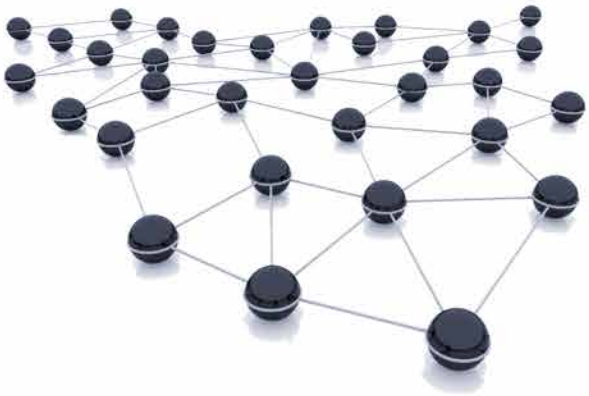
Waspmote Plug & Sense!

Sensor Guide



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1. General

Important:

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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/plug-sense

The “General Conditions of Libelium Sale and Use” document can be found at:
http://www.libelium.com/development/plug-sense/technical_service/

2. Introduction

In this document, all the possible configurations of the Plug & Sense! line are described, including a general description of all the possible applications and the technical specifications of the sensors associated to each one of them.

For a deep description of the characteristics of the Plug & Sense! line, please refer to the Waspmote Plug & Sense! Technical Guide. You can find it, along with other useful information such as the Waspmote and Sensor boards technical and programming guides, in the Development section of the Libelium website at http://www.libelium.com/development/plug-sense

For detailed info about sensors or probes we do NOT recommend this Guide, but the dedicated guide for the sensor board. Example: if you have a Plug & Sense! Smart Cities PRO, we advise reading the Smart Cities PRO Technical Guide.

Note that no code for reading the sensors has been included in this guide. For programming the Waspmote Plug & Sense! notes, please use the default examples provided for each sensor, available at: http://www.libelium.com/development/plug-sense/examples/

Figure: Waspmote Plug & Sense! line

3. Sensors

Figure: Image of Waspmote Plug & Sense!

3.1. Internal sensors

3.1.1. Accelerometer

Waspmote has a built-in acceleration sensor LIS3331LDH, by STMicroelectronics, which informs the mote of acceleration variations experienced on each one of the 3 axes (X,Y, Z).

The integration of this sensor allows the measurement of acceleration on the 3 axes (X, Y, Z), establishing 4 kinds of events: Free Fall, inertial wake up, 6D movement and 6D position which are explained in the **Interruption Programming Guide**.

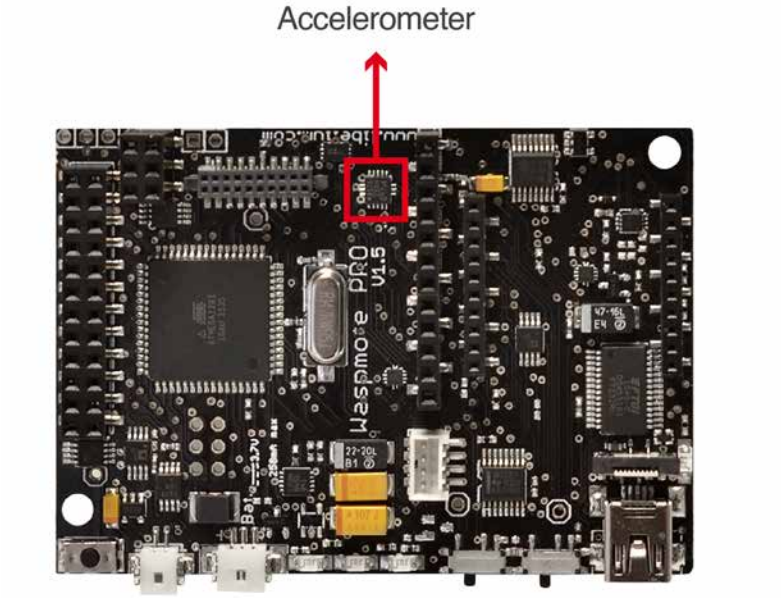


Figure: Accelerometer

The LIS331DLH has dynamically user-selectable full scales of **±2g/±4g/±8g** and it is capable of measuring accelerations with output data rates from **0.5 Hz to 1 kHz**.

The device features ultra low-power operational modes that allow advanced power saving and smart sleep to wake-up functions.

The accelerometer has several power modes, the output data rate (ODR) will depend on the power mode selected. The power modes and output data rates are shown in this table:

Power mode	Output data rate (Hz)
Power down	--
Normal mode	1000
Low-power 1	0.5
Low-power 2	1
Low-power 3	2
Low-power 4	5
Low-power 5	10

This accelerometer has an auto-test capability that allows the user to check the functioning of the sensor in the final application. Its operational temperature range is between -40 ºC and +85 ºC.

The accelerometer communicates with the microcontroller through the I2C interface. The pins that are used for this task are the SCL pin and the SDA pin, as well as another interruption pin to generate the interruptions.

The accelerometer has 4 types of event which can generate an interrupt: free fall, inertial wake up, 6D movement and 6D position.

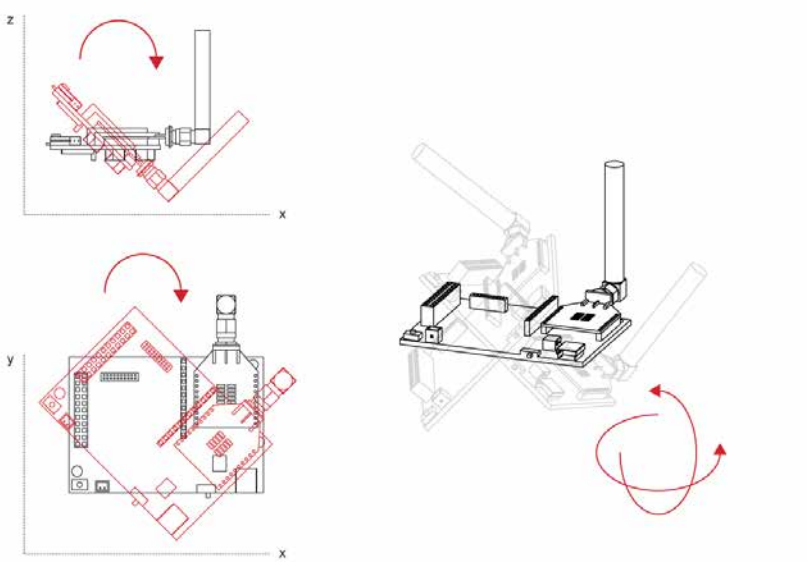
These thresholds and times are set in the WaspACC.h file.

To show the ease of programming, an extract of code about how to get the accelerometer values is included below:

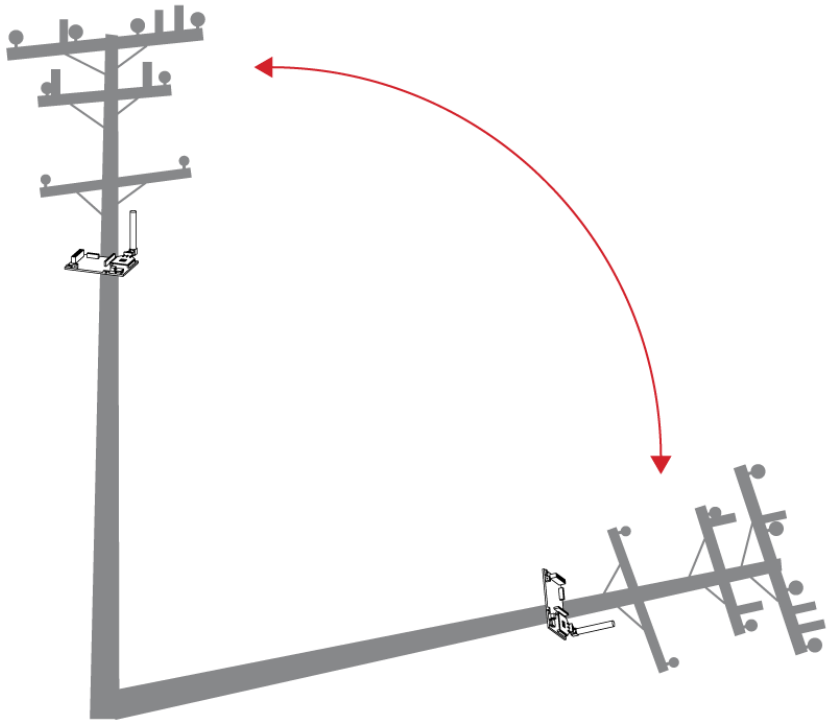
```
{
  ACC.ON();
  ACC.getX();
  ACC.getY();
  ACC.getZ();
}
```

Some figures with possible uses of the accelerometer are shown below:

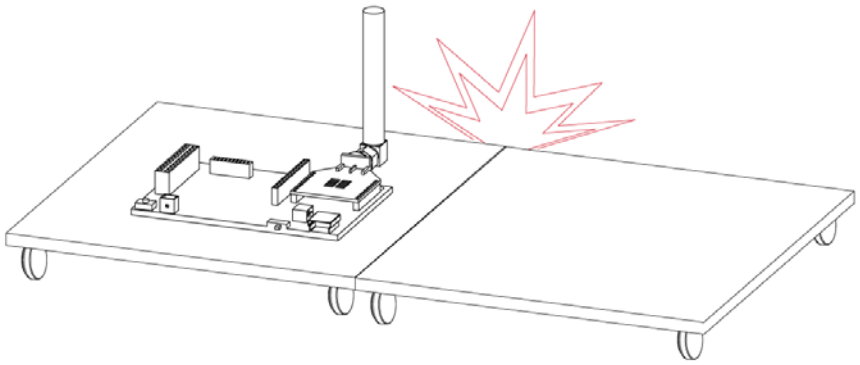
Rotation and twist:



Free fall of objects in which it is installed:



Crash:



More information about interruptions generated by the accelerometer can be found in the chapter “Interruptions” and in the **Interruption Programming Guide**.

Related API libraries: **WaspACC.h, WaspACC.cpp**

All information about their programming and operation can be found in the Accelerometer Programming Guide.

All the documentation is located in the Development section in the Libelium website.

3.2. Sensor probes

All sensing capabilities of Waspmote Plug & Sense! are provided by sensor probes. Each sensor probe contains one sensor, some necessary protections against outdoor environmental conditions and a waterproof male connector.

The standard length of a sensor probe is about 150 mm, including waterproof connector, but it could vary due to some sensors need special dimensions. Weight of a standard probe rounds 20 g, but there are some special cases where this weight can rise.

Sensor probes are designed to be used in vertical position (with the sensor looking to the ground). In this position, the protection cap of each sensor probe is effective against rain.

4. Smart Enviroment PRO

4.1. General description

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 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 Sulfide (H_2S) [Calibrated]	9381-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.

Figure: Sensor sockets configuration for Smart Environment PRO model

4.2. Temperature, Humidity and Pressure Sensor Probe

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

Specifications

Figure: Image of the Temperature, Humidity and Pressure Sensor Probe

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

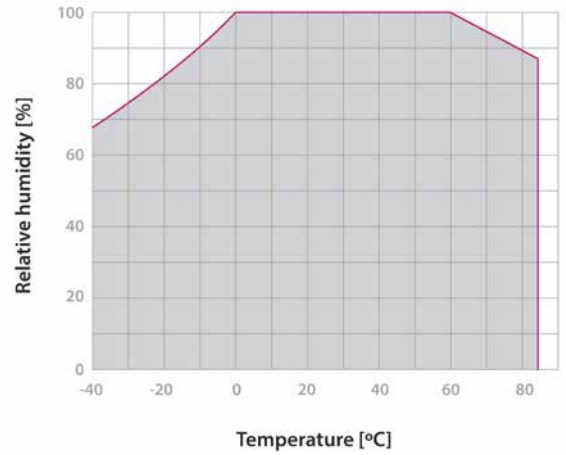


Figure: Humidity sensor operating range

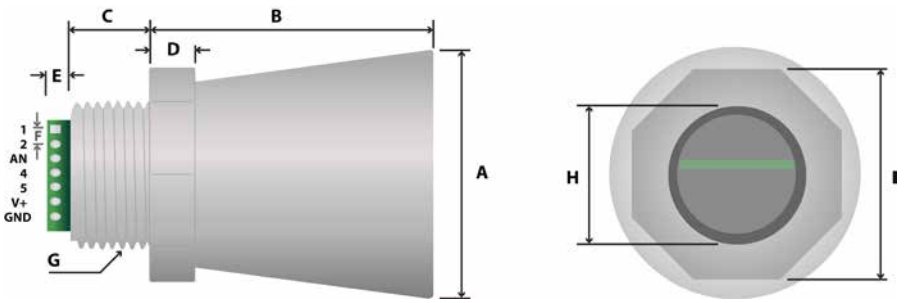
Pressure sensor
Measurement range: 30 ~ 110 kPa
Operational temperature range: -40 ~ +85 ºC
Full accuracy temperature range: 0 ~ +65 ºC
Absolute accuracy: ±0.1 kPa (0 ~ 65 ºC)
Typical consumption: 2.8 µA measuring
Maximum consumption: 4.2 µA measuring

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

I2CXL-MaxSonar®-MB7040™

Operation frequency: 42 kHz
Maximum detection distance: 765 cm
Interface: Digital bus
Power supply: 3.3 V ~ 5 V
Consumption (average): 2.1 mA (powered at 3.3 V) – 3.2 mA (powered at 5 V)
Consumption (peak): 50 mA (powered at 3.3 V) – 100 mA (powered at 5 V)
Usage: Indoors and outdoors (IP-67)

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



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

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):

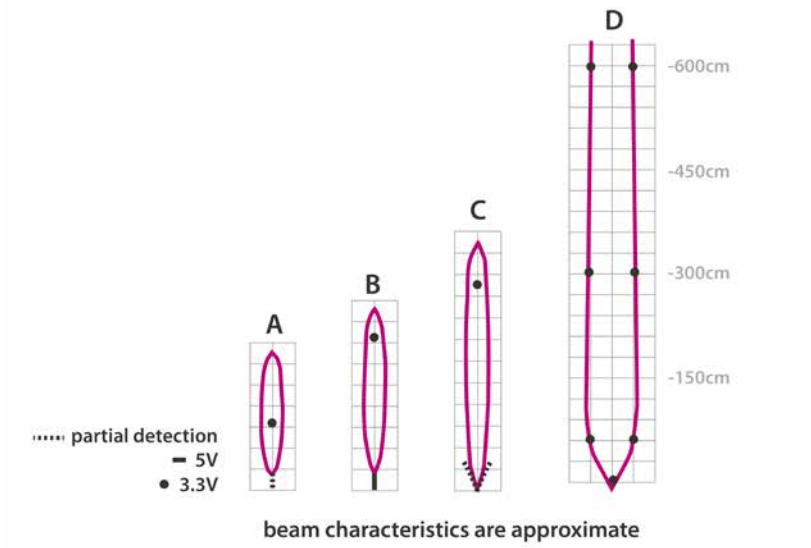


Figure: Diagram of the sensor beam extracted from the data sheet of the XL-MaxSonar®-WRA1™ sensor from MaxBotix

Figure: Image of configurations of the ultrasound sensor probe

As we see in the figure, the ultrasound sensor probe may be placed in different positions. The sensor can be focused directly to the point we want to measure.

