller, power conversion circuits, and additional sensors. A Bluetooth chip antenna is also on the bottom side, for connecting the device to mobile applications (to be supported in the future), and an antenna connector that allows an external Bluetooth antenna to be connected to increase the usable range.

## 2. EVK Functional Description

The Thermopile CO<sub>2</sub> Detector EVK is intended to help evaluate the Renesas RTD120D dual thermopile detector in a micro-controller based circuit, to show how to calibrate such a circuit, and to monitor the performance of an NDIR CO<sub>2</sub> sensor solution based on Renesas thermopiles. The EVK monitors CO<sub>2</sub> levels using the RTD120D [Figure 3](#) below. This dual thermopile package has two identical thermopile elements but with different infrared filters in place. This arrangement allows sensing of IR light emitted from a lamp and passing through an aluminum gas chamber containing an unknown concentration of CO<sub>2</sub>, then using the data obtained to compute the CO<sub>2</sub> concentration.





**Figure 3. RTD120D Dual Thermopile**

Very small voltages that appear across each thermopile (in the microvolts range) in response to incident IR radiation coming from the lamp at one end of the gas chamber can be read by a multi-channel A/D converter. The timing is controlled by a Renesas microcontroller (RA4W1) on the EVK's main board. One of the thermopiles provides "reference" readings and the other provides "CO<sub>2</sub>" readings. This provides a degree of isolation of the effect of the CO<sub>2</sub> in the chamber from the other gases present in the gas sample, since the filters' band pass wavelengths are selected optimally provide this isolation.

To perform a single calculation of CO<sub>2</sub> concentration, each reading is made twice, once with the lamp ON and once with the lamp OFF, resulting in a total of four readings, which are acquired by the A/D converter and stored for processing. After this is done twice for each thermopile, the A/D counts are run through an algorithm that determines the CO<sub>2</sub> concentration, taking into account calibration information that is determined in advance, by a calibration procedure which needs to be done for each EVK. The calibration data depends on and is quite sensitive to the brightness and orientation of the lamp, so if the lamp is moved slightly, whether intentional or not, the calibration should be performed again even if it has been done already. This emphasizes the importance of lamp intensity and orientation not varying in a design using this approach.

An integrated thermistor is encapsulated into the same package, so that the temperature of the device itself can be monitored for compensation of the computed concentration.

## **2.1 Operational Characteristics**

The range of operation for the EVK is for CO<sub>2</sub> values from 0 to 2000 parts per million (ppm).

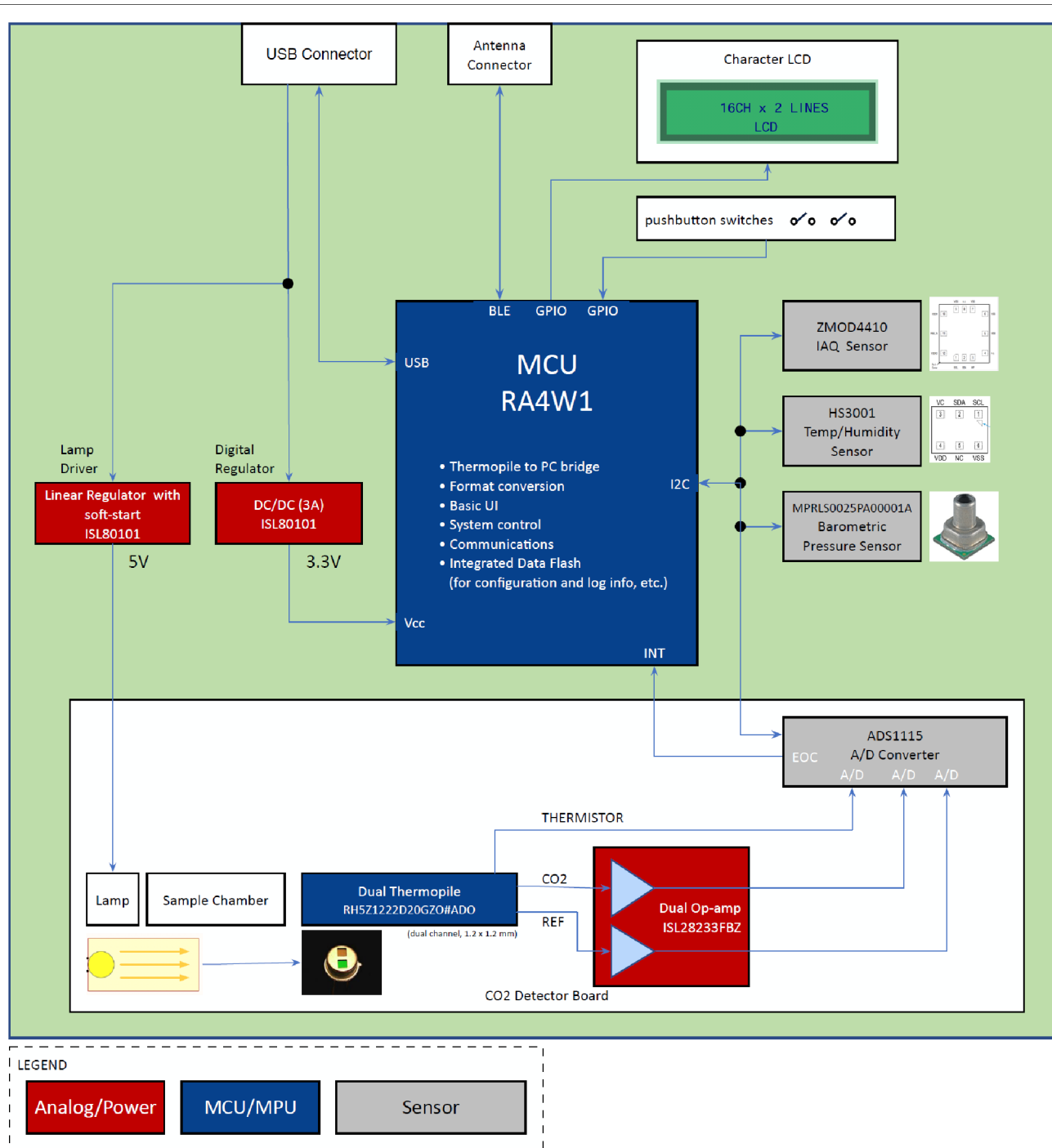
## **2.2 Manufacturing Documentation**

The bill of materials (BOM), schematics and 3D board renderings for the main board and the detector board of the EVK are available on the Renesas web site to support the end-user's target application development. Screen shots of the schematics are also included in this document.

### 3. Working Principle of NDIR CO<sub>2</sub> Sensing

In general, a NDIR technology is a type of spectroscopy based on the principle that gas molecules absorb IR light and that absorption of certain gas occurs at a specific wavelength. In the case of Carbon dioxide, CO<sub>2</sub> strongly absorbs energy with a wavelength of 4.26μm. This makes CO<sub>2</sub> a good absorber of wavelengths falling in the infrared radiation region of the spectrum

The Renesas EVK for CO<sub>2</sub> Detector consists of an infrared light source, gas measurement chamber, dual thermopile detector, low noise amplifier, 16-bit ADC, micro-controller (Renesas RA4W1), LCD user interface and power conversion electronics.



With reference to the above block diagram: gas enters from the openings in the sample chamber, and the infrared light source, in our case a lamp driven by a lamp driver circuit (a linear regulator with soft-start feature) emits infrared light intermittently to penetrate the gas being measured. The dual channel thermopile sensor is used to simultaneously measure the infrared light intensity of both the sensitive wavelength of CO<sub>2</sub>, and of the reference wavelength. The reference light is not affected by CO<sub>2</sub>.

### 3.1 Principle of Thermopile Measurement

The EVK includes a Renesas RTD120D dual thermopile. Each thermopile in the RTD120D package consists of a series connection of a large number of thermocouples. Since such a combination of thermocouples generates much higher thermoelectric voltage than a single thermocouple, the thermopile's sensitivity is increased.

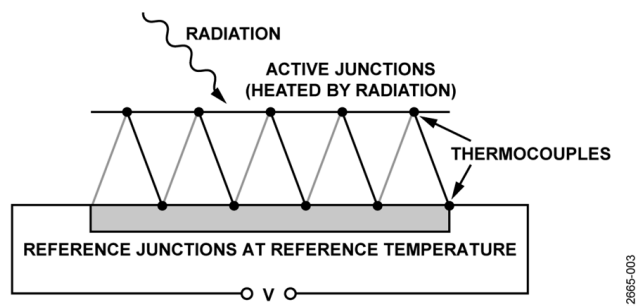


Figure 4. Each Thermopile is Constructed of Multiple Thermocouples

The IR light is applied to the dual thermopile detector fitted with a pair of optical filters. The filter pass band wavelengths are centered at 4260nm and 3910nm, and the concentration of carbon dioxide is measured from the ratios of the two thermopile voltages. The optical filter within the absorption channel serves as the detection channel and the optical filter outside the absorption spectrum serves as the reference channel. Measuring errors caused by dust or diminishing radiation intensity are removed using the reference channel.

