AN313 CO2 SENSOR
DESIGN CONCEPT FOR A SOLAR-POWERED CO2 SENSOR

19 August 2026

Observe precautions! Electrostatic sensitive devices!

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1 Introduction

The concentration of carbon dioxide (CO_2) in a room shows how good the indoor air quality (IAQ) is. CO_2 sensors are used in buildings to measure the air quality and to control the ventilation on demand. Sensors for this task work in a range from 500 ppm to 5000 ppm (ppm = parts per million, for example 10000 ppm = 1 %). Figure 1 shows a typical CO_2 level in an office during one working day.

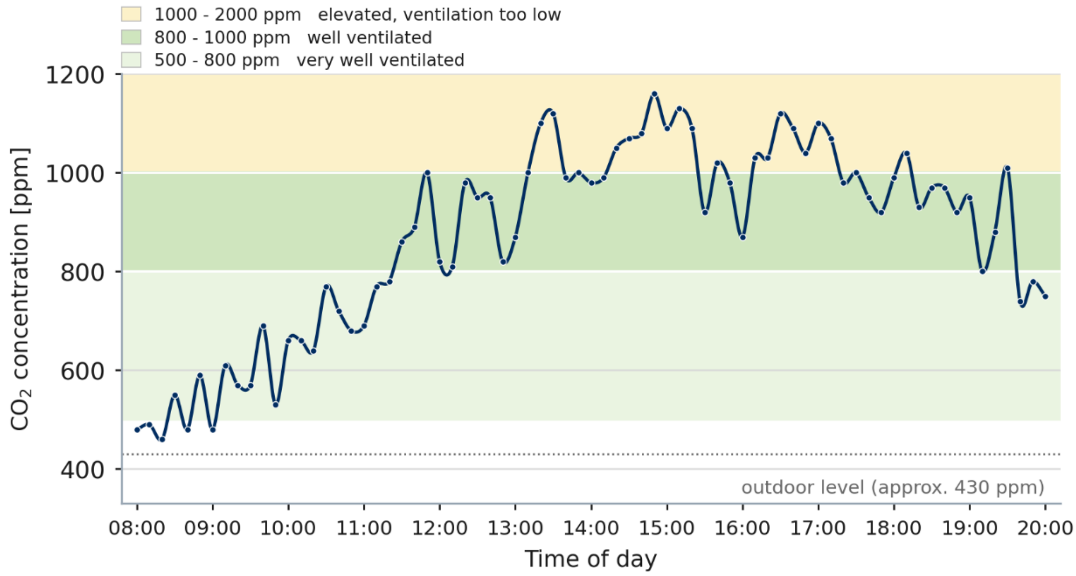

Figure 1 Example of the CO_2 level in an office

Table 1 lists the effects of different CO_2 levels. Inside a building, a level of 800 ppm to 1000 ppm means that the room is well ventilated. A lower level needs additional energy, for example for the fan or for heating and cooling. A higher level can reduce the concentration and the well-being of the people in the room.

Table 1 Physiological effects of CO_2

CO_2 concentration	**Physiological effects**
~430 ppm	Outdoor air. Global average 2026, higher in cities.
500 – 800 ppm	Indoor, very well ventilated.
800 – 1000 ppm	Indoor, well ventilated. Common design target.
1000 – 2000 ppm	Indoor, elevated. Ventilation is too low.
> 2000 ppm	Indoor, unacceptable. Ventilate at once.
5000 ppm (0.5 %)	Workplace limit for an 8-hour shift. German AGW
1 – 3 %	Faster breathing, drowsiness, headache.
4 – 6 %	Dangerous to life. Dizziness, sweating, high pulse.
6 – 10 %	Tremor, poor vision and hearing, unconsciousness.
10 – 20 %	Convulsions and coma. Death within 10 minutes.
20 – 30 %	Unconsciousness and death within one minute.
> 30 %	Flames go out. Fire suppression uses 34 % or more.

1.1 Purpose

The main challenge for a self-powered sensor is the energy consumption. Most CO_2 sensors on the market need far too much energy for such a system. This document shows a self-powered CO_2 sensor. It uses an energy-optimized sensor from Gas Sensing Solutions (see [10]) together with a smart measurement concept based on the EnOcean STM 300 radio module.

Figure 2 Solar-powered CO_2 sensor

This application note explains the principles of such a self-powered CO_2 sensor. It is intended as a basis for your own development. It is not a ready-to-use reference design. The software that belongs to this application note can be made available from EnOcean on request.

> **NOTE:** The software AN313SW, which is part of this application note, is provided on an "as-needed" basis.

