Smart Gases PRO

Technical Guide

libelium

waspmote

INDEX

1. General

Important:

- All documents and any examples they contain are provided as-is and are subject to change without notice. Except to the extent prohibited by law, Libelium makes no express or implied representation or warranty of any kind with regard to the documents, and specifically disclaims the implied warranties and conditions of merchantability and fitness for a particular purpose.
- The information on Libelium's websites has been included in good faith for general informational purposes only. It should not be relied upon for any specific purpose and no representation or warranty is given as to its accuracy or completeness.

1.1. General and safety information

- In this section, the term "Waspmote" encompasses both the Waspmote device itself and its modules and sensor boards.
- Read through the document "General Conditions of Libelium Sale and Use".
- Do not allow contact of metallic objects with the electronic part to avoid injuries and burns.
- NEVER submerge the device in any liquid.
- Keep the device in a dry place and away from any liquid which may spill.
- Waspmote consists of highly sensitive electronics which is accessible to the exterior, handle with great care and avoid bangs or hard brushing against surfaces.
- Check the product specifications section for the maximum allowed power voltage and amperage range and consequently always use a current transformer and a battery which works within that range. Libelium is only responsible for the correct operation of the device with the batteries, power supplies and chargers which it supplies.
- Keep the device within the specified range of temperatures in the specifications section.
- Do not connect or power the device with damaged cables or batteries.
- Place the device in a place only accessible to maintenance personnel (a restricted area).
- Keep children away from the device in all circumstances.
- If there is an electrical failure, disconnect the main switch immediately and disconnect that battery or any other power supply that is being used.
- If using a car lighter as a power supply, be sure to respect the voltage and current data specified in the "Power Supplies" section.
- If using a battery in combination or not with a solar panel as a power supply, be sure to use the voltage and current data specified in the "Power supplies" section.
- If a software or hardware failure occurs, consult the Libelium Web Development section.
- Check that the frequency and power of the communication radio modules together with the integrated antennas are allowed in the area where you want to use the device.
- Waspmote is a device to be integrated in a casing so that it is protected from environmental conditions such as light, dust, humidity or sudden changes in temperature. The board supplied "as is" is not recommended for a final installation as the electronic components are open to the air and may be damaged.

1.2. Conditions of use

- Read the "General and Safety Information" section carefully and keep the manual for future consultation.
- Use Waspmote in accordance with the electrical specifications and the environment described in the "Electrical Data" section of this manual.
- Waspmote and its components and modules are supplied as electronic boards to be integrated within a final product. This product must contain an enclosure to protect it from dust, humidity and other environmental interactions. In the event of outside use, this enclosure must be rated at least IP-65.
- Do not place Waspmote in contact with metallic surfaces; they could cause short-circuits which will permanently damage it.

Further information you may need can be found at: http://www.libelium.com/development/waspmote

The "General Conditions of Libelium Sale and Use" document can be found at:
http://www.libelium.com/development/waspmote/technical_service

2. New version: Gases PRO v3.0

This guide explains the new Gases PRO Sensor Board v3.0. This board was specifically designed for our new product lines Waspmote v15 and Plug & Sense! v15, released on October 2016.

This board is not compatible with Waspmote v12 or Plug & Sense! v12, so it is NOT recommended to mix product generations. If you are using previous versions of our products, please use the corresponding guides, available on our Development website.

You can get more information about the generation change on the document "New generation of Libelium product lines".

Differences of Gases PRO v3.0 with previous versions:

- The 4-electrode AFE has been changed, reducing noise and improving accuracy.
- The library has been improved to make easier the board handling.
- A 2nd CO sensor has been added. This sensor is focus on low concentration CO metering.
- New connectors to improve the Plug & Sense! wiring, making it more robust.

3. Waspmote Plug & Sense!

The Waspmote Plug & Sense! line allows you to easily deploy Internet of Things networks in an easy and scalable way, ensuring minimum maintenance costs. The platform consists of a robust waterproof enclosure with specific external sockets to connect the sensors, the solar panel, the antenna and even the USB cable in order to reprogram the node. It has been specially designed to be scalable, easy to deploy and maintain.

Note: *For a complete reference guide download the "Waspmote Plug & Sense! Technical Guide" in the* Development section *of the* Libelium website.

3.1. Features

- Robust waterproof IP65 enclosure
- Add or change a sensor probe in seconds
- Solar powered external panel option
- Radios available: 802.15.4, 868 MHz, 900 MHz, WiFi, 4G, Sigfox and LoRaWAN
- Over the air programming (OTAP) of multiple nodes at once (via WiFi or 4G radios)
- Special holders and brackets ready for installation in street lights and building fronts
- Graphical and intuitive interface Programming Cloud Service
- Built-in, 3-axes accelerometer
- External, contactless reset with magnet
- Optional industrial protocols: RS-232, RS-485, Modbus, CAN Bus
- Optional GPS receiver
- Optional External Battery Module
- External SIM connector for the 4G models
- Fully certified: CE (Europe), FCC (USA), IC (Canada), ANATEL (Brazil), RCM (Australia), PTCRB (USA, cellular connectivity), AT&T (USA, cellular connectivity)

Figure: Waspmote Plug & Sense!

3.2. General view

This section shows main parts of Waspmote Plug & Sense! and a brief description of each one. In later sections all parts will be described deeply.

3.2.1. Specifications

- **Material:** polycarbonate
- **Sealing:** polyurethane
- **Cover screws:** stainless steel
- **Ingress protection:** IP65
- **Impact resistance:** IK08
- **Rated insulation voltage AC:** 690 V
- **Rated insulation voltage DC:** 1000 V
- **Heavy metals-free:** Yes
- **Weatherproof:** true - nach UL 746 C
- **Ambient temperature (min.):** -30 °C*
- **Ambient temperature (max.):** 70 °C*
- **Approximated weight:** 800 g

* *Temporary extreme temperatures are supported. Regular recommended usage: -20, +60 ºC.*

In the pictures included below it is shown a general view of Waspmote Plug & Sense! main parts. Some elements are dedicated to node control, others are designated to sensor connection and other parts are just identification elements. All of them will be described along this guide.

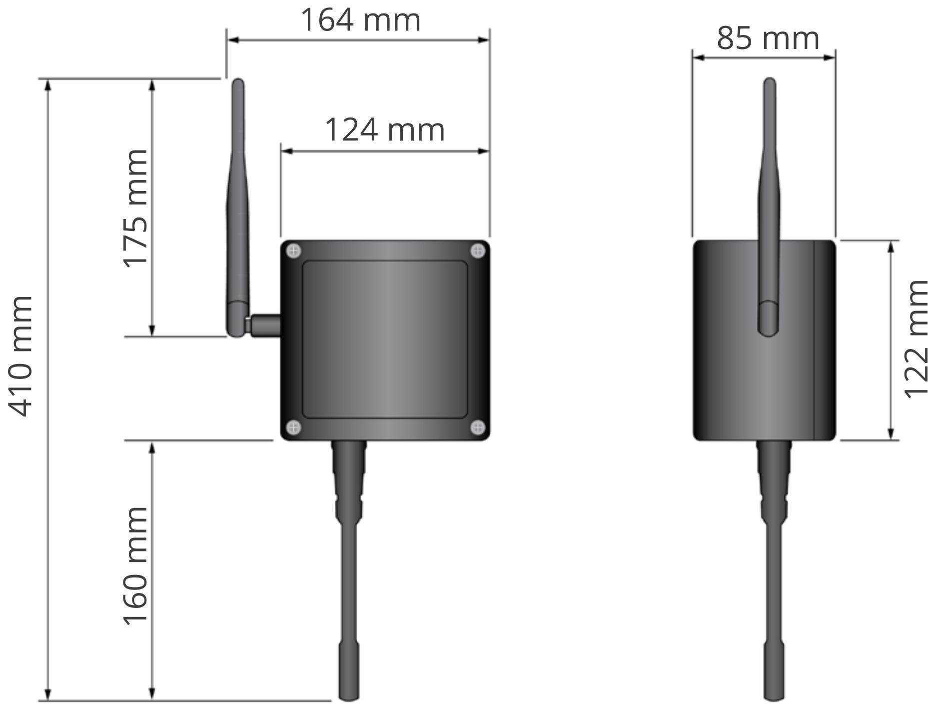


Figure: Main view of Waspmote Plug & Sense!

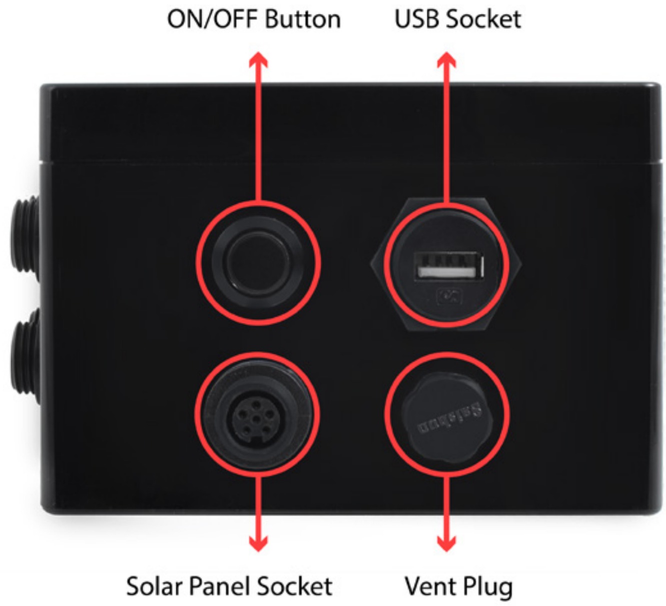


Figure: Control side of the enclosure

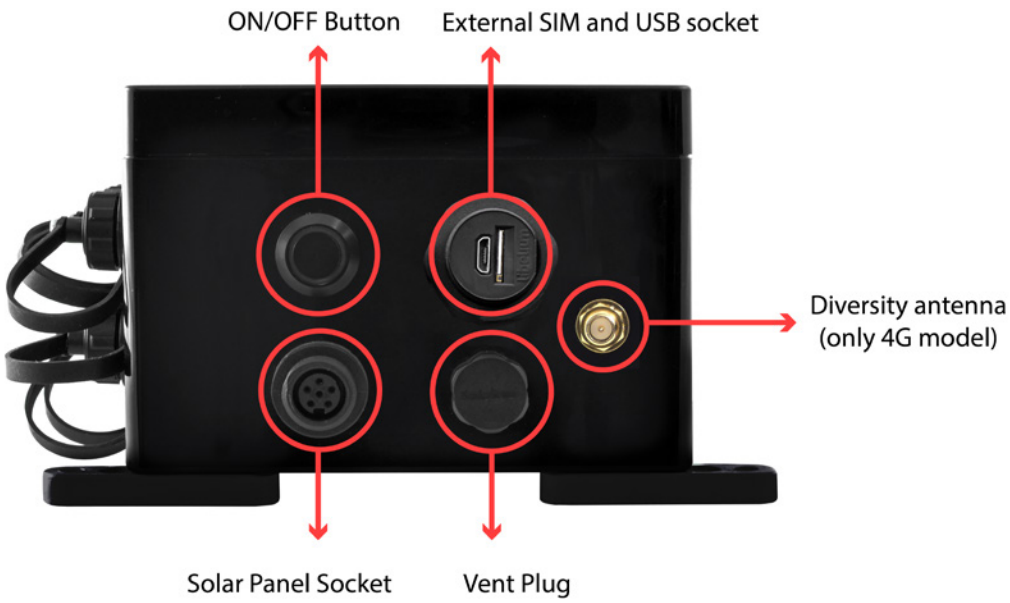


Figure: Control side of the enclosure for 4G model

Figure: Sensor side of the enclosure

Figure: Antenna side of the enclosure

Figure: Front view of the enclosure

Figure: Back view of the enclosure

Figure: Warranty stickers of the enclosure

Important note: *Do not handle black stickers seals of the enclosure (Warranty stickers). Their integrity is the proof that Waspmote Plug & Sense! has not been opened. If they have been handled, damaged or broken, the warranty is automatically void.*

3.2.2. Parts included

Next picture shows Waspmote Plug & Sense! and all of its elements. Some of them are optional accessories that may not be included.

Figure: Waspmote Plug & Sense! accessories: 1 enclosure, 2 sensor probes, 3 external solar panel, 4 USB cable, 5 antenna, 6 cable ties, 7 mounting feet (screwed to the enclosure), 8 extension cord, 9 solar panel cable, 10 wall plugs & screws

3.2.3. Identification

Each Waspmote model is identified by stickers. Next figure shows front sticker.

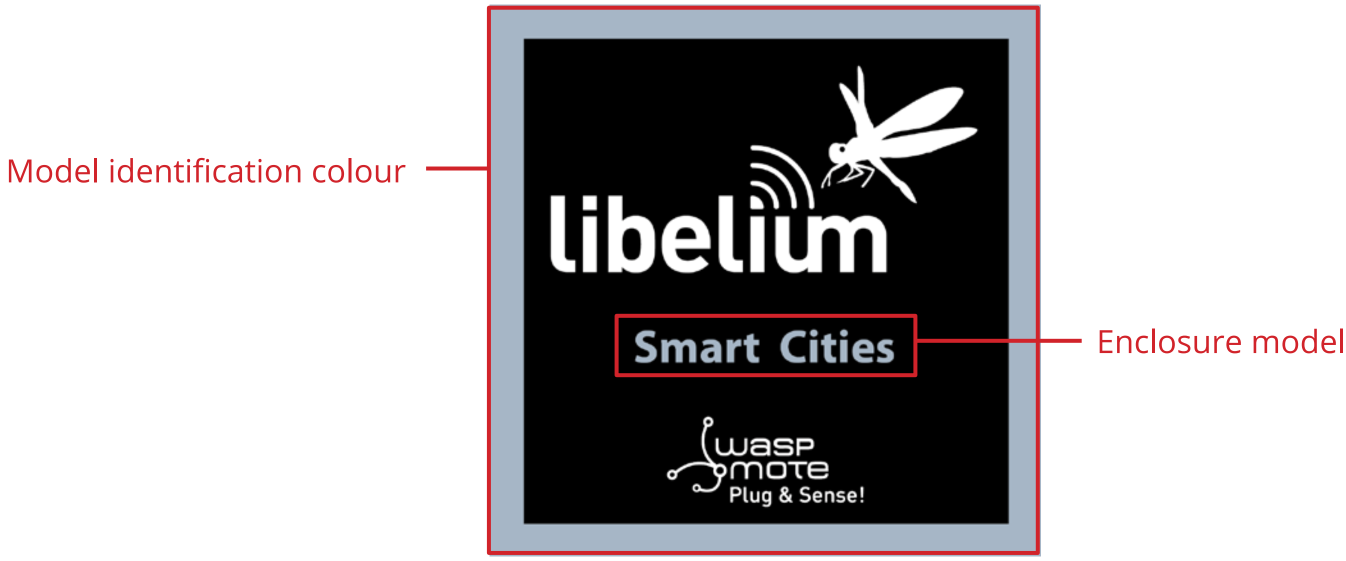


Figure: Front sticker of the enclosure

There are many configurations of Waspmote Plug & Sense! line, all of them identified by one unique sticker. Next image shows all possibilities.

Figure: Different front stickers

Moreover, Waspmote Plug & Sense! includes a back sticker where it is shown identification numbers, radio MAC addresses, etc. It is highly recommended to annotate this information and save it for future maintenance. Next figure shows it in detail.

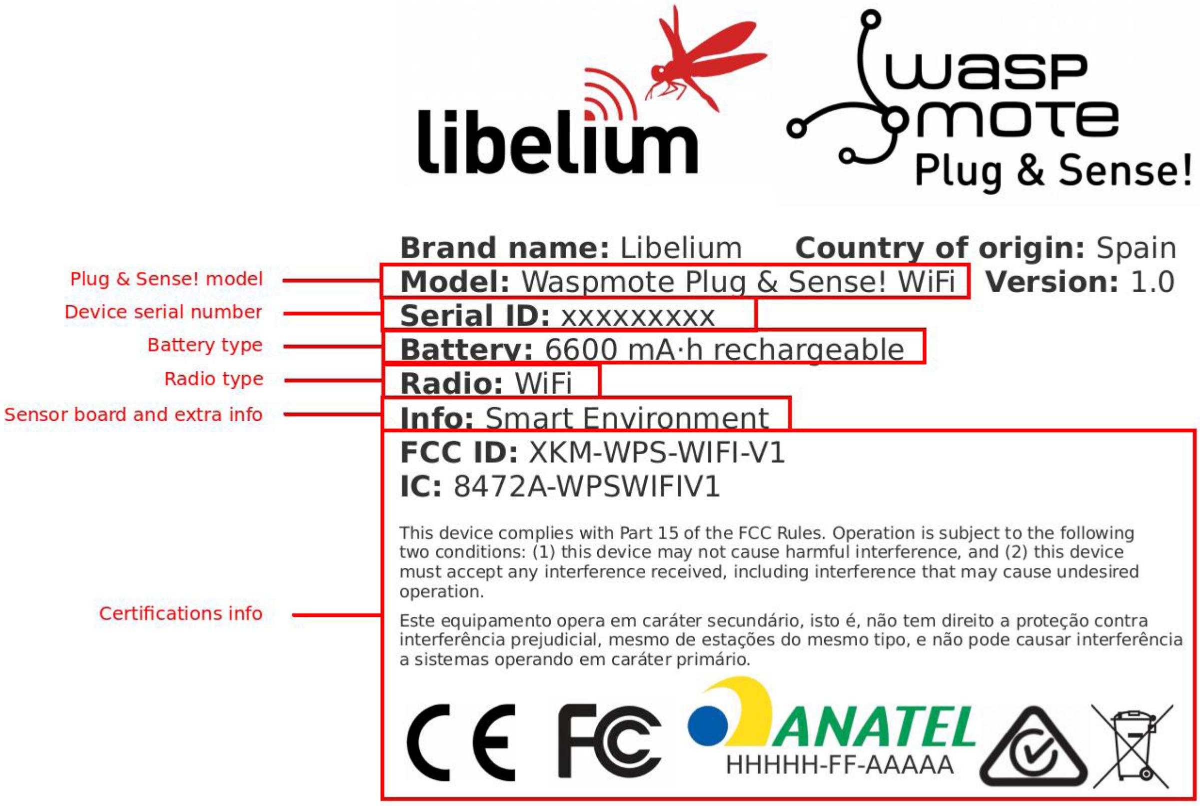


Figure: Back sticker

Sensor probes are identified too by a sticker showing the measured parameter and the sensor manufacturer reference.

Figure: Sensor probe identification sticker

3.3. Sensor probes

Sensor probes can be easily attached by just screwing them into the bottom sockets. This allows you to add new sensing capabilities to existing networks just in minutes. In the same way, sensor probes may be easily replaced in order to ensure the lowest maintenance cost of the sensor network.

Figure: Connecting a sensor probe to Waspmote Plug & Sense!

Go to the [Plug & Sense! Sensor Guide] to know more about our sensor probes.

3.4. Solar powered

The battery can be recharged using the waterproof USB cable but also the external solar panel option.

The external solar panel is mounted on a 45º holder which ensures the maximum performance of each outdoor installation.

Figure: Waspmote Plug & Sense! powered by an external solar panel

3.5. External Battery Module

The External Battery Module (EBM) is an accessory to extend the battery life of Plug & Sense!. The extension period may be from months to years depending on the sleep cycle and radio activity. The daily charging period is selectable among 5, 15 and 30 minutes with a selector switch and it can be combined with a solar panel to extend even more the node's battery lifetime.

Note: Nodes using solar panel can keep using it through the External Battery Module (EBM). The EBM is connected to the solar panel connector of Plug & Sense! and the solar panel unit is connected to the solar panel connector of the EBM.

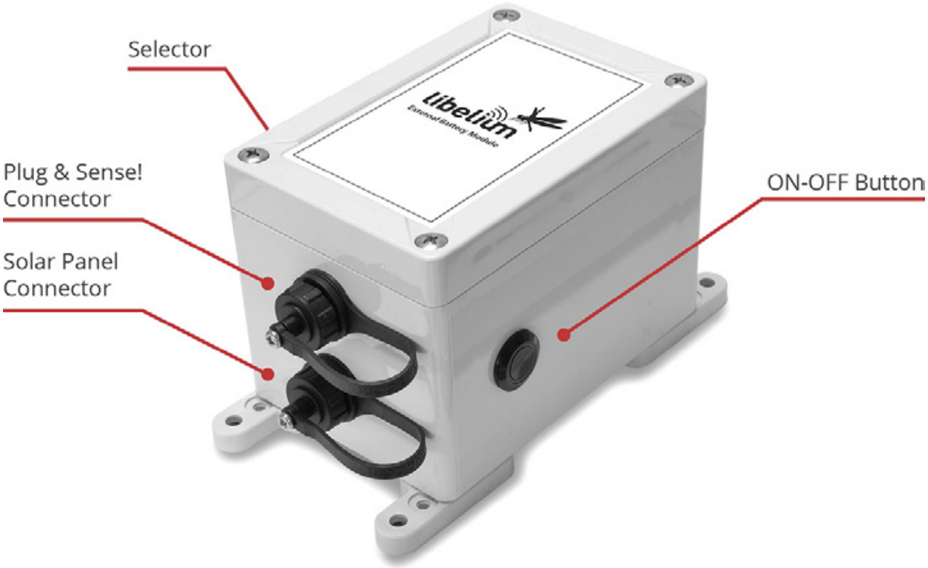


Figure: Plug & Sense! with External Battery Module

Figure: Plug & Sense! with External Battery Module and solar panel

3.6. Programming the Nodes

Waspmote Plug & Sense! can be reprogrammed in two ways:

The basic programming is done from the USB port. Just connect the USB to the specific external socket and then to the computer to upload the new firmware.

Figure: Programming a node

Over the Air Programming (OTAP) is also possible once the node has been installed (via WiFi or 4G radios). With this technique you can reprogram, wireless, one or more Waspmote sensor nodes at the same time by using a laptop and Meshlium.

Figure: Typical OTAP process

3.7. Program in minutes

The Programming Cloud Service is an intuitive graphic interface which creates code automatically. The user just needs to to fill a web form to obtain binaries for Plug & Sense!. Advanced programming options are available, depending on the license selected.