4.4. Luminosity sensor probe (Luxes accuracy)

Sensor specifications (Luxes accuracy)

Dynamic range: 0.1 to 40000 Lux
Spectral range: 300 – 1100 nm
Voltage range: 2.7 – 3.6 V
Operating temperature: -30 ºC to +80 ºC
Typical consumption: 0.24 mA
Maximum consumption: 0.6 mA
Usage: Indoors and outdoors

Figure: Image of the Luminosity sensor probe (Luxes accuracy)

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.

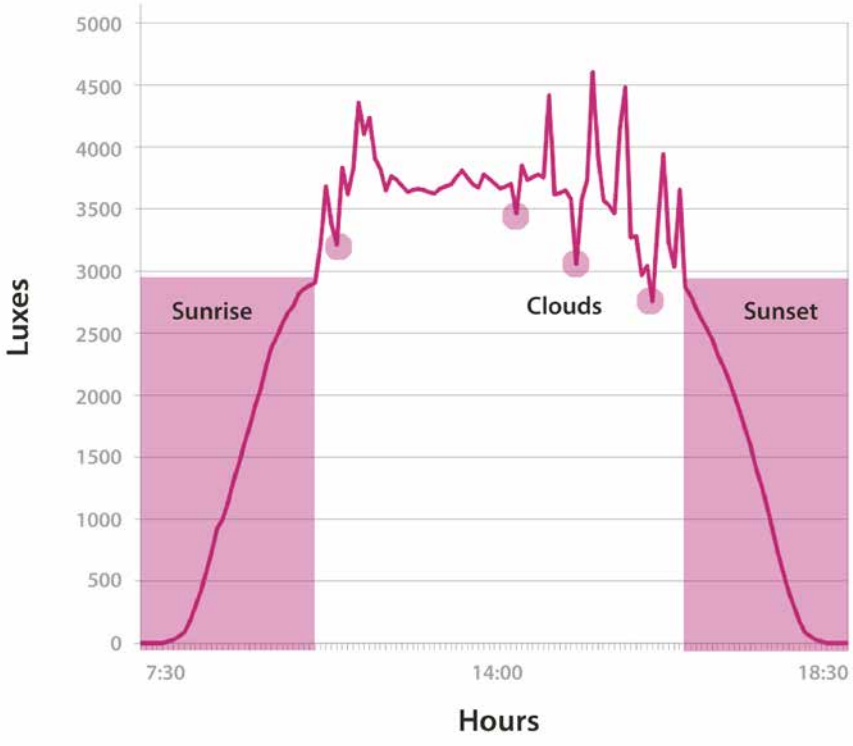


Figure: Image of the Luminosity sensor probe (Luxes accuracy)

4.5. Carbon Monoxide (CO) Gas sensor probe for high concentrations [Calibrated]

Figure: Image of the Carbon Monoxide Sensor Probe for high concentrations

Specifications

Gas: CO
Sensor: 4-CO-500

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

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

4.6. Carbon Monoxide (CO) Gas sensor probe for low concentrations [Calibrated]

Figure: Image of the Carbon Monoxide Sensor Probe for low concentrations

Specifications

Gas: CO
Sensor: CO-A4

Performance Characteristics

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

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: 3 years in air

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

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

Figure: Image of the Carbon Dioxide Sensor Probe

Specifications

Gas: CO_2
Sensor: INE20-CO2P-NCVSP

Performance Characteristics
Nominal Range: 0 to 5000 ppm
Long Term Output Drift: < ±250 ppm/year
Warm up time: 60 seconds @ 25 ºC
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 ºC to 60 ºC
Operating Humidity: 0 to 95% RH non-condensing
Storage Temperature: -40 ºC to 85 ºC
MTBF: ≥ 5 years

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**. Read the Gases PRO Technical Guide for more details.*

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.

4.8. Molecular Oxygen (O_2) Gas Sensor probe [Calibrated]

Specifications

Gas: O_2
Sensor: 4-OL

Figure: Image of the Molecular Oxygen Sensor Probe

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

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

4.9. Ozone (O_3) Gas Sensor probe [Calibrated]

Figure: Image of the Ozone Sensor Probe

Specifications

Gas: O_3
Sensor: OX-A431

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 NO2 gas. Correction could be necessary in ambients with NO2.

Operation Conditions
Temperature Range: -20 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

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

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

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

Specifications

Gas: NO
Sensor: 4-NO-250

Performance Characteristics
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)

Figure: Image of the Nitric Oxide Sensor Probe for high concentrations

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

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

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

Specifications

Gas: NO
Sensor: NO-A4

Figure: Image of the Nitric Oxide Sensor Probe for high concentrations

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

Operation Conditions
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

Average consumption: less than 1 mA
** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

4.12. Nitric Dioxide (NO_2) Gas Sensor probe [Calibrated]

Note: This sensor probe was discontinued in May 2017. Its substitute is the Nitric Dioxide (NO2) high accuracy Gas Sensor Probe [Calibrated]. The information about this alternative sensor probe can be found in the next section of this guide.

Specifications

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 ±0.1 ppm* (ideal conditions)

Figure: Image of the Nitric Dioxide Sensor Probe

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

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

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

Figure: Image of the high accuracy Nitric Dioxide Sensor Probe

Specifications

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 Drift: < 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)
O_3 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

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

4.14. Sulfur Dioxide (SO_2) Gas Sensor probe [Calibrated]

Note: This sensor probe was discontinued in May 2017. Its substitute is the Nitric Dioxide (NO2) high accuracy Gas Sensor Probe [Calibrated]. The information about this alternative sensor probe can be found in the next section of this guide.

Figure: Image of the Sulfur Dioxide Sensor Probe

Specifications

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 ±0.1 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

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

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

Figure: Image of the high accuracy Sulfur Dioxide Sensor Probe

Specifications

Gas: SO_2
Sensor: SO2-A4

Performance Characteristics
Nominal Range: 0 to 20 ppm
Maximum Overload: 100 ppm
Long Term Sensitivity Drift: < ±15% change/year in lab air, monthly
Long Term zero Drift: < 20 ppb equivalent change/year in lab air
Response Time (T90): ≤ 20 seconds
Sensitivity: 320 ± 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

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

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

Specifications

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)

Figure: Image of the Ammonia Sensor Probe for low concentrations

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

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

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

Specifications

Gas: NH_3
Sensor: 4-NH3-500

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

Figure: Image of the Ammonia Sensor Probe for high concentrations

Operation Conditions
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

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

4.18. Methane (CH_4) and Combustible Gas Sensor probe [Calibrated]

Specifications

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)

Figure: Image of the Methane (CH_4) and Combustible Gas Sensor Probe

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

Table : Inhibition and poisoning effects

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**. Read the Gases PRO Technical Guide for more details.*

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.

4.19. Molecular Hydrogen (H_2) Gas Sensor probe [Calibrated]

Specifications

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)

Figure: Image of the Molecular Hydrogen Sensor Probe

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

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

4.20. Hydrogen Sulfide (H_2S) Gas Sensor probe [Calibrated]

Specifications

Gas: H_2S
Sensor: 4-H2S-100

Performance Characteristics
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)

Figure: Image of the Hydrogen Sulfide Sensor Probe

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

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

4.21. Hydrogen Chloride (HCl) Gas Sensor probe [Calibrated]

Specifications

Gas: HCl
Sensor: 4-HCl-50

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)

Figure: Image of the Hydrogen Chloride Sensor Probe

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

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

4.22. Hydrogen Cyanide (HCN) Gas Sensor Probe [Calibrated]

Specifications

Gas: HCN
Sensor: 4-HCN-50

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)

Figure: Image of the Hydrogen Cyanide Sensor Probe

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

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

4.23. Phosphine (PH_3) Gas Sensor probe [Calibrated]

Specifications

Gas: PH_3
Sensor: 4-PH3-20

Figure: Image of the Phosphine Gas Sensor Probe

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

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

4.24. Ethylene Oxide (ETO) Gas Sensor probe [Calibrated]

Specifications

Gas: ETO
Sensor: 4-ETO-100

Figure: Image of the Ethylene Oxide Sensor Probe

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

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

4.25. Chlorine (Cl_2) Gas Sensor probe [Calibrated]

Figure: Image of the Chlorine Sensor Probe

Specifications

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

Average consumption: less than 1 mA

** Accuracy values are only given for the **optimum case**. Read the Gases PRO Technical Guide for more details.*

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.

4.26. 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. Libelium keeps a minimum stock of calibrated gas sensors to ensure the maximum durability. Ensambling process and delivery time takes from 1 to 2 weeks in case the current stock is enough for the order and from 4 to 6 weeks in case the order is higher than the stock available and new sensors units need to be manufactured and calibrated. Please inform as soon as possible of your sensor requirements to our Sales agents so that they can order the units needed to factory.

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% (depending on the external conditions: humidity, temperature, measured gas concentration, if there are another type of gas present which corrode the sensor, etc). 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.

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

Note: Since February 2019, the OPC-N3 sensor is supplied instead of the OPC-N2. The OPC-N3 has taken the success of the older OPC-N2 unit and has improved it further. With the same dimensions and power/ interface as the N2, the OPC-N3 now measures from 0.35 µm to 40 µm, sorting into 24 size bins. Features include improved aerodynamics with reduction of particle deposition, better low end performance, extended upper size measurements and high/low flow rate digital selection. The OPC-N3 can measure from clean rooms to pollution levels to 2,000 µg/m3 with the unique feature of being able to size classify pollen.

Specifications

Sensor: OPC-N3

Performance Characteristics

Laser classification: Class 1 as enclosed housing
Particle range (µm): 0.35 to 40 spherical equivalent size (based on RI of 1.5
Size categorization (standard): 24 software bins
Sampling interval (seconds): 1 to 30 histogram period
Total flow rate: 5.5 L/min
Sample flow rate: 280 mL/min
Max particle count rate: 10000 particles/second
Max coincidence probability: 0.84% at 10,000,000 particles/L
0.24% at 500 particles/L

Figure: Image of the Particle Matter sensor, encapsulated

Power Characteristics

Measurement mode (laser and fan on): 270 mA @ 5 Volts (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.

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 ton 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.

DO NOT remove the external housing: this not only ensures the required airflow but 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.*

4.27.1. 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.

4.27.2. Measurement process

Like conventional optical particle counters, the OPC-N3 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-N3 uses only a miniature low-power fan .

The OPC-N3 classifies each particle size, at rates up to ~10,000 particle per second, adding the particle diameter to one of 24 “bins” covering the size range from ~0.35 to 40 µm. The resulting particle size histograms can be evaluated over user-defined sampling times from 1 to 30 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. Read the Gases PRO Technical Guide to know how to manage and read this sensor.

4.27.3. Installing the Sensor Probe

Libelium offers the OPC-N3 sensor inside a protective enclosure. The enclosure has special input and output accessories for letting the air flow pass, but always keeping the rain or excessive dirt outside. Fixing accessories and one connection cord are also provided. All the system is called the Particle Matter – Dust Sensor Probe.

Figure: Input and output accessories in the enclosure

The system comes with 4 mounting feet (T's). The enclosure should be firmly fixed to a wall with the provided screws, or fixed to a lamppost or tree with 2 metal cable ties.

Figure: Fixing the Particle Matter – Dust Sensor Probe on a wall

Figure: Connecting the Particle Matter – Dust Sensor Probe to Plug & Sense!

The installation of this Sensor Probe must be similar to any Plug & Sense! installation. Please read the "Installation" chapter in the Plug & Sense! Technical Guide for further details.

Figure: Particle Matter – Dust Sensor Probe finally connected to Plug & Sense!

5. Smart Security

5.1. General description

The main applications for this Waspmote Plug & Sense! configuration are perimeter access control, liquid presence detection and doors and windows openings. Besides, a relay system allows this model to interact with external electrical machines.

Figure: Smart Security Waspmote Plug & Sense! model

Note: *The probes attached in this photo could not match the final location. See next table for the correct configuration.*

Sensor Socket	Sensor probes allowed for each sensor socket	
	Parameter	**Reference**
A, C, D or E	Temperature + Humidity + Pressure	9370-P
	Luminosity (Luxes accuracy)	9325-P
	Ultrasound (distance measurement)	9246-P
	Presence - PIR	9212-P
	Liquid Level (combustible, water)	9239-P, 9240-P
	Liquid Presence (Point, Line)	9243-P, 9295-P
	Hall Effect	9207-P
B	Liquid Flow (small, medium)	9296-P, 9297-P
F	Relay Input-Output	9270-P

Figure: Sensor sockets configuration for Smart Security model

As we see in the figure below, thanks to the directional probe, the presence sensor probe (PIR) may be placed in different positions. The sensor can be focused directly to the point we want.