### 3.2 Mathematical Derivation to Find the CO<sub>2</sub> Concentration

We use Beer-Lambert law to find the concentration 'x' of CO<sub>2</sub>. Beer-Lambert law states that the intensity of IR in CO<sub>2</sub> gas decreases exponentially with the concentration 'x', Mathematically it can be represented as:

$$I = I_0 e^{-kIx}$$

Here,

I = intensity of IR in CO<sub>2</sub> gas

I<sub>0</sub> = Intensity of IR in Reference gas (zero gas)

k = absorption coefficient for the specific gas and filter combination

I = equivalent optical path length between the lamp and detectors

x = concentration of CO<sub>2</sub>

Re-arranging:

$$I/I_0 = e^{-kIx}$$

Taking natural log on both sides:

$$\log(I/I_0) = (-kIx)$$

Therefore:

$$x = -\log(I/I_0)$$

**k** and **I** are constants in our case. So the concentration varies as the ratio of intensity of IR in CO<sub>2</sub> gas and the 0 ppm reference gas. The slope of this function relating relative intensity to concentration is a very small number, so we multiply equation 1 by 10000 to make calculations using **x** easier to manage. The number '10000' used here is an arbitrary value that works well with our calculations and the ranges of numbers we typically encounter.

After applying this scaling, the value we end up with we will call the “raw” value. This will be used in the calibration process to represent the partially processed intensity ratio. All that is needed now is a mapping between the “raw” value and the ppm value, which is a simple straight line with a negative slope according to Beer-Lambert law.

If we would plot the “raw” values along the y-axis and the concentration CO<sub>2</sub> along the x-axis, we would in theory get [Figure 5](#) below. Practically we observe a drop, say about 5% at a ppm of 500. The graph would then look like the one in [Figure 6](#) below.

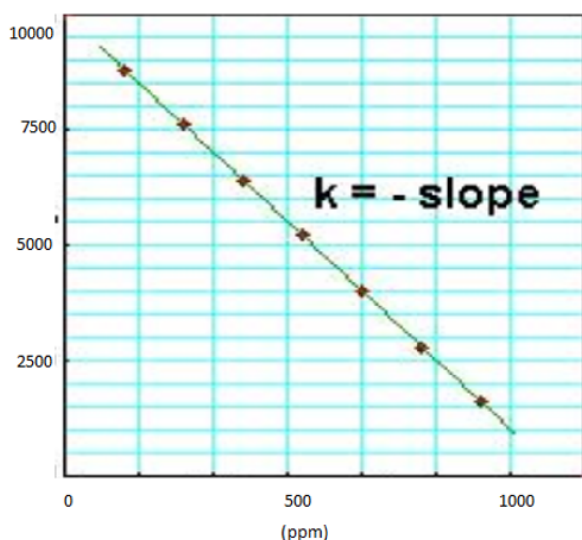


Figure 5. Raw vs ppm - Theoretical

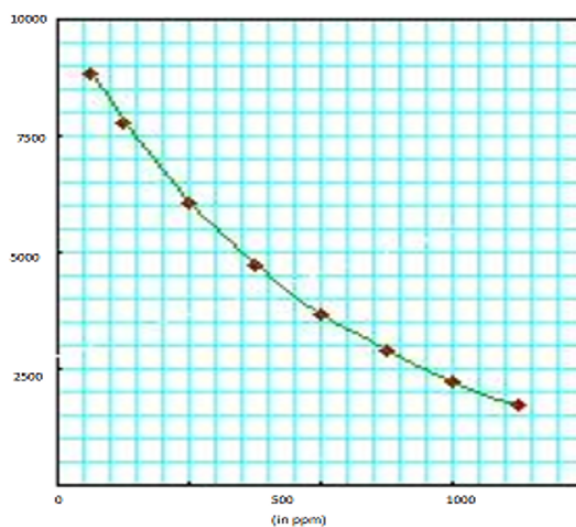


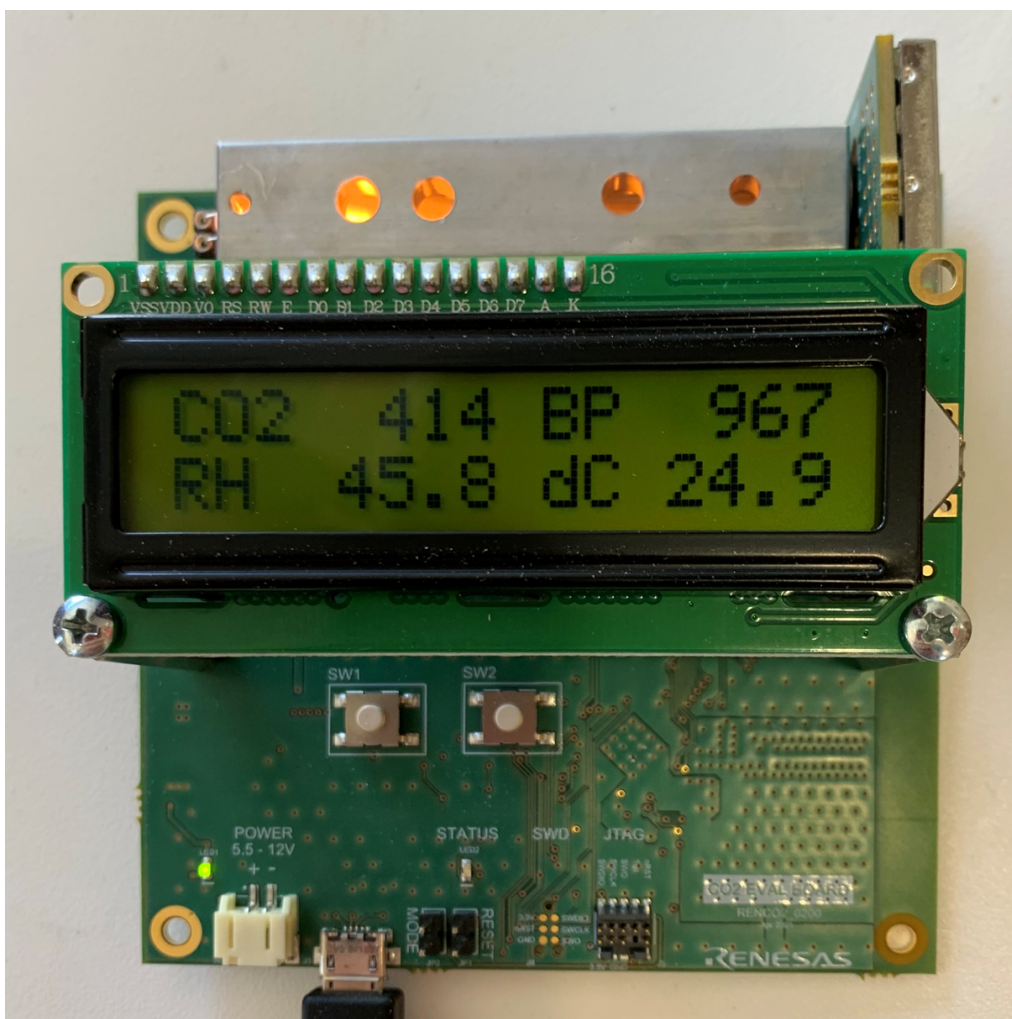
Figure 6. Raw vs ppm - Actual

A first order approximation is thus attainable by finding the straight line function ( $y = mx + b$ ) that passes through two sample points (e.g. 0 ppm and 1000 ppm). But in practice, as shown in [Figure 6](#), there is some non-linearity in this relationship. Specifically, the “raw” value vs concentration function “droops” down a bit in the region between 0 and 1000 ppm (e.g. at 400 ppm, typical outdoor air), and escalates above the line at concentrations above 1000 ppm. So, in the algorithm used on this EVK’s firmware, we support the addition of an additional one or two reference points (pairs of raw and concentration values) to increase the accuracy of measurement at concentrations near the middle of the range between 0 and 1000 ppm, and optionally up above 1000 ppm (e.g. at 2000 ppm), then do piece-wise linear interpolation for values between the reference points.

## 4. Setup and Configuration

To use the EVK standalone (without a connected PC) for monitoring CO<sub>2</sub> concentration, make sure the LCD module is attached, then attach the provided USB cable to the main board and plug the other end into a power source. As the board powers up, two splash screens will be displayed in sequence, identifying the EVK, its software version and serial number. Then the EVK will enter a warm-up state (displaying “CO<sub>2</sub> WARM”) for 30 seconds or so, after which the CO<sub>2</sub> concentration will be displayed on the LCD, and updated every 5 seconds. The LCD will also display Barometric Pressure (BP), Relative Humidity (RH) and ambient temperature in degrees C (dC).

Below is an image of the EVK, displaying CO<sub>2</sub> concentration and other sensor readings...



## 5. Schematics

The main schematic block diagram of the EVK is shown below.