Check how easy it is to handle the Programming Cloud Service at:

https://cloud.libelium.com/

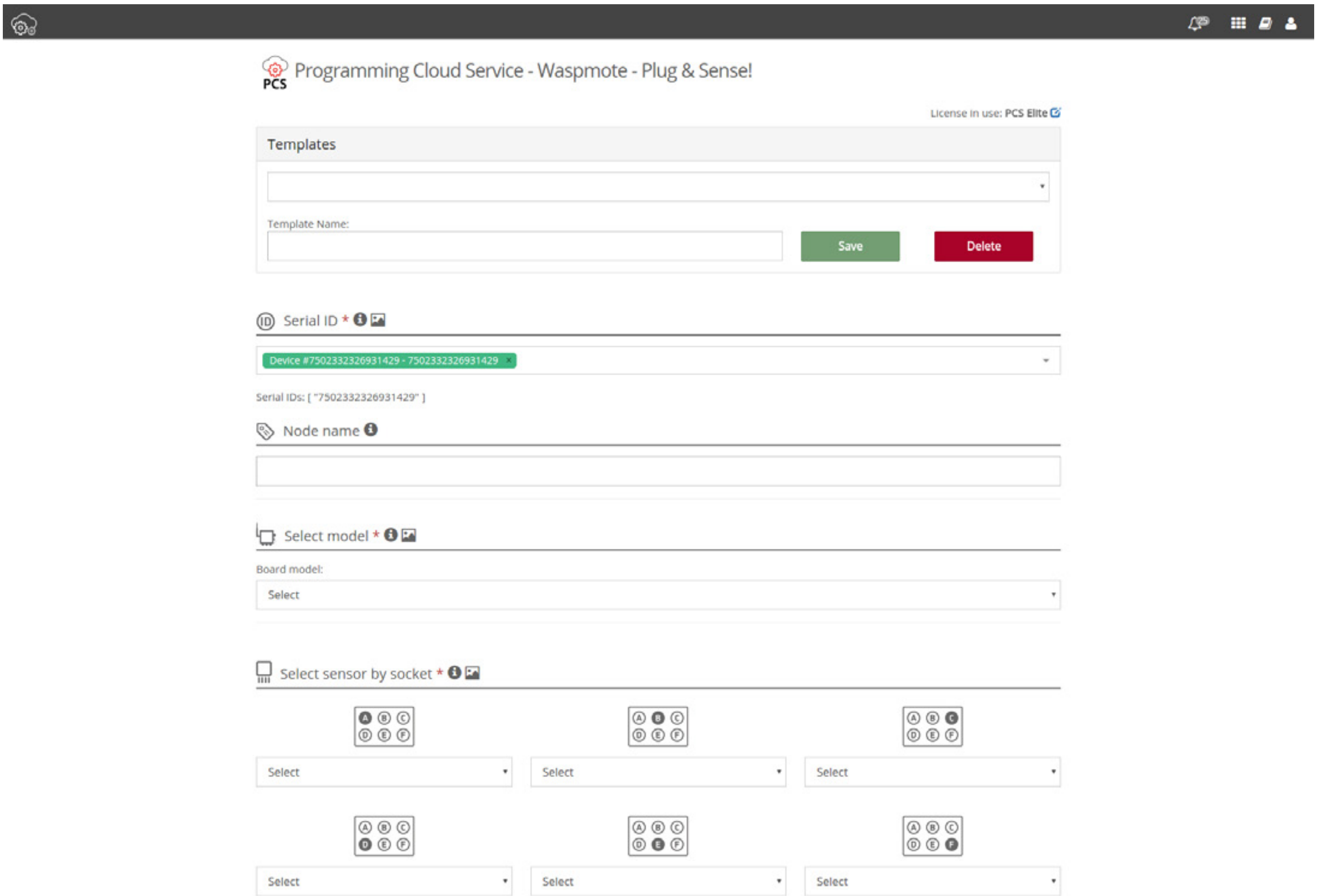


Figure: Programming Cloud Service

3.8. Radio interfaces

Radio	Protocol	Frequency bands	Transmission power	Sensitivity	Range*	Certification
XBee-PRO 802.15.4 EU	802.15.4	2.4 GHz	10 dBm	-100 dBm	750 m	CE
XBee-PRO 802.15.4	802.15.4	2.4 GHz	18 dBm	-100 dBm	1600 m	FCC, IC, ANATEL, RCM
XBee 868LP	RF	868 MHz	14 dBm	-106 dBm	8.4 km	CE
XBee 900HP US	RF	900 MHz	24 dBm	-110 dBm	15.5 km	FCC, IC
XBee 900HP BR	RF	900 MHz	24 dBm	-110 dBm	15.5 km	ANATEL
XBee 900HP AU	RF	900 MHz	24 dBm	-110 dBm	15.5 km	RCM
WiFi	WiFi (HTTP(S), FTP, TCP, UDP)	2.4 GHz	17 dBm	-94 dBm	500 m	CE, FCC, IC, ANATEL, RCM
4G EU/BR	4G/3G/2G (HTTP, FTP, TCP, UDP) GPS	800, 850, 900, 1800, 2100, 2600 MHz	4G: class 3 (0.2 W, 23 dBm)	4G: -102 dBm	- km - Typical base station range	CE, ANATEL
4G US	4G/3G/2G (HTTP, FTP, TCP, UDP) GPS	700, 850, 1700, 1900 MHz	4G: class 3 (0.2 W, 23 dBm)	4G: -103 dBm	- km - Typical base station range	FCC, IC, PTCRB, AT&T
4G AU	4G (HTTP, FTP, TCP, UDP)	700, 1800, 2600 MHz	4G: class 3 (0.2 W, 23 dBm)	4G: -102 dBm	- km - Typical base station range	RCM
Sigfox EU	Sigfox	868 MHz	16 dBm	-126 dBm	- km - Typical base station range	CE
Sigfox US	Sigfox	900 MHz	24 dBm	-127 dBm	- km - Typical base station range	FCC, IC
LoRaWAN EU	LoRaWAN	868 MHz	14 dBm	-136 dBm	> 15 km	CE
LoRaWAN US	LoRaWAN	900 MHz	18.5 dBm	-136 dBm	> 15 km	FCC, IC

* *Line of sight and Fresnel zone clearance with 5dBi dipole antenna.*

3.9. Industrial Protocols

Besides the main radio of Waspmote Plug & Sense!, it is possible to have an Industrial Protocol module as a secondary communication option. This is offered as an accessory feature.

The available Industrial Protocols are RS-232, RS-485, Modbus (software layer over RS-232 or RS-485) and CAN Bus. This optional feature is accessible through an additional, dedicated socket on the antenna side of the enclosure.

Figure: Industrial Protocols available on Plug & Sense!

Finally, the user can choose between 2 probes to connect the desired Industrial Protocol: A standard DB9 connector and a waterproof terminal block junction box. These options make the connections on industrial environments or outdoor applications easier.

Figure: DB9 probe

Figure: Terminal box probe

3.10. GPS

Any Plug & Sense! node can incorporate a GPS receiver in order to implement real-time asset tracking applications. The user can also take advantage of this accessory to geolocate data on a map. An external, waterproof antenna is provided; its long cable enables better installation for maximum satellite visibility.

Figure: Plug & Sense! node with GPS receiver

Chipset: JN3 (Telit)
Sensitivity:

- Acquisition: -147 dBm
- Navigation: -160 dBm
- Tracking: -163 dBm

Hot start time: <1 s
Cold start time: <35 s

Positional accuracy error < 2.5 m
Speed accuracy < 0.01 m/s
EGNOS, WAAS, GAGAN and MSAS capability

Antenna:

- Cable length: 2 m
- Connector: SMA
- Gain: 26 dBi (active)

Available information: latitude, longitude, altitude, speed, direction, date&time and ephemeris management

3.11. Models

There are some defined configurations of Waspmote Plug & Sense! depending on which sensors are going to be used. Waspmote Plug & Sense! configurations allow to connect up to six sensor probes at the same time.

Each model takes a different conditioning circuit to enable the sensor integration. For this reason each model allows to connect just its specific sensors.

This section describes each model configuration in detail, showing the sensors which can be used in each case and how to connect them to Waspmote. In many cases, the sensor sockets accept the connection of more than one sensor probe. See the compatibility table for each model configuration to choose the best probe combination for the application.

It is very important to remark that each socket is designed only for one specific sensor, so **they are not interchangeable**. Always be sure you connected probes in the right socket, otherwise they can be damaged.

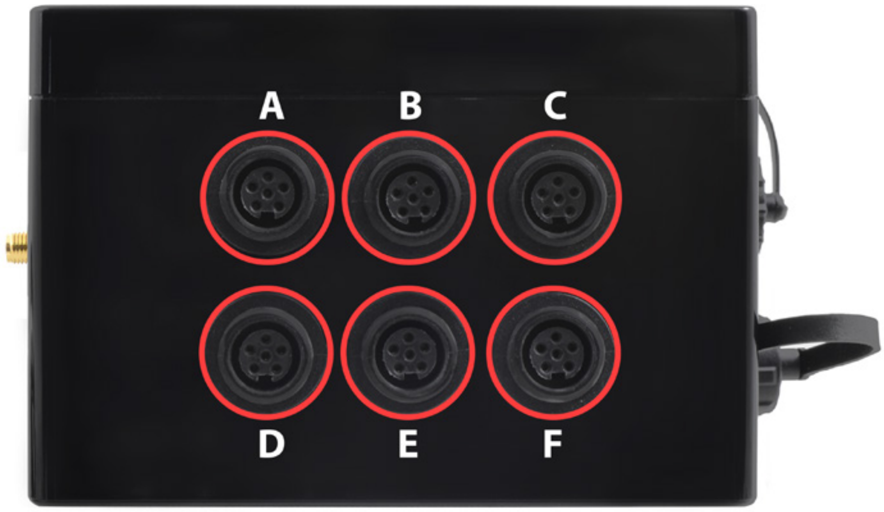


Figure: Identification of sensor sockets

3.11.1. Smart Environment PRO

The Smart Environment PRO model has been created as an evolution of Smart Environment. It enables the user to implement pollution, air quality, industrial, environmental or farming projects with high requirements in terms of high accuracy, reliability and measurement range as the sensors come calibrated from factory.

Figure: Smart Environment PRO Waspmote Plug & Sense! model

Sensor sockets are configured as shown in the figure below.

Sensor Socket	Sensor probes allowed for each sensor socket	
	Parameter	Reference
A, B, C or F	Carbon Monoxide (CO) for high concentrations [Calibrated]	9371-P
	Carbon Monoxide (CO) for low concentrations [Calibrated]	9371-LC-P
	Carbon Dioxide (CO_2) [Calibrated]	9372-P
	Oxygen (O_2) [Calibrated]	9373-P
	Ozone (O_3) [Calibrated]	9374-P
	Nitric Oxide (NO) for low concentrations [Calibrated]	9375-LC-P
	Nitric Dioxide (NO_2) high accuracy [Calibrated]	9376-HA-P
	Sulfur Dioxide (SO_2) high accuracy [Calibrated]	9377-HA-P
	Ammonia (NH_3) for low concentrations [Calibrated]	9378-LC-P
	Ammonia (NH_3) for high concentrations [Calibrated]	9378-HC-P
	Methane (CH_4) and Combustible Gas [Calibrated]	9379-P
	Hydrogen (H_2) [Calibrated]	9380-P
	Hydrogen Sulfide (H_2S) [Calibrated]	9381-P
	Hydrogen Chloride (HCl) [Calibrated]	9382-P
	Hydrogen Cyanide (HCN) [Calibrated]	9383-P
	Phosphine (PH_3) [Calibrated]	9384-P
	Ethylene (ETO) [Calibrated]	9385-P
	Chlorine (Cl_2) [Calibrated]	9386-P
D	Particle Matter (PM1 / PM2.5 / PM10) - Dust	9387-P
E	Temperature, humidity and pressure	9370-P
	Luminosity (Luxes accuracy)	9325-P
	Ultrasound (distance measurement)	9246-P

Figure: Sensor sockets configuration for Smart Environment PRO model

***Note:** For more technical information about each sensor probe go to the [Development section](#) on the Libelium website.*

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

Note: *In March 2017, Smart Environment (which is the Plug & Sense! version for the Gases sensor board) was discontinued. The Gases sensor board is now only available in the Waspmote OEM product line. Libelium currently offers Gases PRO (Smart Environment PRO) and Smart Cities PRO for accurate measuring of gases.*

4. Gases PRO Sensor Board (Calibrated)

This platform enables the user to implement pollution, air quality, industrial, environmental or farming projects with high requirements in terms of high accuracy, reliability and measurement range as the sensors come calibrated from factory. The Gases PRO line is available for both Waspmote and Plug & Sense!.

So we offer to our clients two different sensor boards in order to measure gas levels: Gases Sensor Board (Gases) and Gases PRO Sensor Board *(Gases PRO)*.

Comparative between Gases and Gases PRO sensor boards:

- Gases PRO integrates 17 different gas sensors. Gases integrates 12. See the complete list of parameters in the tables below.
- Gases PRO is useful to measure the exact value in ppm's of a gas concentration. The Gases line provides just the level of concentration low / medium / high. Complete accuracy ranges are shown in the table below.
- Gases PRO is meant to be used in applications that require accurate readings and exact concentrations thus its sensors are more expensive than the Gases regular version that just provides average levels.
- A Particle Matter Sensor -commonly known as "Dust Sensor"- has been integrated in the Gases PRO board. This sensor allows to measure PM1, PM2.5, and PM10 particles. This sensor comes also calibrated from factory.
- Gases PRO is available for the Plug & Sense! product line (as Smart Environment PRO), while Gases is only offered for Waspmote OEM.

Should I choose Gases or Gases PRO?

Libelium created 2 different systems in terms of accuracy and pricing. The customer should consider Gases PRO if he needs maximum performance sensors for metering in accurate ppm or percentage. If the project just needs to detect gas presence or gas levels, the standard Gases Sensor Board can be enough.

The Gases PRO Sensor Board can read up to 17 gas sensors; it also has a high-end sensor for 3 parameters, temperature, humidity and pressure.

Gases PRO v3.0			
Parameter	**Range**	**Calibration***	**Max Consumption**
Temperature	-40 to +85 ºC	Calibrated ±1 ºC (±0.5 ºC at 25 ºC)	2 µA @ 3V3
Humidity	0 to 100% HR	Calibrated ±3% RH (at 25 ºC, range 20 ~ 80% RH)	2.8 µA @ 3V3
Pressure	30 to 110 kPa	Calibrated ±0.1 kPa (range 0 ~ 65 ºC)	4.2 µA @ 3V3
Carbon Monoxide for high concentrations CO	0 to 500 ppm	Calibrated ±1 ppm	351 µA @ 3V3
Carbon Monoxide for low concentrations CO	0 to 25 ppm	Calibrated ±0.1 ppm	312 µA @ 3V3
Carbon Dioxide CO_2	0 to 5000 ppm	Calibrated ±50 ppm (range 0~2500 ppm) ±200 ppm (range 2500~5000 ppm)	85 mA @ 3V3
Molecular Oxygen O_2	0 to 30%	Calibrated ±0.1%	402 µA @ 3V3
Ozone O_3	0 to 18 ppm	Calibrated ±0.2 ppm	< 1 mA @ 3V3

Gases PRO v3.0			
Parameter	**Range**	**Calibration***	**Max Consumption**
Nitric Oxide for low concentrations NO	0 to 20 ppm	Calibrated ±0.2 ppm	< 1mA @ 3V3
Nitric Dioxide high accuracy NO_2	0 to 20 ppm	Calibrated ±0.1 ppm	< 1mA @ 3V3
Sulfur Dioxide high accuracy SO_2	0 to 20 ppm	Calibrated ±0.1 ppm	< 1mA @ 3V3
Ammonia for low concentrations NH_3	0 to 100 ppm	Calibrated ±0.5 ppm	338 µA @ 3V3
Ammonia for high concentrations NH_3	0 to 500 ppm	Calibrated ±3 ppm	338 µA @ 3V3
Methane and other combustible gases CH_4	0 to 100% / LEL	Calibrated ±0.15% LEL	68 mA @ 3V3
Molecular Hydrogen H_2	0 to 1000	Calibrated ±10 ppm	520 µA @ 3V3
Hydrogen Sulfide H_2S	0 to 100 ppm	Calibrated ±0.1 ppm	352 µA @ 3V3
Hydrogen Chloride HCl	0 to 50 ppm	Calibrated ±1 ppm	341 µA @ 3V3
Hydrogen Cyanide HCN	0 to 50 ppm	Calibrated ±0.2 ppm	327 µA @ 3V3
Phosphine PH_3	0 to 20 ppm	Calibrated ±0.1 ppm	361 µA @ 3V3
Ethylene Oxide ETO	0 to 100 ppm	Calibrated ±1 ppm	360 µA @ 3V3
Chlorine Cl_2	0 to 50 ppm	Calibrated ±0.1 ppm	353 µA @ 3V3
Isobutane C_4H_{10}	-	-	-
Ethanol CH_3CH_2OH	-	-	-
Toluene $C_6H_5CH_3$	-	-	-
Volatile Organic Compounds	-	-	-
Hydrocarbons	-	-	-
Particle Matter – Dust	0.5 to 16 µm (16 steps) (includes PM1, PM2.5 and PM10)	Calibrated	200+ mA @ 5 V

** Accuracy values have been calculated at average conditions: 20ºC / 101300 Pa. Accuracy levels may differ with different temperature and pressure levels, aging and in presence of third type of gases which cause cross sensitivity. See the "Calibration" chapter for more detail.*

Gases v3.0			
Parameter	**Range**	**Calibration**	**Consumption**
Temperature	-40 to +85 ºC	Calibrated ±1 ºC (±0.5 ºC at 25 ºC)	2 µA @ 3V3
Humidity	0 to 100% HR	Calibrated ±3% RH (at 25 ºC, range 20 ~ 80% RH)	2.8 µA @ 3V3
Pressure	30 to 110 kPa	Calibrated ±0.1 kPa (range 0 ~ 65 ºC)	4.2 µA @ 3V3
Carbon Monoxide CO	30 to 1000 ppm	Not calibrated	3 mA @ 5V
Carbon Dioxide CO_2	350 to 10000 ppm	Not calibrated	50 mA @ 5V
Molecular Oxygen O_2	0 to 30%	Not calibrated	0 µA
Ozone O_3	0.010 to 1 ppm	Not calibrated	34 mA
Nitric Oxide NO	-	-	-
Nitric Dioxide NO_2	0.05 to 5 ppm	Not calibrated	26 mA
Sulfur Dioxide SO_2	-	-	-
Ammonia NH_3	10 to 100 ppm	Not calibrated	12 mA @ 5V
Methane and other combustible gases CH_4	500 to 10000 ppm	Not calibrated	61 mA @ 5V
Molecular Hydrogen H_2	500 to 10000 ppm	Not calibrated	61 mA @ 5V 46 mA @ 5V
Hydrogen Sulfide H_2S	0.1 to 3 ppm	Not calibrated	61 mA @ 5V
Hydrogen Chloride HCl	-	-	-
Hydrogen Cyanide HCN	-	-	-
Phosphine PH_3	-	-	-
Ethylene Oxide ETO	-	-	-
Chlorine Cl_2	-	-	-
Isobutane C_4H_{10}	50 to 5000 ppm	Not calibrated	61 mA @ 5V
Ethanol CH_3CH_2OH	1 to 30 ppm 50 to 5000 ppm	Not calibrated	61 mA @ 5V
Toluene $C_6H_5CH_3$	1 to 30 ppm	Not calibrated	61 mA @ 5V
Volatile Organic Compounds	30 to 400 ppm	Not calibrated	32 mA
Hydrocarbons	-	Not calibrated	61 mA @ 5V
Particle Matter – Dust	-	-	-

How are the Gases PRO sensors calibrated?

All the Gases PRO sensors are linear, so they behave according to a simple line like $y = f(x) = m \cdot x + c$. On the other hand, the Gases Sensor Board sensors show a logarithmic response, which is harder to handle.

All the gas sensors for Gases PRO are calibrated by the sensor manufacturers, in their laboratories. A two-point calibration process is performed to get maximum accuracy, with controlled concentrations of gas in vacuum chambers. Due to the linear nature of the sensors, those 2 points are enough to correct the 2 possible drifts in m (slope) and c (constant offset). Our sensor manufacturers provide a calibration certificate for each individual sensor, with two calibration parameters. Libelium stores these parameters in an EEPROM, non-volatile memory chip inside each gas sensor. When the user performs a sensor reading, the software system designed by Libelium reads the sensor signal and the 2 parameters. All these 3 values are processed by the system. After this, a **temperature compensation calculation** is applied too. From this data we obtain the concentration value in ppm’s (which is the final value we want to measure).

The Temperature, Humidity and Pressure sensor for Gases PRO is calibrated in factory too. There are 3 calibration points for temperature, 6 points for humidity and 9 points for pressure. These 3 parameters are automatically inter-compensated and this way the user gets extreme accuracy.

5. Hardware

5.1. Gases PRO Sensor Board

5.1.1. General description

The Waspmote Gases PRO v3 Sensor Board has been designed to monitor environmental parameters such as temperature, humidity, pressure, particle matter in the air (dust) and 16 different types of gases. It allows the inclusion of 6 AFE (Analog Front End) modules at the same time (4 in Plug & Sense!).

An AFE module is composed of one round AFE board and one cylindrical sensor. Each AFE board is ready to manage the installed gas sensor and to perform the conversion from a voltage or current signal to a digital value. Also, an EEPROM (non-volatile memory) stores the basic data for the sensor such as kind of gas sensor, sensitivity or baseline. This allows to the user to plug the AFE module in the available sockets of the Gases PRO Sensor Board and program Waspmote easily.

Each AFE module has been programmed and calibrated for a unique gas sensor. Each AFE module contains the specific calibration parameters for the sensor unit it is attached to, so changing the AFE boards between sensors will cause that the sensor reads wrong values. It can even damage the sensor. **So, changing the AFE boards between gas sensors is forbidden. Just do NOT separate the AFE board + sensor couples.**

The gases which can be monitored are:

- Carbon Monoxide – CO
- Carbon Dioxide – CO_2
- Molecular Oxygen – O_2
- Ozone – O_3
- Nitric Oxide – NO
- Nitric Dioxide – NO_2
- Sulfur Dioxide – SO_2
- Ammonia – NH_3
- Methane and other combustible gases – CH_4
- Molecular Hydrogen – H_2
- Hydrogen Sulfide – H_2S
- Hydrogen Chloride – HCl
- Hydrogen Cyanide – HCN
- Phosphine – PH_3
- Ethylene Oxide – ETO
- Chlorine – Cl_2

5.2. 3-electrode AFE board

5.2.1. General description

This AFE board has been developed to manage a 3-electrode electrochemical gas sensor, store the specific parameters of the sensor in its EEPROM (non-volatile memory) and perform a measure using its ADC.

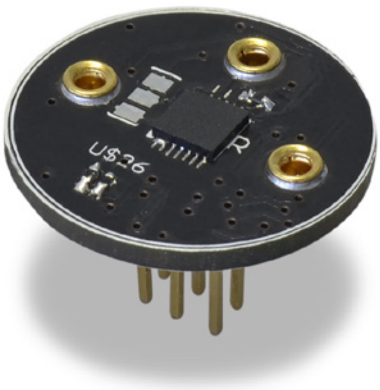


Figure: 3-electrode AFE board

The gases which use the 3-electrode AFE board are:

- Carbon Monoxide for high concentrations – CO
- Molecular Oxygen – O_2
- Ammonia – NH_3
- Molecular Hydrogen – H_2
- Hydrogen Sulfide – H_2S
- Hydrogen Chloride – HCl
- Hydrogen Cyanide – HCN
- Phosphine – PH_3
- Ethylene Oxide – ETO
- Chlorine – Cl_2

As the EEPROM stores the parametric characteristics of a specific sensor, **AFE boards must NOT be interchanged between sensors**.

5.2.2. How to plug

To plug the 3-electrode AFE board into the Gases PRO Sensor Board, white marks must be facing to the right side of the board.

Figure: Bottom view of a 3-electrode AFE board

Figure: Connection of a 3-electrode AFE board

Be careful connecting the 3-electrode AFE board. If the AFE board is connected wrong, the sensor and the AFE board could be damaged.

5.3. 4-electrode AFE board

5.3.1. General description

This AFE board has been developed to manage a 4-electrode electrochemical gas sensor, store the specific parameters of the sensor and the board into its EEPROM (non-volatile memory) and perform a measure using its ADC.