Figure: Configurations of the Presence sensor probe (PIR)

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

5.2. Temperature, Humidity and Pressure Sensor Probe

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

Specifications

Figure: Image of the Temperature, Humidity and Pressure Sensor Probe

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

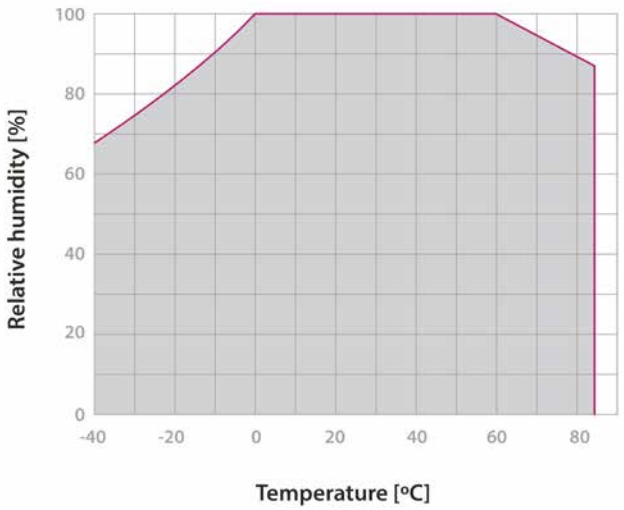


Figure: Humidity sensor operating range

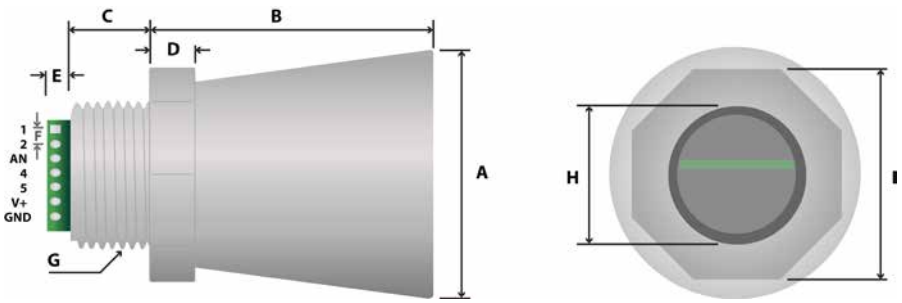
Pressure sensor
Measurement range: 30 ~ 110 kPa
Operational temperature range: -40 ~ +85 ºC
Full accuracy temperature range: 0 ~ +65 ºC
Absolute accuracy: ±0.1 kPa (0 ~ 65 ºC)
Typical consumption: 2.8 µA measuring
Maximum consumption: 4.2 µA measuring

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

I2CXL-MaxSonar®-MB7040™

Operation frequency: 42 kHz
Maximum detection distance: 765 cm
Interface: Digital bus
Power supply: 3.3 V ~ 5 V
Consumption (average): 2.1 mA (powered at 3.3 V) – 3.2 mA (powered at 5 V)
Consumption (peak): 50 mA (powered at 3.3 V) – 100 mA (powered at 5 V)
Usage: Indoors and outdoors (IP-67)

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



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

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):

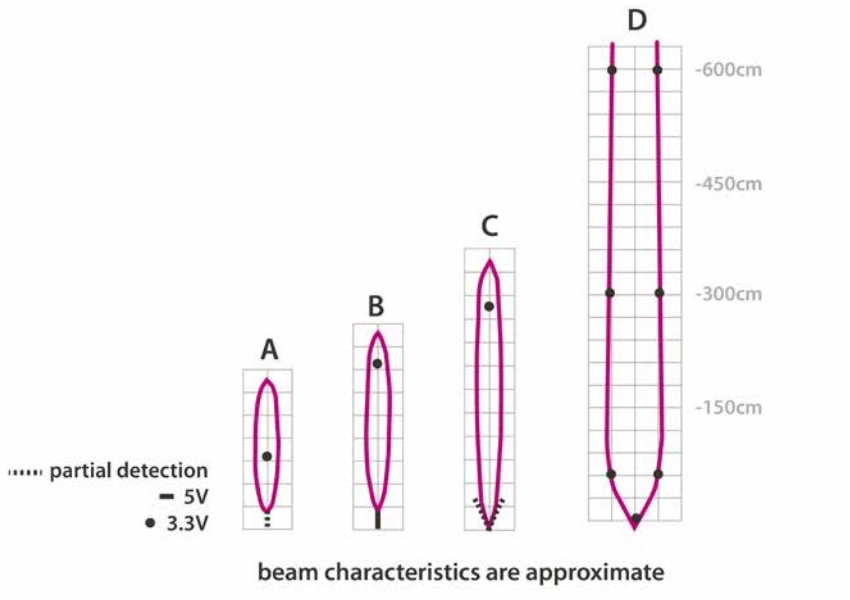


Figure: Diagram of the sensor beam extracted from the data sheet of the XL-MaxSonar®-WRA1™ sensor from MaxBotix

Figure: Image of configurations of the ultrasound sensor probe

As we see in the figure, the ultrasound sensor probe may be placed in different positions. The sensor can be focused directly to the point we want to measure.

5.4. Luminosity sensor probe (Luxes accuracy)

Sensor specifications (Luxes accuracy)

Dynamic range: 0.1 to 40000 Lux
Spectral range: 300 – 1100 nm
Voltage range: 2.7 – 3.6 V
Operating temperature: -30 ºC to +80 ºC
Typical consumption: 0.24 mA
Maximum consumption: 0.6 mA
Usage: Indoors and outdoors

Figure: Image of the Luminosity sensor probe (Luxes accuracy)

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.

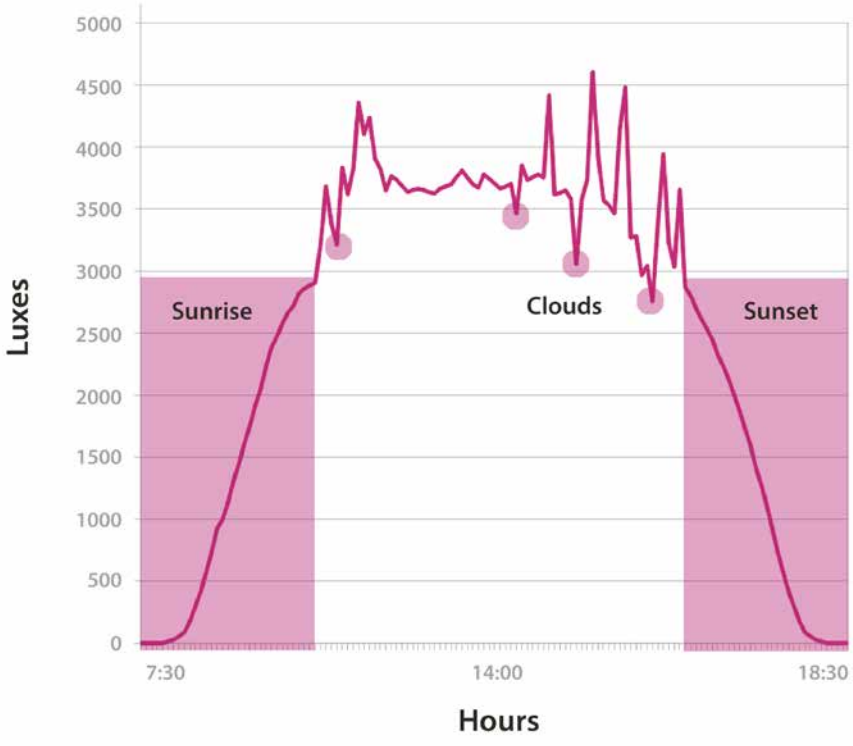


Figure: Image of the Luminosity sensor probe (Luxes accuracy)

5.5. Relay Input-Output (Max: 30VDC, 1A)

5.5.1. Specifications

Contact Ratings VDC: 1 A, 30 VDC
Contact Form: SPDT (1c)
Coil Rated Current: 50 mA

5.5.2. Precautions for Safe Use

- Do not use this feature if you do not have advanced knowledge of electricity and electrical automation.
- The incorrect use of this feature can cause harm to the user or other people and damage any connected equipment.
- The incorrect use of this feature can cause death to the user or other people!
- The incorrect use of this feature can causes fires!
- Use only tools and equipment with non-conducting handles when working on electrical devices.
- Never handle this feature when hands, feet, or body are wet or perspiring, or when standing on a wet floor.
- Do not store highly flammable liquids near this equipment.
- Disconnect the power source before operating on this equipment.
- Do not touch the charged relay terminal area while the power is turned on. Doing so may result in electric shock.
- Do not use a relay for a load that exceeds the relay's switching capacity or other contact ratings. Doing so will reduce the specified performance, causing insulation failure, contact welding, and contact failure, and the relay itself may be damaged or burnt.
- Make sure the number of switching operations is within the permissible range. If a Relay is used after performance has deteriorated, it may result in insulation failure between circuits and burning of the relay itself.
- Do not use Relays where flammable gases or explosive gases may be present. Doing so may cause combustion or explosion due to relay heating or arcing during switching.
- This Limited Warranty does not cover: (a) defects or damage resulting from accident, misuse, abnormal use, abnormal conditions, improper storage, exposure to liquid, moisture, dampness, sand or dirt, neglect, or unusual physical, electrical or electromechanical stress, defects or damage resulting from the use of Product in conjunction or connection with accessories, products, or ancillary/peripheral equipment.

5.5.3. Introduction

The relay that is in Waspmote Events Sensor board v3.0, provides a potential-free contact. This contact can be used to enable low power loads such as relays and contactors, or to enable inputs in a PLC. The IN REL is designed to be used by a potential free contact to join +3v3 with the IN REL, for example in power failure applications.

Its important to remark that the relay Input-Output is not designed for alternate current (VAC), therefore please use only continuous currents (VDC).

NOTE: *the changeover contact is designed to be an auxiliary contact,* ***NEVER TO HANDLE LOADS****. Please never reach the current limitations defined in the relay specifications. The events board can be damaged permanently. The input contact is designed to be used with a relay contact with a 3v3 + IN REL. If you have any question about the usage of the relay, please contact Libelium before any test.*

5.6. Relay Input-Output in Waspmote Plug & Sense!

To provide access to the relay contacts in the Waspmote Plug & Sense! encapsulated line, a waterproof terminal block junction box is provided as a Relay Input-Output probe, making the connections on industrial environments or outdoor applications easier.

Figure: Relay Input-Output probe

It consists of 2 cable glands and 6 terminal block connectors with screw. The junction box can be easily opened by removing the four external screws and the cover. Then, the user is able to make the necessary connections using the terminal block connectors. Finally, the cable glands should be adjusted and the junction box should be closed properly to avoid water ingress.

Figure: Pin-out of the Relay Input-Output junction box

Terminal	Signal
1	Common
2	NC
3	NA
4	3v3
5	Relay Input
6	GND

Note: Please double check the terminal block connections to avoid wrong wirings or short-circuits between poles. The Waspmote Plug & Sense! unit can be seriously damaged. Besides, ensure that the junction box is properly closed to avoid damaged in outdoor applications (because of rain entry, for example). Libelium's warranty will not cover damages caused by a wrong installation.

5.7. Liquid Flow sensor probes

Figure: Image of the Liquid Flow sensor probe (FS400)

Sensor specifications

Water Flow Small, YF-S402:
Flow rate: 0.3 ~ 6 L/Min
Working voltage: +5 V ~ +24 V
Working temperature: 0 ºC ~ 80 ºC
Pipe connection: 1/8”
Max rated current: 15 mA (DC 5 V)

Figure: Image of the YF-S402, Small Liquid Flow sensor

Water Flow Medium, FS300A:
Flow rate: 1 ~ 60 L/Min
Working voltage: +5 V ~ +24 V (not suitable for +3.3 V)
Working temperature: 0 ºC ~ 80 ºC
Pipe connection: 3/4”
Max rated current: 15 mA (DC 5 V)

Figure: Image of the FS-300A, Medium Liquid Flow sensor

The liquid flow sensors output a signal that consists of a series of digital pulses whose frequency is proportional to the flow rate of the liquid through the sensor. That digital signal, whose frequency is in the range between 0 Hz and 100 Hz, is directly read through one of the digital input/output pins of the microcontroller.

5.8. Presence sensor (PIR) probe

Sensor specifications (PIR)

Height: 22mm
Diameter: 20.2mm
Consumption: 170µA
Range of detection: 12m
Circuit Stability Time: 30seconds

Figure: Image of the Presence sensor probe (PIR)

The PIR sensor (Passive Infra-Red) is a pyroelectric sensor mainly consisting of an infra-red receiver and a focusing lens that bases its operation on the monitoring of the variations in the levels of reception of detected infra-reds, reflecting this movement by setting its output signal high. The 10µm spectrum corresponds to the radiation of heat from the majority of mammals as they emit temperatures around 36°C.

Figure: Image of configurations of the Presence sensor probe (PIR)

As we see in the figure, the presence sensor probe (PIR) may be placed in different positions. The sensor can be focused directly to the point we want.

5.9. Liquid Level sensor probe

Figure: Image of the Liquid Level sensor probe (PTFA1103)

Sensor specifications

PTFA3415
Measurement Level: Horizontal
Liquids: Water
Material (box): Propylene
Material (float): Propylene
Operating Temperature: -10 ºC ~ +80 ºC

Figure: Image of the PTFA3415 sensor

PTFA0100
Measurement Level: Horizontal
Liquids: Heavy oils and combustibles
Material (box): Polyamide
Material (float): Polyamide
Operating temperature: -10 ºC ~ +80 ºC

Figure: Image of the PTFA0100 sensor

PTFA1103
Measurement Level: Vertical
Liquids: Water
Material (box): Propylene
Material (float): Propylene
Operating temperature: -10 ºC ~ +80 ºC

Figure: Image of the PTFA1103 sensor

There are three liquid level sensors whose operation is based on the status of a switch which can be opened and closed (depending on its placing in the container) as the level of liquid moves the float at its end. The main differences between the three sensors, regarding its use in Waspmote, are to be found in their process for placing them in the container (horizontal in the case of the PTFA3415 and PTFA0100 sensors, vertical for the PTFA1103 sensor) and in the material they are made of (the PTFA1103 and PTFA3415 sensors recommended for edible liquids and certain acids and the PTFA0100 for heavy oils and combustibles, more specific information can be found in the sensors' manual).

5.10. Liquid Presence sensor probe (Point)

Sensor specifications

Maximum Switching Voltage: 100 V
Operating temperature: +5 ºC ~ +80 ºC
Detectable liquids: Water

Figure: Image of the Liquid Presence sensor probe (Point)

This sensor bases its operation on the variation in resistance between its two contacts in the presence of liquid to commute a switch reed from open to closed, commuting to open again when the liquid disappears (take care when it is used to detect liquids of high viscosity which may remain between the terminals blocking its drainage and preventing it from re-opening).