1.2 References

Further details can be found in the following documents:

[1] DolphinAPI user manual, EO3000I_API latest version 2.6.13.0
https://www.enocean.com/en/product/dolphinapi/

[2] STM 300 user manual, latest version V1.6 Dec 2021
https://www.enocean.com/en/product/stm-300/

[3] EnOcean Equipment Profiles (EEP) specification, version 3.1
https://www.enocean-alliance.org/eep/

[4] COZIR data sheet, GSS COZIR Data Sheet.pdf, Rev. B10/10
https://alcom.be/uploads/GSS-CozIR-A-Rev-4.8_1-Datasheet.pdf
https://www.digikey.de/en/product-highlight/g/gas-sensing-solutions/cozir-a-co2-sensor

[5] COZIR software user's guide, COZIR Software User's Guide AL12, Rev. A
http://www.co2meters.com/Documentation/Manuals/Manual-GSS-Sensors.pdf

[6] MAX1595 step-up/step-down charge pump data sheet, Rev. 2

Useful websites:

[7] EnOcean: https://www.enocean.com/en/

[8] EnOcean Alliance: https://www.enocean-alliance.org/

[9] Non-dispersive infrared sensors: https://en.wikipedia.org/wiki/Nondispersive_infrared_sensor

[10] Gas Sensing Solutions: https://www.gassensing.co.uk/

[11] Analog Devices (formerly Maxim Integrated): https://www.analog.com/en/index.html

2 Demonstration

The demonstration system measures the CO_2 concentration, the ambient temperature (chip temperature) and the charge level of the energy storage every 10 minutes. It sends this data by radio. If the charge level is low (below 20 %), measurement and transmission stop until the charge level is high enough again. The system also has an automatic long-term calibration. This calibration compensates long-term effects such as dust or dirt in the sensor.

The system uses the existing EnOcean equipment profile EEP A5-09-04. In this profile the humidity field carries the charge level of the energy storage capacitor. With DolphinView and a USB 300 as receiver, the system can be monitored in the EEP view window (Figure 3).

> **NOTE:** The current firmware is a feasibility demonstration only. It does not comply with the EEP A5-09-04 specification.

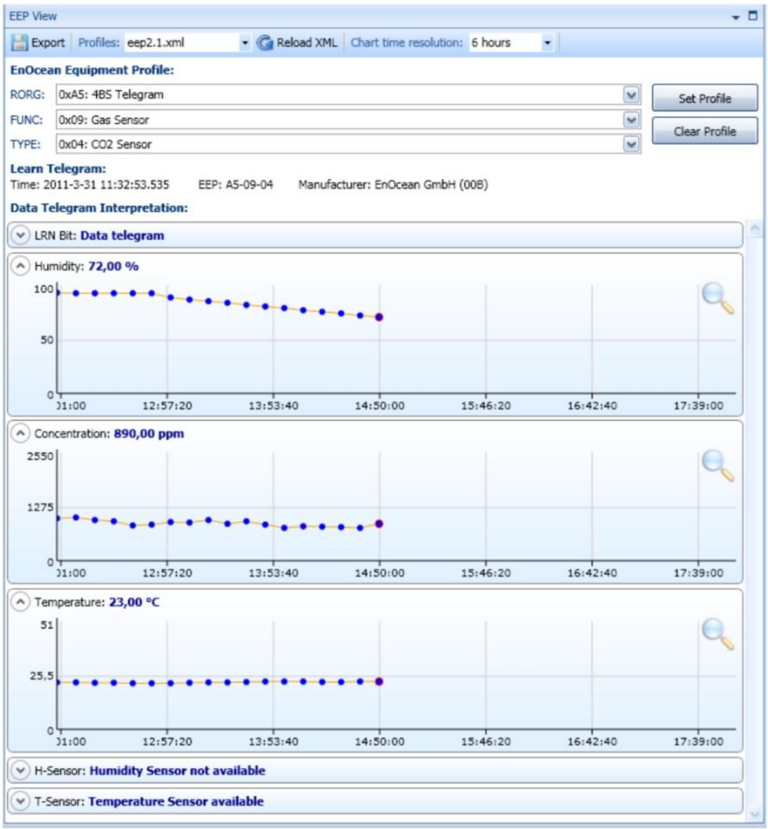

Figure 3 DolphinView / EEP view

2.1 System overview

Figure 4 shows the functional blocks of the self-powered CO_2 sensor system. The solar cell charges a long-term storage capacitor (super cap). This capacitor supplies the operating voltage of the system. The STM 300 controls the power supply of the embedded CO_2 sensor with the WXIDIO pin. The embedded sensor can therefore be switched off during the sleep periods. The embedded sensor needs a constant operating voltage of 3.3 V. A step-up/step-down charge pump (DC/DC converter) generates this voltage.