A 4-electrode electrochemical gas sensor works as a 3-electrode gas sensor. Counter, reference and working electrode are used normally to set the bias voltage and generate the current. The fourth electrode, commonly called auxiliary electrode, works as an extra working electrode and it is used to compensate the variations produced by the temperature in the baseline current and get a better gas accuracy. The compensation will be performed automatically by the API library.

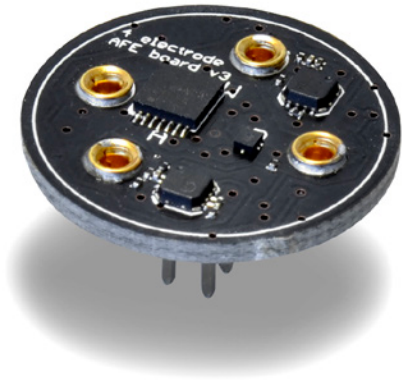


Figure: 4-electrode AFE board

The gases which use 4-electrode AFE board are:

- Ozone – O_3
- Carbon Monoxide for low concentrations – CO
- Nitric Oxide for low concentrations - NO
- Nitric Dioxide high accuracy – NO_2
- Sulfur Dioxide high accuracy – SO_2

5.3.2. How to plug

To plug the 4-electrode AFE board into the Gases PRO Sensor Board the white marks must be facing to the right side of the board.

Figure: Bottom view of a 4-electrode AFE board

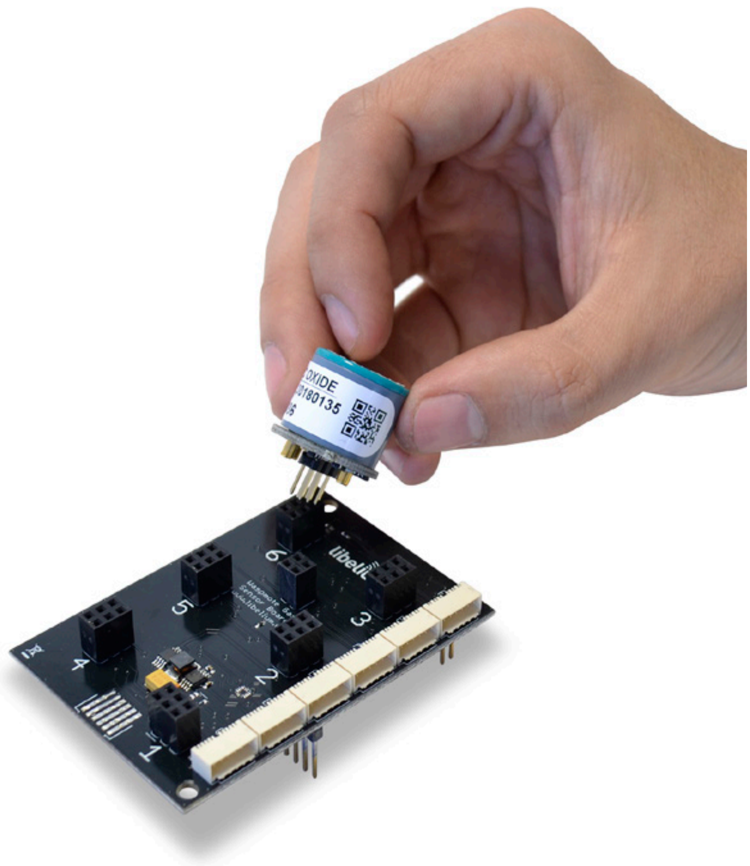


Figure: Connection of a 4-electrode AFE board

Be careful connecting the 4-electrode AFE board. If the AFE board is connected wrong, the sensor and the AFE board could be damaged.

5.4. Pellistor/NDIR AFE board

5.4.1. General description

The pellistor/NDIR AFE board has been developed to manage a pellistor gas sensor or an NDIR sensor, store the specific parameters of the sensor and the board into the EEPROM (non-volatile memory) and perform a measure using an ADC.

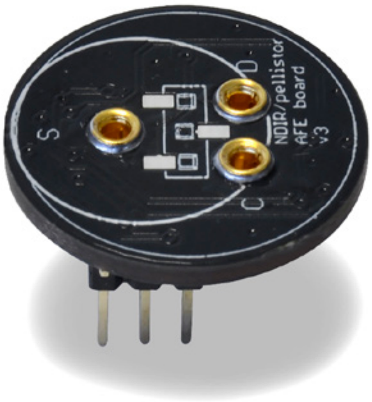


Figure: AFE board for pellistor and NDIR

The gases which use pellistor AFE board are:

- Methane and other combustible gases – CH_4
- Carbon Dioxide – CO_2

5.4.2. How to plug

To plug the pellistor/NDIR AFE board into the Gases PRO Sensor Board the white marks must be facing inside of the board.

Figure: Bottom view of a pellistor/NDIR AFE board

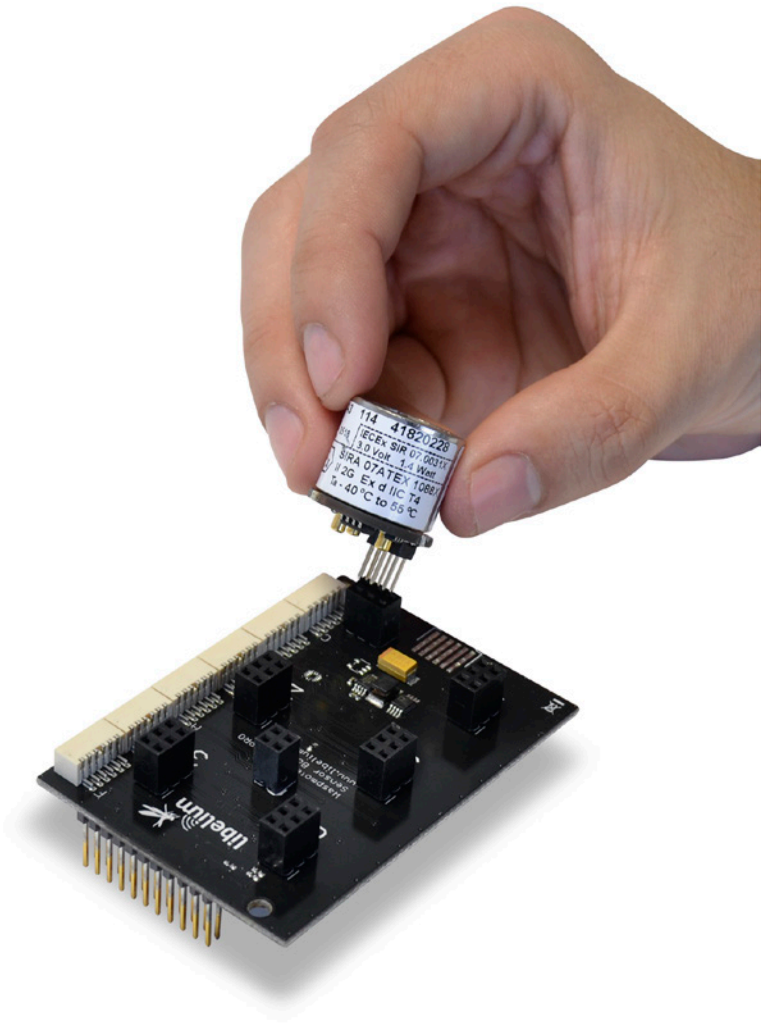


Figure: Connection of a pellistor/NDIR AFE board

Be careful connecting the pellistor/NDIR AFE board. If the AFE board is connected wrong, the sensor and the AFE board could be damaged.

5.5. Specifications

All the available sensors are connected to Waspmote through the “mother board”, the Gases PRO Sensor Board.

Weight: 20 g

Dimensions: 73.5 x 51 x 22 mm (without sensors)

Tª range: [-20 ºC, 65 ºC]

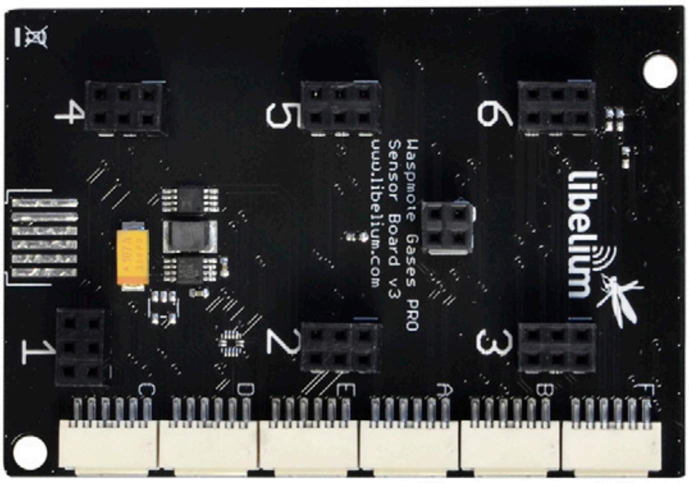


Figure: Top side of the Gases PRO Sensor Board

Sensors compatibility:

- The CH_4 and Combustible Gases Sensor AFE, and the CO_2 Sensor AFE can only use socket 1, so the total number of these sensors per board is limited to 1
- The central socket is reserved for the BME280 sensor (Temperature, humidity and pressure Sensor)
- The rest of the sensors can use all sockets

Electrical characteristics:

- **Board power voltage:** 3.3 V and 5 V
- **Sensor power voltage**: Gas sensors and BME280, 3.3 V. Particles-dust sensor, 3.3 V and 5 V
- **Maximum admitted current (continuous):** 200 mA
- **Maximum admitted current (peak):** 400 mA

6. Sensors

6.1. Starting with the gas sensors

In this section we are going to explain the first steps to start with the sensors used in the Gases PRO Sensor Board.

6.1.1. Important notes for Calibrated Sensors

1º - Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. Manufacturing process and delivery may take from 4 to 6 weeks.

2º - Lifetime of calibrated gas sensors is 6 months working at its maximum accuracy as every sensor looses a small percentage of its original calibration monthly in a range that may go from 0.5% to 2%. We strongly encourage our customers to buy extra gas sensor probes to replace the originals after that time to ensure maximum accuracy and performance. Any sensor should be understood as a disposable item; that means that after some months it should be replaced by a new unit.

3º - Electrochemical calibrated gas sensors are a good alternative to the professional metering gas stations however they have some limitations. The most important parameters of each sensor are the nominal range and the accuracy. If you need to reach an accuracy of ±0.1 ppm remember not to choose a sensor with an accuracy of ±1 ppm. Take a look in the chapter dedicated to each sensor in the Gases PRO Guide (Development section on the Libelium website). We show a summary table at the end of the current document for quick reference.

4º - Libelium indicates an accuracy for each sensor just as an **ideal reference** (for example, "±0.1 ppm"). This theoretical figure has been calculated as the best error the user could expect, the optimum case. In real conditions, the measurement error **may be bigger** (for example, "±0.3 ppm"). The older the sensor is, the more deteriorated it is, so the accuracy gets worse. Also, the more extreme the concentration to meter is, the worse the accuracy is. And also, the more extreme the environmental conditions are, the quicker the sensor decreases its accuracy.

5º - In order to increase the accuracy and reduce the response time we strongly recommend to keep the gas sensor board ON as electrochemical sensors have a very low consumption (less than 1 mA). So these sensors should be left powered ON while Waspmote enters into deepsleep mode. Latest code examples implement in the new API of Waspmote v15 follow this strategy. If you are using the old version of the API and boards (v12) write in our Forum and we will help you to modify your code.

6º - These sensors need a stabilization time to work properly, in some cases hours. We recommend wait 24hours of functioning (always with the gas sensor board ON) to ensure that the values of the sensors are stable.

7º - AFE boards for electrochemical gas sensors have different gain options. The system integrator must choose the adequate gain according to the concentration range to measure. For low concentrations, higher gains are recommended. To know how choosing the right gain, see the chapter "How to choose the right gain resistor" from the Gases PRO Guide.

8º - A digital smoothing filter based on previous values is interesting to reduce noise. It will increase the accuracy of the gases PRO sensors. The filter adequate for its application (note that every sample given by the library has already been filtered inside Waspmote) means from 4 to 8 values.

A simple moving average can be used to increase the accuracy and reduce the noise.

$$\text{Filtered value} = \frac{\text{sample}_t + \text{sample}_{t-1} + \text{sample}_{t-2} + \ldots + \text{sample}_{t-(n-1)}}{n}$$

Where:

- Filtered value are the concentration value with the mean filter applied
- sample are the measurements taken by the gas sensors being $sample_t$ the last measurement, $sample_{t-1}$ the penultimate measurement, etc
- *n* are the number of samples to calculate the moving mean

Other filters can be applied according to the project requirements.

9º - Take into account that developing a robust application for gases detection or measurement may take an important effort of testing and knowing the insights of the sensor probes and code that reads them.

Calibrated Gas Table

Parameter	Range	Calibration	Max consumption
Temperature	-40 to +85 ºC	Calibrated ±1 ºC (±0.5 ºC at 25 ºC)	2 µA @ 3V3
Humidity	0 to 100% HR	Calibrated ±3% RH (at 25 ºC, range 20 ~ 80% RH)	2.8 µA @ 3V3
Pressure	30 to 110 kPa	Calibrated ±0.1 kPa (range 0 ~ 65 ºC)	4.2 µA @ 3V3
Carbon Monoxide for high concentrations CO	0 to 500 ppm	Calibrated ±1 ppm	351 µA @ 3V3
Carbon Monoxide for low concentrations CO	0 to 25 ppm	Calibrated ±0.1 - 0.7 ppm	312 µA @ 3V3
Carbon Dioxide CO_2	0 to 5000 ppm	Calibrated ±50 ppm (range 0~2500 ppm) ±200 ppm (range 2500~5000 ppm)	85 mA @ 3V3
Molecular Oxygen O_2	0 to 30%	Calibrated ±0.1%	402 µA @ 3V3
Ozone O_3	0 to 18 ppm	Calibrated ±0.2 - 0.7 ppm	< 1 mA @ 3V3
Nitric Oxide for low concentrations NO	0 to 18 ppm	Calibrated ±0.2 - 0.5 ppm	392 µA @ 3V3
Nitric Dioxide NO_2 high accuracy	0 to 20 ppm	Calibrated ±0.1- 0.2 ppm	330 µA @ 3V3
Sulfur Dioxide SO_2 high accuracy	0 to 20 ppm	Calibrated ±0.1 - 0.4 ppm	333 µA @ 3V3
Ammonia for low concentrations NH_3	0 to 100 ppm	Calibrated ±0.5 ppm	338 µA @ 3V3

Ammonia for high concentrations NH_3	0 to 500 ppm	Calibrated ±3 ppm	338 µA @ 3V3
Methane and other combustible gases CH_4	0 to 100% / LEL	Calibrated ±0.15% LEL	68 mA @ 3V3
Molecular Hydrogen H_2	0 to 1000 ppm	Calibrated ±10 ppm	520 µA @ 3V3
Hydrogen Sulfide H_2S	0 to 100 ppm	Calibrated ±0.1 ppm	352 µA @ 3V3
Hydrogen Chloride HCl	0 to 50 ppm	Calibrated ±1 ppm	341 µA @ 3V3
Hydrogen Cyanide HCN	0 to 50 ppm	Calibrated ±0.2 ppm	327 µA @ 3V3
Phosphine PH_3	0 to 20 ppm	Calibrated ±0.1 ppm	361 µA @ 3V3
Ethylene Oxide ETO	0 to 100 ppm	Calibrated ±1 ppm	360 µA @ 3V3
Chlorine Cl_2	0 to 50 ppm	Calibrated ±0.1 ppm	353 µA @ 3V3
Particle Matter – Dust	0.5 to 16 µm (16 steps) (includes PM1, PM2.5 and PM10)	Calibrated	200+ mA @ 5 V

Comparative between Libelium HW with Alphasense sensors and Alphasense HW with Alphasense sensors

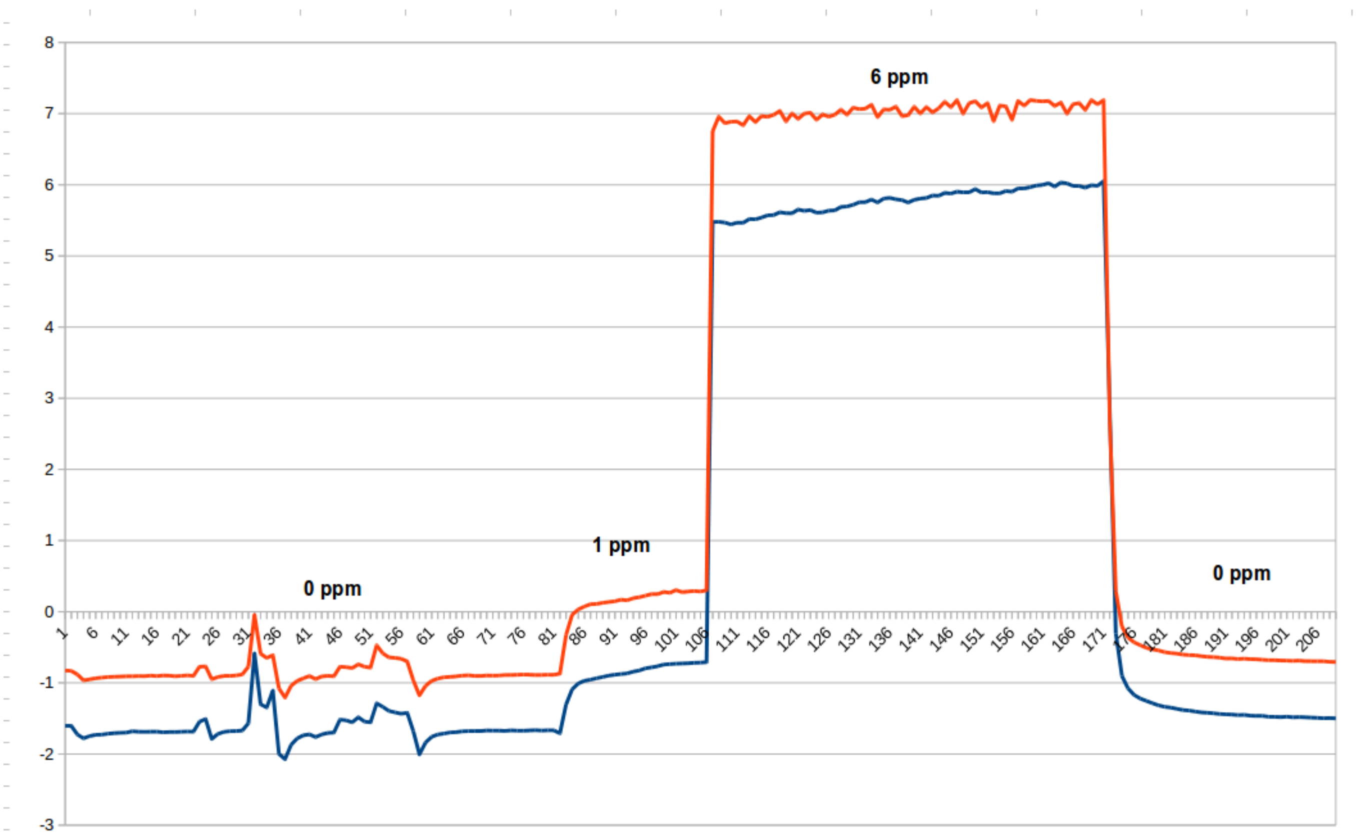
1. Ozone

Sensor 1 – Alphasense (blue)

Real Input (ppm)	Medium Measured Value (ppm)	Error (ppm)
0 ppm	-1,641	1,641
1 ppm	-0,815	1,815
6 ppm	5,77	0,221

Sensor 2 – Libelium (red)

Real Input (ppm)	Medium Measured Value	Error
0 ppm	-0,861	0,861
1 ppm	0,210	0,789
6 ppm	7,039	1,039



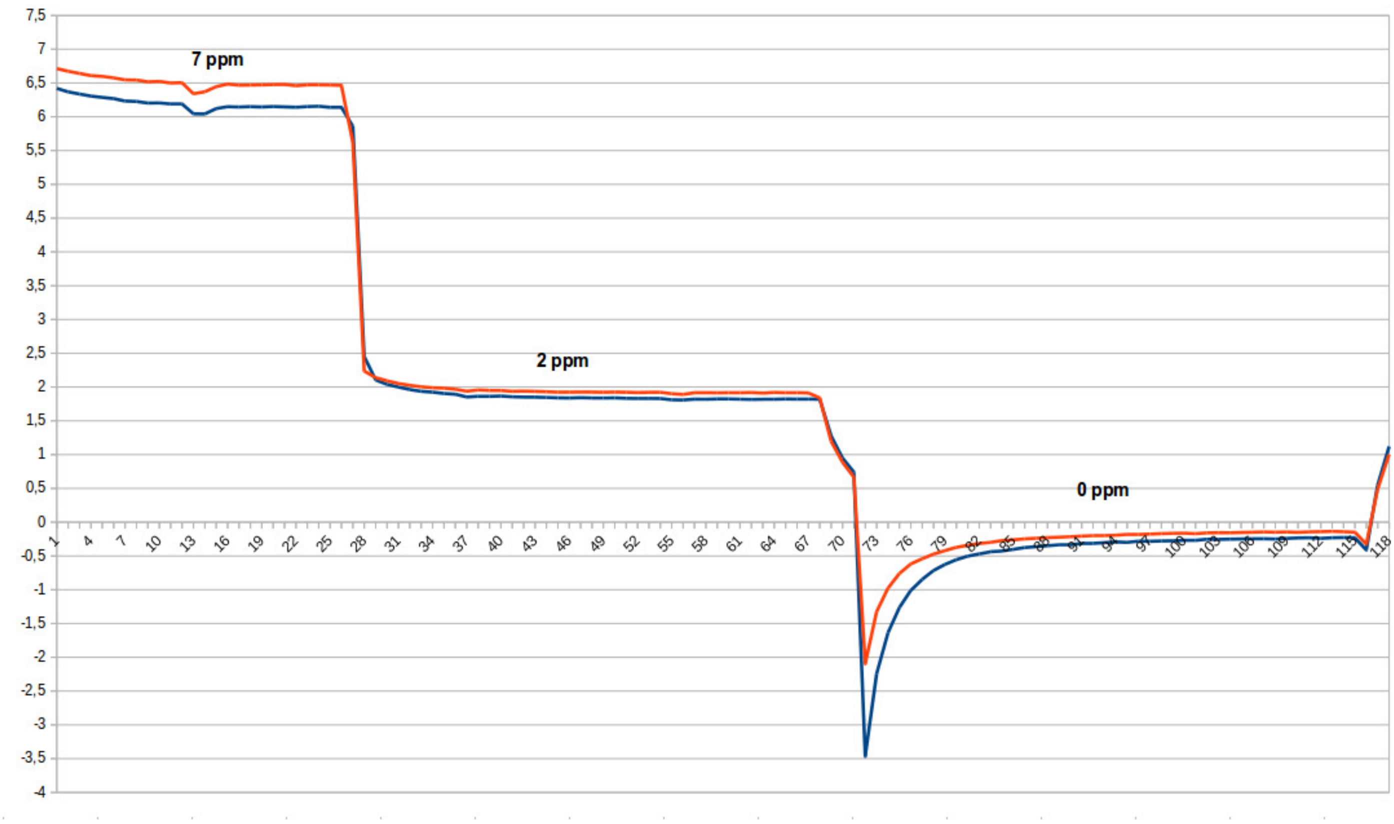
2. NO

Sensor 1 – Alphasense (blue)