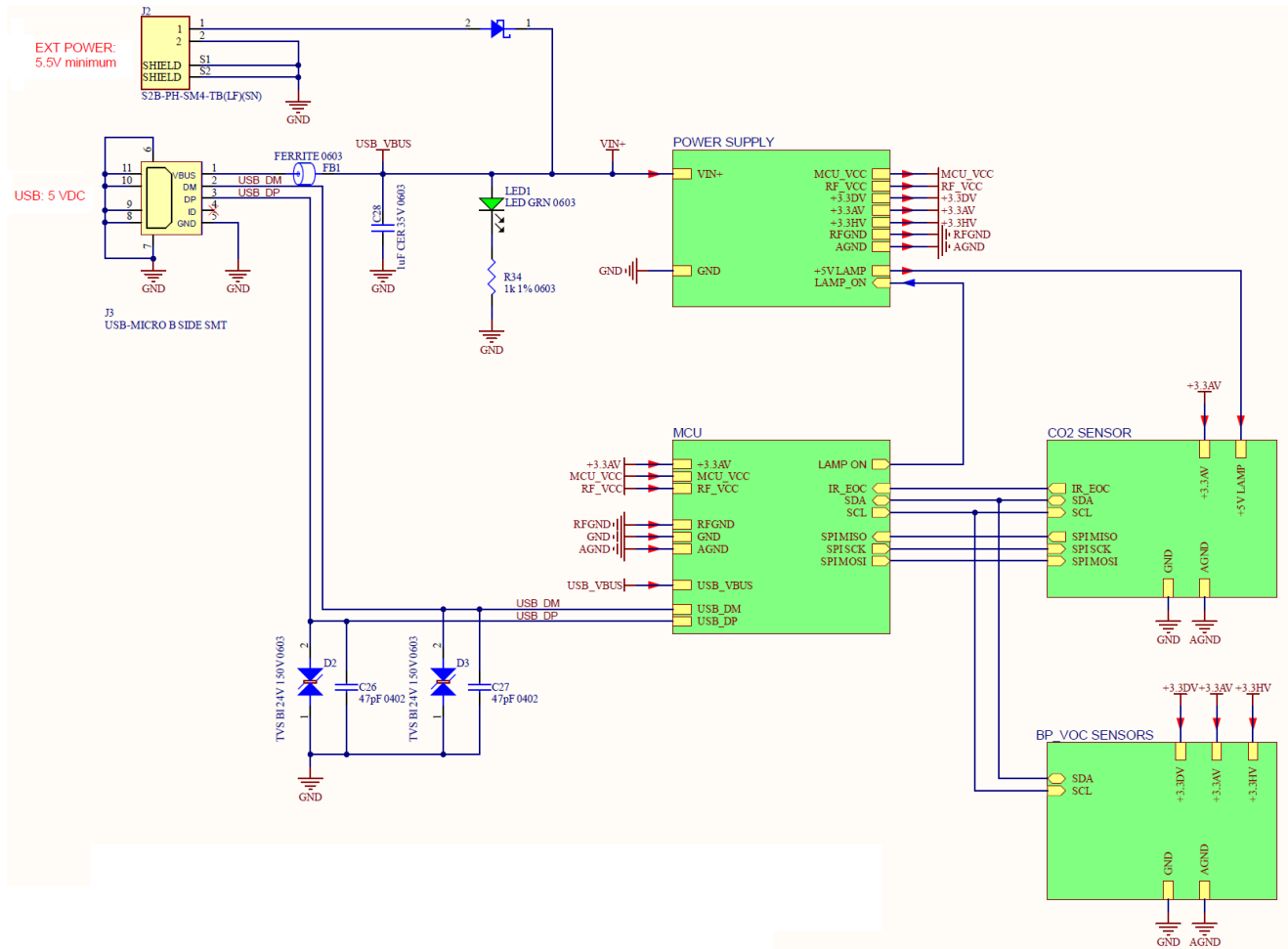


Figure 7. Main Schematic



Also, individual schematics for or each section of the EVK are shown below.