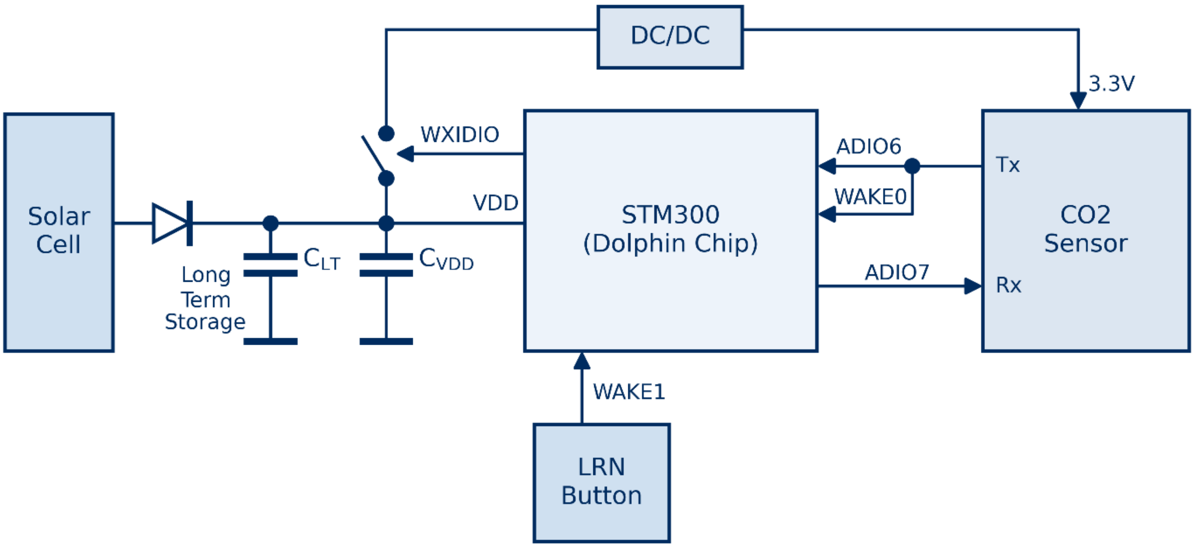

Figure 4 Block diagram of the CO_2 sensor

As shown in chapter 2.2 Schematics, the interface between powered and unpowered components needs special care. This is most important between the embedded sensor and the STM 300, for example on ADIO6 and ADIO7.

2.2 Schematics

The demonstration uses an amorphous silicon (a-Si) indoor solar panel. The panel is similar to the ECS 3x0, but larger. Table 2 lists its parameters.

Table 2 Parameters of the solar panel

Parameter	Value
Size	67.0 x 28.0 x 1.1 mm
Number of cells	8
Open-circuit voltage at 200 lx, 25 °C	4 V
Short-circuit current at 200 lx, 25 °C	25 µA
Operating voltage at 200 lx, 25 °C	3 V
Operating current at 200 lx, 25 °C	19 µA

Two super caps of 0.22 F (NEC TOKIN FC0H224ZTBR24) store the energy from the solar cell. For the demonstration, the super caps were selected for a high capacitance in combination with the capability to deliver a few milliamperes. The STM 300 and the embedded CO_2 sensor need this current.