Real Input (ppm)	Medium Measured Value (ppm)	Error (ppm)
7 ppm	6,182	0,818
2 ppm	1,840	0,160
0 ppm	-0,4098	0,4098

Sensor 2 – Libelium (red)

Real Input (ppm)	Medium Measured Value (ppm)	Error (ppm)
7 ppm	6,478	0,521
2 ppm	1,919	0,08
0 ppm	-0,260	0,260



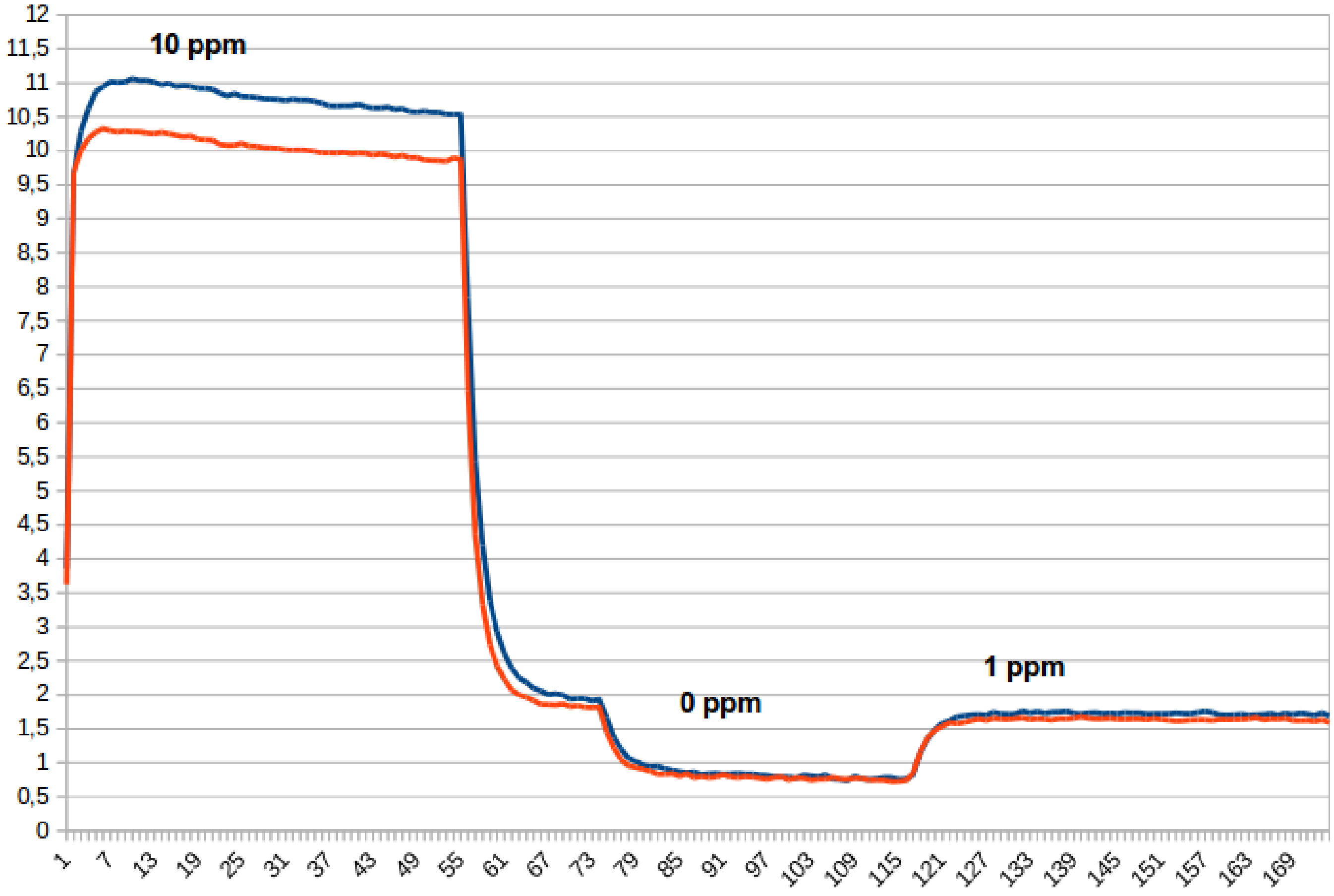
3. CO

Sensor 1 – Alphasense (blue)

Real Input (ppm)	Medium Measured Value (ppm)	Error (ppm)
10 ppm	10,76	-0,766
0 ppm	0,826	-0,826
1 ppm	1,718	-0,718

Sensor 2 – Libelium (red)

Real Input (ppm)	Medium Measured Value (ppm)	Error (ppm)
10 ppm	10,66	-0,066
0 ppm	0,790	-0,790
1 ppm	1,636	-0,636



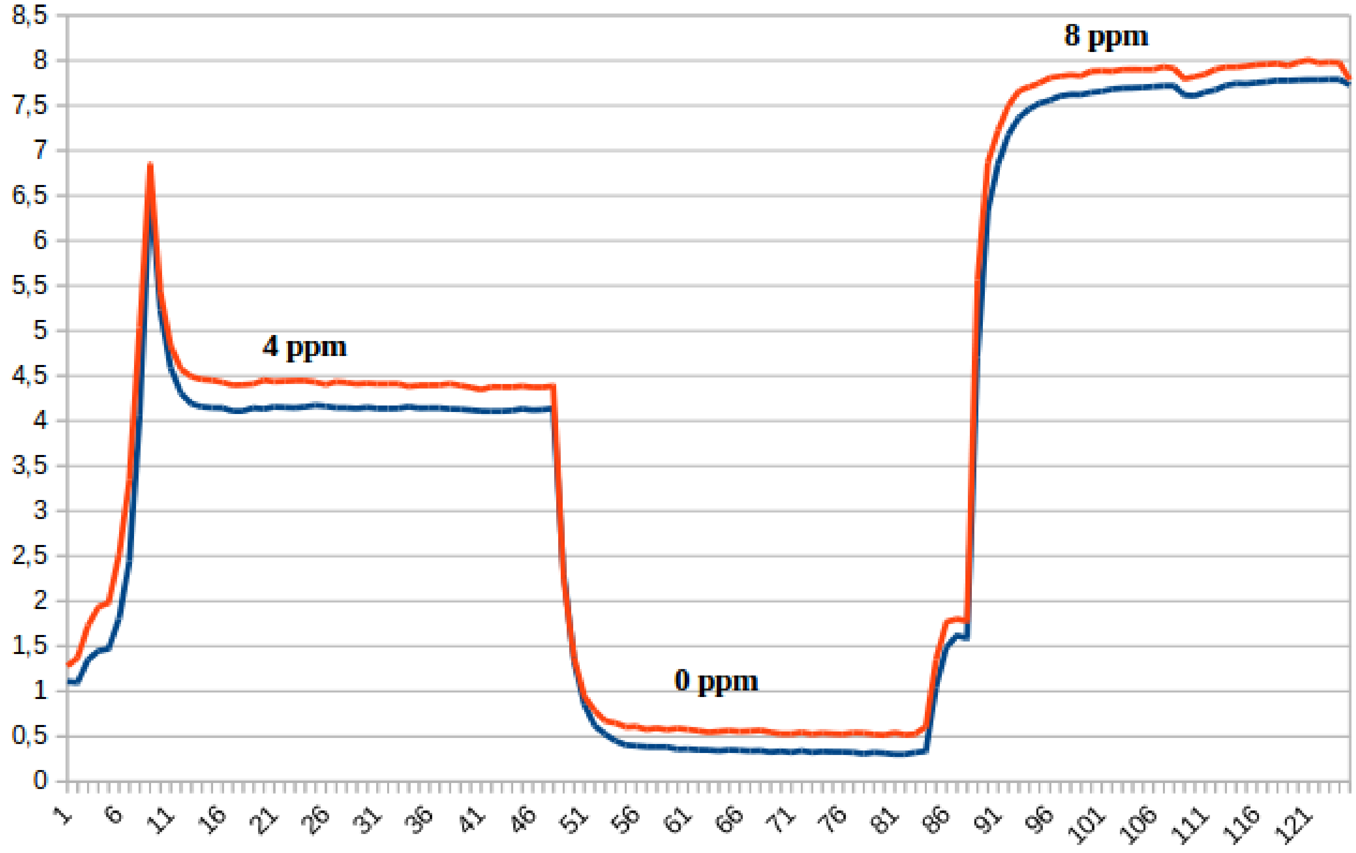
4. SO2

Sensor 1 – Alphasense (blue)

Real Input (ppm)	Medium Measured Value (ppm)	Error (ppm)
4 ppm	4,183	-0,183
0 ppm	0,373	-0,373
8 ppm	7,85	0,146

Sensor 2 – Libelium (red)

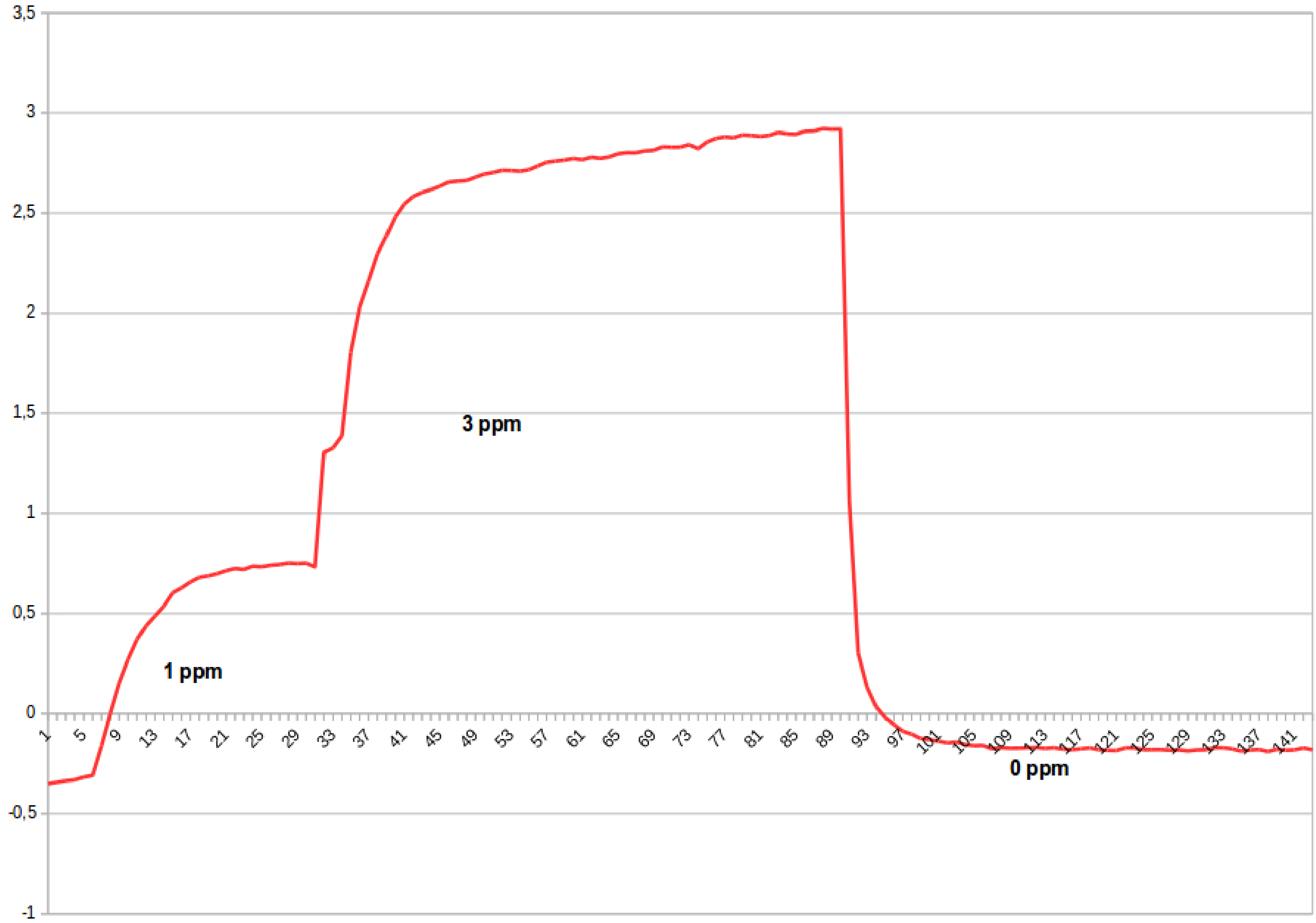
Real Input (ppm)	Medium Measured Value (ppm)	Error (ppm)
4 ppm	4,451	-0,451
0 ppm	0,5779	-0,5779
8 ppm	7,641	0,358



5. NO2

Sensor 1 – Libelium (red)

Real Input (ppm)	Medium Measured Value (ppm)	Error (ppm)
1	0,721	0,278
3	2,776	0,223
0	-0,163	0,163



6.1.2. Understanding the basics of electrochemical sensors

Gas sensors (except the combustible gases sensor and the CO_2 sensor) are electrochemical cells that operate in the amperometric mode. That is, they generate a current that is linearly proportional to the fractional volume of the target gas. These sensors are composed by three metal strips connecting each electrode to the three pins outside of the sensor body and a cell electrolyte. Each electrode have its own specific function:

- Working electrode reacts with the target gas to generate a current
- Counter electrode supplies a current that balances that generated by the working electrode current
- Reference electrode sets the operating potential (bias voltage) of the working electrode

The cell electrolyte provides ionic electrical contact between the electrodes.

To convert the current generated by the working electrode in a voltage for the ADC, the AFE module uses a transimpedance stage with a selectable gain resistor.

The bias voltage is managed by the AFE module and it is automatically fixed by the sensor parameters stored into the EEPROM. **These sensors use the 3-electrode AFE board.**

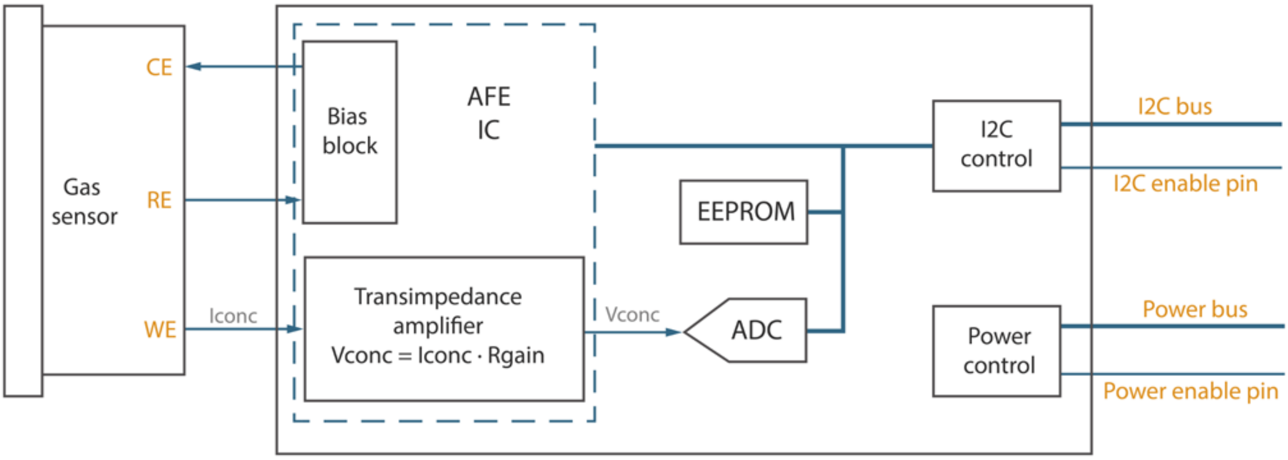


Figure: 3-electrode AFE module diagram block

The Ozone, Nitric Oxide (low concentrations), Nitric Dioxide (high accuracy) and Sulphur Dioxide (high accuracy) sensors have a fourth electrode. This electrode, commonly called auxiliary electrode, works as an extra working electrode and it is used to compensate the variations produced by the temperature in the baseline current. The compensation will be performed automatically by the API library. **These sensors use the 4-electrode AFE board.**

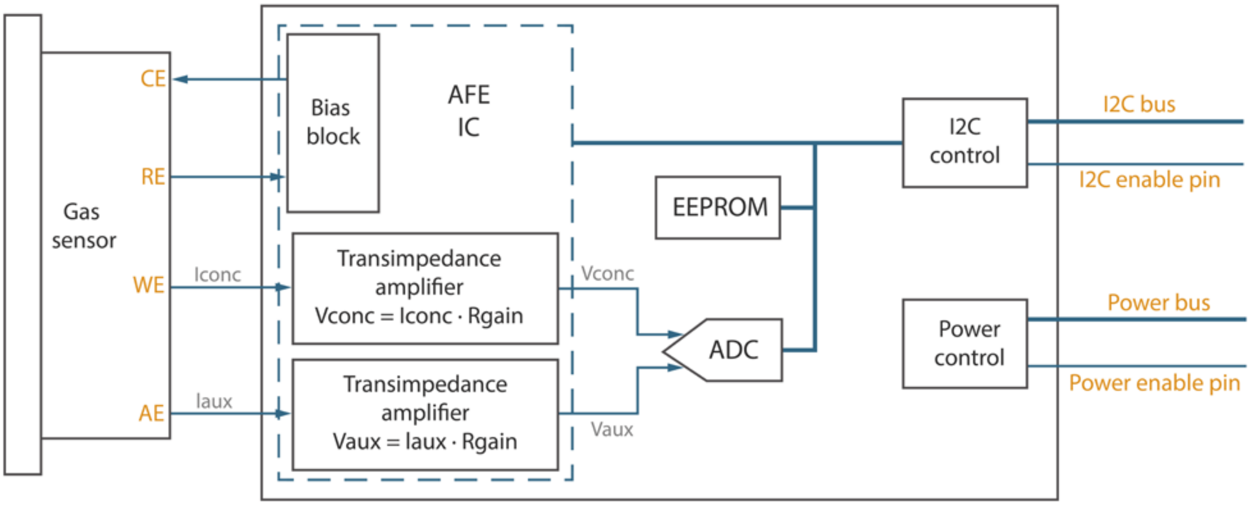


Figure: 4-electrode AFE module diagram block

Electrochemical sensors have a very low consumption (less than 1 mA) so, to increase the accuracy and reduce the response time, these sensors can keep powered while Waspmote enters into deepsleep mode.

These sensors needs a stabilization time to work properly, in some cases hours. It implies that the first reads of the sensors may have an offset level.

Electrochemical sensors have a very low consumption (less than 1 mA) so, to increase the accuracy and reduce the response time, these sensors can keep powered while Waspmote enters into deepsleep mode.

These sensors needs a stabilization time to work properly, in some cases hours. It implies that the first reads of the sensors may have an offset level.

6.1.3. Understanding the combustible gas sensor

The CH_4 and combustible gases sensor uses the pellistor technology to detect the gas concentration. A pellistor consists of a very fine coil of platinum wire, embedded within a ceramic pellet. On the surface of the pellet there is a layer of a high surface area noble metal, which, when hot, acts as a catalyst to promote exothermic oxidation of flammable gases. In operation, the pellet and so the catalyst layer is heated by passing a current through the underlying coil. In the presence of a flammable gas or vapour, the hot catalyst allows oxidation to occur in a similar chemical reaction to combustion. Just as in combustion, the reaction releases heat, which causes the temperature of the catalyst together with its underlying pellet and coil to rise. This rise in temperature results in a change in the electrical resistance of the coil, and it is this change in electrical resistance which constitutes the signal from the sensor.

Pellistors are always manufactured in pairs, the active catalyzed element being supplied with an electrically matched element which contains no catalyst and is treated to ensure no flammable gas will oxidize on its surface. This “compensator” element is used as a reference resistance to which the sensor’s signal is compared, to remove the effects of environmental factors other than the presence of a flammable gas. In the case of the CH-A3 gas sensor from Alphasense, detector and compensator are inside the same encapsulated. One pin of the each resistor are connected to a pin of the encapsulated. The other pins are connected together inside the sensor to the signal pin.

The AFE module fixes the supply voltage to the resistors and reads the voltage of the signal pin. **This sensor uses the pellistor/NDIR AFE board**.

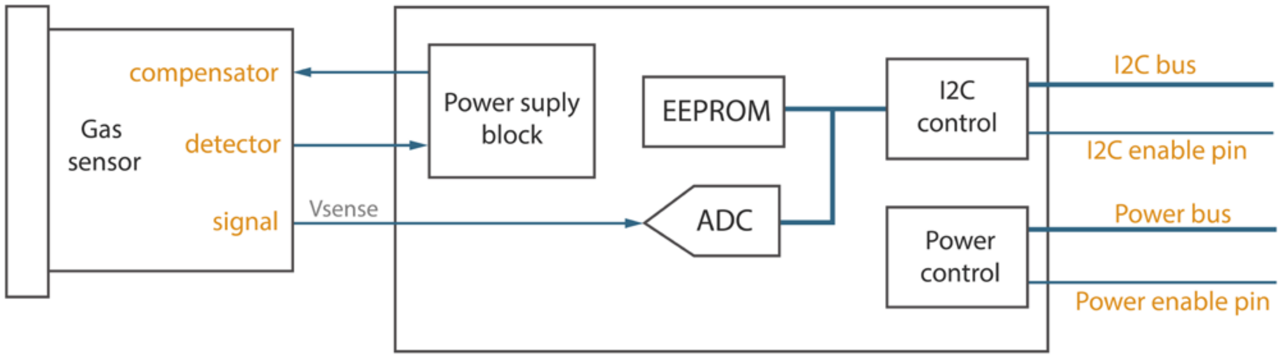


Figure: CH_4 and Combustible Gases Sensor AFE module diagram block

6.1.4. Understanding the CO_2 sensor

The IR series of infrared gas detection sensors use the technique of NDIR (Non Dispersive Infrared) to monitor the presence of hydrocarbons or carbon dioxide. This technique is based on the fact that the gas has a unique and well defined light absorption curve in the infrared spectrum that can be used to identify the specific gas. The gas concentration can be determined by using a suitable infrared source and analyzing the optical absorption of the light that passes through the gas. The IRSS-E sensor contains the same optics as the related and simpler model IRSS-X, but is also equipped with incorporated electronics and software in order to provide an output that is linearized and temperature compensated.

In the standard version of IRSS-E, the sensor provides a linearized and temperature compensated analogue voltage output that is proportional to the gas concentration. The AFE module sets the supply voltage and reads the voltage of the signal pin. **This sensor uses the pellistor/NDIR AFE board**.