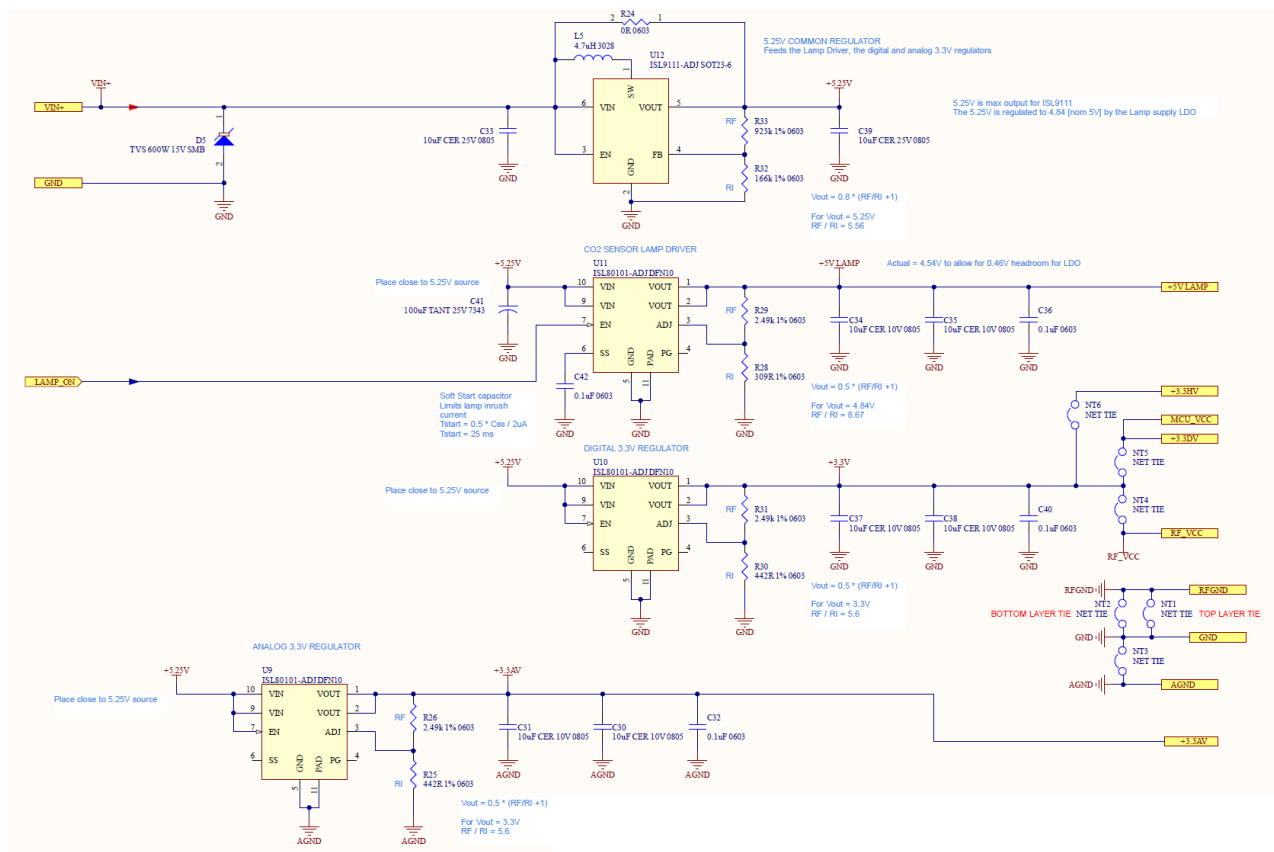


Figure 8. Power Supply Schematic

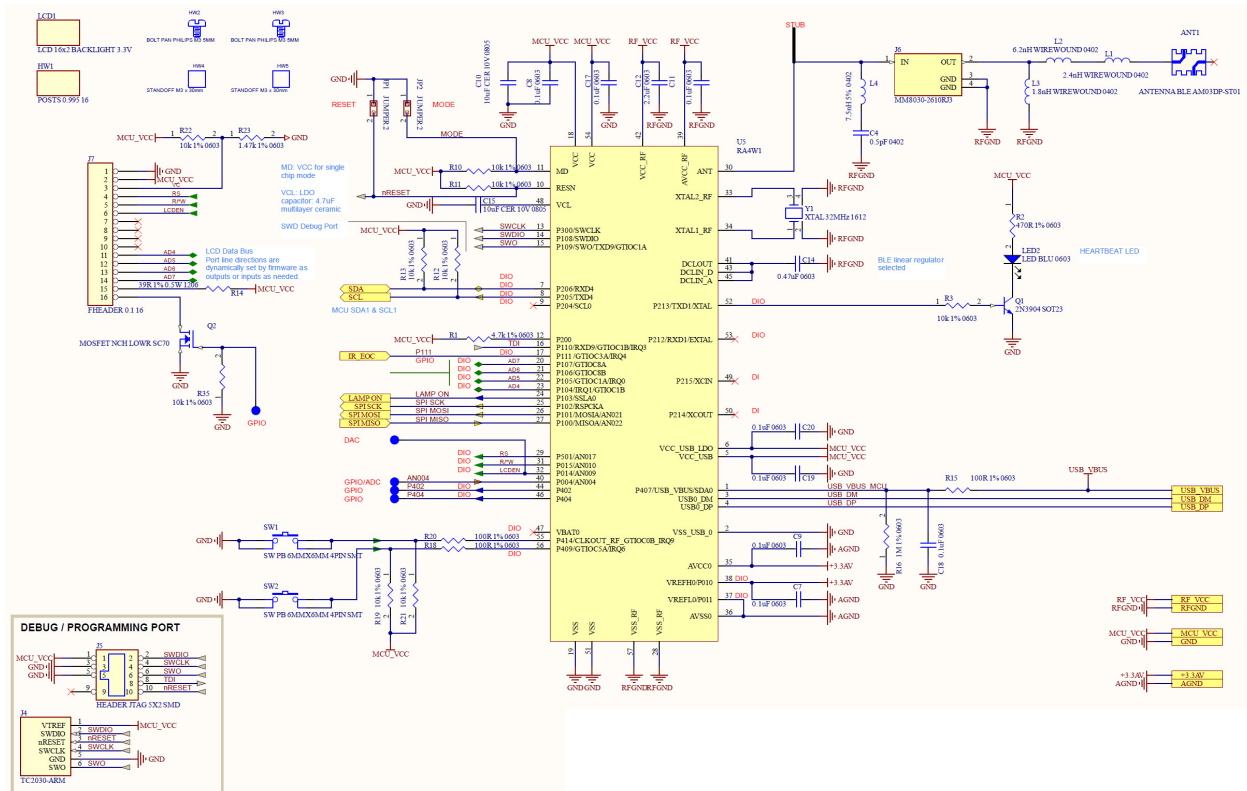


Figure 9. MCU Schematic

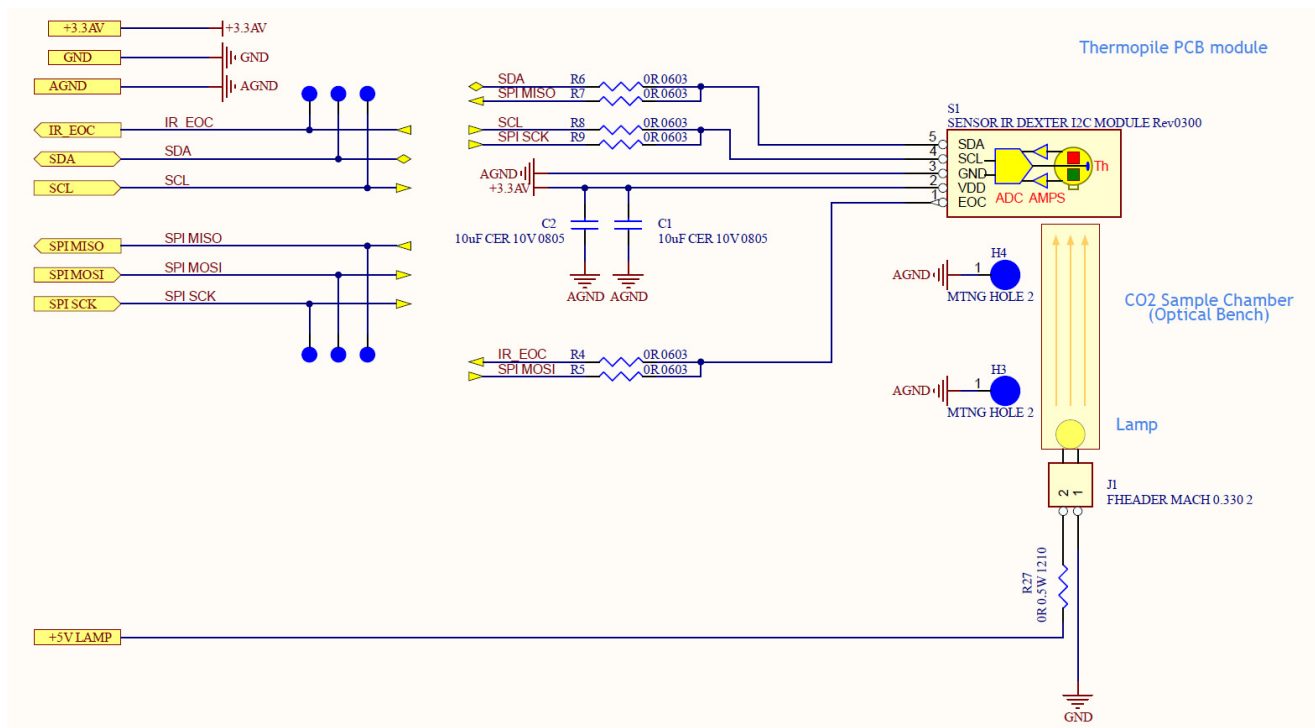


Figure 10. Detector Board Schematic

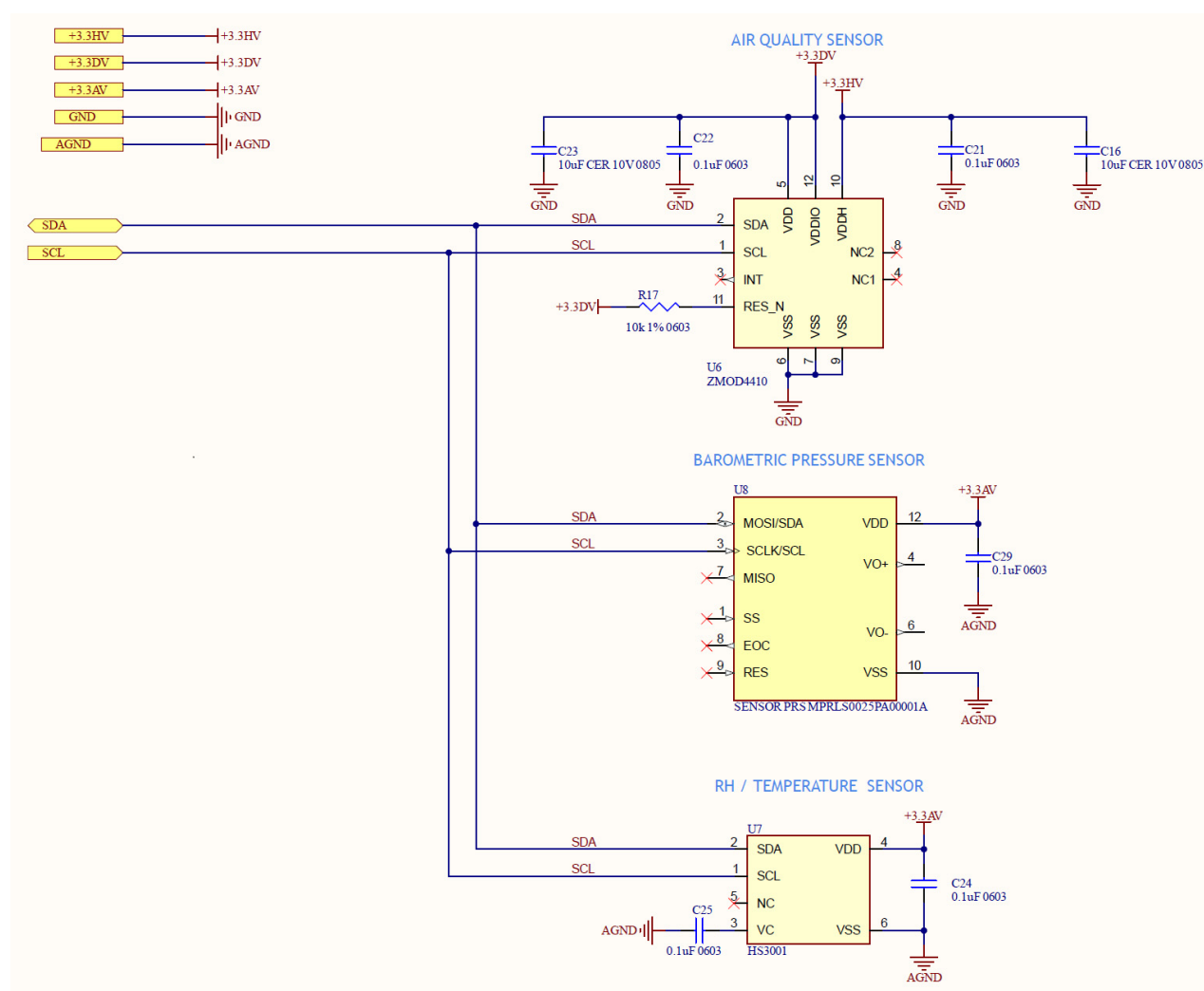


Figure 11. Additional Sensors Schematic

## 6. Images

### 6.1 Front and Back

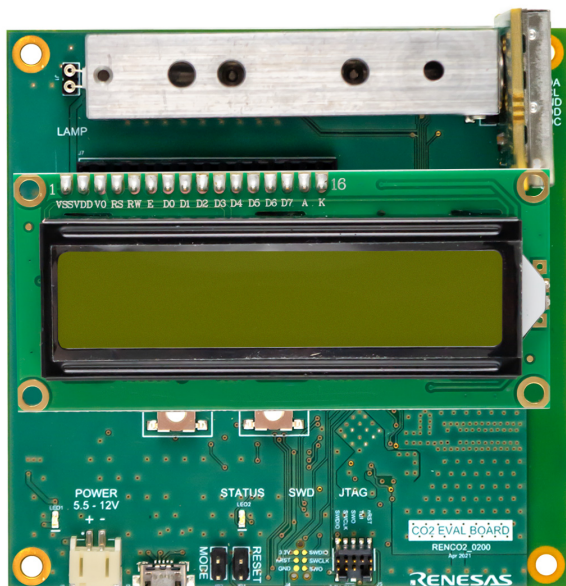


Figure 12. Front

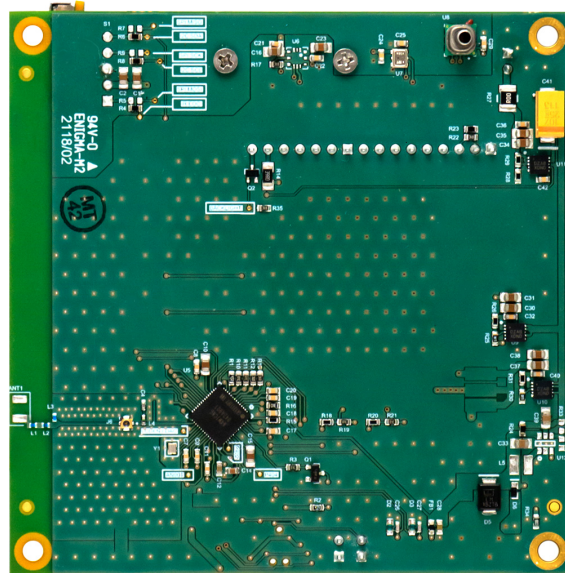


Figure 13. Back

### 6.2 Evaluation Kit with Debugger

For debugging custom applications, a Segger J-Link can be used. Seen below is the top view of EVK, with a J-Link Lite debugger connected (supported but not included).