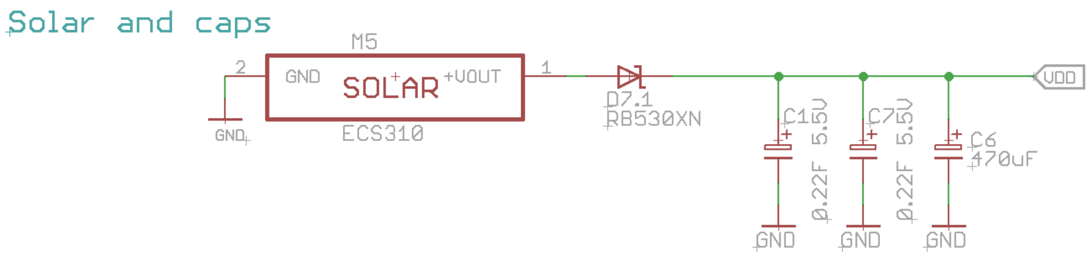

Figure 5 Solar cell and storage capacitors

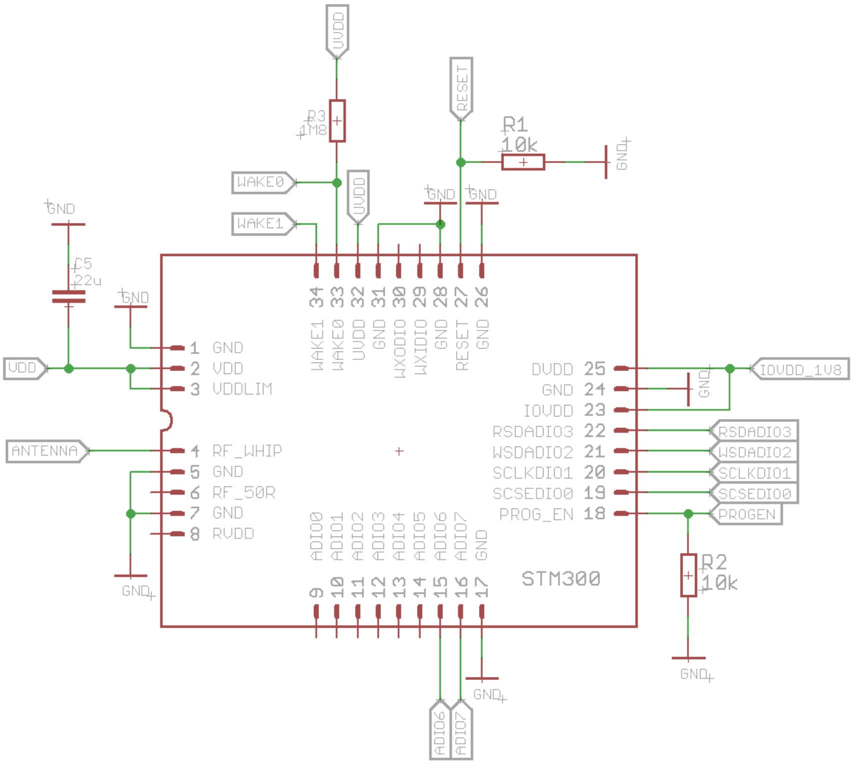

Figure 6 STM 300 with its external components

The embedded CO_2 sensor needs a fixed supply voltage of 3.3 V (VDD2). A DC/DC converter generates this voltage from VDD. The MAX1595 charge-pump regulator generates 3.3 V from an input voltage between 1.8 V and 5.5 V. The VDD generated by the solar cell can vary from 1.8 V up to 5.5 V during operation. Two MOSFETs switch the sensor supply off to save energy. The WXIDIO pin controls these MOSFETs. WXIDIO is also supplied during deep sleep. The STM 300 can therefore supply the sensor even in deep sleep mode. The pins ADIO 0-7, SCSEDIO0, SCLKDIO1, WSDADIO2 and RSDADIO3 are not supplied in deep sleep mode and cannot be used for this purpose.

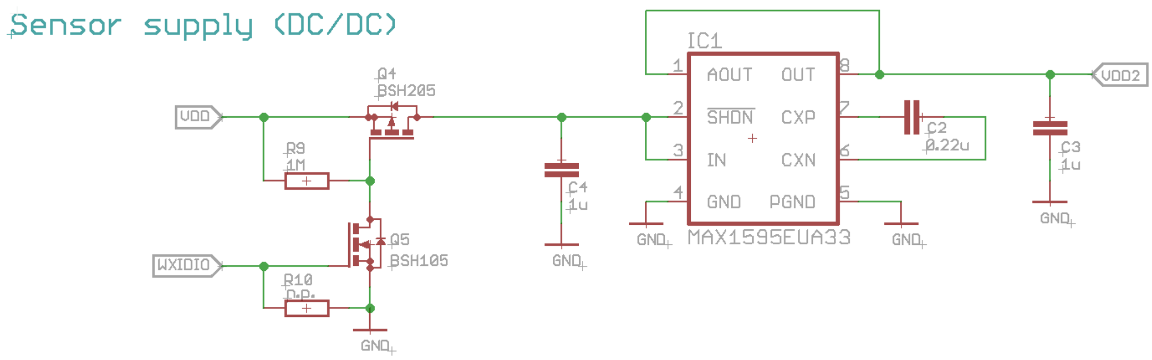

Figure 7 Sensor supply (DC/DC)

As mentioned before, the electrical interface between the powered and the unpowered parts of the system needs special care. For example, no voltage may be applied to the ADIO6 pin (diode D1) during deep sleep mode (see [2], chapter “GPIO supply voltage”).

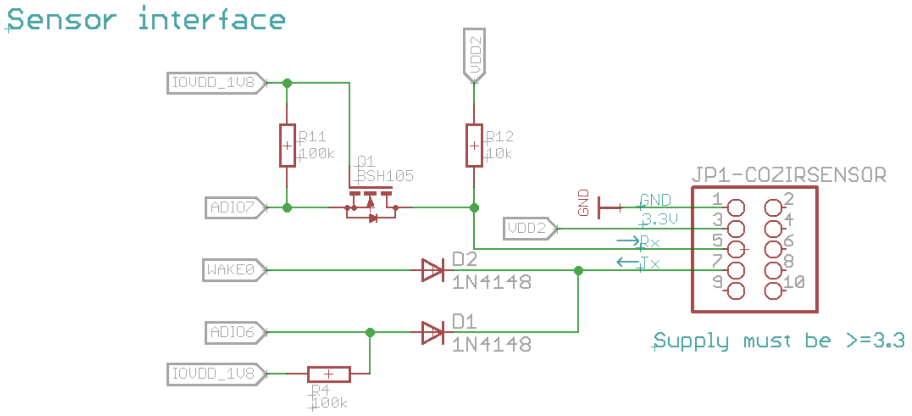

Figure 8 Sensor interface

A connector for the EOP 3x0 programmer allows in-system programming of the STM 300. The EOP 3x0 must be operated with 3.3 V. The 0 Ω resistors R7 and R8 are optional. They give access to the serial port for debugging.