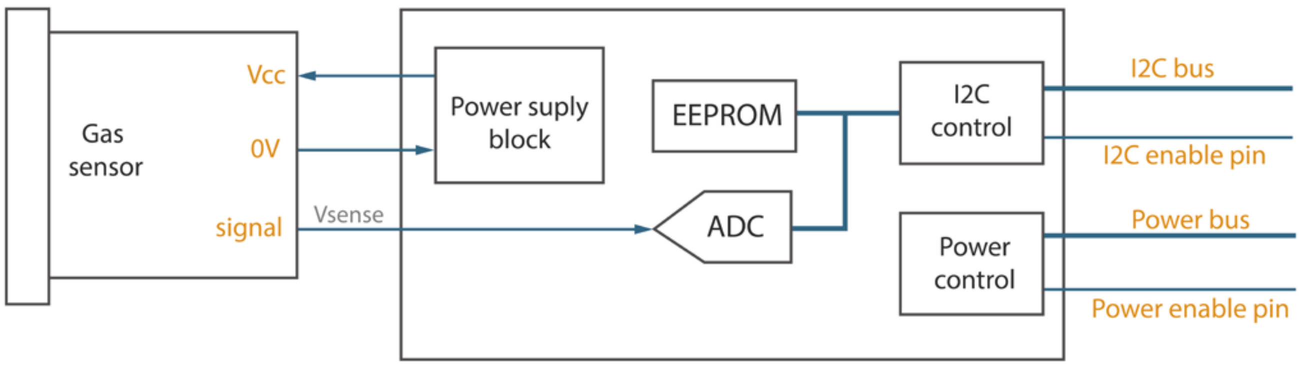


Figure: NDIR AFE module diagram block

6.1.5. Lifetime of the Gas sensors

All sensors provided by Libelium for the Gases PRO Sensor Board have been calibrated in the origin factory by the manufacturer. Calibration parameters are stored inside the EEPROM (non-volatile memory) of each AFE board for a unique gas sensor. Thus, changing the AFE boards between gas sensors is forbidden.

The **maximum accuracy for each sensor is valid only for 6 months**. Every sensor loses a small percentage of its original calibration monthly in a range that may go from 0.5% to 2%.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. Manufacturing process and delivery may **take from 4 to 6 weeks.** Lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers **to buy extra gas sensor probes to replace the originals** after that time to ensure maximum performance.

Libelium indicates an accuracy for each sensor just as an ideal reference (for example, "±50 ppm"). This theoretical figure has been calculated as the best error the user could expect, the optimum case. In real conditions, the measurement error will be bigger (for example, "±90 ppm"). As stated before, the older the sensor is, the more deteriorated it is, so the accuracy gets worse. Also, the more extreme the concentration to meter is, the worse the accuracy is. And also, the more extreme the environmental conditions are, the quicker the sensor ages.

The sensors have been tested at 20 ºC / 101300 Pa. Cross sensitivity gases are not target gases. Relation can change with aging. The cross sensitivity may fluctuate between +/- 30% and may differ from batch to batch or from sensor's lifetime. The cross sensitivities are including but not limited to the gases from the tables. It may also respond to other gases.

The data offered solely for consideration, investigation, and verification. Any use of these data and information must be determined by the user to be in accordance with federal, state, and local laws and regulations. Specifications are subject to change without notice.

6.2. Temperature, Humidity and Pressure sensor

The BME280 is a digital temperature, humidity and pressure sensor developed by Bosch Sensortec.

6.2.1. Specifications

Figure: Image of the Temperature, Humidity and Pressure sensor

Electrical characteristics:
Supply voltage: 3.3 V
Sleep current typical: 0.1 µA
Sleep current maximum: 0.3 µA

Temperature sensor:
Operational range: -40 ~ +85 ºC
Full accuracy range: 0 ~ +65 ºC
Accuracy: ±1 ºC (range 0 ºC ~ +65 ºC)
Response time: 1.65 seconds (63% response from +30 to +125 °C)
Typical consumption: 1 µA measuring

Humidity sensor:
Measurement range: 0 ~ 100% of Relative Humidity (for temperatures < 0 °C and > 60 °C see figure below)
Accuracy: < ±3% RH (at 25 ºC, range 20 ~ 80%)
Hysteresis: ±1% RH
Operating temperature: -40 ~ +85 ºC
Response time (63% of step 90% to 0% or 0% to 90%): 1 second
Typical consumption: 1.8 µA measuring
Maximum consumption: 2.8 µA measuring

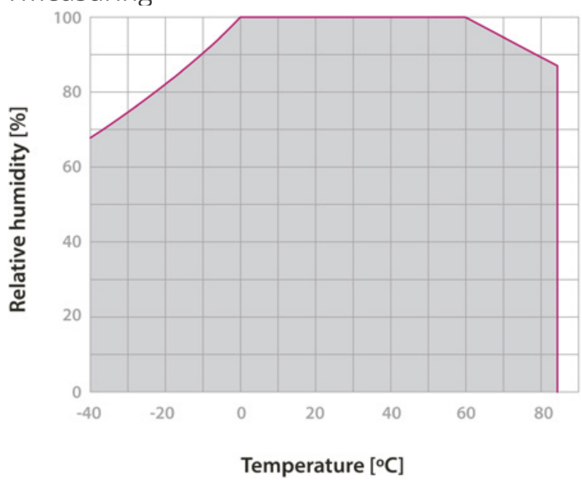


Figure: Humidity sensor operating range

Pressure sensor
Measurement range: 30 ~ 110 kPa
Operational temperature range: -40 ~ +85 ºC
Full accuracy temperature range: 0 ~ +65 ºC
Absolute accuracy: ±0.1 kPa (0 ~ 65 ºC)
Typical consumption: 2.8 µA measuring
Maximum consumption: 4.2 µA measuring

You can find a complete example code for reading the Temperature, Humidity and Pressure sensor in the following link:
http://www.libelium.com/development/waspmote/examples/gp-v30-05-temperature-humidity-and-pressure-sensor

6.3. Carbon Monoxide (CO) Gas Sensor for high concentrations [Calibrated]

6.3.1. Specifications

Gas: CO
Sensor: 4-CO-500

Figure: Image of the Carbon Monoxide Sensor for high concentrations mounted on its AFE module

__Performance Characteristics__
Nominal Range: 0 to 500 ppm
Maximum Overload: 2000 ppm
Long Term Output Drift: < 2% signal/month
Response Time (T90): ≤ 30 seconds
Sensitivity: 70 ± 15 nA/ppm
Accuracy: as good as ±1 ppm* (ideal conditions)

__Operation Conditions__
Temperature Range: -20 ºC to 50 ºC
Operating Humidity: 15 to 90% RH non-condensing
Pressure Range: 90 to 110 kPa
Storage Temperature: 0 ºC to 20 ºC
Expected Operating Life: 5 years in air

Sockets for Waspmote OEM:
- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. See the "Calibration" chapter for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.3.2. Cross-sensitivity data

Gas	Formula	Concentration (ppm)	Output Signal (ppm CO equivalent)
Hydrogen Sulfide	H_2S	24	0
Sulfur Dioxide	SO_2	5	0
Chlorine	Cl_2	10	0-1
Nitric Oxide	NO	25	0
Nitric Dioxide	NO_2	5	0
Hydrogen	H_2	100	40
Ethylene	C_2H_4	100	16

Figure: Cross-sensitivity data for the CO Sensor for high concentrations

You can find a complete example code for reading the CO Sensor for high concentrations in the following link: http://www.libelium.com/development/waspmote/examples/gp-v30-01-electrochemical-gas-sensors

6.4. Carbon Monoxide (CO) Gas Sensor for low concentrations [Calibrated]

6.4.1. Specifications

Figure: Image of the Carbon Monoxide Sensor for low concentrations mounted on its AFE module

Gas: CO
Sensor: CO-A4

<u>**Performance Characteristics**</u>
Nominal Range: 0 to 25 ppm
Maximum Overload: 2000 ppm
Long Term Sensitivity Drift: < 10% change/year in lab air, monthly test
Long Term zero Drift: < ±100 ppb equivalent change/year in lab air
Response Time (T90): ≤ 20 seconds
Sensitivity: 220 to 375 nA/ppm
Accuracy: as good as ±0.1 ppm* (ideal conditions)
H2S filter capacity: 250000 ppm·hrs

<u>**Operation Conditions**</u>
Temperature Range: -30 ºC to 50 ºC
Operating Humidity: 15 to 90% RH non-condensing
Pressure Range: 80 to 120 kPa
Storage Temperature: 0 ºC to 20 ºC
Expected Operating Life: 3 years in air

Sockets for Waspmote OEM:
- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. See the "Calibration" chapter in the Gases PRO Technical Guide for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.4.2. Cross-sensitivity data

Gas	Formula	Concentration (ppm)	Output signal (ppm CO equivalent)
Hydrogen Sulfide	H_2S	5	< 0.1
Nitric Dioxide	NO_2	5	< -2
Chlorine	Cl_2	5	< 0.1
Nitric Oxide	NO	5	< -2
Sulfur Dioxide	SO_2	5	< 0.1
Hydrogen	H_2	100	< 10
Ethylene	C_2H_4	100	< 0.5
Ammonia	NH_3	20	< 0.1

Figure: Cross-sensitivity data for the CO Sensor for low concentrations

You can find a complete example code for reading the CO Sensor for low concentrations in the following link: http://www.libelium.com/development/waspmote/examples/gp-v30-01-electrochemical-gas-sensors

6.5. Carbon Dioxide (CO_2) Gas Sensor [Calibrated]

6.5.1. Specifications

Gas: CO_2
Sensor: INE20-CO2P-NCVSP

Figure: Image of the Carbon Dioxide Sensor mounted on its AFE module

Performance Characteristics
Nominal Range: 0 to 5000 ppm
Long Term Output Drift: < ± 250 ppm/year
Warm up time: 60 seconds @ 25 °C
At least 30 min for full specification @ 25 °C
Response Time (T90): ≤ 60 seconds
Resolution: 25 ppm
Accuracy: as good as ±50 ppm*, from 0 to 2500 ppm range (ideal conditions)
as good as ±200 ppm*, from 2500 to 5000 ppm range (ideal conditions)

Operation Conditions
Temperature Range: -40 °C to 60 °C
Operating Humidity: 0 to 95% RH non-condensing
Storage Temperature: -40 °C to 85 °C
MTBF: ≥ 5 years

Sockets for Waspmote OEM:
- SOCKET_1

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: 80 mA

> ***Note:*** *The CO_2 Sensor and the Methane (CH_4) and Combustible Gas Sensor have high power requirements and cannot work together in the same Gases PRO Sensor Board. The user must choose one or the other, but not both.*

** Accuracy values are only given for the **optimum case**. See the "Calibration" chapter for more detail.*

> *Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.*

You can find a complete example code for reading the CO_2 Sensor in the following link:
http://www.libelium.com/development/waspmote/examples/gp-v30-02-ndir-gas-sensors

6.6. Molecular Oxygen (O_2) Gas Sensor [Calibrated]

6.6.1. Specifications

Gas: O_2
Sensor: 4-OL

Figure: Image of the Molecular Oxygen Sensor mounted on its AFE module

Performance Characteristics
Nominal Range: 0 to 30 Vol.%
Maximum Overload: 90 Vol.%
Long Term Output Drift: < 2% signal/3 months
Response Time (T90): ≤ 30 seconds
Sensitivity: 1.66 ± 0.238 nA/ppm
Accuracy: as good as ± 0.1% (ideal conditions)

Operation Conditions
Temperature Range: -20 ºC to 50 ºC
Operating Humidity: 5 to 90% RH non-condensing
Pressure Range: 90 to 110 kPa
Storage Temperature: 0 ºC to 20 ºC
Expected Operating Life: 2 years in air

Sockets for Waspmote OEM:
- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA
** Accuracy values are only given for the **optimum case**. See the "Calibration" chapter for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

You can find a complete example code for reading the O_2 Sensor in the following link:
http://www.libelium.com/development/waspmote/examples/gp-v30-01-electrochemical-gas-sensors

6.7. Ozone (O_3) Gas Sensor [Calibrated]

6.7.1. Specifications

Gas: O_3
Sensor: OX-A431

Figure: Image of the Ozone Sensor mounted on its AFE module

Performance Characteristics
Nominal Range: 0 to 18 ppm
Maximum Overload: 50 ppm
Long Term sensitivity Drift: -20 to -40% change/year
Response Time (T90): ≤ 45 seconds
Sensitivity: -200 to -550 nA/ppm
Accuracy: as good as ±0.2 ppm* (ideal conditions)
High cross-sensitivity with NO_2 gas. Correction could be necessary in ambients with NO_2.

Operation Conditions
Temperature Range: -30 ºC to 40 ºC
Operating Humidity: 15 to 85 %RH non-condensing
Pressure Range: 80 to 120 kPa
Storage Temperature: 3 ºC to 20 ºC
Expected Operating Life: > 24 months in air

Sockets for Waspmote OEM:
- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA
** Accuracy values are only given for the **optimum case**. See the "Calibration" chapter in the Gases PRO Technical Guide for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.7.2. Cross-sensitivity data

Gas	Formula	Concentration (ppm)	% measured gas
Hydrogen Sulfide	H_2S	5	< -100
Nitric Dioxide	**NO_2**	**5**	**70 to 120**
Chlorine	Cl_2	5	< 30
Nitric Oxide	NO	5	< -3
Sulfur Dioxide	SO_2	5	< -6
Carbon Monoxide	CO	5	< 0.1
Hydrogen	H_2	100	< 0.1
Ethylene	C_2H_4	100	< 0.1
Ammonia	NH_3	20	< 0.1
Carbon Dioxide	CO_2	50000	< 0.1
Halothane	Halothane	100	< 0.1

Figure: Cross-sensitivity data for the O_3 Sensor

*This sensor has a **very high cross-sensitivity with NO_2 gas**. So, the output in ambients with NO_2 will be a mix of O_3 and NO_2. A simple way to correct this effect is to subtract NO_2 concentration from O_3 concentration with an NO_2 gas sensor. The measure from the NO_2 sensor must be accurate in order to subtract the right value. **See the related section in the "Library for gas sensors" chapter to use the right function.***

You can find a complete example code for reading the O_3 Sensor in the following link:
http://www.libelium.com/development/waspmote/examples/gp-v30-01-electrochemical-gas-sensors

6.8. Nitric Oxide (NO) Gas Sensor for high concentrations [Calibrated]

Note: This sensor was discontinued in March 2017. Its substitute is the Nitric Monoxide (NO) for low concentrations Gas Sensor [Calibrated]. The information about this alternative sensor can be found in the next section of this guide.

6.8.1. Specifications

Figure: Image of the Nitric Oxide Sensor for high concentrations mounted on its AFE module

Gas: NO
Sensor: 4-NO-250

<u>**Performance Characteristics**</u>
Nominal Range: 0 to 250 ppm
Maximum Overload: 1000 ppm
Long Term Output Drift: < 2% signal/month
Response Time (T90): ≤ 30 seconds
Sensitivity: 400 ± 80 nA/ppm
Accuracy: as good as ±0.5 ppm* (ideal conditions)

<u>**Operation Conditions**</u>
Temperature Range: -20 ºC to 50 ºC
Operating Humidity: 15 to 90% RH non-condensing
Pressure Range: 90 to 110 kPa
Storage Temperature: 0 ºC to 20 ºC
Expected Operating Life: 2 years in air

Sockets for Waspmote OEM:
- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA
** Accuracy values are only given for the* ***optimum case****. See the "Calibration" chapter for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.8.2. Cross-sensitivity data

Gas	Formula	Concentration (ppm)	Output signal (ppm NO equivalent)
Carbon Monoxide	CO	300	0
Sulfur Dioxide	SO_2	5	0
Nitric Dioxide	NO_2	5	1.5
Hydrogen Sulfide	H_2S	15	-1.5

Figure: Cross-sensitivity data for the NO Sensor for high concentrations

You can find a complete example code for reading the NO Sensor for high concentrations in the following link:
http://www.libelium.com/development/waspmote/examples/gp-v30-01-electrochemical-gas-sensors

6.9. Nitric Oxide (NO) Gas Sensor for low concentrations [Calibrated]

6.9.1. Specifications

Gas: NO
Sensor: NO-A4

Figure: Image of the Nitric Oxide Sensor for low concentrations mounted on its AFE module

<u>**Performance Characteristics**</u>
Nominal Range: 0 to 18 ppm
Maximum Overload: 50 ppm
Long Term Sensitivity Drift: < 20% change/year in lab air, monthly test
Long Term zero Drif: 0 to 50 ppb equivalent change/year in lab air
Response Time (T90): ≤ 25 seconds
Sensitivity: 350 to 550 nA/ppm
Accuracy: as good as ±0.2 ppm* (ideal conditions)

<u>**Operation Conditions**</u>
Temperature Range: -30 ºC to 50 ºC
Operating Humidity: 15 to 85% RH non-condensing
Pressure Range: 80 to 120 kPa
Storage Temperature: 0 ºC to 20 ºC
Expected Operating Life: 2 years in air

Sockets for Waspmote OEM:

- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:

- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA
** Accuracy values are only given for the **optimum case**. See the “Calibration” chapter for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.9.2. Cross-sensitivity data

Gas	Formula	Concentration (ppm)	Sensitivity % measured gas
Hydrogen Sulfide	H_2S	5	< 20
Nitric Dioxide	NO_2	5	< 7
Chlorine	Cl_2	5	< 4
Sulfur Dioxide	SO_2	5	< 4
Hydrogen	H_2	100	< 0.1
Carbon Monoxide	CO	5	< 0.3
Ammonia	NH_3	5	<0.1
Carbon Dioxide	CO_2	5% vol.	<0.1
Halothane sensitivity		100	<0.1

Figure: Cross-sensitivity data por the NO sensor for low concentrations

You can find a complete example code for reading the NO Sensor for low concentrations in the following link:

www.libelium.com/development/waspmote/examples/scp-v30-01-electrochemical-gas-sensors

6.10. Nitric Dioxide (NO_2) Gas Sensor [Calibrated]

Note: This sensor was discontinued in May 2017. Its substitute is the Nitric Dioxide (NO_2) high accuracy Gas Sensor [Calibrated]. The information about this alternative sensor can be found in the next section of this guide.

6.10.1. Specifications

Figure: Image of the Nitric Dioxide Sensor mounted on its AFE module

Gas: NO_2
Sensor: 4-NO2-20

__**Performance Characteristics**__
Nominal Range: 0 to 20 ppm
Maximum Overload: 250 ppm
Long Term Output Drift: < 2% signal/month
Response Time (T90): ≤ 30 seconds
Sensitivity: 600 ± 150 nA/ppm
Accuracy: as good as ±0.2 ppm* (ideal conditions)

__**Operation Conditions**__
Temperature Range: -20 ºC to 50 ºC
Operating Humidity: 15 to 90% RH non-condensing
Pressure Range: 90 to 110 kPa
Storage Temperature: 0 ºC to 20 ºC
Expected Operating Life: 2 years in air

Sockets for Waspmote OEM:
- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA
** Accuracy values are only given for the **optimum case**. See the "Calibration" chapter for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.10.2. Cross-sensitivity data

Gas	Formula	Concentration (ppm)	Output Signal (ppm NO_2 equivalent)
Carbon Monoxide	CO	300	0
Hydrogen Sulfide	H_2S	15	-1.2
Sulfur Dioxide	SO_2	5	-5
Nitric Oxide	NO	35	0
Chlorine	Cl_2	1	-1

Figure: Cross-sensitivity data for the NO_2 Sensor

You can find a complete example code for reading the NO_2 Sensor in the following link:
http://www.libelium.com/development/waspmote/examples/gp-v30-01-electrochemical-gas-sensors

6.11. Nitric Dioxide (NO_2) high accuracy Gas Sensor [Calibrated]

6.11.1. Specifications

Figure: Image of the high accuracy Nitric Dioxide Sensor mounted on its AFE module

Gas: NO_2
Sensor: NO2-A43F

__Performance Characteristics__
Nominal Range: 0 to 20 ppm
Maximum Overload: 50 ppm
Long Term Sensitivity Drift: < -20% to -40% change/year in lab air, monthly test
Long Term zero Drif: < 20 ppb equivalent change/year in lab air
Response Time (T90): ≤ 60 seconds
Sensitivity: -175 to -450 nA/ppm
Accuracy: as good as ±0.1 ppm* (ideal conditions)
O3 filter capacity @ 2 ppm: > 500 ppm·hrs

__Operation Conditions__
Temperature Range: -30 ºC to 40 ºC
Operating Humidity: 15 to 85% RH non-condensing
Pressure Range: 80 to 120 kPa
Storage Temperature: 0 ºC to 20 ºC
Expected Operating Life: 2 years in air

Sockets for Waspmote OEM:

- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:

- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA
** Accuracy values are only given for the optimum case. See the "Calibration" chapter in the Gases PRO Technical Guide for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.11.2. Cross-sensitivity data

Gas	Formula	Concentration (ppm)	Sensitivity % measured gas
Hydrogen Sulfide	H_2S	5	< -80
Nitric Oxide	NO	5	< 5
Chlorine	Cl_2	5	< 75
Sulfur Dioxide	SO_2	5	< -5
Carbon Monoxide	CO	5	< -5
Ethylene	C_2H_4	100	< 1
Ammonia	NH_3	20	<0.2
Hydrogen	H_2	100	< 0.1
Carbon Dioxide	CO_2	5% vol.	0.1
Halothane		100	nd

Figure: Cross-sensitivity data for the high accuracy NO_2 Sensor

You can find a complete example code for reading the high accuracy NO_2 Sensor in the following link:

www.libelium.com/development/waspmote/examples/scp-v30-01-electrochemical-gas-sensors

6.12. Sulfur Dioxide (SO_2) Gas Sensor [Calibrated]

Note: This sensor was discontinued in March 2017. Its substitute is the Sulfur Dioxide (SO_2) high accuracy Gas Sensor [Calibrated]. The information about this alternative sensor can be found in the next section of this guide.