Figure 14. RTD120D-EVK Evaluation Kit with Debugger

### 6.3 Board Layout

The images below show the main board and detector board each as viewed from the top and bottom.

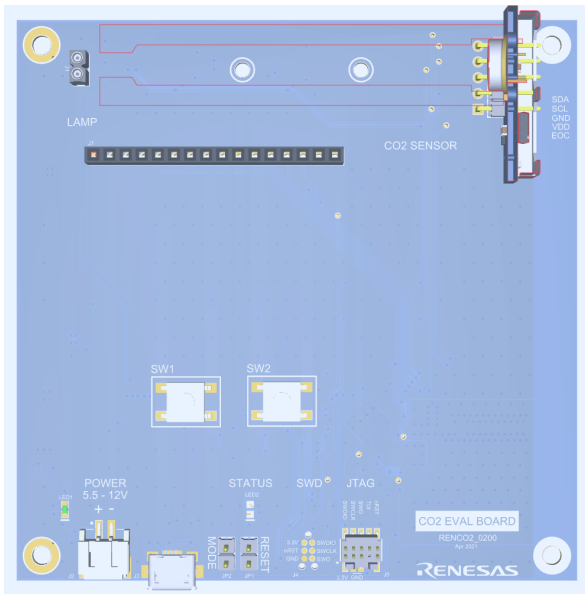


Figure 15. Main Board - Top View

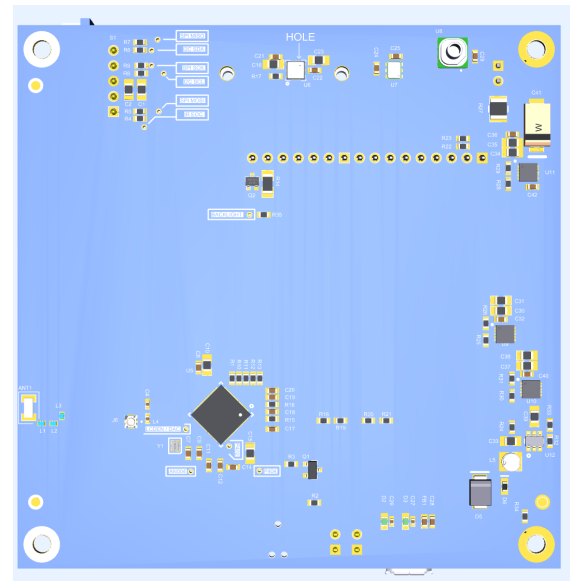


Figure 16. Main Board - Bottom View

And here is the detector board layout.

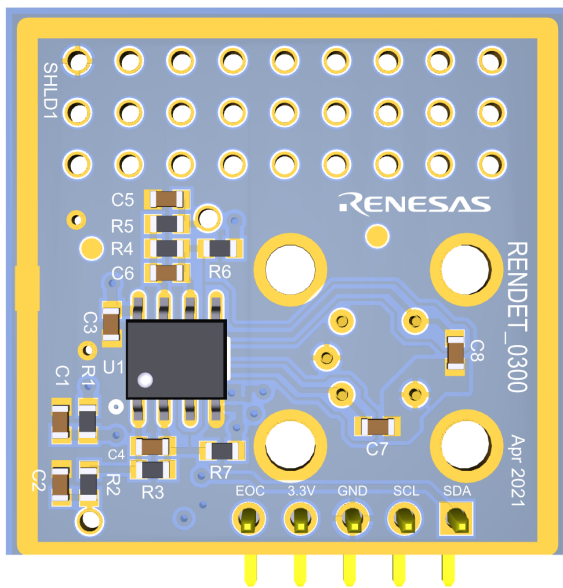


Figure 17. Detector Board - Top View

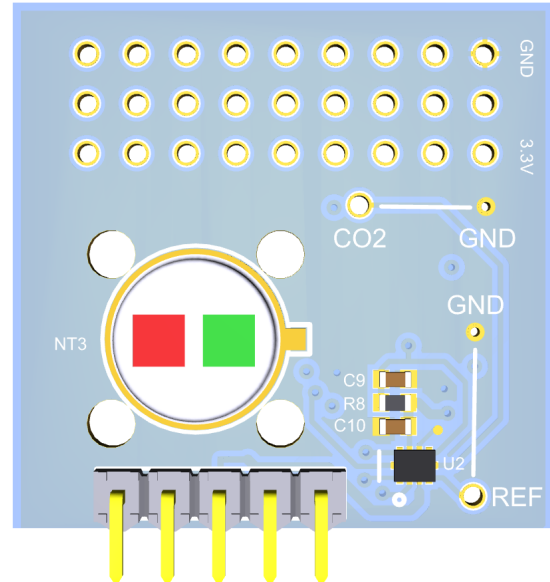


Figure 18. Detector Board - Bottom View

The detector board is attached to the main board and aluminum gas chamber.



## 7. Usage Guide

The EVK can be used stand-alone or with a Graphical User Interface that runs on a connected PC.

### 7.1 Basic CO<sub>2</sub> Measurement

Right out of the box, the EVK can begin measuring CO<sub>2</sub> levels right away. Simply attach the LCD module to the main EVK board, connect the provided USB cable to the board and to a power source, such as a phone charger or a PC USB port. The LCD will display the software title and version number briefly, then it will begin displaying CO<sub>2</sub> concentration readings in ppm (part per million). It will also display readings of other sensors on the board – barometric pressure, relative humidity and ambient temperature.

### 7.2 Using the LCD/Pushbutton Menu

Functioning along with the LCD module, two pushbuttons on the main board of the EVK are used for viewing additional information and for calibrating the last stage of the CO<sub>2</sub> concentration algorithm. These buttons, also located on the main board, just below the LCD module, are labeled **Sw1** and **Sw2**. Their primary function is to cycle through displaying available modes and to select the currently displayed mode for further operations, respectively.

One exception is that when the main screen is displayed, **Sw2** instead cycles through several diagnostic screens that each show various sets of parameters and process variables. But the primary purpose of **Sw1** and **Sw2** is to perform stand-alone calibration (see section “Calibration Using LCD” below).

### 7.3 CO<sub>2</sub> Detector Software

A software package for use with the EVK is available for download on the Renesas web site at [www.renesas.com/rtd120d-evk](http://www.renesas.com/rtd120d-evk). This requires a separate installation of a data acquisition platform, *DAQFactory Express* (free software) available from Azeotech. This is a GUI application that can acquire data from the EVK, display and plot process variables published by the EVK using ModBus over USB, and perform various system control and data analysis functions.

The free version of DAQFactory, “DAQFactory Express”, has all the functionality needed for access to basic features of the EVK, including monitoring readings of CO<sub>2</sub>, viewing intermediate variables, calibrating the CO<sub>2</sub> detection algorithm, and monitoring the temperature, relative humidity, and barometric pressure from the other sensors on the EVK.

“Control” files (with extension .ctl) contain GUI screen definitions and application specific communication settings and scripts for various purposes. Various control files for use with the EVK can be downloaded from the EVK product page on Renesas’ web site. Opening a control file in DAQFactory is all that is needed to start using the GUI with the EVK for control, monitoring and calibrating.

#### 7.3.1 Installing DAQFactory Express

To install DAQFactory Express, go to the Azeotech web site and download the *DAQFactory Express*. Use this link: <https://www.azeotech.com/j/downloads.html>. Be sure to download version 18.1 or later. This will install an “Evaluation” version of the full DAQFactory application, as well as the “Express” version (which has no time limit, but some functionality is limited).

For basic monitoring and visualization (plotting) of on-board sensors and system parameters, as well as calibration of the CO<sub>2</sub> algorithm and misc. control of the EVK, the “Express” version of *DAQFactory* has all the functionality you need. Other applications capable of acting as a *ModBus RTU* master over USB can also be used. This is supported by the EVK’s firmware, but additional configuration is required that is specific to the ModBus application chosen. ModBus is described here: <https://en.wikipedia.org/wiki/ModBus>.



**Note:** After installing DAQFactory, either version can be run from the Start menu, but it is recommended to run the Express version, as it does not have a time limit. If you want more capability beyond the needs of using this Renesas EVK, you may at a later date purchase from, one of the more full-featured versions of DAQFactory directly from Azeotech. Renesas has no affiliation with Azeotech.