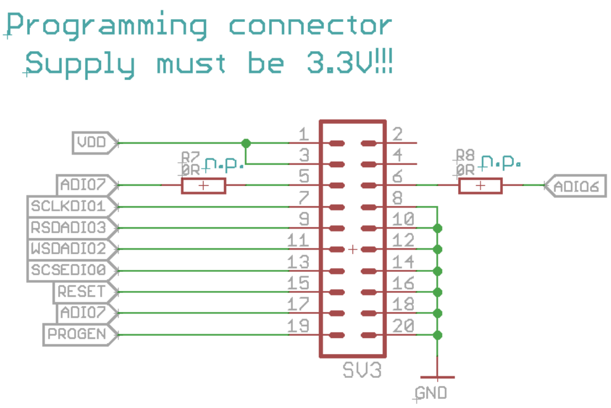

Figure 9 Programming interface

Figure 10 shows the complete schematic of the demonstration board.

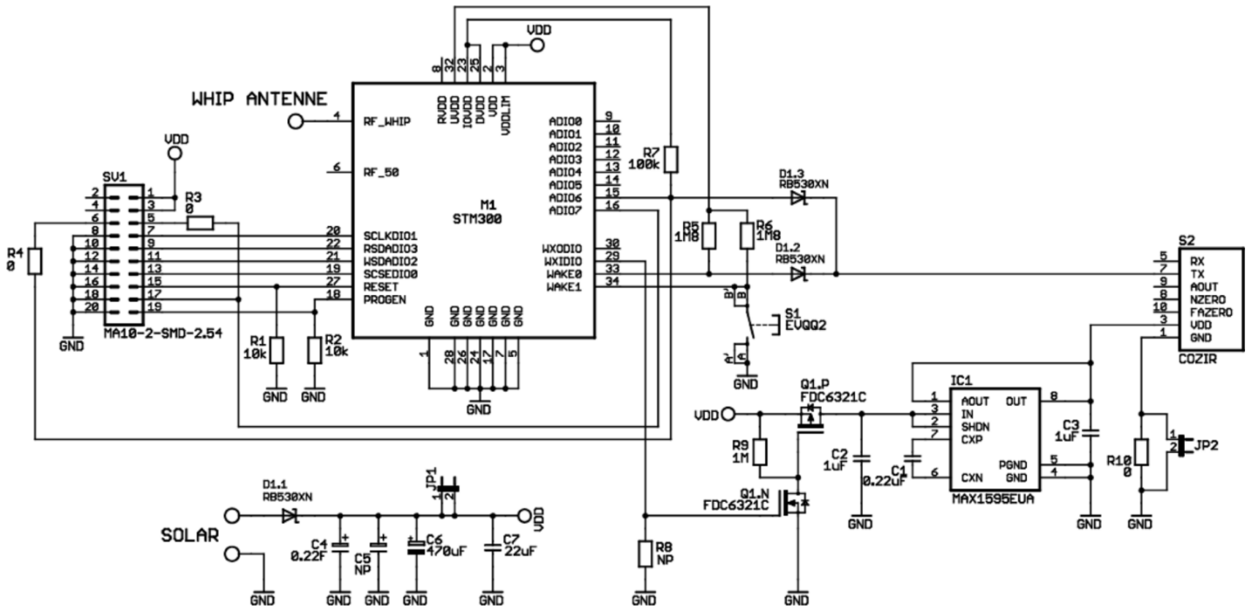

Figure 10 Implementation example of the demonstration board

2.3 Embedded CO_2 sensor

The COZIR™ ultra-low-power carbon dioxide sensor uses a non-dispersive infrared (NDIR) measurement, see [9]. It uses a mid-infrared light emitting diode as a light source and a photo diode as the detector.

The sensor is optimized for battery-powered applications. Its key features are:

- low power consumption (3.5 mW in continuous operation)
- fast power-up time
- battery operation (3.3 V)
- automatic calibration
- standard digital output (serial interface)
- optional humidity and temperature measurement

The COZIR carbon dioxide sensor is available in two ranges:

- COZIR ambient, range 0 ppm to 2000 ppm, for applications such as heating, ventilation and air conditioning (HVAC), indoor air quality (IAQ), education and horticulture
- COZIR wide range, range 0 % to 100 %, for process control applications such as diving, industry, safety and automotive

2.4 CO_2 measurement

In a self-powered application, there is not enough energy to supply the embedded sensor all the time. A dynamic power concept is therefore needed to reduce the energy consumption.