5.11. Liquid Presence sensor probe (Line)

Sensor specifications

Length: 5 meters sensor + 2 meters jumper wire
Material: PE + alloy lend
Weight: 18 g/meter
Pull force limit: 60 kg
Cable diameter: 5.5 mm
Core resistance: 3 ohm/100 meters
Maximum exposed temperature: 75 ºC
Detectable liquids: Water

Figure: Image of the Liquid Presence sensor probe (Line)

This sensor detects conductive liquids anywhere along its length. After it is installed, once the cable senses the leakage of liquids, it will trigger an alarm. The sensor cable can detects the leakage of water.

Installation of this sensor should be in a safe place, far away from high magnetic fields and damp environment. In the installation, let sensor cable keep away from sharp material to avoid scuffing the sensor.

5.12. Hall Effect sensor probe

Sensor specifications

Length: 64 mm
Width: 19 mm
Thickness: 13 mm
Maximum contact resistance (closed): 200 mΩ
Minimum contact resistance (open): 100 GΩ

Figure: Image of the Hall Effect sensor probe

This is a magnetic sensor based on the Hall effect. The sensor's switch remains closed in the presence of a magnetic field, opening up in its absence. Together with its complementary magnet it can be used in applications of monitoring proximity or opening mechanisms.

6. Smart Water

6.1. General description

The Smart Water model has been conceived to facilitate the remote monitoring of the most relevant parameters related to water quality. With this platform you can measure more than 5 parameters, including the most relevant for water control such as dissolved oxygen, oxidation-reduction potential, pH, conductivity and temperature.

The Smart Water Ions line is complementary for these kinds of projects, enabling the control of concentration of ions like Ammonium (NH4+), Bromide (Br-), Calcium (Ca2+), Chloride (Cl-), Cupric (Cu2+), Fluoride (F-), Iodide (I-), Lithium (Li+), Magnesium (Mg2+), Nitrate (NO3-), Nitrite (NO2-), Perchlorate (ClO4-), Potassium (K+), Silver (Ag+), Sodium (Na+) and pH. Take a look to the Smart Water Ions line in the next section.

Refer to Libelium website for more information.

Figure: Smart Water 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	pH	9328
B	Dissolved Oxygen (DO)	9327
C	Conductivity	9326
E	Oxidation-Reduction Potential (ORP)	9329
F	Soil/Water Temperature	9255-P (included by default)

Figure: Sensor sockets configuration for Smart Water model

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

6.2. Soil/Water Temperature (Pt-1000) sensor probe

Sensor specifications

Measurement range: 0 ~ 100 ºC
Accuracy: DIN EN 60751
Resistance (0 ºC): 1000 Ω
Diameter: 6 mm
Length: 40 mm
Cable: ~5 m

Figure: Image of the Soil/Water Temperature sensor probe

The resistance of the Pt-1000 sensor varies between approximately 920 Ω and 1200 Ω in the range considered useful in agriculture applications (-20 ~ 50 ºC approximately), which results in too low variations of voltage at significant changes of temperature for the resolution of the Waspmote's analog-to-digital converter. The temperature value is returned in Celsius degree (ºC).

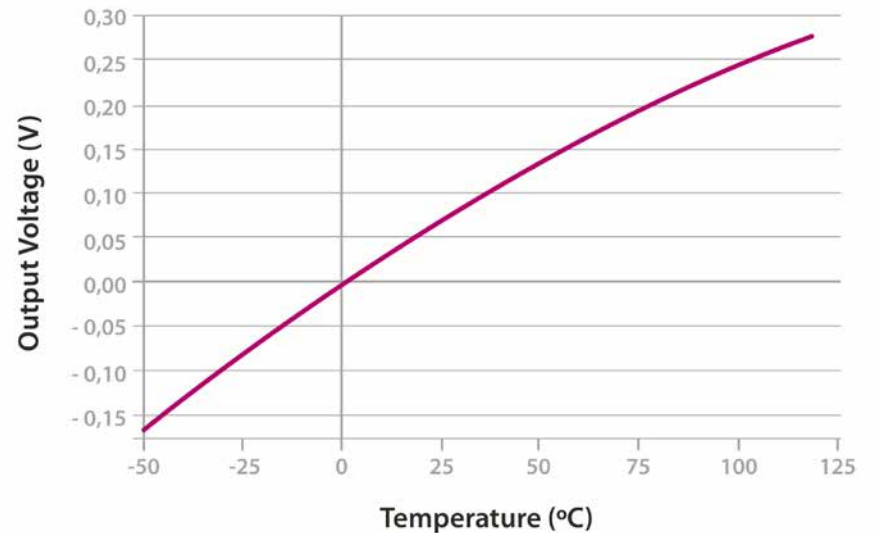


Figure: Output voltage of the PT-1000 sensor with respect to temperature

6.3. Conductivity sensor probe

Sensor specifications

Sensor type: Two electrodes sensor
Electrode material: Platinum
Conductivity cell constant: 1 ± 0.2 cm^{-1}
Cable length: ~5 m

Figure: Image of the Conductivity sensor probe

The conductivity sensor is a two-pole cell whose resistance varies in function of the conductivity of the liquid it is immersed in. That conductivity will be proportional to the conductance of the sensor (the inverse of its resistance), multiplied by the constant cell, in the case of the Libelium sensor around 1 cm^{-1}, leading to a value in Siemens per centimeter (S/cm). For an accurate measurement, please take a look at section "Calibration Procedure" in the Smart Water Technical Guide, where the calibration procedure is detailed.

To power the conductivity sensor an alternating current circuit has been installed in order to avoid the polarization of the platinum electrodes.

6.4. Dissolved Oxygen sensor probe

Sensor specifications

Sensor type: Galvanic cell
Range: 0~20 mg/L
Accuracy: ±2%
Maximum operation temperature: 50 ºC
Saturation output: 33 mV ± 9 mV
Pressure: 0~100 psig (7.5 Bar)
Calibration: Single point in air
Response Time: After equilibration, 2 minutes for 2 mV
Cable length: ~5 m

Figure: Image of the Dissolved Oxygen sensor probe

The galvanic cell provides an output voltage proportional to the concentration of dissolved oxygen in the solution under measurement without the need of a supply voltage. This value is amplified to obtain a better resolution and measured with the analog-to-digital converter placed on the Smart Water board.

This sensor should be calibrated with the calibration solution for more accurate measurements.

6.5. pH sensor probe

Sensor specifications

Sensor type: Combination electrode
Measurement range: 0~14 pH
Temperature of operation: 0~80 ºC
Zero electric potential: 7 ± 0.25 p
Response time: < 1 min
Internal resistance: ≤250 MΩ
Repeatability: 0.017
PTS: >98.5
Noise: <0.5 mV
Alkali error: 15 mV
Reader accuracy: up to 0.01 (in function of calibration)
Cable length: ~5 m

Figure: Image of the pH sensor probe

The pH sensor integrated in the Smart Water board is a combination electrode that provides a voltage proportional to the pH of the solution, corresponding the pH 7 with the voltage reference of 2.048 V of the circuit, with an uncertainty of ±0.25 pH. To get an accurate value from these sensors it is necessary both to carry out a calibration and to compensate the output of the sensor for the temperature variation from that of the calibration moment.

6.6. Oxidation-reduction potential sensor probe

Sensor specifications

Sensor type: Combination electrode
Electric Potential: 245~270 mV
Reference impedance: 10 kΩ
Stability: ±8 mV/24 h
Cable length: ~5 m

Figure: Image of the Oxidation-reduction potential sensor probe

Like the pH sensor, the ORP probe is a combination electrode whose output voltage is equivalent to the potential of the solution, so it will share the connection sockets with that sensor. The output of the circuitry to which it is connected is directly read from the analog-to-digital converter of the Smart Water sensor board, being the 2.048 V reference subtracted to obtain the actual oxidation-reduction potential in volts (in this case, since this parameter is directly a voltage it is not necessary to call a conversion function).

This sensor should be calibrated with the calibration solution for more accurate measurements.

•

7. Smart Water Xtreme

7.1. General description

Smart Water Xtreme was created as an evolution of Smart Water. This model integrates high-end sensors, calibrated in factory, with enhanced accuracy and performance. Their reduced recalibration requirements and robust design enlarge maintenance periods, making it more affordable to deploy remote Smart Water applications. This line includes a great combination of the most significant water parameters like dissolved oxygen, pH, oxidation-reduction potential, conductivity, salinity, turbidity, suspended solids, sludge blanket and temperature.

Refer to Libelium website for more information.

Figure: Smart Water Xtreme Waspmote Plug & Sense! model

Sensor sockets are configured as shown in the figure below.

Sensor	Sensor probes allowed for each sensor socket	
	Parameter	**Reference**
A, B, C, D and E	Optical dissolved oxygen and temperature OPTOD	9488-P
	Titanium optical dissolved oxygen and temperature OPTOD	9489-P
	pH, ORP and temperature PHEHT	9485-P
	Conductivity, salinity and temperature C4E	9486-P
	Inductive conductivity, salinity and temperature CTZN	9487-P
	Turbidity and temperature NTU	9353-P
	Suspended solids, turbidity, sludge blanket and temperature MES5	9490-P
A and D	Temperature, air humidity and pressure	9370-P
	Luxes	9325-P
	Ultrasound	9246-P
F	Manta+40	-
	Chlorophyll	-
	BGA	-
	Organic matter CDOM/FDOM	-
	Ammonium	-
	Nitrate	-
	Chloride	-
	Sodium	-
	Calcium	-

Figure: Sensor sockets configuration for Smart Water Xtreme model

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

7.2. Optical dissolved oxygen and temperature OPTOD sensor probe

The Optical dissolved oxygen and temperature OPTOD sensor probe, based on a luminescent optical technology, meets the demands of long term smart water applications. The OPTOD sensor probe measures accurately without oxygen consumption, especially with very low concentrations and very weak water flow. It is designed in a compact, robust and light probe with a stainless steel body.

Figure: Optical dissolved oxygen and temperature OPTOD sensor probe

7.2.1. Specifications

Dissolved oxygen sensor:

- **Technology:** Optical luminescence
- **Ranges**:
  - 0 to 20.00 mg/L
  - 0 to 20.00 ppm
  - 0 – 200%
- **Resolution**: 0.01
- **Accuracy**:
  - ±0.1 mg/L
  - ±0.1 ppm
  - ±1%
- **Response time:** 90% of the value in less than 60 seconds
- **Frequency of recommended measure**: > 5 s
- **Cross sensitivity**: Organic solvents, such as acetone, toluene, chloroform or methylene chloride. Chlorine gas.

Temperature sensor:

- **Technology:** NTC
- **Range**: 0 °C to +50 °C
- **Resolution**: 0.01 °C
- **Accuracy**: ±0.5 °C
- **Response time**: < 5 s

Common:

- **Storage temperature**: -10 °C to +60 °C
- **Water flow is not necessary**
- **Default cable length:** 15 m
- **Maximum pressure**: 5 bars
- **Body material**: Stainless steel (titanium option available on demand for sea water applications)
- **IP classification**: IP68
- **Storage temperature:** -10 °C to +60 °C

7.3. pH, ORP and temperature PHEHT sensor probe

The pH, ORP and temperature PHEHT sensor probe combines 3 sensors in one probe, which has been designed to measure under hard conditions like pure snow melting water with low conductivity, lakes, rivers, sea water or even waste waters with high conductivity values.

Figure: pH, ORP and temperature PHEHT sensor probe

7.3.1. Specifications

pH sensor:

- **Technology**: Combined electrode
- **Measurement range**: 0~14 pH
- **Resolution**: 0.01 pH
- **Accuracy**: ±0.1 pH

ORP sensor:

- **Technology**: Combined electrode
- **Measurement range:** -1000 to +1000 mV
- **Resolution**: 0.1 mV
- **Accuracy**: ±2 mV

Temperature sensor:

- **Technology**: NTC
- **Range**: 0 °C to +50 °C
- **Resolution**: 0.01 °C
- **Accuracy**: ±0.5 °C
- **Response time:** < 5 s

Common:

- **Default cable length**: 15 m
- **Maximum pressure**: 5 bars
- **IP classification**: IP68
- **Storage temperature**: 0 °C to +60 °C

7.4. Conductivity, salinity and temperature C4E sensor probe

The Conductivity, salinity and temperature C4E sensor probe uses a four-electrode technology that offers a great accuracy with low maintenance. For this, the electrolytes do not need to be replaced. Besides, calibration intervals are long due to the low drift of its measures.

The conductivity values are internally compensated with the temperature provided by the embedded sensor. Moreover, it does not consume oxygen and therefore does not require a minimum inflow.

Figure: Conductivity, salinity and temperature C4E sensor probe

7.4.1. Specifications

Conductivity sensor:

- **Technology**: 4 electrode (2 graphite, 2 platinum)
- **Ranges**:
  - 0 - 200 µS/cm
  - 0 - 2 mS/cm
  - 0 - 20 mS/cm
  - 0 - 200 mS/cm
- **Resolution**: 0.01 to 1 according the range
- **Accuracy**: ±1% of the full range
- **Measurement range (salinity)**: 5 - 60 g/kg
- **Measurement range (TDS - Kcl)**: 0 - 133 000 ppm

Temperature sensor:

- **Technology**: NTC
- **Range**: 0 °C to +50 °C
- **Resolution**: 0.01 °C
- **Accuracy**: ±0.5 °C
- **Response time**: < 5 s

Common:

- **Default cable length**: 15 m
- **Maximum pressure**: 5 bars
- **Body material:** PVC
- **IP classification**: IP68
- **Storage temperature**: 0 °C to +60 °C

7.5. Inductive conductivity, salinity and temperature CTZN sensor probe

The Inductive conductivity, salinity and temperature CTZN sensor probe has a ring-type coil to measure the conductivity. This technology allows the sensor to avoid biofilm interferences, increasing the time between calibration periods and even avoiding most of the maintenance tasks.

In addition to conductivity, the CTZN sensor probe is able to measure salinity and temperature, all included in a compact and robust probe suitable for the most typical applications.