## 7.4 Calibration

The CO<sub>2</sub> EVK comes pre-calibrated, but it can be re-calibrated by the user if desired. CO<sub>2</sub> calibration can be performed in either of two ways:

- In a stand-alone fashion, using the LCD and pushbutton user interface on the EVK itself, or
- With a graphical user interface (GUI), using a connected PC for a more interactive and visual experience.

### 7.4.1 General Principles of Calibration

The CO<sub>2</sub> EVK continuously reads the two thermopile channels once with the lamp ON and once then with the lamp OFF, resulting in 4 readings. After each such sequence, a “raw” value (a positive integer typically between a few hundred and a few thousand) is calculated from those 4 readings. The sequence occurs every 5 seconds. So, a “raw” value is always available in the microcontroller’s memory to be used for further processing, such as for calculating CO<sub>2</sub> concentration or calibrating the kit so that accurate CO<sub>2</sub> concentration determination is possible.

Calibration consists of allowing various gas mixtures of known CO<sub>2</sub> concentration to enter the gas chamber (where CO<sub>2</sub> concentration is measured), and storing in memory the resulting “raw” values that result from those gas mixtures, associating those values with the known CO<sub>2</sub> concentration of each gas. For example, gas with no CO<sub>2</sub> (CO<sub>2</sub> concentration of 0 ppm) results in a raw value that gets stored in a variable “raw\_1”, gas with a CO<sub>2</sub> concentration of 1000 ppm results in another raw value that gets stored in a variable “raw\_2”, and so on. At least 3 such values need to be stored: raw\_1, raw\_2 and raw\_3 corresponding to CO<sub>2</sub> concentrations of 0 ppm, 1000 ppm and 400 ppm, respectively. For more accuracy in ranges above 1000 ppm, a 4th raw value (raw\_4) can optionally be stored as well, which corresponds to a CO<sub>2</sub> concentration of 2000 ppm. These 3 or 4 raw values get stored in flash memory, and are used later when the kit is determining CO<sub>2</sub> concentration of unknown gases (such as ambient air in the vicinity of the kit). This is done by computing raw readings and applying a function that interpolates the CO<sub>2</sub> concentration from the known concentrations associated with the stored raw values.

### 7.4.2 Calibration Using LCD

Two pushbuttons on the main board of the EVK are used in the procedure of CO<sub>2</sub> calibrating with the LCD and pushbutton switches. These buttons, also located on the main board, just below the LCD module, are labeled SW1 and SW2. Their primary function is to cycle through displaying available modes and to select the currently displayed mode for further operations.

Once a mode is selected, further operations can be carried out using the same two buttons.

Starting from the “home screen” (where the CO<sub>2</sub> concentration and three other sensor readings are displayed), pressing **Sw1** sequences through several screens and comes back to the home screen if no selection is made. Selection is done by pressing **Sw2** when the desired screen is displayed, then further actions can be carried out by pressing **Sw1** and **Sw2**, depending on which screen is selected.

Calibrating is done using the first 3 or all 4 of these screens:

**Table 1. Calibration Steps (LCD)**

Screen	CO <sub>2</sub> Concentration	Note
Zero Gas (N)	0 ppm	mandatory (typically pure Nitrogen)
CO <sub>2</sub> (1000 ppm)	1000 ppm	calibration gas

Table 1. Calibration Steps (LCD) (Cont.)

Screen	CO <sub>2</sub> Concentration	Note
CO <sub>2</sub> (400 ppm)	400 ppm	calibration gas or outdoor air
CO <sub>2</sub> (2000 ppm)	2000 ppm	calibration gas ( <i>optional step</i> )

To calibrate a kit using the LCD, first apply power to the kit and wait at least 10 minutes for the gas chamber to warm up. Since it has a lamp that turns on and off at a regular constant rate, the internal temperature will rise slightly above ambient but soon it will reach a steady state temperature. The temperature is typically stable enough after 5 minutes, but 10 minutes is recommended.

Next, for each of the 3 (or 4) calibration points of CO<sub>2</sub> concentration, follow the steps below.

1. Apply the calibration gas mixture (or outdoor air if that is being used for the 400 ppm sample) by one of these methods:
  - a. Place the kit in an enclosure (gas chamber, plastic bag, etc.) containing the respective concentration of CO<sub>2</sub> gas, or
  - b. Connect a supply hose from a calibration gas canister flowing at approximately 3 liters per minute, to a fitting that guides the flow of gas into one of the holes at the top edge of the kit's aluminum gas chamber, or
  - c. Place the kit in a location where the ambient gas is the gas with the known CO<sub>2</sub> (such as outdoor air).
2. Press **Sw1** to cycle through the list of CO<sub>2</sub> concentrations to find the one you are calibrating to.
3. When the desired calibration concentration is displayed (e.g. 1000 ppm), press **Sw2** to select it.
4. Now the first line of the display shows the calibration value (e.g. "1000 ppm:1000") and the second line shows the current "Raw" (R) value reading (e.g. **R:2575**) and a decimal number representing the largest amount the raw reading has changed in the last several samples, as a peak-to-peak value (e.g. **PP:5.75**). Both of these values get updated every 5 seconds or so (the normal sample period).  
 Watch the peak-to-peak value change as it goes down in value, until it dips below 1.0. This should not take more than a minute or two. If the peak-to-peak value never dips below 1.0, then just wait until it stabilizes around a certain value. It will change a bit continually, but only by a small amount.
5. Once the peak-to-peak value is below 1.0 (or stabilizes slightly about that value) store the raw value as follows:
  - a. Press **Sw2** repeatedly until the top line of the display reads "Sw1 save R?P?". The bottom line will read "Save nothing". At this point, pressing Sw1 would cycle through these 3 states: "Save nothing", "Save RAW", "Save RAW & PPM". "Save RAW" is the one to use to just save the raw value associated with the current concentration, so,
  - b. Press Sw1 to get to the "Save RAW" state, then,
  - c. Press Sw2 to proceed with saving the raw value.
6. Now you can turn off the gas supply valve if you are using a calibration gas canister, or otherwise remove the reference gas source (or remove the kit from the gas chamber, plastic bag, etc). If you are using outdoor air as the reference gas, then nothing more needs to be done. The mode can be changed by pressing Sw1 (Next) again, cycling through "1 Point cal", "2 Point cal" and "Manual cal" as needed.
7. Repeat the above steps for each of the remaining calibration points of CO<sub>2</sub> concentration.

The EVK is now calibrated, and the kit will immediately begin computing and displaying the CO<sub>2</sub> concentration of gas in the aluminum gas chamber. It may take a minute or two for the calibration gas (especially 1000 or 2000 ppm) in the chamber to be replaced by nearby ambient air, so the CO<sub>2</sub> concentration reading will gradually converge toward the measured value.

Note: You can repeat the calibration steps at any time for any or all of the 3 or 4 calibration points (0, 1000, 400 and/or 2000 ppm) independently and in any order. The last saved raw reading for any given calibration points will be used in the CO<sub>2</sub> concentration calculation.

### 7.4.3 Calibration Using GUI

When the EVK is used with the available GUI application running on a PC, real time display of a graph of CO<sub>2</sub> concentration and other kit parameters can be viewed, and that data can also be processed, analyzed and logged for further processing and use with other tools.

A useful capability provided by the GUI is to allow the calibration procedure to be performed in a more interactive, visual manner. For this, a control file must be loaded by DAQFactory which defines user interface elements such as live graphs and buttons to aid in performing calibration.

From DAQFactory, open the control file “calibrate.ctf”. This file is included in the GUI download from the CO<sub>2</sub> EVK product page.

The initial display of the calibration GUI consists of several graphs, live value displays and buttons.

The graphs are:

1. Raw value
2. Raw value peak-to-peak variation
3. CO<sub>2</sub> concentration

At a high level, calibration is performed by determining and storing “raw” values for several reference CO<sub>2</sub> concentrations.

For each reference value, these steps will be done:

1. Apply a calibration gas of the reference concentrations to the kit.
2. Watch the graphs to determine when the “raw” reading for the current reference concentration has stabilized (stopped changing).
3. Press the appropriate button to accept the “raw” value, which will be saved for later storing in flash memory. This value will be associated with the current CO<sub>2</sub> reference concentration.

After calibration points have been found for all reference concentrations, store those values into flash memory so that they will persist even after the kit has been powered down.

Detailed instructions follow.

To calibrate a kit using the GUI, first connect the kit to a PC running DAQFactory with the supplied USB cable.

*If the kit was already warmed up in advance, then the following step is not necessary:* Wait at least 10 minutes for the gas chamber to warm up. Since the kit has a lamp that turns on and off at a regular constant rate, the internal temperature will rise slightly above ambient but soon it will reach a steady state temperature. The temperature is typically stable enough after 5 minutes, but 10 minutes is recommended.

Next, follow the steps using the GUI:

**Table 2. Calibration Steps (GUI)**

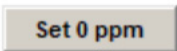
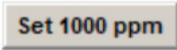
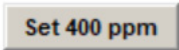
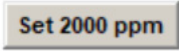

Step	Button to “accept” raw value or save all results	Note
Determine “raw” value for Zero gas (N)		Mandatory ( <i>typically pure Nitrogen</i> )
Determine “raw” value for CO <sub>2</sub> (1000 ppm)		Calibration gas

Table 2. Calibration Steps (GUI) (Cont.)