After power-up, the sensor needs about two seconds until it delivers the first measurement result on the serial interface. During these two seconds the sensor performs four internal measurements and calculates the first result from them. The STM 300 stays in deep sleep mode during this time to reduce the current consumption. After it has received the measurement result, the STM 300 switches the sensor supply off and sends the result by radio. The STM 300 then enters deep sleep mode for the next 10 minutes.

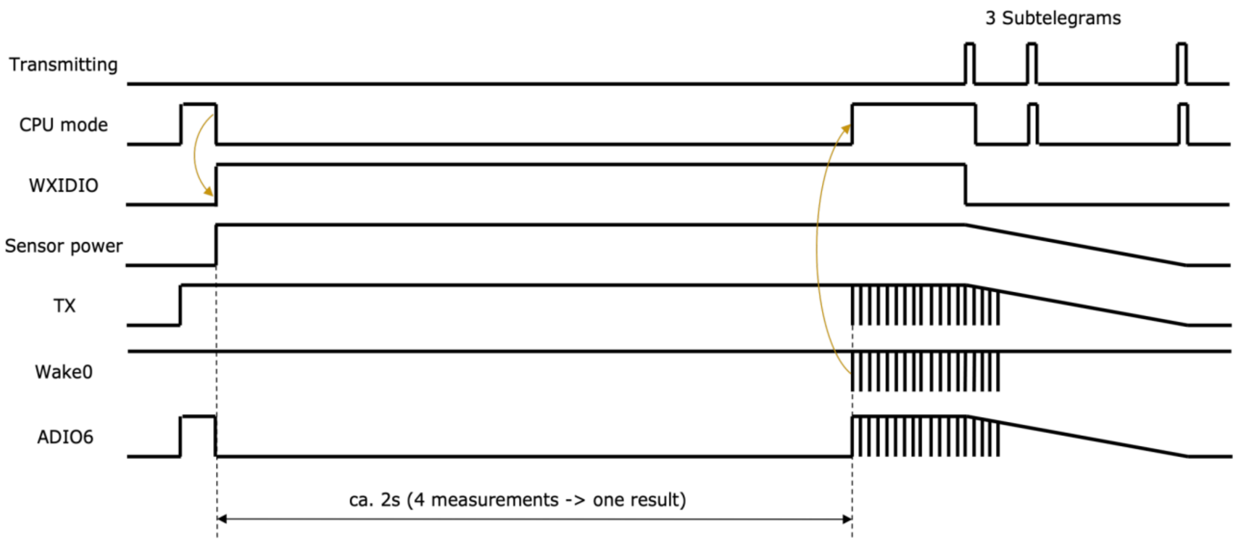

Figure 11 One measurement cycle

One measurement cycle runs as follows:

1. The STM 300 wakes up from deep sleep mode after the preset time (watchdog timer reset).
2. The STM 300 switches the sensor power on (WXIDIO set to high).
3. The STM 300 enables the wake-up on the sensor Tx line and sets the watchdog timer for the sensor timeout (3 seconds, in case the sensor does not answer).
4. The STM 300 enters deep sleep mode and waits for the sensor result or for the timeout.
5. The sensor measures the CO_2 concentration (four single measurements are made internally). After about two seconds the result is sent on the serial Tx line:
   ```
   Z 00879 z 00875\r\n
   ```
6. The first falling edge on the Tx line creates a falling edge on the WAKE0 pin. This wakes up the STM 300.
7. The STM 300 starts from reset, enables the UART and receives the remaining characters on the serial line (the first space is lost). It switches the sensor power off as soon as it has received the necessary first characters
   ```
   Z 00879
   ```
8. The STM 300 converts the value and sends the information by radio.
9. The STM 300 sets the watchdog timer to 10 minutes and enters deep sleep mode with

the WAKE0 wakeups disabled.

2.5 Chip temperature sensor

The demonstration uses the internal chip temperature sensor of the STM 300 to measure the ambient temperature. This works in an application where the chip has the same temperature as the ambient air and where no power dissipation falsifies the result.

> **NOTE:** The STM 300 module must be calibrated before the internal chip temperature sensor can be used.

2.6 Energy monitoring - charge level

To monitor the energy consumption, the system calculates a charge level of the capacitors and sends it by radio. The charge level is derived from the voltage VDD on the energy storage. The usable voltage ranges from 2.4 V up to 4.5 V is scaled to 0 % up to 100 %.