Figure: Inductive conductivity, salinity and temperature CTZN sensor probe

7.5.1. Specifications

Conductivity sensor:

- **Technology**: Inductive coil
- **Ranges**: 0 – 100 mS/cm
- ***Resolution***: 0.1
- **Measurement range (salinity)**: 5 - 60 g/kg
- **Working temperature**: 0 to 50 °C
- **Response time**: 90% of the value in less than 30 seconds

Temperature sensor:

- **Technology**: NTC
- **Range**: 0 °C to +50 °C
- **Resolution**: 0.01 °C
- **Accuracy**: ±0.5 °C

Common:

- **Default cable length**: 15 m
- **Maximum pressure**: 5 bars
- **Body material**: PVC
- **IP classification**: IP68
- **Storage temperature**: -10 °C to +60 °C

7.6. Turbidity and temperature NTU sensor probe

The Turbidity and temperature NTU sensor probe is based in infrared light reflections which allows measuring turbidity in a great range of applications. Besides, the sensor measures suspended solids and also an internal temperature sensor is included for temperature compensation of the turbidity measures.

Some sensors in the market calculate the suspended solids from the turbidity value. By contrast, the NTU sensor probe takes its own measure. However, to measure suspended solids correctly, the NTU sensor probe is directly calibrated on the material to be measured and an external laboratory is needed to analyze the sample. This service is not provided by Libelium.

The NTU sensor probe measures according to DIN EN ISO 7027, required in many Smart Water quality applications.

Figure: Turbidity and temperature NTU sensor probe

7.6.1. Specifications

Turbidity sensor:

- **Technology**: Optical infrared (IR 880 nm)
- **Ranges NTU**: 0 to 4000 NTU in 5 ranges:
  - 0 - 50 NTU
  - 0 - 200 NTU
  - 0 - 1000 NTU
  - 0 - 4000 NTU
  - AUTOMATIC
- **Ranges mg/L**: 0 to 4500 mg/L
  - Range 0 - 500 mg/L according to NF EN 872
  - Range >500 mg/L according to NF T 90 105 2
- **Resolution**: 0.01 to 1 NTU - mg/L
- **Accuracy**: < 5% of the reading
- **Response time**: <5 s

Temperature sensor:

- **Technology**: NTC
- **Range**: 0 °C to +50 °C
- **Resolution**: 0.01 °C
- **Accuracy**: ±0.5 °C

Common:

- **Default cable length**: 15 m
- **Maximum pressure**: 5 bars
- **Body material**: DELRIN
- **IP classification**: IP68
- **Storage temperature**: 0 °C to +60 °C

7.6.2. Turbidity: the parameter

Turbidity is the haziness of a fluid caused by individual solid particles that are generally invisible to the naked eye. The measurement of turbidity is a key test of water quality. Nephelometers, or nephelometric turbidimeters, measure the light scattered at an angle of 90° by one detector from the incident light beam generated by an incandescent light bulb. Readings are reported in Nephelometric Turbidity Units, or NTUs. NTU has been the traditional reporting unit for turbidity and is still recognized by some as the “universal” unit of measure, regardless of the technology used.

The measurement of the turbidity is important in the next scenarios:

- Urban waste water treatment (inlet / outlet controls)
- Sanitation network
- Industrial effluent treatment
- Surface water monitoring
- Drinking water

7.7. Suspended solids, turbidity, sludge blanket and temperature MES5 sensor probe

The Suspended solids, turbidity, sludge blanket and temperature MES5 sensor probe gives 4 different parameters in a single probe. It is based on the attenuation of an infrared signal through an optical path in the probe's head. The given measures are temperature compensated to increase the accuracy.

However, to measure suspended solids, the MES5 sensor probe is directly calibrated on the material to be measured (sample of sludge) and an external laboratory is needed to analyze the sample. This service is not provided by Libelium.

Figure: Suspended solids, turbidity, sludge blanket and temperature MES5 sensor probe

7.7.1. Specifications

Turbidity sensor:

- **Technology**: Optical infrared (IR 870 nm)
- **Ranges**:
  - SS : 0 - 50 g/L
  - Turbidity : 0 - 4000 FAU
  - Sludge blanket : 0 - 100%
- **Resolution**:
  - SS : 0.01 g/L
  - Turbidity : 0.01 to 1 FAU
  - Sludge blanket : 0.01 to 0.1%
- **Accuracy**:
  - SS< 10%
  - Turbidity : ±5% (range 200 - 4000 FAU)
  - Sludge blanket : ±2%
- **Response time**: < 35 seconds

Temperature sensor:

- **Technology**: NTC
- **Range**: -5 °C to +50 °C
- **Resolution**: 0.01 °C
- **Accuracy**: ±0.5 °C

Common:

- **Default cable length**: 15 m
- **IP classification**: IP68
- **Maximum pressure**: 5 bars
- **Body material**: DELRIN
- **Storage temperature**: 0 °C to +60 °C

7.8. COD, BOD, TOC, SAC254 and temperature StacSense sensor probe

The StacSense sensor probe uses optical technology to measure the ultraviolet spectrum at 254 nm, allowing the measurement of multiple parameters related to the organic water content.

Normally, there are several components related to the organic life, so it is usual to obtain the organic matter though parameters like Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Organic Carbon (TOC) and Spectral Absorption Coefficient at 254 nm (SAC254).

> ***Note:*** The StacSense probes are not recommended for seawater applications. Contact your Sales agent for more information.

Specifications

Measurement principle: UV 254 nm absorption

Compensation: Turbidity at 530 nm. Internal temperature

Wave lengths: 254 nm (turbidity correction at 530 nm)

Type of detector: Silicon photodiode

Optical paths: 2 mm and 50 mm

Maximum sample rate: 2 seconds

IP classification: IP68

Maximum immersion depth: 50 meters

Maximum pressure: 5 bars

Operating temperature: 0-40°C

Storage temperature: -10°C to +50°C

pH range: pH2 to pH12

Dimensions: 420 x 50 mm

Measurement ranges:

Figure: COD, BOD, TOC, SAC254 and temperature StacSense sensor probe

Optical path	Parameter	Range	Units	Detection limit	Quantification limit	1 or ±3%
2 mm	SEC254	0-750	Abs/m	1.7	5	2 or ±3%
	CODEQ	0-1300	mg/L	3	9	1 or ±3%
	BODEQ	0-350	mg/L	1	3	1 or ±3%
	TOCEQ	0-500	mg/L	1.5	4	5 or ±5%
	TurbidityEQ	0-500	FAU	1.5	5	0.1 or ±3%
50 mm	SEC254	0-30	Abs/m	0.2	0.3	0.2 or ±3%
	CODEQ	0-50	mg/L	0.15	0.6	0.1 or ±3%
	BODEQ	0-15	mg/L	0.1	0.2	0.1 or ±3%
	TOCEQ	0-20	mg/L	0.1	0.2	1 or ±7%
	TurbidityEQ	0-40	FAU	0.4	1.2	

7.9. Total coliform bacteria, TLF, turbidity and temperature Proteus sensor probe

Total coliform bacteria are usually found in the natural environment and they are not necessarily harmful.

Fecal coliforms represent a sub-group of coliform bacteria, being found in large quantities in the intestines/feces of animals and humans. E.coli is a major sub-group of the fecal coliform group and represents the best indicator for fecal pollution monitoring.

The Total coliform bacteria, TLF, turbidity and temperature Proteus sensor probe is a reliable and accurate sensor to measure coliforms (total, e. coli or faecal) in permanent and temporary applications. Besides, it can measure other organic parameters like:

- BOD (biochemical oxygen demand)
- COD (chemical oxygen demand)
- TOC (total organic carbon)

Moreover, this multi-parametric probe is able to measure standard water quality parameters such as dissolved oxygen, pH, temperature, ORP / REDOX, electro-conductivity / salinity / TDS (total dissolved solids) or turbidity, besides than other more specific like refined oils, crude oils CDOM, optical brighteners, ammonium, nitrate or chloride. Contact your Sales agent for more details.

Specifications

Operating temperature: 0 to 50 °C, non-freezing

Length: 483 mm

Diameter: variable between 75 and 102 mm

Depth rating: 200 m

Number of sensors: up to 13 depending model and sensors

The next table describes each sensor in deep:

Figure: Total coliform bacteria, TLF, turbidity and temperature Proteus sensor probe

Parameter		Range	Resolution	Accuracy	Comments
BOD	BOD mg/l	0-300 mg/l	0.01 mg/l -1	±5 % of reading*	Local site calibration can improve accuracy.
Coliform Counts	CFU/100 ml	>1 count/100ml-1	1 count/100ml-1	±10 Coliforms*	Local site calibration can improve accuracy. Can be used for faecal coliforms, e-coli or total coliforms.
COD	COD mg/l	0-600 mg/l	0.01 mg/l	±5 % of reading*	Local site calibration can improve accuracy.
DOC	DOC mg/l	0 - 400 mg/l-1	0.01 mg/l	±5 % of reading*	Local site calibration can improve accuracy.

TOC	TOC mg/l	0 - 400 mg/l-1	0.01 mg/l	±5 % of reading*	Local site calibration can improve accuracy.
Temperature	Water Temperature	-5 to 50°C	0.01	±0.1	Never needs calibration
pH/ORP	pH	0 to 14 units	0.1	±0.1 within 10°C of calibration, 0.2 °C otherwise	Refillable reference electrode; corrected for temperature; typical sensor life > 4 years
	ORP	-999 to 999 mV	1	±20 mV	Platinum ORP sensor is combined with pH sensor
Turbidity	TSS Turbidity	0 to 500 mg/l	4 digits with maximum of two decimals	±2% of reading or 0.2	Compensated for temperature; filtered for non-turbidity spikes; includes wiper to clean the optics
		0-500 FNU		±2% of reading or 0.2	
		400-5000 FNU		±2% of range	
	Transmissivity	0 to 100% transmission	4 digits	Linearity of 0.99R²	Mounts alongside the Proteus
Optical Dissolved Oxygen	Concentration	0 to 20 mg/l	0.01	±0.1	Compensated for temperature and salinity; EPA approved "lifetime" luminescence method; typical sensor cap life > 4 years
		20 to 30 mg/l	0.01	±0.15	
		30 to 50 mg/l	0.1	±5%	
	% saturation	0 to 500% saturation	0.1%	Corresponds with the accuracy of the concentration reading	
Conductivity	Specific conductance, µS/cm	0 to 5000 µS/cm	4 digits max one decimal	±0.5% of reading ±0.001	Corrected for temperature; four easy-to-clean graphite electrodes; optional sensor provides ±0.5% of reading accuracy to 100 mS/cm.
	Specific conductance, mS/cm	0 to 10 mS/cm		±1% of reading ±0.001	
		10 to 100 mS/cm		±1% of reading	
		100 to 275 mS/cm		±2% of reading	
	Salinity	0 to 70 PSS	0.01	±0.2	Calculated from specific conductance; PSS = Practical Salinity Scale which is roughly equivalent to ppt
	Total dissolved solids (TDS)	0 to 65 g/	0.1	±5% of reading	Calculated from specific conductance

Pressure	Depth	0 to 25 m	0.01	±0.05	Compensated for temperature and salinity
		0 to 200 m		±0.4	
	Vented depth (level)	0 to 10 m	0,001	±0.003 m	Compensated for temp, salinity, barometric pressure
	Barometric pressure	400 to 900 mm Hg	0.1 mmHg	±1.5 mmHg	Included with (non-vented) depth sensor
Fluorometers	Chlorophyll a - blue	0 to 500 µg/l	6 digits with maximum of two decimals	Linearity of 0.99R^2	Highest-quality LED based fluorometric sensors rated to 600 m depth otherwise max depth same as depth sensor
	Chlorophyll b - red	0 to 500 µg/l			
	Rhodamine dye	0 to 1000 ppb			
	Phycocyanin (freshwater BGA)	0 to 40,000 ppb			
	Phycoerythrin (marine BGA)	0 to 750 ppb			
	CDOM/fDOM	0 to 1250 or 0 to 5000 ppb			
	CDOM/fDOM custom	0 to 1250 or 0 to 5000 ppb			
	Optical brighteners	0 to 15,000 ppb			
	Tryptophan	0 to 20,000 ppb			
	Fluorescein dye				
	Refined oil	0 to 10,000pb			
	Crude oil	0 to 1500 ppb			
Ion-selective electrodes (ISE's)	Ammonium	0 to 100 mg/l as nitrogen	0.1	±5% or 2 mg/l	Corrected for ionic strength (via conductivity readings); the accuracy specification relies on non-trivial maintenance practice and frequent calibration near the temperature of measurement; ammonium and nitrate require tip replacement every 3 - 6 months. Please contact us for applications >10 meters
	Ammonium	0 to 100 mg/l as nitrogen			
	Nitrate	0 to 100 mg/l as nitrogen			
	Chloride	0 to 18,000 mg/l			
	Sodium	0 to 20,000 mg/l			
	Calcium	0 to 40,000 mg/l			
	Bromide	0 to 80,000 mg/l			

TDG	Total Dissolved Gas	600-800 mmHg	0.1 mmHg	±0.1 mmHg	Pressure sensor with gas permeable membrane, max depth 15m
PAR	Photometric PAR	10,000 µmol/ sm2	4 digits	±5% of reading	LiCor spherical sensor

7.10. Radar level VEGAPULS C21 sensor probe

The Radar level VEGAPULS C21 sensor provides reliable measurement results under all conditions thanks to its 80 GHz radar technology. Compared to ultrasonic measuring instruments, radar sensors measure unaffected by temperature fluctuations, vacuum or high pressures and are insensitive to contamination.

Due to the high focusing of the 80 GHz technology, the radar beam can be aligned almost precisely to the medium to be measured. It is suitable for use in water treatment, pumping stations and rain overflow basins, for flow measurement in open channels and level monitoring. In bulk solids the sensors are used in small bulk solids silos or open containers.