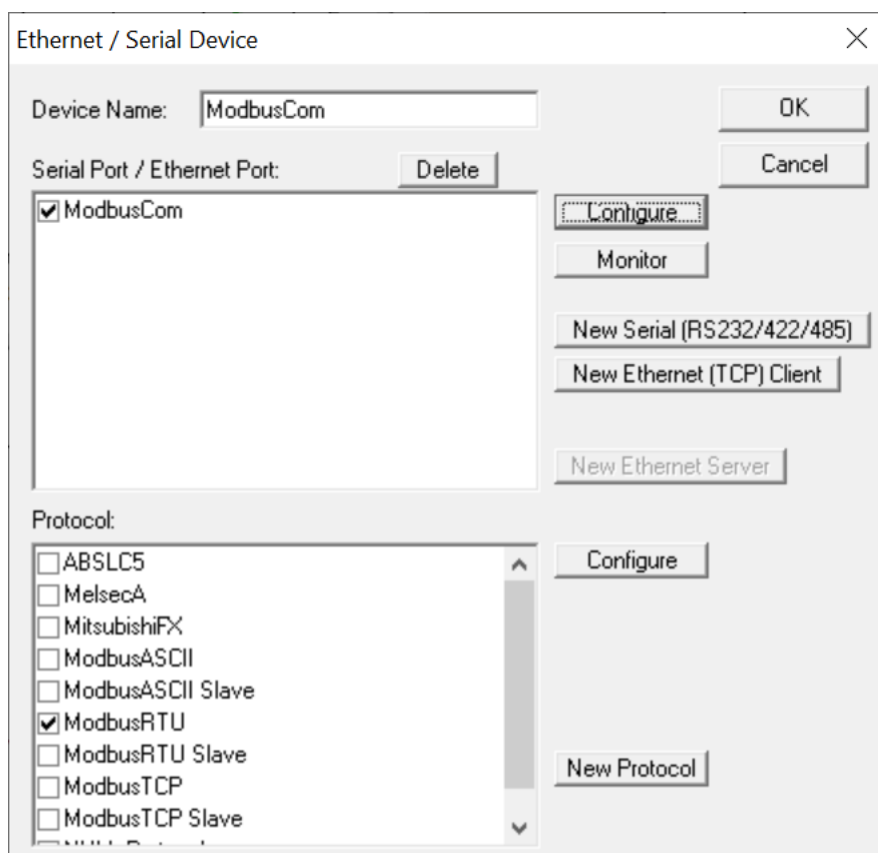
Step	Button to “accept” raw value or save all results	Note
Determine “raw” value for CO <sub>2</sub> (400 ppm)		Calibration gas or outdoor air
Determine “raw” value for CO <sub>2</sub> (2000 ppm)		Calibration gas ( <i>optional step</i> )
Save all “raw” values to flash		

So other than the method of determining when the raw value has stabilized and for accepting and storing those values, the procedure is very similar to that used with the LCD and switches. Using the GUI, the detailed procedure is as follows. For each of the 3 (or 4) calibration points of CO<sub>2</sub> concentration:

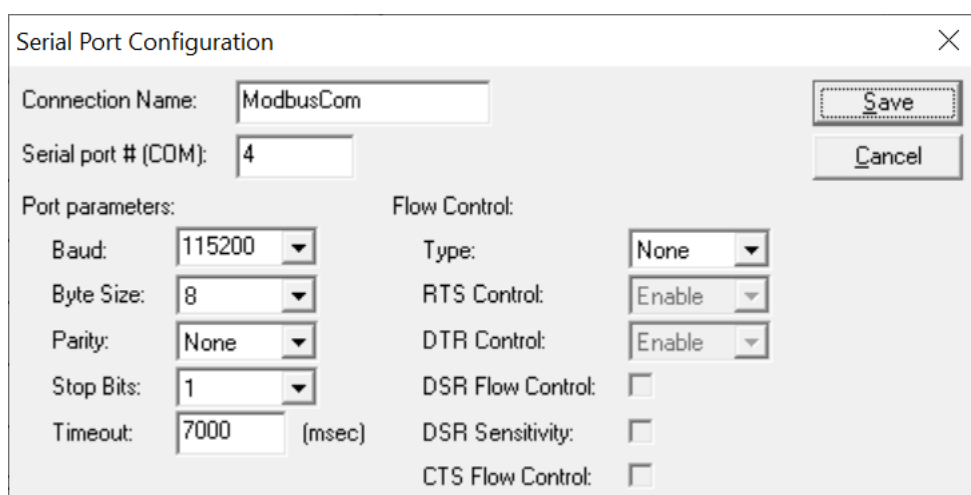
1. Apply the calibration gas mixture (or outdoor air if that is being used for the 400 ppm sample) by one of these methods:
  - a. Place the kit in an enclosure (gas chamber, plastic bag, etc.) containing the respective concentration of CO<sub>2</sub> gas,
  - b. Connect a supply hose from a calibration gas canister flowing at approximately 3 liters per minute, to a fitting that guides the flow of gas into one of the holes at the top edge of the kit’s aluminum gas chamber, or
  - c. Place the kit in a location where the ambient gas is the gas with the known CO<sub>2</sub> (such as outdoor air).

## 2. Connect DAQFactory to the EVK

- a. Menu: Quick - Device Configuration - ModbusCOM - Select - Configure

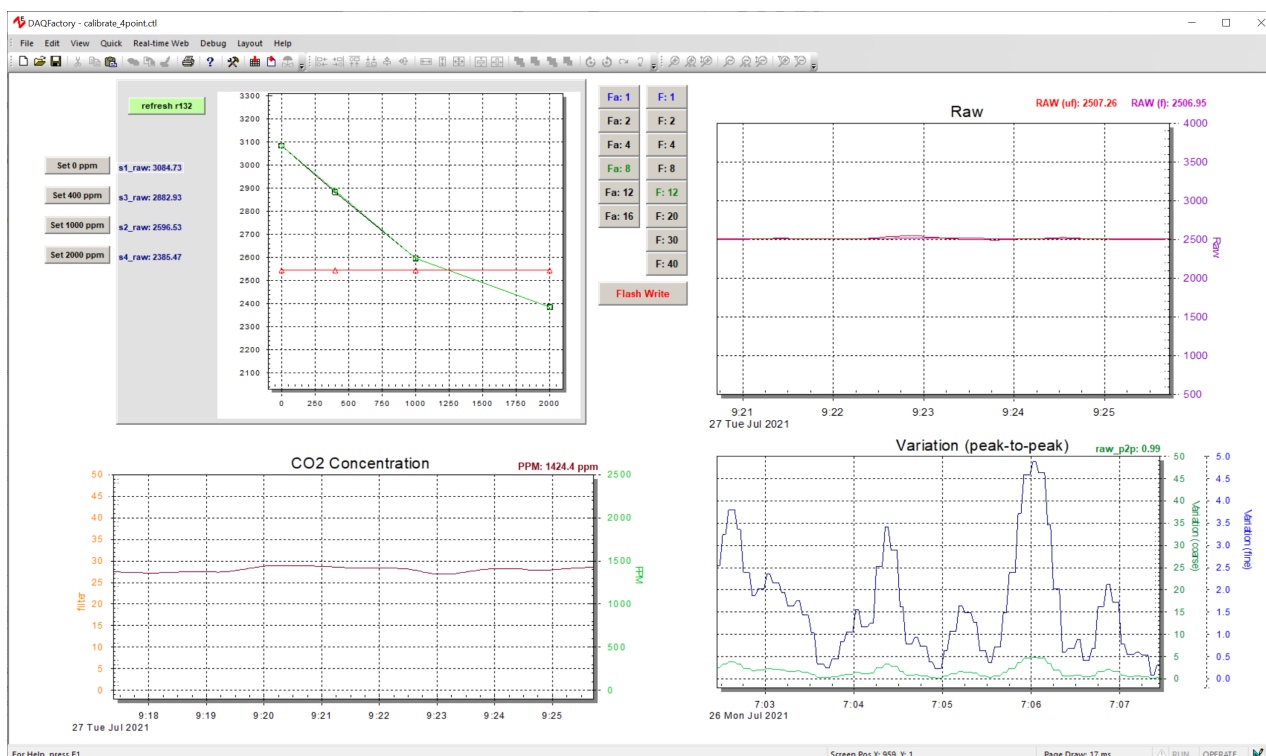


- b. Set Serial Port # (COM) to the port the EVK is connected to (e.g. 4 for COM4). This is remembered, so it will already be correct if you most recently connected to an EVK on this port.