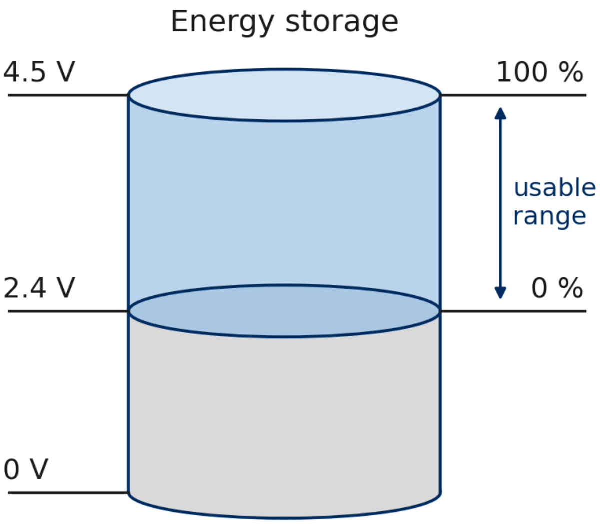

Figure 12 Charge level of the energy storage

The charge level is sent for diagnostics and for energy evaluation. The system also uses it to stay in a safe operating range, down to 20 %. When the embedded sensor is switched on, the higher current consumption causes voltage dips of up to 0.6 V. Such voltage dips can cause undervoltage resets.

2.7 Radio telegram

The CO_2 sensor sends a telegram similar to EEP A5-09-04. The first data field carries the charge level (see the chapter Energy monitoring - charge level) instead of the relative humidity. Table 3 lists the data fields.

> **NOTE:** The current implementation does not comply with the EEP A5-09-04 specification. An end product needs modifications.

Table 3 Data fields of the radio telegram

Offset	Size	Description	Valid range	Scale	Unit
0	8	Charge level (linear, 0.5 %)	0..200	0..100	%
8	8	CO_2 concentration (linear, 10 ppm)	0..255	0..2550	ppm
16	8	Temperature (linear, 0.2 °C)	0..255	0..+51.0	°C
28	1	LRN bit	1 = data		
29	1	Humidity valid	0 = not valid		
30	1	Temperature valid	1 = valid		

Figure 13 shows the original EEP A5-09-04 profile as a reference.

A5-09: Gas Sensor

RORG	A5	4BS Telegram
FUNC	09	Gas Sensor
TYPE	04	CO2 Sensor

Offset	Size	Bitrange	Data	ShortCut	Description	Valid Range	Scale	Unit
0	8	DB3.7...DB3.0	Humidity	HUM	Rel. Humidity (linear), 0.5 % = 1 bit	0...200	0...100	%
8	8	DB2.7...DB2.0	Concentration	Conc	Concentration (linear), increment = 10 ppm	0...255	0...2550	ppm
16	8	DB1.7...DB1.0	Temperature	TMP	Temperature (linear), increment = 0.2 °C	0...255	0...+51.0	°C
24	4	DB0.7...DB0.4	Not Used (= 0)					
28	1	DB0.3	LRN Bit	LRNB	LRN Bit	Enum: 0: Teach-in telegram 1: Data telegram		
29	1	DB0.2	H-Sensor	HSN	..	Enum: 0: Humidity Sensor not available 1: Humidity Sensor available		
30	1	DB0.1	T-Sensor	TSN	..	Enum: 0: Temperature Sensor not available 1: Temperature Sensor available		
31	1	DB0.0	Not Used (= 0)					

Figure 13 EEP A5-09-04 profile

2.8 Recalibration of the embedded CO_2 sensor

The embedded CO_2 sensor needs a recalibration from time to time, because dust or dirt in the optics changes the result. The recalibration method assumes that the sensor measures a "fresh air" CO_2 level at least once during a longer period, for example within 2 to 3 weeks.

In applications where the embedded sensor is supplied all the time, the sensor performs this recalibration automatically. In the self-powered system, the STM 300 has to take care of this function.

For the recalibration the STM 300 monitors the lowest measured CO_2 level in a given period and the elapsed time. This data is stored in the RAM0 area during the deep sleep periods.

```
// -----------------------------------------------------------------
// Structure of RAM0 area
typedef struct
{
  uint8  u8State;         // system state during deep sleep
  uint8  u8ChargeLevel;   // charge level during deep sleep
  uint16 u16MinCO2Level;  // for the dynamic sensor calibration
  uint16 u16WakeupCnt;    // for the dynamic sensor calibration
} tRam0;
```

To measure the time, the STM 300 simply counts the number of wakeups. After a defined period, it starts the recalibration and sends an "F" command (see [5]) to the embedded sensor.

2.8.1 Recalibration with the "F" command

The recalibration uses the difference between the lowest CO_2 level measured during the period (assumed to be the "fresh air" level) and a known "fresh air" level, for example 450 ppm. If the lowest CO_2 reading was 460 ppm, the STM 300 sends the command to the sensor:

```
F 460 450\r\n
```

The following steps are needed:

- Make sure that the sensor is ready to receive commands. Wait at least 100 ms after power-on.
- Send the "F" command with the calibration values.
- Wait until the "F" command is executed and the calibration data is stored in the EEPROM of the embedded sensor. This can be checked by waiting for the reply of the sensor.