6.12.1. Specifications

Figure: Image of the Sulfur Dioxide Sensor mounted on its AFE module

Gas: SO_2
Sensor: 4-SO2-20

Performance Characteristics
Nominal Range: 0 to 20 ppm
Maximum Overload: 150 ppm
Long Term Output Drift: < 2% signal/month
Response Time (T90): ≤ 45 seconds
Sensitivity: 500 ± 150 nA/ppm
Accuracy: as good as ±0.2 ppm* (ideal conditions)

Operation Conditions
Temperature Range: -20 ºC to 50 ºC
Operating Humidity: 15 to 90% RH non-condensing
Pressure Range: 90 to 110 kPa
Storage Temperature: 0 ºC to 20 ºC
Expected Operating Life: 2 years in air

Sockets for Waspmote OEM:
- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. See the "Calibration" chapter for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.12.2. Cross-sensitivity data

Gas	Formula	Concentration (ppm)	Output Signal (ppm SO_2 equivalent)
Carbon Monoxide	CO	300	3
Hydrogen Sulfide	H_2S	15	0
Nitric Oxide	NO	35	0
Nitric Dioxide	NO_2	5	-5

Figure: Cross-sensitivity data for the SO_2 Sensor

You can find a complete example code for reading the SO_2 Sensor in the following link:
http://www.libelium.com/development/waspmote/examples/gp-v30-01-electrochemical-gas-sensors

6.13. Sulfur Dioxide (SO_2) high accuracy Gas Sensor [Calibrated]

6.13.1. Specifications

Figure: Image of the high accuracy Sulfur Dioxide Sensor mounted on its AFE module

Gas: SO_2
Sensor: SO2-A4

__Performance Characteristics__
Nominal Range: 0 to 20 ppm
Maximum Overload: 100 ppm
Long Term Output Drift: < ±15% change/year in lab air, monthly test
Long Term zero Drift: <±20 ppb equivalent change/year in lab air
Response Time (T90): ≤ 20 seconds
Sensitivity: 320 to 480 nA/ppm
Accuracy: as good as ±0.1 ppm* (ideal conditions)

__Operation Conditions__
Temperature Range: -30 ºC to 50 ºC
Operating Humidity: 15 to 90% RH non-condensing
Pressure Range: 80 to 120 kPa
Storage Temperature: 0 ºC to 20 ºC
Expected Operating Life: 2 years in air

Sockets for Waspmote OEM:
- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. See the "Calibration" chapter for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.13.2. Cross-sensitivity data

Gas	Formula	Concentration (ppm)	Sensitivity % measured gas
Hydrogen Sulfide	H_2S	5	< 40
Nitric Oxide	NO	5	< -160
Chlorine	Cl_2	5	< -70
Sulfur Dioxide	SO_2	5	< -1.5
Carbon Monoxide	CO	5	< 2
Hydrogen	H_2	100	< 1
Ethylene	C_2H_4	100	< 1
Ammonia	NH_3	20	< 0.1
Carbon Dioxide	CO_2	5% vol.	< 0.1

Figure: Cross-sensitivity data for the high accuracy SO_2 Sensor

You can find a complete example code for reading the high accuracy SO_2 Sensor in the following link:

http://www.libelium.com/development/waspmote/examples/gp-v30-01-electrochemical-gas-sensors

6.14. Ammonia (NH_3) Gas Sensor for low concentrations [Calibrated]

6.14.1. Specifications

Figure: Image of the Ammonia Sensor for low concentrations mounted on its AFE module

Gas: NH_3
Sensor: 4-NH3-100

__Performance Characteristics__
Nominal Range: 0 to 100 ppm
Long Term Output Drift: < 2% signal/month
Response Time (T90): ≤ 90 seconds
Sensitivity: 135 ± 35 nA/ppm
Accuracy: as good as ±0.5 ppm* (ideal conditions)

__Operation Conditions__
Temperature Range: -20 ºC to 50 ºC
Operating Humidity: 15 to 90% RH non-condensing
Pressure Range: 90 to 110 kPa
Storage Temperature: 0 ºC to 20 ºC
Expected Operating Life: ≥1 year in air

Sockets for Waspmote OEM:
- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. See the "Calibration" chapter for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.14.2. Cross-sensitivity data

Gas	Formula	Concentration (ppm)	Output Signal (ppm NH_3 equivalent)
Carbon Monoxide	CO	300	0
Hydrogen Sulfide	H_2S	5	1.5
Carbon dioxide	CO_2	5	-3
Hydrogen	H_2	15	30
Isobutylene		35	-1
Ethanol		100	0

Figure: Cross-sensitivity data for the NH_3 Sensor for low concentrations

You can find a complete example code for reading the NH_3 Sensor for low concentrations in the following link:
http://www.libelium.com/development/waspmote/examples/gp-v30-01-electrochemical-gas-sensors

6.15. Ammonia (NH_3) Gas Sensor for high concentrations [Calibrated]

6.15.1. Specifications

Gas: NH_3
Sensor: 4-NH3-500

Figure: Image of the Ammonia Sensor for high concentrations mounted on its AFE module

<u>**Performance Characteristics**</u>
Nominal Range: 0 to 500 ppm
Long Term Output Drift: < 10% signal per 6 months
Response Time (T90): ≤ 90 seconds
Sensitivity: 135 ± 35 nA/ppm
Accuracy: as good as ±3 ppm* (ideal conditions)

<u>**Operation Conditions**</u>
Temperature Range: -20 ºC to 40 ºC
Operating Humidity: 15 to 90% RH non-condensing
Pressure Range: 90 to 110 kPa
Storage Temperature: 0 ºC to 20 ºC
Expected Operating Life: ≥1 year in air

Sockets for Waspmote OEM:
- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. See the "Calibration" chapter for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.15.2. Cross-sensitivity data

Gas	Concentration (ppm)	Output Signal (ppm NH_3 equivalent)
Carbon Monoxide	50	-1
Hydrogen Sulfide	25	85
Carbon Dioxide	5000	-2.5
Hydrogen	1000	-1.5
Isobutylene	100	-1
Ethanol	1000	-1
Sulphur Dioxide	5	8
Nitric Oxide	35	0
Nitric Dioxide	5	-5
Chlorine	10	-5

Figure: Cross-sensitivity data for the NH_3 Sensor for high concentrations

You can find a complete example code for reading the NH_3 Sensor for high concentrations in the following link:

http://www.libelium.com/development/waspmote/examples/gp-v30-01-electrochemical-gas-sensors

6.16. Methane (CH_4) and Combustible Gases Sensor [Calibrated]

6.16.1. Specifications

Figure: Image of the Methane (CH_4) and Combustible Gases Sensor (pellistor) mounted on its AFE module

Main gas: Methane CH_4
Sensor: CH-A3

Performance Characteristics
Nominal Range: 0 to 100% LEL methane
Long Term Output Drift: < 2% signal/month
Response Time (T90): ≤ 30 seconds
Accuracy: as good as ±0.15% LEL* (ideal conditions)

Operation Conditions
Temperature Range: -40 ºC to 55 ºC
Expected Operating Life: 2 years in air

Inhibition/Poisoning

Gas	Conditions	Effect
Chlorine	12 hrs 20 ppm Cl_2, 50% sensitivity loss, 2 day recovery	< 10% loss
Hydrogen Sulfide	12 hrs 40 ppm H_2S, 50% sensitivity loss, 2 day recovery	< 50% loss
HMDS	9 hrs @ 10 ppm HMDS	50% activity loss

Figure: Inhibition and poisoning effects

Sockets for Waspmote OEM:
- SOCKET_1

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: 68 mA

Note: *The Methane (CH_4) and Combustible Gas Sensor and the CO_2 Sensor have high power requirements and cannot work together in the same Gases PRO Sensor Board. The user must choose one or the other, but not both.*

** Accuracy values are only given for the **optimum case**. See the "Calibration" chapter for more detail.*

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.16.2. Sensitivity data

Hydrocarbon/Gas	% Sensitivity relative to Methane	% LEL Sensitivity to Methane
Hydrogen	130 to 140	160 to 175
Propane	150 to 190	350 to 450
Butane	150 to 180	420 to 500
n-Pentane	180 to 200	600 to 670
Nonane	150 to 170	800 to 950
Carbon Monoxide	42 to 44	17 to 18
Acetylene	150 to 170	300 to 340
Ethylene	150 to 170	270 to 320
Isobutylene	180 to 200	450 to 500

Figure: Sensitivity data for the CH_4 and Combustible Gases Sensor

You can find a complete example code for reading the Methane (CH_4) and Combustible Gases Sensor in the following link:
http://www.libelium.com/development/waspmote/examples/gp-v30-03-pellistor-gas-sensors

6.17. Molecular Hydrogen (H_2) Gas Sensor [Calibrated]

6.17.1. Specifications

Figure: Image of the Molecular Hydrogen Sensor mounted on its AFE module

Gas: H_2
Sensor: 4-H2-1000

Performance Characteristics
Nominal Range: 0 to 1000 ppm
Maximum Overload: 2000 ppm
Long Term Output Drift: < 2% signal/month
Response Time (T90): ≤ 70 seconds
Sensitivity: 20 ± 10 nA/ppm
Accuracy: as good as ±10 ppm* (ideal conditions)

Operation Conditions
Temperature Range: -20 ºC to 50 ºC
Operating Humidity: 15 to 90% RH non-condensing
Pressure Range: 90 to 110 kPa
Storage Temperature: 0 ºC to 20 ºC
Expected Operating Life: 2 years in air

Sockets for Waspmote OEM:
- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. See the "Calibration" chapter for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.17.2. Cross-sensitivity data

Gas	Formula	Concentration (ppm)	Output Signal (ppm H_2 equivalent)
Hydrogen Sulfide	H_2S	24	0
Sulfur Dioxide	SO_2	5	0
Nitric Oxide	NO	35	10
Nitric Dioxide	NO_2	5	0
Carbon Monoxide	CO	50	200
Ethylene	C_2H_4	100	80
Chlorine	Cl_2	10	0

Figure: Cross-sensitivity data for the H_2 Sensor

You can find a complete example code for reading the H_2 Sensor in the following link:
http://www.libelium.com/development/waspmote/examples/gp-v30-01-electrochemical-gas-sensors

6.18. Hydrogen Sulfide (H_2S) Gas Sensor [Calibrated]

6.18.1. Specifications

Gas: H_2S
Sensor: 4-H2S-100

Figure: Image of the Hydrogen Sulfide Sensor mounted on its AFE module

<u>**Performance Characteristics**</u>
Nominal Range: 0 to 100 ppm
Maximum Overload: 50 ppm
Long Term Output Drift: < 2% signal/month
Response Time (T90): ≤ 20 seconds
Sensitivity: 800 ± 200 nA/ppm
Accuracy: as good as ±0.1 ppm* (ideal conditions)

<u>**Operation Conditions**</u>
Temperature Range: -20 ºC to 50 ºC
Operating Humidity: 15 to 90% RH non-condensing
Pressure Range: 90 to 110 kPa
Storage Temperature: 0 ºC to 20 ºC
Expected Operating Life: 2 years in air

Sockets for Waspmote OEM:
- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. See the "Calibration" chapter for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.18.2. Cross-sensitivity data

Gas	Formula	Concentration (ppm)	Output Signal (ppm H_2S equivalent)
Carbon Monoxide	CO	50	≤6
Sulfur Dioxide	SO_2	5	1
Nitric Oxide	NO	35	1
Nitric Dioxide	NO_2	5	-1
Hydrogen	H_2	10000	25
Ethylene	C_2H_4	100	0
Ethanol	C_2H_6O	5000	±1.5

Figure: Cross-sensitivity data for the H_2S Sensor

You can find a complete example code for reading the H_2S Sensor in the following link:
http://www.libelium.com/development/waspmote/examples/gp-v30-01-electrochemical-gas-sensors

6.19. Hydrogen Chloride (HCl) Gas Sensor [Calibrated]

6.19.1. Specifications

Gas: HCl
Sensor: 4-HCl-50

Figure: Image of the Hydrogen Chloride Sensor mounted on its AFE module

Performance Characteristics
Nominal Range: 0 to 50 ppm
Maximum Overload: 100 ppm
Long Term Output Drift: < 2% signal/month
Response Time (T90): ≤ 70 seconds
Sensitivity: 300 ± 100 nA/ppm
Accuracy: as good as ±1 ppm* (ideal conditions)

Operation Conditions
Temperature Range: -20 ºC to 50 ºC
Operating Humidity: 15 to 90% RH non-condensing
Pressure Range: 90 to 110 kPa
Storage Temperature: 0 ºC to 20 ºC
Expected Operating Life: 2 years in air

Sockets for Waspmote OEM:
- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. See the "Calibration" chapter for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.19.2. Cross-sensitivity data

Gas	Formula	Concentration (ppm)	Output Signal (ppm HCl equivalent)
Hydrogen	H_2	2000	0
Carbon Monoxide	CO	100	0
Nitric Oxide	NO	20	50
Nitric Dioxide	NO_2	10	1
Hydrogen Sulfide	H_2S	25	130
Sulfur Dioxide	SO_2	20	35
Nitrogen	N	1000000	0

Figure: Cross-sensitivity data for the HCl Sensor

You can find a complete example code for reading the HCl Sensor in the following link:
http://www.libelium.com/development/waspmote/examples/gp-v30-01-electrochemical-gas-sensors

6.20. Hydrogen Cyanide (HCN) Gas Sensor [Calibrated]

6.20.1. Specifications

Gas: HCN
Sensor: 4-HCN-50

Figure: Image of the Hydrogen Cyanide Sensor mounted on its AFE module

Performance Characteristics
Nominal Range: 0 to 50 ppm
Maximum Overload: 100 ppm
Long Term Output Drift: < 2% signal/month
Response Time (T90): ≤ 120 seconds
Sensitivity: 100 ± 20 nA/ppm
Accuracy: as good as ±0.2 ppm* (ideal conditions)

Operation Conditions
Temperature Range: -20 ºC to 50 ºC
Operating Humidity: 15 to 90% RH non-condensing
Pressure Range: 90 to 110 kPa
Storage Temperature: 0 ºC to 20 ºC
Expected Operating Life: 2 years in air

Sockets for Waspmote OEM:
- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA

** Accuracy values are only given for the* ***optimum case****. See the "Calibration" chapter for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.20.2. Cross-sensitivity data

Gas	Formula	Concentration (ppm)	Output Signal (ppm HCN equivalent)
Carbon Monoxide	CO	300	0
Sulfur Dioxide	SO_2	5	1.5
Nitric Dioxide	NO_2	5	-3
Hydrogen Sulfide	H_2S	15	30
Nitric Oxide	NO	35	-1
Ethylene	C_2H_4	100	0

Figure: Cross-sensitivity data for the HCN Sensor

You can find a complete example code for reading the HCN Sensor in the following link:
http://www.libelium.com/development/waspmote/examples/gp-v30-01-electrochemical-gas-sensors

6.21. Phosphine (PH_3) Gas Sensor [Calibrated]

6.21.1. Specifications

Gas: PH_3
Sensor: 4-PH3-20

Figure: Image of the Phosphine Gas Sensor mounted on its AFE module

Performance Characteristics
Nominal Range: 0 to 20 ppm
Maximum Overload: 100 ppm
Long Term Output Drift: < 2% signal/month
Response Time (T90): ≤ 60 seconds
Sensitivity: 1400 ± 600 nA/ppm
Accuracy: as good as ±0.1 ppm* (ideal conditions)

Operation Conditions
Temperature Range: -20 ºC to 50 ºC
Operating Humidity: 15 to 90% RH non-condensing
Pressure Range: 90 to 110 kPa
Storage Temperature: 0 ºC to 20 ºC
Expected Operating Life: 2 years in air

Sockets for Waspmote OEM:
- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. See the "Calibration" chapter for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.21.2. Cross-sensitivity data

Gas	Formula	Concentration (ppm)	Output Signal (ppm PH_3 equivalent)
Carbon Monoxide	CO	1000	0
Hydrogen Sulfide	H_2S	15	12
Sulfur Dioxide	SO_2	5	0.9
Hydrogen	H_2	1000	0
Ethylene	C_2H_4	100	0
Ammonia	NH_3	50	0

Figure: Cross-sensitivity data for the PH_3 Sensor

You can find a complete example code for reading the PH_3 Sensor in the following link:
http://www.libelium.com/development/waspmote/examples/gp-v30-01-electrochemical-gas-sensors

6.22. Ethylene Oxide (ETO) Gas Sensor [Calibrated]

6.22.1. Specifications

Figure: Image of the Ethylene Oxide Sensor mounted on its AFE module

Gas: ETO
Sensor: 4-ETO-100

Performance Characteristics
Nominal Range: 0 to 100 ppm
Long Term Sensitivity Drift: < 2% signal/month
Response Time (T90): ≤ 120 seconds
Sensitivity: 250 ± 125 nA/ppm
Accuracy: as good as ±1 ppm* (ideal conditions)

Operation Conditions
Temperature Range: -20 ºC to 50 ºC
Operating Humidity: 15 to 90% RH non-condensing
Pressure Range: 90 to 110 kPa
Storage Temperature: 0 ºC to 20 ºC
Expected Operating Life: 5 years in air

Sockets for Waspmote OEM:
- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. See the “Calibration” chapter for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.22.2. Cross-sensitivity data

Gas	Formula	Sensitivity of ETO/Sensitivity of test gas
Ethylene Oxide	ETO	1.0
Carbon Monoxide	CO	2.5
Ethanol	C_2H_6O	2.0
Methanol	CH_4O	0.5
Isopropanol	C_3H_8O	5.0
i-Butylene		2.5
Butadiene	C_4H_6	0.9
Ethylene	C_2H_4	0.8
Propene	C_3H_6	1.7
Vinyl Chloride	C_2H_3Cl	1.3
Vinyl Acetate	$C_4H_6O_2$	2.0
Formic Acid	CH_2O_2	3.3
Ethyl ether	$(C_2H_5)_2O$	2.5
Formaldehyde	CH_2O	1.0

Figure: Cross-sensitivity data for the ETO Sensor

You can find a complete example code for reading the ETO Sensor in the following link:
http://www.libelium.com/development/waspmote/examples/gp-v30-01-electrochemical-gas-sensors

6.23. Chlorine (Cl_2) Gas Sensor [Calibrated]

6.23.1. Specifications

Figure: Image of the Chlorine Sensor mounted on its AFE module

Gas: Cl_2
Sensor: 4-Cl2-50

__Performance Characteristics__
Nominal Range: 0 to 50 ppm
Maximum Overload: 100 ppm
Long Term Output Drift: < 2% signal/month
Response Time (T90): ≤ 30 seconds
Sensitivity: 450 ± 200 nA/ppm
Accuracy: as good as ±0.1 ppm* (ideal conditions)

__Operation Conditions__
Temperature Range: -20 ºC to 50 ºC
Operating Humidity: 15 to 90% RH non-condensing
Pressure Range: 90 to 110 kPa
Storage Temperature: 0 ºC to 20 ºC
Expected Operating Life: 2 years in air

Sockets for Waspmote OEM:
- SOCKET_1
- SOCKET_2
- SOCKET_3
- SOCKET_4
- SOCKET_5
- SOCKET_6

Sockets for Plug & Sense!:
- SOCKET_A
- SOCKET_B
- SOCKET_C
- SOCKET_F

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. See the "Calibration" chapter for more detail.*

The electrochemical sensors must be always powered on in order to get optimum measurements. This implies a power consumption, however it improves the performance of the sensor. This should also be applied when entering sleep modes so the sensor is not powered off selecting the proper sleep option.

Calibrated gas sensors are manufactured once the order has been placed to ensure maximum durability of the calibration feature. The manufacturing process and delivery may take from 4 to 6 weeks. The lifetime of calibrated gas sensors is 6 months working at maximum accuracy. We strongly encourage our customers to buy extra gas sensors to replace the original ones after that time to ensure maximum accuracy and performance.

6.23.2. Cross-sensitivity data

Gas	Formula	Concentration (ppm)	Output Signal (ppm Cl_2 equivalent)
Hydrogen Sulfide	H_2S	20	-4
Carbon Monoxide	CO	100	0
Sulfur Dioxide	SO_2	20	0
Nitric Oxide	NO	35	0
Nitric Dioxide	NO_2	10	12
Hydrogen	H_2	3000	0
Ammonia	NH_3	100	0
Carbon Dioxide	CO_2	10000	0
Chlorine Dioxide	ClO_2	1	3.5

Figure: Cross-sensitivity data for the Cl_2 Sensor

You can find a complete example code for reading the Cl_2 Sensor in the following link:
http://www.libelium.com/development/waspmote/examples/gp-v30-01-electrochemical-gas-sensors

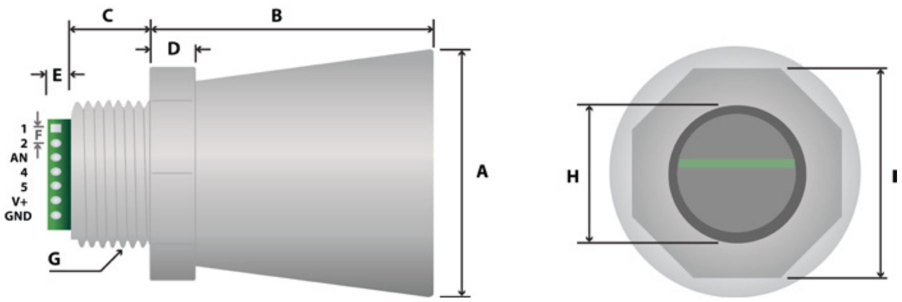
6.24. Ultrasound sensor probe (MaxSonar® from MaxBotix™)

6.24.1. Specifications

Figure: Ultrasonic I2CXL-MaxSonar®-MB7040 from MaxBotix™ sensor

I2CXL-MaxSonar®-MB7040™

Operation frequency: 42 kHz
Maximum detection distance: 765 cm
Interface: Digital bus
Consumption (average): 2.1 mA
Consumption (peak): 50 mA
Usage: Indoors and outdoors (IP-67)



A	1.72" dia.	43.8 mm dia.
B	2.00"	50.7 mm
C	0.58"	14.4 mm
D	0.31"	7.9 mm
E	0.18"	4.6 mm
F	0.1"	2.54 mm
G	*3/4" National Pipe Thread Straight*	
H	1.032" dia.	26.2 dia.
I	1.37"	34.8 mm
weight: 1.76 oz. ; 50 grams		

Figure: Ultrasonic I2CXL-MaxSonar®-MB7040 sensor dimensions

Note: *Only one MB7040 sensor is supported.*

In the figure below we can see a diagram of the detection range of the sensor developed using different detection patterns (a 0.63 cm diameter dowel for diagram A, a 2.54 cm diameter dowel for diagram B, an 8.25cm diameter rod for diagram C and a 28 cm wide board for diagram D):

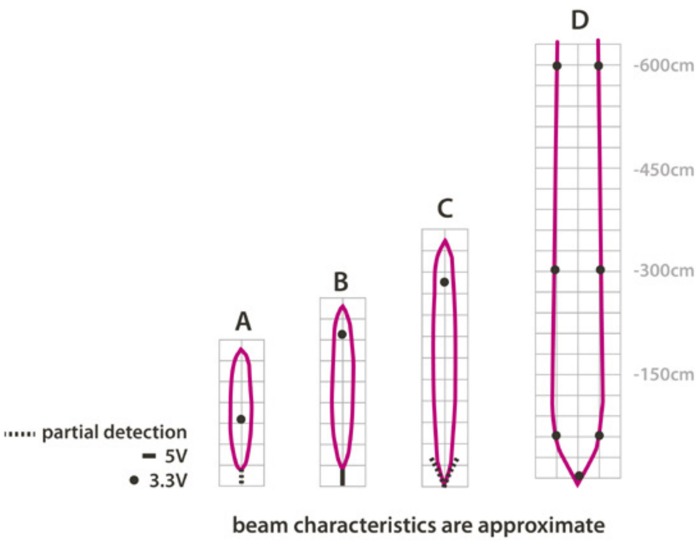
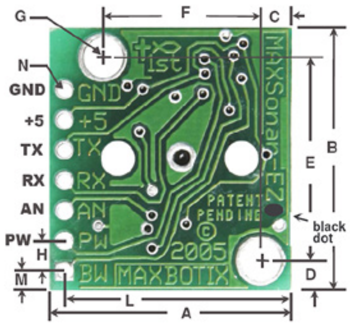


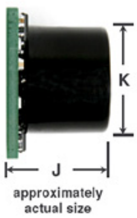
Figure: Diagram of the sensor beam extracted from the data sheet of the XL-MaxSonar®-WRA1™ sensor from MaxBotix

Figure: Ultrasonic I2CXL-MaxSonar®- MB1202 from MaxBotix™ Sensor

I2CXL-MaxSonar®-MB1202™:

- **Operation frequency:** 42 kHz
- **Maximum detection distance:** 765 cm
- **Consumption (average):** 2 mA
- **Consumption (peak):** 50 mA
- **Usage:** Indoors only





A	0.785”	19.9 mm	H	0.100”	2.54 mm
B	0.870”	22.1 mm	J	0.645”	16.4 mm
C	0.100”	2.54 mm	K	0.610”	15.5 mm
D	0.100”	2.54 mm	L	0.735”	18.7 mm
E	0.670”	17.0 mm	M	0.065”	1.7 mm
F	0.510”	12.6 mm	N	0.038” dia.	1.0 mm dia.
G	0.124” dia.	3.1 mm dia.	weight: 4.3 grams		

Figure: Ultrasonic I2CXL-MaxSonar®-MB1202 Sensor dimensions

In the figure below we can see a diagram of the detection range of the sensor developed using different detection patterns (a 0.63 cm diameter dowel for diagram A, a 2.54 cm diameter dowel for diagram B, an 8.25 cm diameter rod for diagram C and a 28 cm wide board for diagram D):

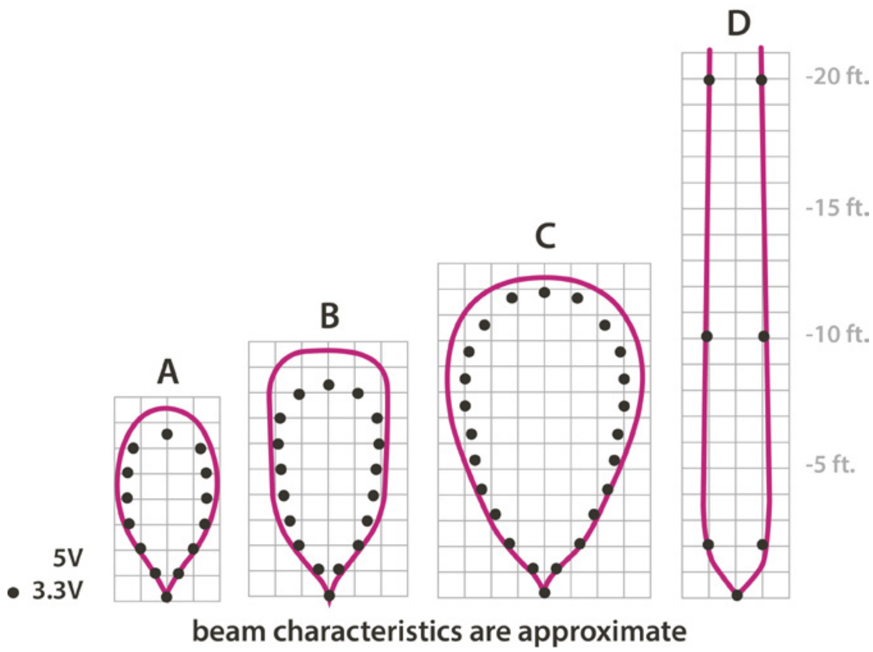


Figure: Diagram of the sensor beam extracted from the data sheet of the Ultrasonic I2CXL-MaxSonar®-MB1202 sensor from MaxBotix

6.24.2. Measurement Process

The MaxSonar® sensors from MaxBotix can connects through digital bus interface. In the next figure, we can see a drawing of two example applications for the ultrasonic sensors, such as liquid level monitoring or presence detection.