Specifications

Operation frequency: 80 GHz

Maximum detection distance: 15 m

Accuracy: ±2 mm

Operating temperature: -40 to 80 °C

Usage: water or bulk solid tanks

Protection rating: IP66/IP68 (3 bar), type 6P

7.11. Temperature, Humidity and Pressure Sensor Probe

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

Specifications

Figure: Image of the Temperature, Humidity and Pressure Sensor Probe

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

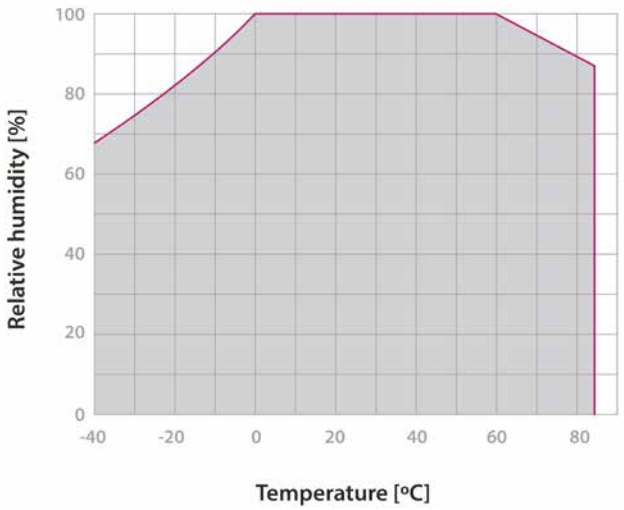


Figure: Humidity sensor operating range

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

7.12. Luminosity sensor probe (Luxes accuracy)

Sensor specifications (Luxes accuracy)

Dynamic range: 0.1 to 40000 Lux
Spectral range: 300 – 1100 nm
Voltage range: 2.7 – 3.6 V
Operating temperature: -30 ºC to +80 ºC
Typical consumption: 0.24 mA
Maximum consumption: 0.6 mA
Usage: Indoors and outdoors

Figure: Image of the Luminosity sensor probe (Luxes accuracy)

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.

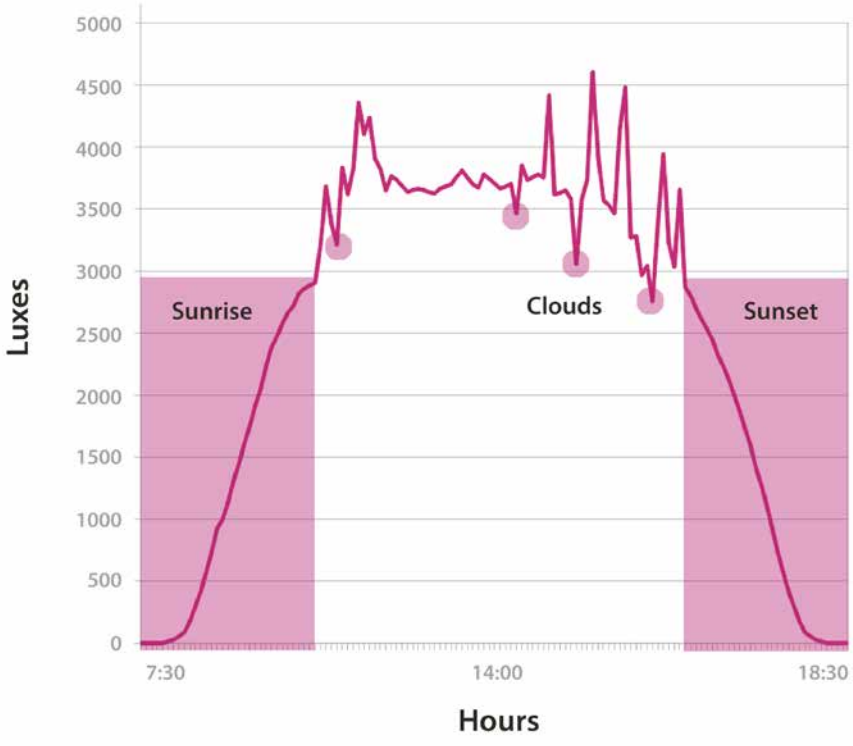


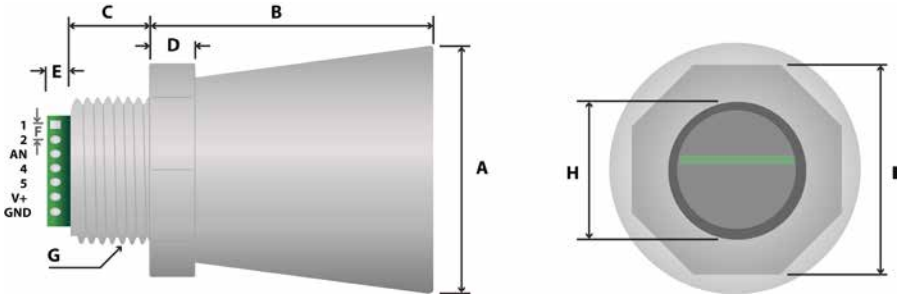
Figure: Image of the Luminosity sensor probe (Luxes accuracy)

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

I2CXL-MaxSonar®-MB7040™

Operation frequency: 42 kHz
Maximum detection distance: 765 cm
Interface: Digital bus
Power supply: 3.3 V ~ 5 V
Consumption (average): 2.1 mA (powered at 3.3 V) – 3.2 mA (powered at 5 V)
Consumption (peak): 50 mA (powered at 3.3 V) – 100 mA (powered at 5 V)
Usage: Indoors and outdoors (IP-67)

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



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

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):

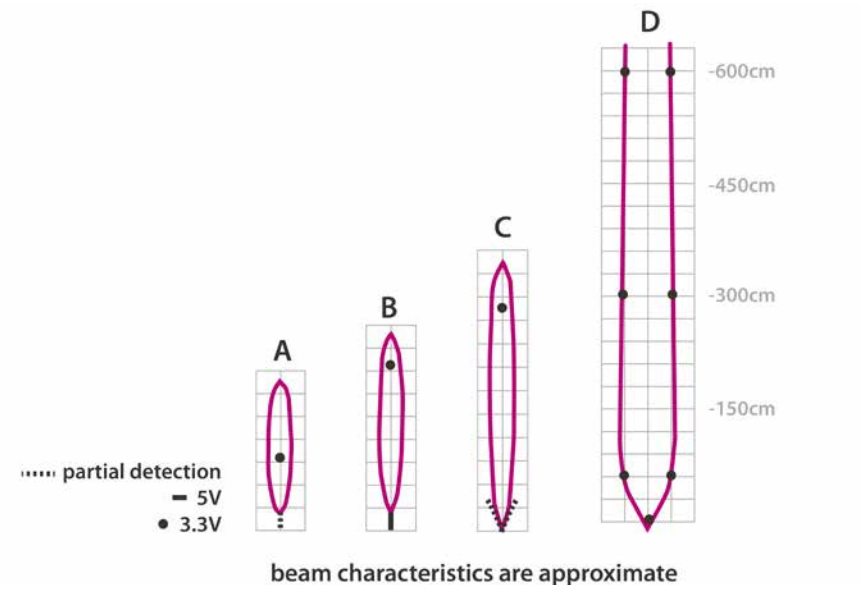


Figure: Diagram of the sensor beam extracted from the data sheet of the XL-MaxSonar®-WRA1™ sensor from MaxBotix

7.14. Eureka Manta multi sensor probe

The Eureka manta sensor probe is designed to unify a large number of sensors in only one probe. Owing to that, the Eureka Manta multi probe is highly configurable, offering a great number of parameter combinations to meet the requirements even for the most demanding applications.

Parameters like chlorophyll, Blue-Green Algae (BGA, also known as cyanobacteria), organic matter (CDOM and FDOM), ammonium, nitrates, chloride, sodium or calcium can be measured with this multi probe, achieving up to 13 different measures.

Figure: Eureka Manta multi sensor probe

7.14.1. Common specifications

Fluorometers:

- **Chlorophyll a – blue**: 0 to 500 g/l
- **Chlorophyll a – red:** > 500 g/l
- **CDOM/FDOM**: 0 to 1250 or 0 to 5000 ppb
- **Resolution**: 6 digits with maximum of two decimals
- **Accuracy**: linearity of 0.99R^2

Ion selective electrodes (ISE):

- **Ammonium**: 0 to 100 mg/l as nitrogen
- **Nitrate**: 0 to 100 mg/l as nitrogen
- **Chloride**: 0 to 18000 mg/l
- **Sodium**: 0 to 20000 mg/l
- **Calcium**: 0 to 40000 mg/l
- **Resolution**: 0.1
- **Accuracy**: 5% or 2 mg/l
- Ammonium and nitrate require tip replacement every 3 - 6 months

Common:

- **Diameter**: 3.5” or 4”
- **Length**: 19”
- **Temperature Range**: -5 °C to +50 °C
- **Depth rating**: 200 m, maximum for ISE and TDG sensor is 15 meters
- **IP classification**: IP68 (complete and continuous immersion in water, up to 200 meters depth)

7.14.2. Fluorometer Chlorophyll

Fluorometric sensors emit light at a certain wavelength and look for a very specific wavelength in return. The magnitude of the return light is relatable to the amount of the analyzed parameter. They require non-trivial calibration.

In the case of chlorophyll, two fluorometers are available with the ranges shown below:

- **Chlorophyll a – blue**: 0 to 500 g/l
- **Chlorophyll a – red**: > 500 g/l

7.14.3. Fluorometer Phycocyanin (freshwater BGA)

Phycocyanin fluorometer works in the same way as chlorophyll fluorometer. The main applications are lakes, rivers, ground water, oceanographic, process waters, waste waters or laboratory research. The range of this fluorometer is 0 to 40,000 ppb.

7.14.4. Fluorometer Phycoerythrin (marine BGA)

There is a specific version of the fluorometer BGA for sea water applications with a range of 0 to 750 ppb.

7.14.5. Fluorometer CDOM / FDOM

The CDOM (Colored Dissolved Organic Matter) and the FDOM (Fluorescent Dissolved Organic Matter) fluorometers work in the same way as previous fluorometers.

The ranges for these fluorometers are:

- CDOM: 0 to 1250 ppb
- FDOM: 0 to 5000 ppb

7.14.6. Rhodamine

The Rhodamine sensor works in the same way as previous fluorometers. The range of this sensor is 0 to 1000 ppb.

7.14.7. Crude Oil

The Crude Oil sensor has a range of 0 to 1500 ppb.

7.14.8. Refined Oil

The Refined Oil sensor has a range of 0 to 1000 ppb.

7.14.9. Fluorescein

The fluorescein sensor has a range of 0 to 500 ppb.

7.14.10. Tryptophan

The tryptophan sensor has a range of 0 to 20000 ppb.

7.14.11. Optical Brighteners

The optical brigteners sensor has a range of 0 to 15000 ppb.

7.14.12. Ion selective electrode – Ammonium

This sensor has a membrane that is selective for ammonium. The electrode's filling solution contains a salt sensitive to ammonium, and the difference between that salt's concentration and the ammonium concentration in the measured water produces a charge separation. That charge separation is measured, relative to the reference electrode, as a voltage that changes predictably with changes in the ammonium concentration in the water adjacent the membrane.

The range of this sensor is 0 to 100 mg/l as nitrogen.

7.14.13. Ion selective electrode – Nitrate

This sensor has a membrane that is selective for nitrate and works in the same way as Ammonium electrode.

The range of this sensor is 0 to 100 mg/l as nitrogen.

7.14.14. Ion selective electrode – Chloride

This sensor has a membrane that is selective for chloride and works in the same way as Ammonium electrode.

The range of this sensor is 0 to 18000 mg/l.

7.14.15. Ion selective electrode – Sodium

This sensor has a membrane that is selective for sodium and works in the same way as Ammonium electrode.

The range of this sensor is 0 to 20000 mg/l.

7.14.16. Ion selective electrode – Calcium

This sensor has a membrane that is selective for calcium and works in the same way as Ammonium electrode.

The range of this sensor is 0 to 40000 mg/l.

7.14.17. Ion selective electrode – Bromide

This sensor has a membrane that is selective for bromide and works in the same way as Ammonium electrode.

The range of this sensor is 0 to 40000 mg/l.

7.14.18. Total Dissolved Gas (TGD)

This sensor is compensated for temperature and the maximum depth 15m.

The range of this sensor is 400 to 1,400 mm Hg.

8. Smart Water Ions

8.1. General description

The Smart Water Ions models specialize in the measurement of ions concentration for drinking water quality control, agriculture water monitoring, swimming pools or waste water treatment.

The Smart Water line is complementary for these kinds of projects, enabling the control of parameters like turbidity, conductivity, oxidation-reduction potential and dissolved oxygen. Take a look to the Smart Water line in the previous section. Refer to Libelium website for more information.

There are 3 variants for Smart Water Ions: Single, Double and PRO. This is related to the type of ion sensor that each variant can integrate. Next section describes each configuration in detail.

Figure: Smart Water Ions Waspmote Plug & Sense! model

Single

This variant includes a Single Junction Reference Probe, so it can read all the single type ion sensors.
Sensor sockets are configured as shown in the table below.

Sensor Socket	Sensor probes allowed for each sensor socket	
	Parameter	**Reference**
A, B, C and D	Calcium Ion (Ca^{2+})	9352
	Fluoride Ion (F^-)	9353
	Fluoroborate Ion ($BF4^-$)	9354
	Nitrate Ion (NO_3^-)	9355
	pH (for Smart Water Ions)	9363
E	Single Junction Reference	9350 (included by default)
F	Soil/Water Temperature	9255 (included by default)

Figure: Sensor sockets configuration for Smart Water Ions model, single variant

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

Double

This variant includes a Double Junction Reference Probe, so it can read all the double type ion sensors.
Sensor sockets are configured as shown in the table below.

Sensor Socket	Sensor probes allowed for each sensor socket	
	Parameter	**Reference**
A, B, C and D	Bromide Ion (Br^-)	9356
	Chloride Ion (Cl^-)	9357
	Cupric Ion (Cu^{2+})	9358
	Iodide Ion (I^-)	9360
	Silver Ion (Ag^+)	9362
	pH (for Smart Water Ions)	9363
E	Double Junction Reference	9351 (included by default)
F	Soil/Water Temperature	9255 (included by default)

Figure: Sensor sockets configuration for Smart Water Ions model, double variant

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

Pro

This special variant integrates extreme quality sensors, with better performance than the Single or Double lines. In this case, there is only one type of reference probe and up to 16 different ion parameters can be analyzed in 4 sockets.

Sensor sockets are configured as shown in the table below.