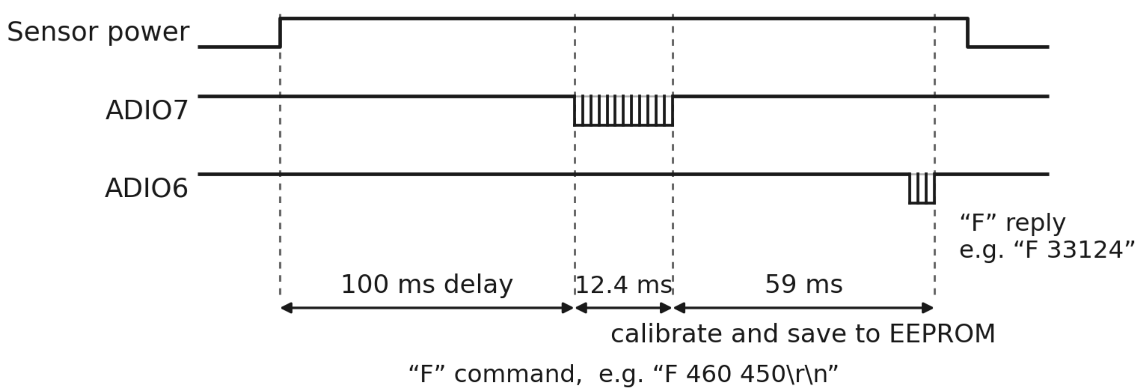

Figure 14 Recalibration with the "F" command

NOTE: The current implementation does not wait for the reply. It waits 100 milliseconds and then switches the sensor supply off.

2.9 Energy considerations

The evaluation of the energy consumption shows that the solar cell provides enough energy to operate the sensor. About 180 lx are needed to maintain a steady state, which means that the energy provided by the solar cell equals the energy used by the application, with a wake-up every 10 minutes. This corresponds to about 16.6 µA x 600 s = 10000 µAs during a 10-minute interval.

Figure 15 shows how the energy is shared between the different functional blocks. Most of the energy is needed for the CO_2 measurement: about 60 % is used by the embedded sensor during the measurement, where the sensor is powered for two seconds. Another 40 % is caused by the quiescent current and by the conversion efficiency of the DC/DC converter.

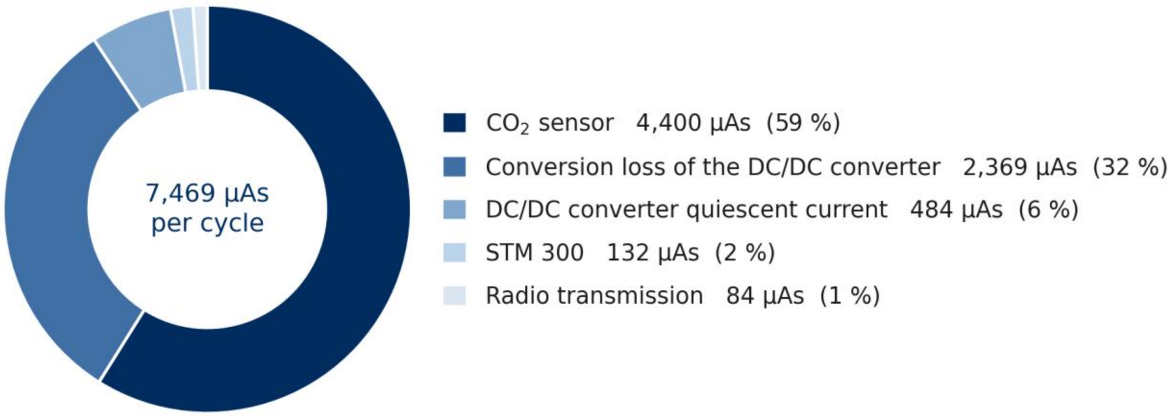

Figure 15 Energy consumption of the functional blocks

3 Outlook and limitations

The demonstration proves that a solar-powered wireless CO_2 sensor is feasible. It is not optimized for energy management. For example, it does not survive the night, because the solar cell cannot recharge the storage in the dark. A final product needs additional work. The following points must be considered in more detail:

- the required measurement rate
- a measurement rate that adapts to the available energy (charge level) or to the time of day, for example a lower rate during the night or when the room is dark
- the size of the solar cell and of the capacitors
- the need for long-term and short-term storage, including charge management
- the synchronization of the UART communication after the wake-up (see the chapter CO_2 measurement). The present implementation enables the UART with uart_init() at a fixed time after the wake-up. It has not been evaluated whether this works under all conditions. An alternative approach is to monitor the first bit changes on the Tx line and to enable the UART when a specific bit pattern is detected.

DISCLAIMER

The information provided in this document describes typical features of the EnOcean radio transmission system and should not be misunderstood as specified operating characteristics. No liability is assumed for errors and / or omissions. We reserve the right to make changes without prior notice. For the latest documentation visit the EnOcean website at **www.enocean.com**.