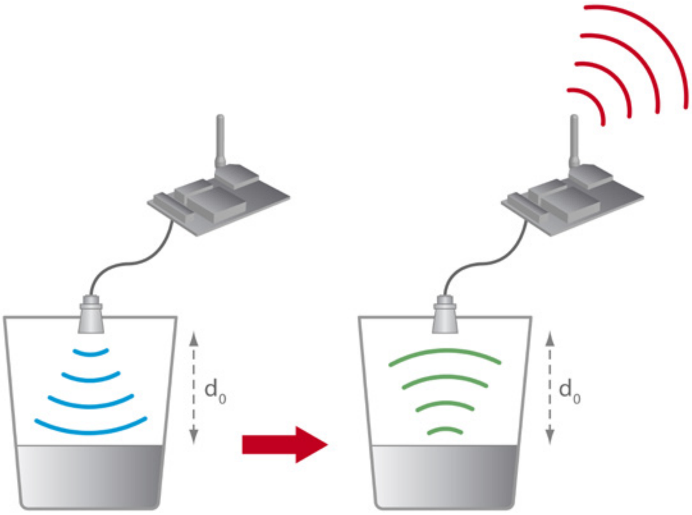


Figure: Examples of application for the MaxSonar® sensors

The MB7040 sensor is endowed with an IP-67 casing, so it can be used in outdoors applications, such as liquid level monitoring in storage tanks. Below a sample code to measure with the ultrasound sensors is shown:

Reading code:

```
{
  uint16_t distance;
  distance = Ultrasound.getDistance();
}
```

You can find a complete example code for reading the distance in the following link:
http://www.libelium.com/development/waspmote/examples/gp-v30-06-ultrasound-sensor

6.24.3. Socket

These sensors share the sockets with the Temperature, Humidity and Pressure sensor. The pin correspondence, highlighted in the figure below, is the same for both.

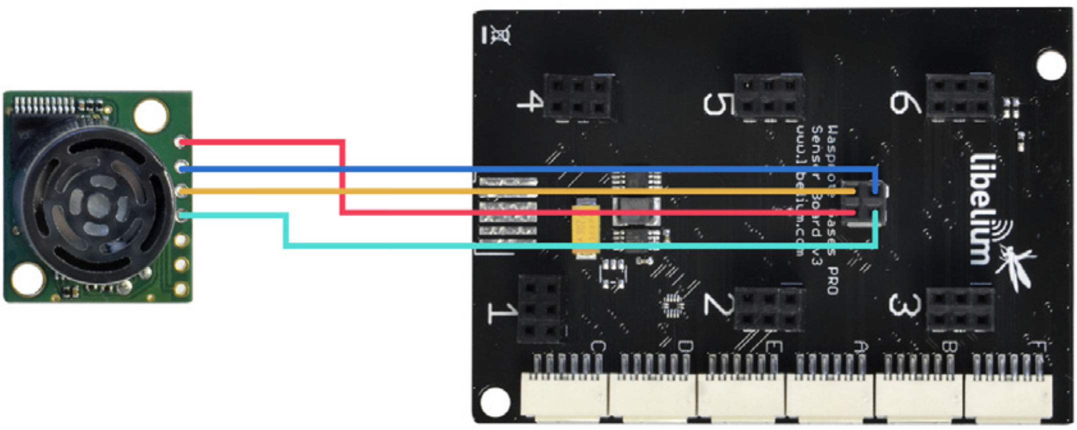


Figure: Image of the socket for connecting the MaxSonar® Sensors

6.25. Luminosity Sensor

6.25.1. Specifications

Electrical characteristics
Dynamic range: 0.1 to 40000 lux
Spectral range: 300 ~ 1100 nm
Voltage range: 2.7 ~ 3.6 V
Supply current typical: 0.24 mA
Sleep current maximum: 0.3 μA
Operating temperature: -30 ~ 70 ºC

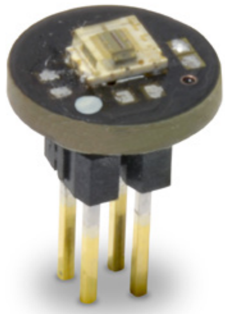


Figure: Image of the Luminosity Sensor

> ***Note:*** *Only one TSL2561 sensor is supported.*

6.25.2. Measurement process

This is a light-to-digital converter that transforms light intensity into a digital signal output. This device combines one broadband photo-diode (visible plus infrared) and one infrared-responding photo-diode on a single CMOS integrated circuit capable of providing a near-photopic response over an effective 20-bit dynamic range (16-bit resolution). Two integrating ADCs convert the photo-diode currents to a digital output that represents the irradiance measured on each channel. This digital output in lux is derived using an empirical formula to approximate the human eye response.

Reading code:

```
{
  // Read luxes
  luxes = TSL.getLuxes();
}
```

You can find a complete example code for reading the luminosity in the following link:
www.libelium.com/development/waspmote/examples/scp-v30-07-luxes-sensor

6.25.3. Socket

This sensor can be connected in socket 2 and 4 in Waspmote OEM and sockets A and E in Plug & Sense!

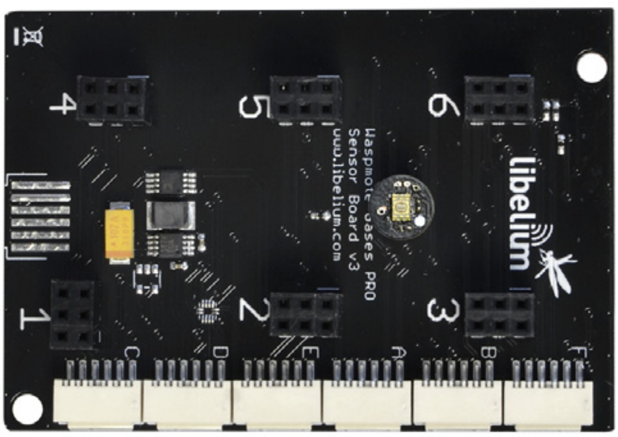


Figure: Image of the socket for the luxes sensor

In the image above we can see highlighted the four pins of the terminal block where the sensor must be connected to the board. The white dot luxes board, must match the mark of the Gases PRO Sensor Board.

6.26. Particle Matter (PM1 / PM2.5 / PM10) - Dust Sensor

6.26.1. Specifications

Sensor: OPC-N2

Figure: Image of the Particle Matter sensor, encapsulated

__Performance Characteristics__
Laser classification: Class 1 as enclosed housing
Particle range (um): 0.38 to 17 spherical equivalent size (based on RI of 1.5
Size categorization (standard): 16 software bins
Sampling interval (seconds): 1 to 10 histogram period
Total flow rate: 1.2 L/min
Sample flow rate: 220 mL/min
Max particle count rate: 10000 particles/second
Max Coincidence probability: 0.91% at 10 particles/L
0.24% at 500 particles/mL

__Power Characteristics__
Measurement mode (laser and fan on): 250 mA @ 5 V (typical)
Voltage Range: 4.8 to 5.2 V DC

__Operation Conditions__
Temperature Range: -10 ºC to 50 ºC
Operating Humidity: 0 to 99% RH non-condensing

This sensor has a high current consumption. It is very important to turn on the sensor to perform a measure and then, turn it off to save battery. Also, it is advised to operate with a minimum battery level of 40%, just to avoid voltage drops (due to high current peaks) which could lead to resets in the system.

Dust, dirt or pollen may be accumulated inside the dust sensor structure, especially when the sensor is close to possible solid particle sources: parks, construction works, deserts. That is why it is highly recommended to perform maintenance/cleaning tasks in order to have accurate measures. This maintenance/cleaning frequency may vary depending on the environment conditions or amount of obstructing dust. In clean atmospheres or with low particle concentrations, the maintenance/cleaning period will be longer than a place with a high particle concentrations.

Important note: *Do not handle the stickers seals of the enclosure (Warranty stickers). Their integrity is the proof that the sensor enclosure has not been opened. If they have been handled, damaged or broken, the warranty is automatically void.*

DO NOT remove the external housing: this not only ensures the required airflow, also protects the user from the laser light. Removal of the casing may expose the user to Class 3B laser radiation. You must avoid exposure to the laser beam. Do not use if the outer casing is damaged. Return to Libelium. Removal of the external housing exposes the OPC circuitry which contains components that are sensitive to static discharge damage.

Note: *The Particle Matter (PM1 / PM2.5 / PM10) – Dust Sensor is available only for the Plug & Sense! line.*

6.26.2. Particle matter: the parameter

Particle matter is composed of small solid or liquid particles floating in the air. The origin of these particles can be the industrial activity, exhaust fumes from diesel motors, building heating, pollen, etc. This tiny particles enter our bodies when we breath. High concentrations of particle matter can be harmful for humans or animals, leading to respiratory and coronary diseases, and even lung cancer. That is why this is a key parameter for the Air Quality Index.

Some examples:

- Cat allergens: 0.1-5 μm
- Pollen: 10-100 μm
- Germs: 0.5-10 μm
- Oil smoke: 1-10 μm
- Cement dust: 5-100 μm
- Tobacco smoke: 0.01-1 μm

The smaller the particles are, the more dangerous, because they can penetrate more in our lungs. Many times, particles are classified:

- PM1: Mass (in μg) of all particles smaller than 1 μm, in 1 m^3.
- PM2.5: Mass (in μg) of all particles smaller than 2.5 μm, in 1 m^3.
- PM10: Mass (in μg) of all particles smaller than 10 μm, in 1 m^3.

Many countries and health organizations have studied the effect of the particle matter in humans, and they have set maximum thresholds. As a reference, the maximum allowed concentrations are about 20 μm/m^3 for PM2.5 and about 50 μm/m^3 for PM10.

6.26.3. Measurement process

Like conventional optical particle counters, the OPC-N2 measures the light scattered by individual particles carried in a sample air stream through a laser beam. These measurements are used to determine the particle size (related to the intensity of light scattered via a calibration based on Mie scattering theory) and particle number concentration. Particle mass loading- PM2.5 or PM10, are then calculated from the particle size spectra and concentration data, assuming density and refractive index. To generate the air stream, the OPC-N2 uses only a miniature low-power fan.

The OPC-N2 classifies each particle size, at rates up to ~10,000 particle per second, adding the particle diameter to one of 16 “bins” covering the size range from ~0.38 to 17 μm. The resulting particle size histograms can be evaluated over user-defined sampling times from **1 to 10 seconds duration**, the histogram data being transmitted along with other diagnostic and environmental data (air temperature and air pressure). When the histogram is read, the variables in the library are updated automatically. See the ”Library” section to know how to manage and read this sensor.

You can find a complete example code for reading the Particle Matter Sensor in the following link:
http://www.libelium.com/development/waspmote/examples/gp-v30-04-particle-matter-sensor

6.27. Design and connections

The different connectors used for the sensors connection can be used for the integration of different sensors to those previously planned, provided that the organization of the pins is followed, as well as the defined electrical specifications in the Waspmote manual. In this sense, two types of different sensors are available:

Firstly, the central socket has been reserved to connect a BME280 sensor (Temperature, Humidity and Pressure Sensor) , ultrasonic sensor or luminosity sensor..

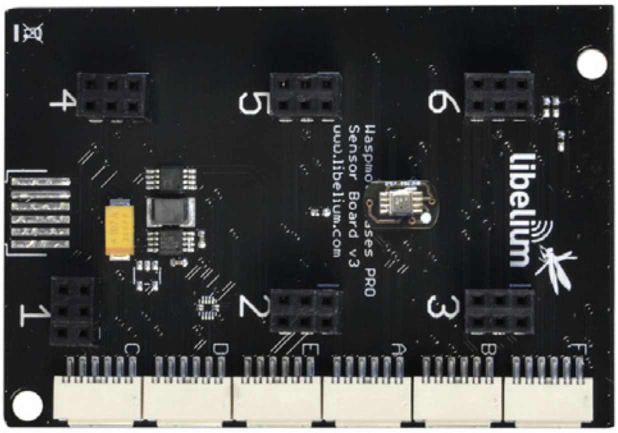


Figure: Image of central socket with a BME280 sensor connected

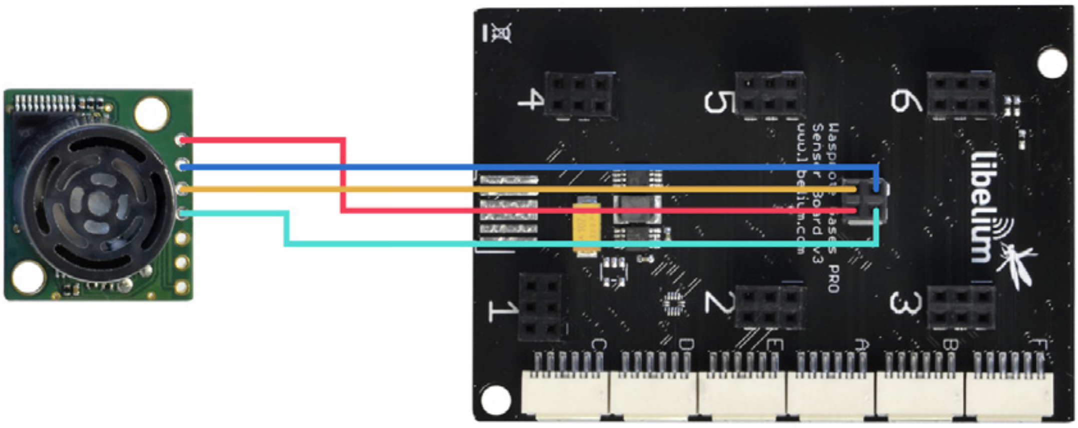


Figure: Image of central socket with ultrasound sensor connected

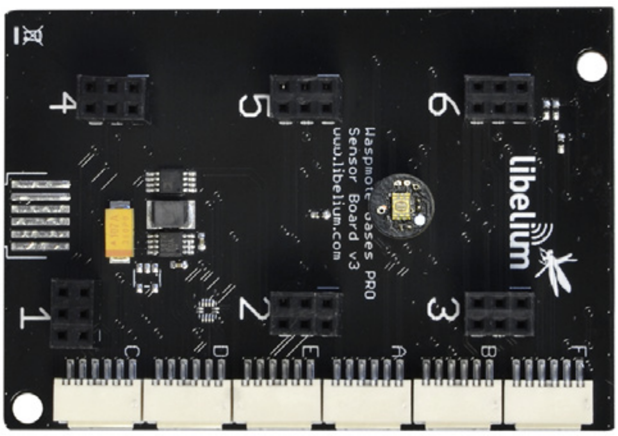


Figure: Image of central socket with a luminosity sensor connected

Next the rest of the connectors used for gas sensors are described.

6.27.1. Socket 1

Socket 1 has been designed to connect 4 different kinds of sensors: 3-electrode, 4-electrode, combustible gases and CO_2 gas sensor.

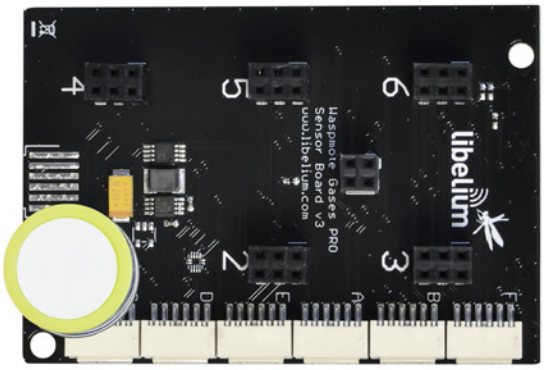


Figure: Image of socket 1 with a 3-electrode sensor

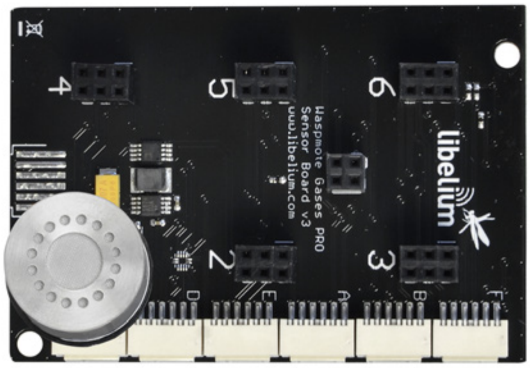


Figure: Image of socket 1 with a CO_2 gas sensor

6.27.2. Socket 2

Socket 2 has been designed to connect 2 different kinds of sensors: 3-electrode and 4-electrode gas sensors.

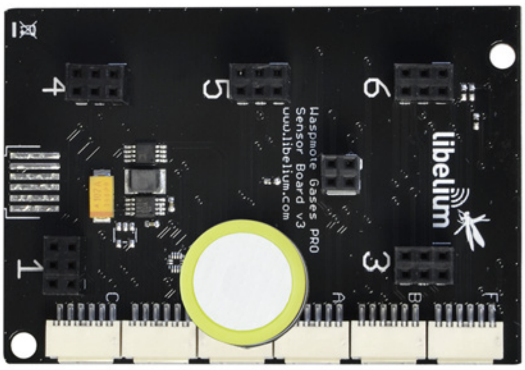


Figure: Image of socket 2 with a 3-electrode sensor

6.27.3. Socket 3

Socket 3 has been designed to connect 2 different kinds of sensors: 3-electrode and 4-electrode gas sensors.

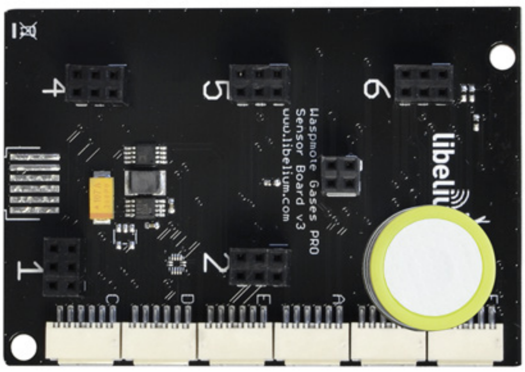


Figure: Image of socket 3 with a 4-electrode sensor

6.27.4. Socket 4

Socket 4 has been designed to connect 2 different kinds of sensors: 3-electrode and 4-electrode gas sensors.

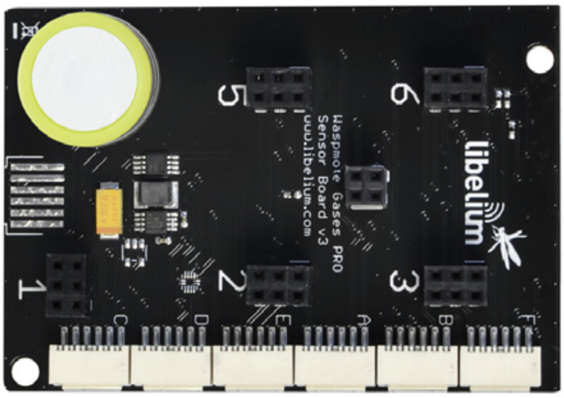


Figure: Image of socket 4 with a 3-electrode sensor

6.27.5. Socket 5

Socket 5 has been designed to connect 2 different kinds of sensors: 3-electrode and 4-electrode gas sensors.

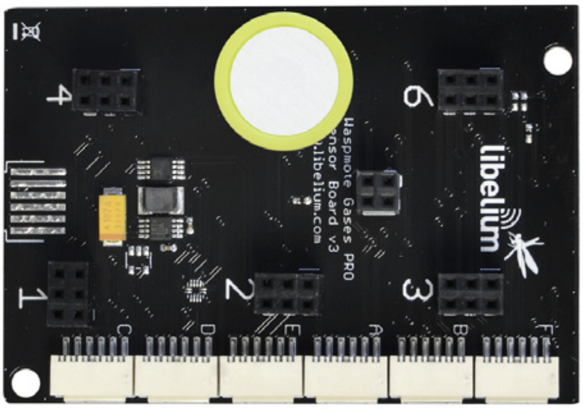


Figure: Image of socket 5 with a 3-electrode sensor

6.27.6. Socket 6

Socket 6 has been designed to connect 2 different kinds of sensors: 3-electrode and 4-electrode gas sensors.

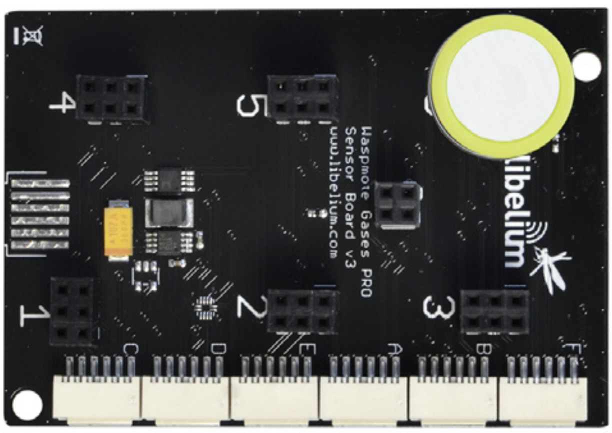


Figure: Image of socket 6 with a 4-electrode sensor

7. Library for gas sensors

7.1. Before starting

The Gases PRO Sensor Board for Waspmote has its own library which contains the set of necessary instructions to easily configure and read each one of the sensors which can be connected to the board. Next, each one of the functions is described and the process of configuration detailed for each sensor. The specific configuration which must be applied to each one of the sensors is explained in the specific sensor's section.