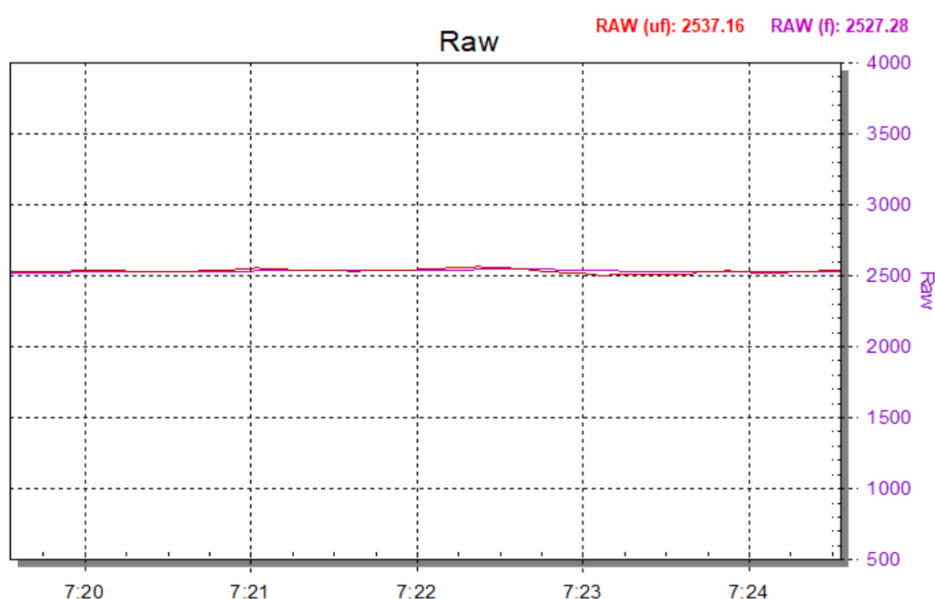


- c. Click "Save"

- After communication is established, and monitoring of the kit's data immediately begins. Below is a screen shot of the DAQFactory GUI running the calibration application (calibrate\_4point) for 4-point or 3-point calibration:

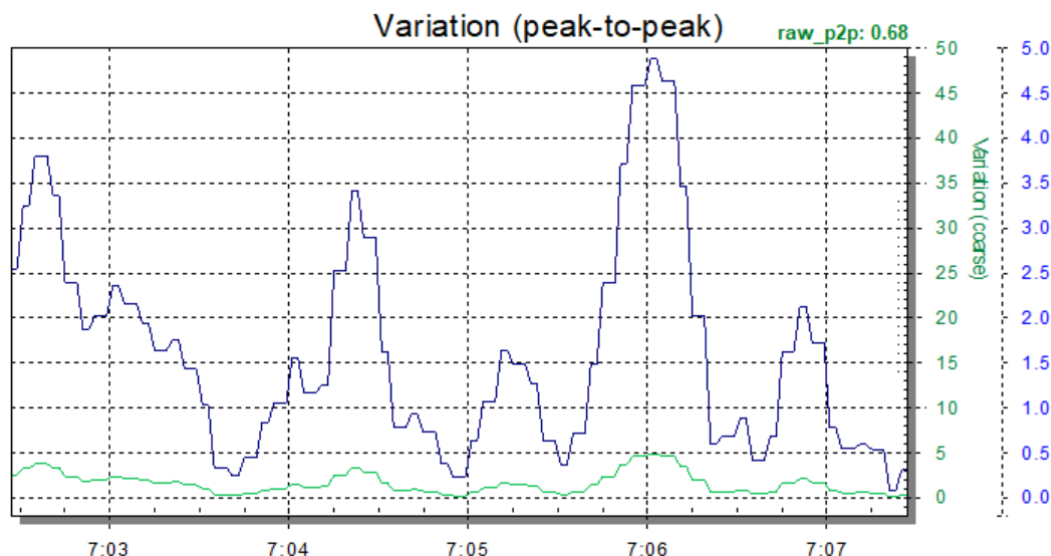


- The plot on the top-left passively shows the current calibration points visually: raw value vs concentration in ppm. Pressing the green “refresh r132” button refreshes this image at any time during the calibration process. If you do 3-point calibration instead of 4-point, the right-most point will show a value of -1, which is okay. It will be ignored in that case, and the extrapolated values over 1000 ppm will be co-linear with the middle segment, instead of bending upward in the piecewise linear graph.
- Once connected, the displayed variables and graphs in the GUI will begin to update. The plot labeled “Raw” will show how the raw value changes over time.



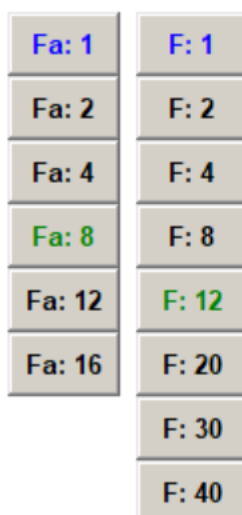


6. The amount of change of the raw value in the last several samples is shown in the plot labeled “Variation (peak-to-peak)”. In this plot, there is a normal (green) and a magnified (blue) trace.



These peak-to-peak values get updated every 5 seconds or so (the normal sample period). Watch the blue trace as it goes down in value, until it dips below 1.0. This should not take more than a minute or two. If the peak-to-peak variation never dips below 1.0, then just wait until it stabilizes around a certain value. It will change a bit continually, but only by a small amount.

7. *Advanced Operation:* If you learn and understand the effect of adjusting the digital filter stages while you are watching the raw value change, you can use them to save some time in this part of the procedure. The filter buttons can be used to change the number of samples used in the two digital filter stages, to speed up the convergence of the raw value (and also the calculated CO<sub>2</sub> concentration value) to a steady reading. If you do use these buttons, be sure to restore the filter settings to the **default** values (shown with button text in **green**).



The left column of buttons (“Fa: #”) sets the number of sample used in the first filter stage, which filters A/D readings (actually, it filters the difference between ICO<sub>2</sub> and Reference A/D readings). The right column (“F: #”) is for the second filter stage, which filters raw readings after the  $\log(I/I_0)$  function has been applied.

8. Once the peak-to-peak variation is below 1.0 (or stabilizes slightly about that value) store the raw value by clicking the “Set” button associated with the CO<sub>2</sub> concentration you are currently calibrating. For example, for 1000 ppm CO<sub>2</sub>, click:

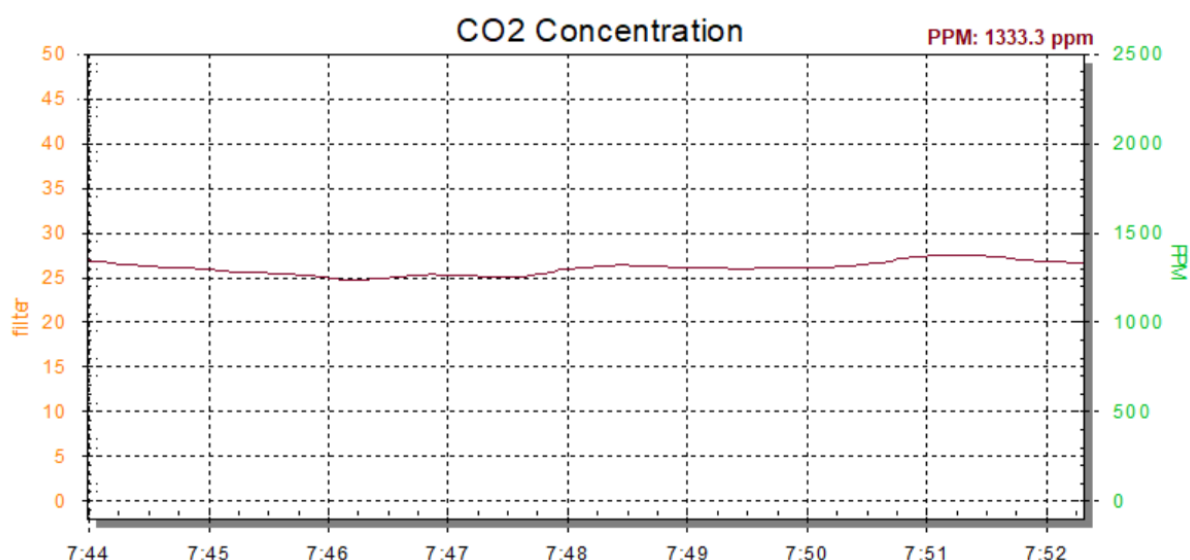
Set 1000 ppm

9. To write this calibration point to flash memory, press:

Flash Write

10. Now you can turn off the gas supply valve if you are using a calibration gas canister, or otherwise remove the reference gas source (or remove the kit from the gas chamber, plastic bag, etc). If you are using outdoor air as the reference gas, then nothing more needs to be done.
11. Repeat the above steps for each of the remaining calibration points of CO<sub>2</sub> concentration. Note that it is okay if you only click “Flash Write” once, after setting all of the calibration points, but it doesn’t hurt to save after each one.

The EVK is now calibrated, and the kit will immediately begin computing and reporting the CO<sub>2</sub> concentration of gas in the aluminum gas chamber. While DAQFactory is still connected to the kit, the “CO<sub>2</sub> Concentration” plot will continuously display the CO<sub>2</sub> values over time.



It may take a minute or two for the calibration gas (especially 1000 or 2000 ppm) in the chamber to be replaced by nearby ambient air, so the CO<sub>2</sub> concentration reading will gradually converge toward the measured value.

Note: You can repeat the calibration steps at any time for any or all of the 3 or 4 calibration points (0, 1000, 400 and/or 2000 ppm) independently and in any order. The last saved raw reading for any given calibration points will be used in the CO<sub>2</sub> concentration calculation.

## 8. Ordering Information

Part Number	Description
RTKH5Z1222SD2000BE	Thermopile CO <sub>2</sub> Gas Detector Evaluation Kit

## 9. Revision History

Date	Description
Jul 29, 2021	Initial release.

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