Sensor Socket	Sensor probes allowed for each sensor socket	
	Parameter	**Reference**
A, B, C or D	Ammonium Ion (NH_4^+) [PRO]	9412
	Bromide Ion (Br^-) [PRO]	9413
	Calcium Ion (Ca^{2+}) [PRO]	9414
	Chloride Ion (Cl^-) [PRO]	9415
	Cupric Ion (Cu^{2+}) [PRO]	9416
	Fluoride Ion (F^-) [PRO]	9417
	Iodide Ion (I^-) [PRO]	9418
	Lithium Ion (Li^+) [PRO]	9419
	Magnesium Ion (Mg^{2+}) [PRO]	9420
	Nitrate Ion (NO_3^-) [PRO]	9421
	Nitrite Ion (NO_2^-) [PRO]	9422
	Perchlorate Ion (ClO_4^-) [PRO]	9423
	Potassium Ion (K^+) [PRO]	9424
	Silver Ion (Ag^+) [PRO]	9425
	Sodium Ion (Na^+) [PRO]	9426
	pH [PRO]	9411
E	Reference Sensor Probe [PRO]	9410 (included by default)
F	Soil/Water Temperature	9255 (included by default)

Figure: Sensor sockets configuration for Smart Water Ions model, PRO variant

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

8.2. Soil/Water Temperature (Pt-1000) sensor probe

Sensor specifications

Measurement range: 0 ~ 100 ºC
Accuracy: DIN EN 60751
Resistance (0 ºC): 1000 Ω
Diameter: 6 mm
Length: 40 mm
Cable: ~5 cm

Figure: Image of the Soil/Water Temperature sensor probe

The resistance of the Pt-1000 sensor varies between approximately 920 Ω and 1200 Ω in the range considered useful in agriculture applications (-20 ~ 50 ºC approximately), which results in too low variations of voltage at significant changes of temperature for the resolution of the Waspmote's analog-to-digital converter. The temperature value is returned in Celsius degree (ºC).

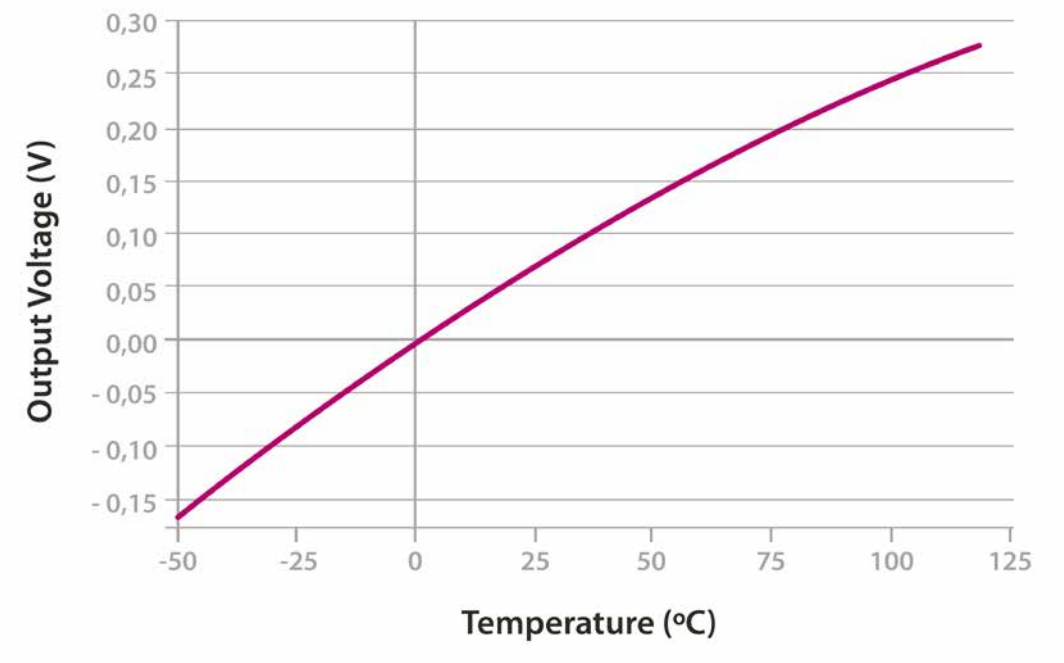


Figure: Output voltage of the PT-1000 sensor with respect to temperature

8.3. Reference probes

A reference electrode is an electrode which has a stable and well-known electrode potential. Reference electrodes are critical to acquiring good electrochemical data. Drift in the reference electrode potential can cause quantitative and qualitative errors in data collection and analysis beyond simple inaccuracies in the measured potential.

Plug & Sense! Smart Water Ions line has 3 different variants, according to the Reference Probes each Plug & Sense! includes:

- The Single variant always include a Single Junction Reference
- The Double variant always include a Double Junction Reference
- The PRO variant always include a PRO Junction Reference

Figure: Reference Probe

The next sensors must be used with the Single Junction Reference Probe:

- Fluoride Ion (F^-) Sensor Probe
- Fluoroborate Ion (BF_4^-) Sensor Probe
- Nitrate Ion (NO_3^-) Sensor Probe

The next sensors must be used with the Double Junction Reference Probe:

- Bromide Ion (Br^-) Sensor Probe
- Chloride Ion (Cl^-) Sensor Probe
- Cupric Ion (Cu^{2+}) Sensor Probe
- Iodide Ion (I^-) Sensor Probe
- Silver Ion (Ag^+) Sensor Probe

The pH (for Smart Water Ions) Sensor must be always used with the Single **or** the Double Reference Probe.

All the PRO sensors must be used with the PRO Reference Probe (including the pH [PRO] sensor).

The Soil/Water Temperature Sensor is the only sensor in this board which does not need any Reference Probe.

Reference probes have a length of about 500 cm.

One Reference Probe must **always** be connected in the corresponding socket marked as REFERENCE in the Smart Water Ions Sensor Board. **Only one** Reference Probe can be connected at the same time in the Smart Water Ions Sensor Board. One single-type sensor and one double-type sensor can **never be mixed** in the same system at the same time.

8.4. Ion sensors

In this table we can see the main features of the ions sensors. The ion sensors are divided in two groups depending on the required reference (double, or single junction). In the Smart Water Ions Sensor Board, only one reference can be connected at the same time, so is no possible to mix different sensor types.

Species	Construction	Concentration range (mol/L)	pH range	Temperature range (ºC)	Dimensions (mm)	Required Reference
Bromide (Br^-)	Solid State Half-cell	10^{-1}-10^{-6}	2-11	5-60	Ø10x155	Double Junction
Chloride (Cl^-)	Solid State Half-cell	10^{-1}-$5x10^{-5}$	2-12	5-60	Ø10x155	Double Junction
Cupric (Cu^{2+})	Solid State Half-cell	10^{-1}-10^{-6}	2-12	5-60	Ø10x155	Double Junction
Iodide (I^-)	Solid State Half-cell	10^{-1}-$5x10^{-7}$	2-12	5-60	Ø10x155	Double Junction
Silver (Ag^+)*	Solid State Half-cell	10^{-1}-$3x10^{-7}$	2-8 (Ag^+)	5-60	Ø10x155	Double Junction
Fluoride (F^-)	Plastic Membrane Half-cell	10^{-1}-10^{-6}	5-7	5-60	Ø10x155	Single Junction
Fluoroborate (BF_4^-)	Plastic Membrane Half-cell	10^{-1}-$3x10^{-6}$	2.5-11	5-60	Ø10x155	Single Junction
Nitrate (NO_3^-)	Plastic Membrane Half-cell	10^{-1}-10^{-5}	2.5-11	5-60	Ø10x155	Single Junction

* This sensor is also sensitive to Sulfide (S2-) ions; take this into account in terms of cross-sensitivity if the monitored water could contain Sulfide. The user could even use this sensor to meter Sulfide ion if he is able to calibrate the sensor by his own means.

The ion sensors have a cable length of ~500 cm.

8.5. pH sensor (for Smart Water Ions)

The pH sensor integrated in the Smart Water Ions Sensor Board are specific to be used with this board and in combination with one of the Reference Probes. This pH sensor cannot be used with Smart Water Sensor Board, which integrates another pH sensor, different from the one exposed in this section.

- **pH Range:** 0-14
- **Temp. Range (ºC):** 5-60
- **Internal Reference Type:** Ag/AgCl
- **Dimensions (mm):** Ø12x160
- **Reader accuracy:** in function of calibration
- **Cable length:** ~5 m

8.6. PRO Ion Sensors

This is a special line of ion sensors. These sensors are solid state carbon nanotube-based selective electrodes. This feature reduces the maintenance of the sensors and increases their stability on time. Also, these sensors can be combined using a unique reference probe. In this table we can see the main features of the PRO ion sensors.

Ion	Sensitivity	Temp (ºC)	pH	Lineal Range	Dimensions (mm)
Ammonium Ion (NH_4^+) Sensor Probe [PRO]	-54 ± 5	5 - 50	4 - 8,5	0,09 - 9000 mg/L	K (-0,8); Na (-2,7); Mg (-3,2); Ca (-4)
Bromide Ion (Br^-) Sensor Probe [PRO]	-54 ± 5	5 - 50	1 - 12	0,4 - 8000 mg/L	Cl (-2,7); OH (-4,5)
Calcium Ion (Ca^{2+}) Sensor Probe [PRO]	24 ± 5	5 - 50	3,5 - 8	0,4 - 4000 mg/L	NH_4 (-3); K (-3,6); Na (-3,7)
Chloride Ion (Cl^-) Sensor Probe [PRO]	-54 ± 5	5 - 50	2 - 12	1,5 - 35000 mg/L	Error presence of Ag or S
Cupric Ion (Cu^{2+}) Sensor Probe [PRO]	24 ± 5	5 - 50	2 - 7	0,06 - 3200 mg/L	Error presence of Ag or Cl
Fluoride Ion (F^-) Sensor Probe [PRO]	-54 ± 5	5 - 50	4 - 8	0,1 - 1900 mg/L	OH (-1); Maintain pH < 8
Iodide Ion (I-) Sensor Probe [PRO]	-54 ± 5	5 - 50	2 - 12	0,1 - 12000 mg/L	Error presence Ag or S; Br (-3,4); Cl (-6)
Lithium Ion (Li^+) Sensor Probe [PRO]	-54 ± 5	5 - 50	2 - 12	0,1 - 5000 mg/L	Na (-2,3); K (-2,4) H (-3)
Magnesium Ion (Mg^{2+}) Sensor Probe [PRO]	24 ± 5	5 - 50	3 - 8,5	2,4 - 2400 mg/L	Ca (-1); K (-3,6); Na (-3,9)
Nitrate Ion (NO_3^-) Sensor Probe [PRO]	-54 ± 5	5 - 50	2 - 11	0,6 - 31000 mg/L	Br (-1,2); NO_2 (-1,7); OH (-1,8); AcO (-2,2)
Nitrite Ion (NO_2^-) Sensor Probe [PRO]	-54 ± 5	5 - 50	4 - 8	2,5 - 1000 mg/L	SCN (-0,2); I (-2,2); ClO_4 (-2,4); Br (-3,3)
Perchlorate Ion (ClO_4^-) Sensor Probe [PRO]	-54 ± 5	5 - 50	1 - 11	1 - 10000 mg/L	SCN (-1,7); NO_3 (-1,7); I (-1,7)
Potassium Ion (K^+) Sensor Probe [PRO]	-54 ± 5	5 - 50	1 - 9	0,4 - 3900 mg/L	NH_4 (-2,1); Ca (-3,9), Li (-4,3); Na (-4,6)
Sodium Ion (Na^+) Sensor Probe [PRO]	-27 ± 5	5 - 50	1 - 9	0,1 - 3200 mg/L	K (-2,5); Ca (-3), Li (-3,2)
Silver Ion (Ag^+) Sensor Probe [PRO]	56 ± 5	5 - 50	1 - 9	0,1 - 10000 mg/L	Error presence S o Hg
pH Sensor Probe [PRO]	-54 ± 5	5 - 50	0 - 14	0 - 14	-
Smart Water Ions Reference Sensor Probe [PRO]	-	5 - 50	-	-	-

The PRO Ion Sensor Probes are composed of two independent parts: the head (the ion membrane) and the holder. We just need to change the header when it is not working properly due to the maximum lifetime was reached.

Figure: Ion sensor holder

Figure: Ion sensor header

The image below shows how the sensor head must be connected in the holder.

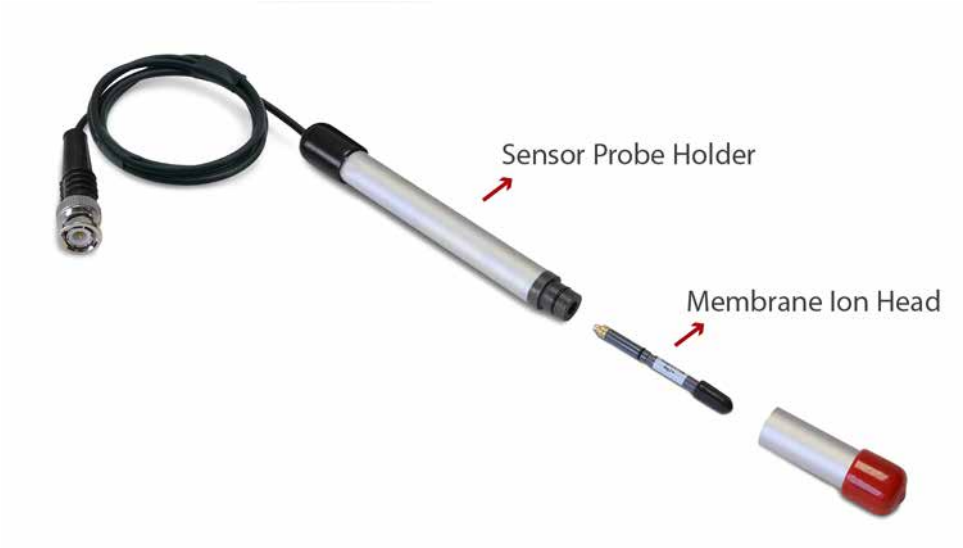


Figure: Connecting the sensor head to the sensor holder

The PRO sensors have a cable length of ~500 cm.