When using the Gases PRO Sensor Board on Waspmote, remember it is mandatory to include the WaspSensorGas_Pro library by introducing the next line at the beginning of the code:

```
#include <WaspSensorGas_PRO.h>
```

Each gas sensor needs its own object. So, between the include of the library and the global variables declaration, the object must be created following the next structure:

- Name of the class: `Gas`
- Name of the object. We recommend to use the formula of the gas sensor. In this case `CO`.
- In brackets the socket selected for the sensor. In this case `SOCKET_1`.

See the example below:

```
Gas CO(SOCKET_1);
```

7.2. Power and configuration

7.2.1. Initializing the sensor

Before reading the concentration values, the sensor must be powered using the function `ON()`. Unlike with other sensor boards, the user does not need to power on the board. The API library performs the next tasks in the power on process from each sensor:

- Powers on the board (if necessary)
- Powers on the sensor
- Reads the parameters from the EEPROM
- Sets the AFE module to work with the sensor

```
gas_sensor.ON();
gas_sensor.ON(R_gain);
```

Where `R_gain` is the gain associated to the transimpedance amplifier. Allowed values for sensors that uses the 3-electrode AFE are:

```
LMP91000_GAIN_1
LMP91000_GAIN_2
LMP91000_GAIN_3
LMP91000_GAIN_4
LMP91000_GAIN_5
LMP91000_GAIN_6
LMP91000_GAIN_7
```

In all cases the function returns:

- 1 if OK
- -1 no communication with AFE module

The Methane and Combustible Gases Sensor and the CO_2 Gas Sensor and the CO low concentration Gas Sensor do not have a transimpedance stage so they do not admit a gain value. If `R_gain` is not selected, a default value will be loaded.

The BME280 (Temperature, Humidity and Pressure Sensor) is automatically powered on when any gas sensor is powered on.

7.2.2. Switching sensor off

In order to save battery, the sensor could be powered off (Methane and Combustible Gases and CO_2) using the function `OFF()`. Unlike other sensor boards, the Gases PRO Sensor Board does not need to power off the board. The API library powers off the board automatically when the last sensor is turned off.

```
gas_sensor.OFF();
```

If the sensor needs to be powered off for a long time (weeks or months) is recommendable to power off with the parameter 1 in the off function.

```
gas_sensor.OFF(1);
```

In all cases the function returns the `pwrGasPRORegister`. Each bit of this register represents the status of a sensor. ‘1’ for the powered on sensors and ‘0’ for the powered off.

- 7: not used
- 6: gas sensor in socket 6
- 5: gas sensor in socket 5 or socket B in Plug & Sense!
- 4: gas sensor in socket 4 or socket A in Plug & Sense!
- 3: gas sensor in socket 3 or socket F in Plug & Sense!
- 2: gas sensor in socket 2
- 1: gas sensor in socket 1 or socket C in Plug & Sense!
- 0: particles-dust sensor (socket D in Plug & Sense!)

7.2.3. Setting gain resistor for transimpedance stage

The transimpedance stage converts a current into a proportional voltage. The conversion factor is fixed by the resistor of the stage (V = R·I). The resistor, and therefore the gain, can be selected by the user according to the gas concentration to measure. High gains should be used to measure at low concentrations. On the other hand, low gains should be used at high concentrations. Using high gains with high concentrations, the voltage input for the ADC will be out of its range, so the measured concentration will be wrong.

```
gas_sensor.configureAFE(float R_gain);
```

Allowed values for `R_gain` in 3-electrode sensors:

```
LMP91000_GAIN_1
LMP91000_GAIN_2
LMP91000_GAIN_3
LMP91000_GAIN_4
LMP91000_GAIN_5
LMP91000_GAIN_6
LMP91000_GAIN_7
```

In all cases the function returns:

- 1 if OK
- -1 no communication with AFE module

7.2.4. How to choose the right gain resistor

As has been annotated in other chapter, electrochemical sensors generate a current proportional to the gas concentration. The transimpedance stage converts the current (using a multiplication factor) in a voltage for the ADC, but it has a limit. For 3-electrode gas sensors, it can only generate ±1024 mV. So, the multiplication factor (gain resistor) must be selected according the current generated by the sensor.

To know the current generated, the expected concentration to measure and the approximated sensitivity of the sensor must be applied into the next equation:

$$concentration*sensitivity = I_{sensor}$$

The tables below show the maximum currents for each `R_gain` setting.

Gain setting	Max. current allowed (µA)
`LMP91000_GAIN_1`	±370
`LMP91000_GAIN_2`	±290
`LMP91000_GAIN_3`	±146
`LMP91000_GAIN_4`	±73
`LMP91000_GAIN_5`	±29
`LMP91000_GAIN_6`	±8'5
`LMP91000_GAIN_7`	±2'9

Figure: Maximum current by gain setting for a 3-electrode AFE

- An example with a H_2 Gas Sensor (3-electrode) is shown below:
- expected H_2 concentration: 524 ppm
- H_2 Gas Sensor sensitivity: 20 nA/ppm

$$concentration*sensitivity = I_{sensor}$$

$$524*20 = 10480nA \rightarrow 10{,}48\ \mu A$$

The current is 25.56 µA, very high for `LMP91000_GAIN_6` and `LMP91000_GAIN_7`, but not for `LMP91000_GAIN_5`. So, the right gain should be `LMP91000_GAIN_5` or less.

7.2.5. Power modes

The 3-electrode and 4-electrode AFEs can change the power mode of the circuits that manages the electrochemical sensor. The power modes allowed are below:

- `AFE_DEEP_SLEEP:` AFE module changes to deep sleep mode. ADC changes to low power standby mode (0.1 µA typical consumption), bias stage and transimpedance amplifier are powered off (0.6 µA typical consumption).
- `AFE_STAND_BY:` AFE module changes to standby mode. ADC changes to low power standby mode (0.1 µA typical consumption), bias stage is active and transimpedance amplifier is off (6.5 µA typical consumption).
- `AFE_AMPERIOMETRIC:` AFE module changes to amperometric mode. ADC changes to low power standby mode (0.1 µA typical consumption), bias stage and transimpedance amplifier are on (10 µA typical consumption).

In all cases, the ADC only exits of low power standby mode to performs the conversion. When the conversion finishes, the ADC changes automatically to low power standby mode.

```
gas_sensor.setPowerMode(power_mode);
```

The CH_4 and combustible gases module, and the CO_2 module have only 2 states: on and off. So, this function cannot be used.

The function returns:

- 1 if OK

7.3. Reading the sensors

7.3.1. Temperature

The developer can read two temperature sensors. One of them is inside the AFE module for the 3- sensors. The other one is the BME280 sensor. If no parameter is passed, `getTemp()` function will read the BME280 sensor and, if the BME280 sensor fails, it will read the temperature sensor installed in the AFE.

```
float temperature;
// Reads the temperature sensor
temperature = gas_sensor.getTemp();
```

The sensor to read can be selected with '0' to read the sensor of the AFE and '1' to read the BME280.

```
float temperature;
// Reads the temperature sensor from the AFE module
temperature = gas_sensor.getTemp(0);
// Reads the BME280 sensor
temperature = gas_sensor.getTemp(1);
```

The CH_4 and combustible gases module, the CO_2 module and all the 4 electrode sensors can only read the BME280 sensor.

In all cases the function returns:

- the temperature in ºC
- - 1000 if I2C bus communication error

7.3.2. Humidity

Humidity sensor from BME280 environmental sensor can be read with the function `getHumidity()`. This function does not need any parameter.

```
float humidity;
// Reads the environmetal humidity from BME280 sensor
humidity = gas_sensor.getHumidity();
```

The function returns:

- the percentage of relative humidity (% RH)
- - 1000 if I2C bus communication error

7.3.3. Pressure

Pressure sensor from BME280 environmental sensor can be read with the function `getPressure()`. This function does not need any parameter.

```
float pressure;
// Reads the environmetal pressure from BME280 sensor
pressure = gas_sensor.getPressure();
```

The function returns:

- the pressure in Pascals (Pa)
- - 1000 if I2C bus communication error

7.3.4. Gas concentration

There are 4 functions to read the gas concentration, according to the parameters passed to the function. The first one is `getConc()`. This function performs a high resolution A-D conversion, reads the temperature sensor to compensate baseline and sensitivity and converts to ppm automatically. In the case of a 4-electrode AFE, it will read the both electrodes and compensate them.

The second one, `getConc(resolution)`, performs the A-D conversion with the resolution passed as parameter, reads the temperature sensor to compensate baseline and sensitivity and converts to ppm automatically. In the case of a 4-electrode AFE, it will read both electrodes and compensate them. Allowed resolution parameters are:

- `MCP3421_LOW_RES:` 12 bits conversion
- `MCP3421_MEDIUM_RES:` 14 bits conversion
- `MCP3421_HIGH_RES:` 16 bits conversion
- `MCP3421_ULTRA_HIGH_RES:` 18 bits conversion

The third one, `getConc(resolution, NO2_conc)`, must only be used with a ozone sensor. In this case, the function performs the A-D conversion with the resolution passed as parameter, reads the temperature sensor to compensate the sensitivity and converts to ppm automatically. Also, it compensates the NO2 cross-sensitivity with the NO2 concentration, passed as parameter. Allowed resolution values are:

- `MCP3421_LOW_RES:` 12 bits conversion
- `MCP3421_MEDIUM_RES:` 14 bits conversion
- `MCP3421_HIGH_RES:` 16 bits conversion
- `MCP3421_ULTRA_HIGH_RES:` 18 bits conversion

The last one is `getConc(resolution, temperature, NO2_conc)`. In this case, the function performs the A-D conversion with the resolution passed as parameter, reads the temperature sensor to compensate the sensitivity and converts to ppm automatically. Also, it compensates the NO_2 cross-sensitivity with the NO_2 concentration, passed as parameter. The function only will be used with ozone sensors. Allowed resolution values are:

- `MCP3421_LOW_RES:` 12 bits conversion
- `MCP3421_MEDIUM_RES:` 14 bits conversion
- `MCP3421_HIGH_RES:` 16 bits conversion
- `MCP3421_ULTRA_HIGH_RES:` 18 bits conversion

Temperature must be in Celsius degrees. If the value is -1000 ºC (means error in the temperature sample), the function does not compensate the baseline and sensitivity.

```
float gas_concentration;
// Read gas concentration
gas_concentration = gas_sensor.getConc();

// Read gas concentration with ultra high resolution (18 bits)
gas_concentration = gas_sensor.getConc(MCP3421_ULTRA_HIGH_RES);

// Read gas concentration from O3 sensor with low res and compensate NO2 gas
gas_concentration = gas_sensor.getConc(MCP3421_LOW_RES,
                                       0.125);

// Read gas concentration
gas_concentration = gas_sensor.getConc(MCP3421_MEDIUM_RES,
                                       24.5,
                                       1.25);
```

In all cases the function returns:

- concentration value in ppm or %LEL
- - 1000 if I2C bus communication error

7.4. Autogain process

The function `autoGain()` has been developed to fix the voltage generated in the transimpedance stage out of the limits of the ADC. It must only be used with 3-electrode sensors. The function will change internally the values of the gain resistor and the voltage reference until the voltage measured by the ADC is out of the limits or more changes cannot be done.

`autoGain()` should be used when the sensor has completed the warm up time.

```
// Performs autoGain process
gas_sensor.autoGain();
```

The function returns the changes done:

- high nibble (4 MSB): steps in voltage reference (0..15)
- low nibble (4 LSB): steps in gain resistor (0..15)

7.5. Showing sensor information

The function `showSensorInfo()` shows the sensor data via USB. This function does not need any parameters and returns nothing.

```
// Show sensor data
gas_sensor.showSensorInfo();
```

The files of the sensor board itself are: **WaspSensorGas_Pro.cpp, WaspSensorGas_Pro.h**

They can be downloaded from: http://www.libelium.com/development/waspmote/sdk_and_applications

8. API for the Particle Matter (PM1 / PM2.5 / PM10) – Dust Sensor

8.1. Before starting

When using the Particle Matter Sensor on Plug&Sense!, remember it is mandatory to include the WaspOPC_N2 library by introducing the next line at the beginning of the code:

```
#include <WaspOPC_N2.h>
```

8.2. Library variables

The WaspOPC_N2 library has some variables used by the functions to store the data received from the OPC-N2 sensor. These variables are listed in the table below:

Variable	Type of variable	Description	Functions that updated it
`_bin[]`	Array of unsigned long	Number of particles detected for each bin.	`getHistogram()` `getPM()`
`_temp`	float	Temperature from sensor in Celsius degrees. This sensor is not available inside the sensor yet.	`getHistogram()` `getPM()`
`_pressure`	float	Pressure from sensor in Pascals. This sensor is not available inside the sensor yet.	`getHistogram()` `getPM()`
`_periodCount`	Unsigned long	The histogram's actual sampling period. It is recorded as a number of 12 MHz clock cycles.	`getHistogram()` `getPM()`
`_bin1_MToF`	Unsigned short	Represents the average amount of time that particles sized in the stated bin took to cross the OPS's laser beam. Each value is in μs multiplied by 3.	`getHistogram()` `getPM()`
`_bin3_MToF`	Unsigned short	Represents the average amount of time that particles sized in the stated bin took to cross the OPS's laser beam. Each value is in μs multiplied by 3.	`getHistogram()` `getPM()`
`_bin5_MToF`	Unsigned short	Represents the average amount of time that particles sized in the stated bin took to cross the OPS's laser beam. Each value is in μs multiplied by 3.	`getHistogram()` `getPM()`
`_bin7_MToF`	Unsigned short	Represents the average amount of time that particles sized in the stated bin took to cross the OPS's laser beam. Each value is in μs multiplied by 3.	`getHistogram()` `getPM()`
`_PM1`	float	The mass (in μg/m^3) of all particles below 1 μm in size.	`getHistogram()` `getPM()`
`_PM2_5`	float	The mass (in μg/m^3) of all particles below 2.5 μm in size.	`getHistogram()` `getPM()`
`_PM10`	float	The mass (in μg/m^3) of all particles below 10 μm in size.	`getHistogram()` `getPM()`

Figure: Variables from the WaspOPC_N2 library

8.3. Power and configuration

8.3.1. Initializing the sensor

Before reading the concentration values, the sensor must be powered using the function `ON()`. Unlike with other sensor boards, the user does not need to power on the board. The API library performs the next tasks in the power-on process from each sensor:

- Powers on the board (if necessary)
- Powers on the sensor
- Configures the communication bus and checks if the sensor is ready to work.

```
OPC_N2.ON();
```

The function returns:

- 0 if the sensor does not init correctly
- 1 if init OK

If a sensor for gases PRO v1 is used, the `ON()` function must include the parameter `'0'`. So, the function to use should be:

```
OPC_N2.ON(0);
```

8.3.2. Switching the sensor off

In order to save battery, the sensor could be powered off using the function `OFF()`. Unlike other sensor boards, the user does not need to power off the board. The API library powers off the board automatically when the last sensor is turned off.

```
OPC_N2.OFF();
```

The function returns the `pwrGasPRORegister`. Each bit of this register represents the status of a sensor. ‘1’ for the powered on sensors and ‘0’ for the powered off.

- 7: not used
- 6: gas sensor in socket 6
- 5: gas sensor in socket 5 or socket B in Plug & Sense!
- 4: gas sensor in socket 4 or socket A in Plug & Sense!
- 3: gas sensor in socket 3 or socket F in Plug & Sense!
- 2: gas sensor in socket 2
- 1: gas sensor in socket 1 or socket C in Plug & Sense!
- 0: particles-dust sensor (socket D in Plug & Sense!)

8.4. Reading the sensor

8.4.1. Reading bin and PM values

The functions `getPM(timeSample)` and `getPM(waitSample, timeSample)` perform a measure of the particles from the atmosphere. `timeSample` is the period in milliseconds to sample the air absorbed by the built-in fan. `waitSample` is a time in milliseconds with the fan powered on before the sample measurement.

```
// Reads PM and bin values with a period of 5 seconds

OPC_N2.getPM(5000);
// Reads PM and bin values with a period of 9 seconds and a wait sample of 5 seconds
OPC_N2.getPM(5000, 9000);
```

The function returns:

- 1 if OK
- 4 if error with the parameters
- 100 if error sending the command digital pot on
- 101 if error receiving data
- 102 if error sending the command read histogram
- 103 if error receiving data
- 104 if error sending the command read histogram
- 105 if error receiving data
- 106 if error sending the command digital pot off
- 107 if error receiving data

If the function ends successfully, the next variables will be updated:

- `_bin`
- `_temp`
- `_pressure`
- `_periodCount`
- `_bin1_MToF`
- `_bin3_MToF`
- `_bin5_MToF`
- `_bin7_MToF`
- `_PM1`
- `_PM2_5`
- `_PM10`

8.4.2. Reading histogram

The function `getHistogramData()` reads the data calculated by the OPC-N2 sensor. When the function reads the sensor, the data from the sensor will be reset.

```
// Reads histogram data
OPC_N2.getHistogramData();
```

The function returns:

- 1 if OK
- 4 if error with the parameters
- 110 if error sending the command
- 111 if error receiving data (CRC)

If the function ends successfully, the next variables will be updated:

```
_bin
_temp
_pressure
_periodCount
_bin1_MToF
_bin3_MToF
_bin5_MToF
_bin7_MToF
_PM1
_PM2_5
_PM10
```

8.4.3. Reading the information string

The OPC-N2 sensor stores a string (60 bytes) with information about the sensor model and the firmware. This string can be read using the function `getInfoString(string_pointer)` and passing a string pointer as parameter. The information will be stored in the string pointer.

```
char information[61];
// Reads the configuration variables
OPC_N2.getInfoString(information);
// Prints the string
USB.println(information);
```

The function returns:

- 1 if OK
- -1 if error sending the command

The files of the sensor itself are: **OPC_N2.cpp, OPC_N2.h**

They can be downloaded from: http://www.libelium.com/development/waspmote/sdk_and_applications

9. Consumption

9.1. Consumption table

In the following table, the consumption shown by the board when active is detailed, the minimum consumption (constant, fixed by the permanently active components, such as the adaptation electronics and the BME280 sensor) and the individual consumptions of each of the sensors connected alone to the board (the total consumption of the board with a determined sensor will be calculated as the sum of the constant minimum consumption of the board plus the minimum consumption of the group to whom the sensor belongs plus the consumption of the sensor).

Remember that the board's power can be completely disconnected, reducing the consumption to zero, powering off all the sensors.

	Switch on
Minimum (constant)	5-10 µA
Carbon Monoxide (CO) for high concentrations	351 µA
Carbon Monoxide (CO) for low concentrations	312 µA
Carbon Dioxide (CO_2)	85 mA
Molecular Oxygen (O_2)	332 µA
Ozone (O_3)	< 1 mA
Nitric Oxide (NO) for high concentrations	441 µA
Nitric Oxide (NO) for low concentrations	< 1 mA
Nitric Dioxide (NO_2)	335 µA
Nitric Dioxide (NO_2) high accuracy	< 1 mA
Sulfur Dioxide (SO_2)	333 µA
Sulfur Dioxide (SO_2) high accuracy	< 1mA
Ammonia (NH_3) for low concentrations	338 µA
Ammonia (NH_3) for high concentrations	338 µA
Methane (CH_4) and other combustible gases	68 mA
Molecular Hydrogen (H_2)	520 µA
Hydrogen Sulfide (H_2S)	352 µA
Hydrogen Chloride (HCl)	341 µA
Hydrogen Cyanide (HCN)	327 µA
Phosphine (PH_3)	361 µA
Ethylene Oxide (ETO)	360 µA
Chlorine (Cl_2)	353 µA
Particle Matter – Dust	260 mA @ 5 V

Figure: Consumption for each sensor

9.2. Low consumption mode

From the point of view of optimizing Waspmote resources when the Gases PRO Sensor Board is used, it is recommended to follow the following instructions:

- **Optimize the time the sensors are switched on depending on your application**

The accuracy of each sensor's measurement will vary depending on the time that the sensor remains powered before reading, or on the power supply cycles which are continually applied, depending on the type of sensor. Knowing the required time to take a measurement in a determined application will allow saving of consumption without losing resolution in the sampled value.

10. API changelog

Keep track of the software changes on this link:
www.libelium.com/development/waspmote/documentation/changelog/#Gases_Pro

11. Documentation changelog

From v7.3 to v7.4

- Added comparative analysis between Alphasense' and Libelium's hardware
- Added explanation about I2C error code

From v7.2 to v7.3:

- Added use and power recommendations for electrochemical sensors
- Added references to the Programming Cloud Service
- Added references to the External Battery Module accessory
- The operating temperature range and maximum recharging current were updated

From v7.1 to v7.2:

- Added references to the Nitric Oxide (NO) Gas Sensor for low concentrations
- Added references to the Nitric Dioxide (NO_2) high accuracy Gas Sensor
- Added references to the Sulfur Dioxide (SO_2) high accuracy Gas Sensor
- Added references to the Ammonia (NH_3) Gas Sensor for high concentrations
- Added notes for discontinued sensors
- Added references for the new GPS accessory for Plug & Sense!

From v7.0 to v7.1:

- Added references to the integration of Industrial Protocols for Plug & Sense!

12. Certifications

Libelium offers 2 types of IoT sensor platforms, Waspmote OEM and Plug & Sense!:

- **Waspmote OEM** is intended to be used for research purposes or as part of a major product so it needs final certification on the client side. More info at: www.libelium.com/products/waspmote
- **Plug & Sense!** is the line ready to be used out-of-the-box. It includes market certifications. See below the specific list of regulations passed. More info at: www.libelium.com/products/plug-sense

Besides, Meshlium, our multiprotocol router for the IoT, is also certified with the certifications below. Get more info at:

www.libelium.com/products/meshlium

List of certifications for Plug & Sense! and Meshlium:

- CE (Europe)
- FCC (US)
- IC (Canada)
- ANATEL (Brazil)
- RCM (Australia)
- PTCRB (cellular certification for the US)
- AT&T (cellular certification for the US)

Figure: Certifications of the Plug & Sense! product line

You can find all the certification documents at:

www.libelium.com/certifications

13. Maintenance

- In this section, the term "Waspmote" encompasses both the Waspmote device itself as well as its modules and sensor boards.
- Take care with the handling of Waspmote, do not drop it, bang it or move it sharply.
- Avoid putting the devices in areas of high temperatures since the electronic components may be damaged.
- The antennas are lightly threaded to the connector; do not force them as this could damage the connectors.
- Do not use any type of paint for the device, which may damage the functioning of the connections and closure mechanisms.

14. Disposal and recycling

- In this section, the term "Waspmote" encompasses both the Waspmote device itself as well as its modules and sensor boards.
- When Waspmote reaches the end of its useful life, it must be taken to a recycling point for electronic equipment.
- The equipment has to be disposed on a selective waste collection system, different to that of urban solid waste. Please, dispose it properly.
- Your distributor will inform you about the most appropriate and environmentally friendly waste process for the used product and its packaging.