9. Smart Cities PRO

9.1. General description

The main applications for this Waspmote Plug & Sense! model are noise maps (monitor in real time the acoustic levels in the streets of a city), air quality, waste management, smart lighting, etc. Refer to Libelium website for more information.

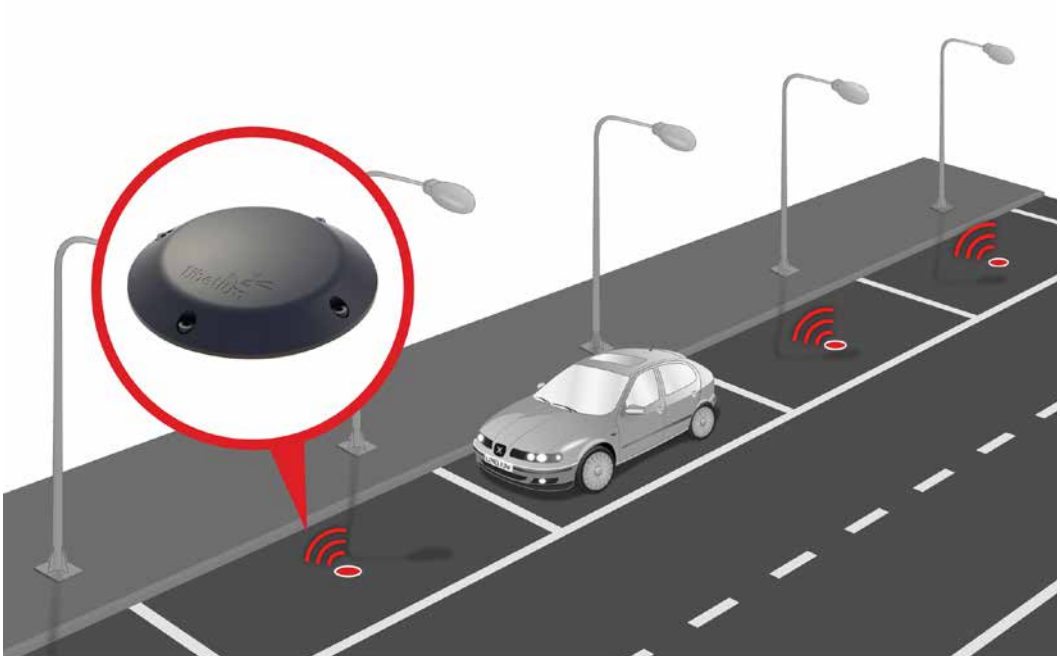


Figure: Smart Cities PRO Waspmote Plug & Sense! model

Sensor sockets are configured as shown in the figure below.

Sensor Socket	Sensor probes allowed for each sensor socket	
	Parameter	Reference
A	Noise level sensor	NLS
	Temperature + Humidity + Pressure	9370-P
	Luminosity (Luxes accuracy)	9325-P
	Ultrasound (distance measurement)	9246-P
B, C, and F	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 Sulfide (H_2S) [Calibrated]	9381-P
	Hydrogen Chloride (HCl) [Calibrated]	9382-P
	Temperature + Humidity + Pressure	9370-P
	Luminosity (Luxes accuracy)	9325-P
	Ultrasound (distance measurement)	9246-P
D	Particle Matter (PM1 / PM2.5 / PM10) - Dust	9387-P
E	Temperature + Humidity + Pressure	9370-P
	Luminosity (Luxes accuracy)	9325-P
	Ultrasound (distance measurement)	9246-P

Figure: Sensor sockets configuration for Smart Cities PRO model

Note: *For more technical information about each sensor probe go to the Development section in 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.

As we see in the figure below, thanks to the directional probe, the ultrasound sensor probe may be placed in different positions. The sensor can be focused directly to the point we want to measure.

Figure: Configurations of the ultrasound sensor probe

> ***Note:*** *For more technical information about each sensor probe go to the Development section in Libelium website.*

9.2. Noise / Sound Level Sensor sensor prob

Figure: Noise / Sound Level sensor

9.2.1. Specifations of the Noise Level Sensor probe

- **Target parameter:** LeqA
- **Microphone sensitivity:** 12.7 mV / Pa
- **Range of the sensor:** 50 dBA to 100 dBA
- **Accuracy:** ±0.5 dBA (at 1 kHz)
- **Frequency range:** 20 Hz – 20 kHz
- Omni-directional microphone
- **A-weighting** measure
- Sound pressure level measurement (no weighting filter)
- **FAST** mode (125 ms) and **SLOW** mode (1 second), software configurable

9.2.2. Specifications of the enclosure

- **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**
- **Weatherproof:** true - nach UL 746 C
- **Ambient temperature (min.):** -10 °C
- **Ambient temperature (max.):** 50 °C
- **Approximated weight:** 800 g

9.2.3. Calibration tests

In order to ensure the high quality of the Noise / Sound Level Sensor, each device is verified in an independent test laboratory. After those tests, an official test report is issued by the laboratory for every Noise / Sound Level Sensor, so the customer can verify the accuracy in dBA at different frequencies for each sound level probe. ee below an example of this document.

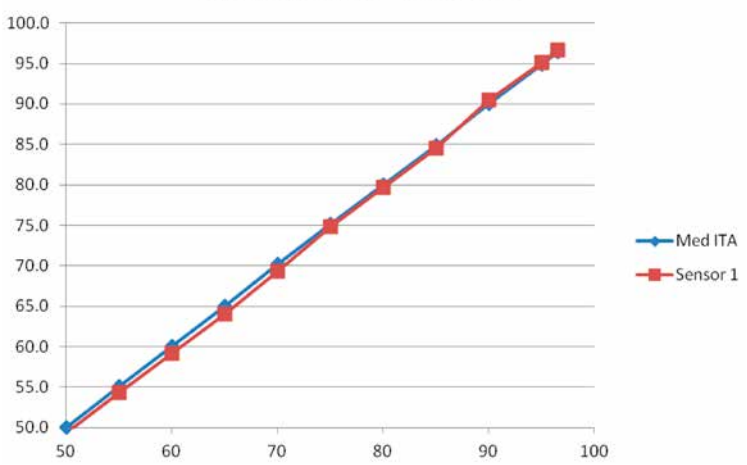


Figure: Example of test report obtained in the laborator

9.3. Smart environment PRO sensors

The Plug & Sense! Smart Cities PRO models allow to connect the sensors available on the Plug & Sense! Smart Environment PRO sensors, including gas sensors, the Particle Matter sensor, the triple temperature, humidity and pressure sensor, the Luxes sensor and the ultrasound sensor. You can find detailed info in the chapter “Smart Environment PRO” and also in the Gases PRO Guide for these sensor probes:

- Particle Matter (PM1 / PM2.5 / PM10) - Dust
- Carbon Monoxide (CO) for high concentrations [Calibrated]
- Carbon Dioxide (CO2) [Calibrated]
- Molecular Oxygen (O_2) [Calibrated]
- Ozone (O_3) [Calibrated]
- Ammonia (NH_3) for low concentrations [Calibrated]
- Ammonia (NH3) for high concentrations [Calibrated]
- Nitric Oxide (NO) for low concentrations [Calibrated]
- Nitric Dioxide (NO2) high accuracy [Calibrated]
- Sulfur Dioxide (SO2) high accuracy [Calibrated]Methane (CH_4) and Combustible Gases [Calibrated]
- Hydrogen Sulfide (H_2S) [Calibrated]
- Temperature, Humidity and Pressure
- Ultrasound sensor probe
- Luminosity (Luxes accuracy)

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.

9.4. 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. Libelium keeps a minimum stock of calibrated gas sensors to ensure the maximum durability. Ensambling process and delivery time takes from 1 to 2 weeks in case the current stock is enough for the order and from 4 to 6 weeks in case the order is higher than the stock available and new sensors units need to be manufactured and calibrated. Please inform as soon as possible of your sensor requirements to our Sales agents so that they can order the units needed to factory.

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% (depending on the external conditions: humidity, temperature, measured gas concentration, if there are another type of gas present which corrode the sensor, etc). 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.

10. Smart Parking

10.1. General description

The Smart Parking node allows to detect available parking spots by placing the node on the pavement. It works with a radar sensor and a magnetic sensor which detect when a vehicle is present or not.

The node benefits from LoRaWAN technology, getting ubiquitous coverage with few base stations. The device is very optimized in terms of power consumption, resulting in a long battery life. Its small size and the robust and surface-mount enclosure enables a fast installation, without the need of digging a hole in the ground. Finally, the developer does not need to program the node, but just configure some key parameters. Remote management and bidirectional communication allow to change parameters from the Cloud.

Figure: Smart Parking node

Note: *There are specific documents for parking applications on the Libelium website. Refer to the Smart Parking Technical Guide to see typical applications for this model and how to make a good installation.*

Figure: Smart Parking application diagram

11. Smart Agriculture

11.1. General description

The Smart Agriculture models allow to monitor multiple environmental parameters involving a wide range of applications. It has been provided with sensors for air and soil temperature and humidity, solar visible radiation, wind speed and direction, rainfall, atmospheric pressure, etc.

The main applications for this Waspmote Plug & Sense! model are precision agriculture, irrigation systems, greenhouses, weather stations, etc. Refer to Libelium website for more information.

Two variants are possible for this model, normal and PRO. Next section describes each configuration in detail.

Figure: Smart Agriculture Waspmote Plug & Sense! model

Normal

Sensor sockets are configured as shown in the figure below.

Sensor Socket	Sensor probes allowed for each sensor socket	
	Parameter	**Reference**
A	Weather Station WS-3000 (anemometer + wind vane + pluviometer)	9256-P
B	Soil Moisture 1	9248-P, 9324-P, 9323-P
C	Soil Moisture 3	9248-P, 9324-P, 9323-P
D	Soil Temperature	86949*
	Temperature + Humidity + Pressure	9370-P
	Luminosity (Luxes accuracy)	9325-P
	Ultrasound (distance measurement)	9246-P
E	Leaf Wetness	9249-P
	Soil Moisture 2	9248-P, 9324-P, 9323-P
F (digital bus)	Temperature + Humidity + Pressure	9370-P
	Luminosity (Luxes accuracy)	9325-P
	Ultrasound (distance measurement)	9246-P

Figure: Sensor sockets configuration for Smart Agriculture model

* Ask Libelium Sales Department for more information.

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

PRO

Sensor sockets are configured as shown in the figure below.

Sensor Socket	Sensor probes allowed for each sensor socket	
	Parameter	**Reference**
A	Weather Station WS-3000 (anemometer + wind vane + pluviometer)	9256-P
B	Soil Moisture 1	9248-P, 9324-P, 9323-P
	Solar Radiation (PAR)	9251-P
	Ultraviolet Radiation	9257-P
C	Soil Moisture 3	9248-P, 9324-P, 9323-P
	Dendrometers	9252-P, 9253-P, 9254-P
D (digital bus)	Soil Temperature (Pt-1000)	9255-P
	Temperature + Humidity + Pressure	9370-P
	Luminosity (Luxes accuracy)	9325-P
	Ultrasound (distance measurement)	9246-P
E	Leaf Wetness	9249-P
	Soil Moisture 2	9248-P, 9324-P, 9323-P
F (digital bus)	Temperature + Humidity + Pressure	9370-P
	Luminosity (Luxes accuracy)	9325-P
	Ultrasound (distance measurement)	9246-P

Figure: Sensor sockets configuration for Smart Agriculture PRO model

* Ask Libelium Sales Department for more information.

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

11.2. Temperature, Humidity and Pressure Sensor Probe

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

Specifications

Figure: Image of the Temperature, Humidity and Pressure Sensor Probe

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

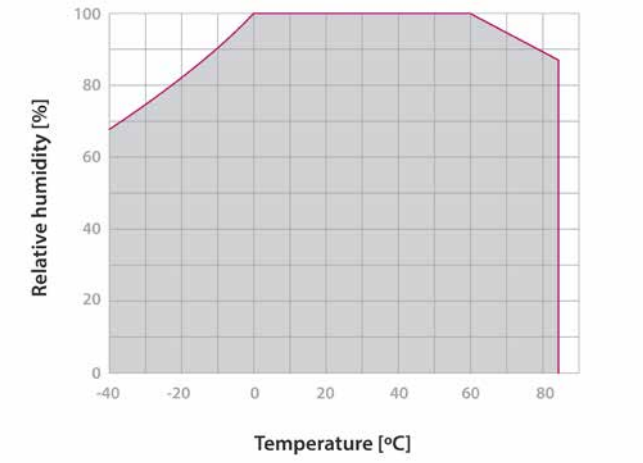


Figure: Humidity sensor operating range

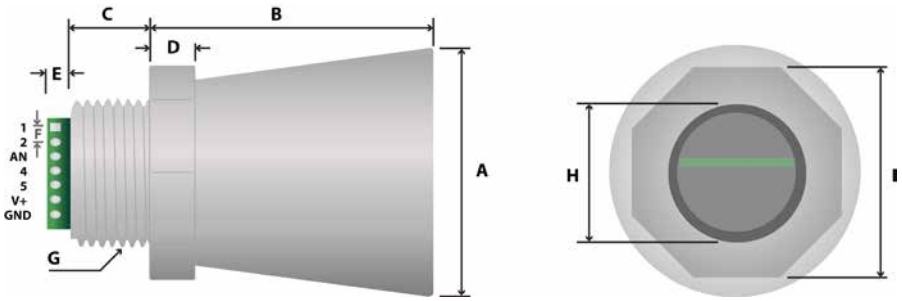
Pressure sensor
Measurement range: 30 ~ 110 kPa
Operational temperature range: -40 ~ +85 ºC
Full accuracy temperature range: 0 ~ +65 ºC
Absolute accuracy: ±0.1 kPa (0 ~ 65 ºC)
Typical consumption: 2.8 µA measuring
Maximum consumption: 4.2 µA measuring

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

I2CXL-MaxSonar®-MB7040™

Operation frequency: 42 kHz
Maximum detection distance: 765 cm
Interface: Digital bus
Power supply: 3.3 V ~ 5 V
Consumption (average): 2.1 mA (powered at 3.3 V) – 3.2 mA (powered at 5 V)
Consumption (peak): 50 mA (powered at 3.3 V) – 100 mA (powered at 5 V)
Usage: Indoors and outdoors (IP-67)

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



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

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):

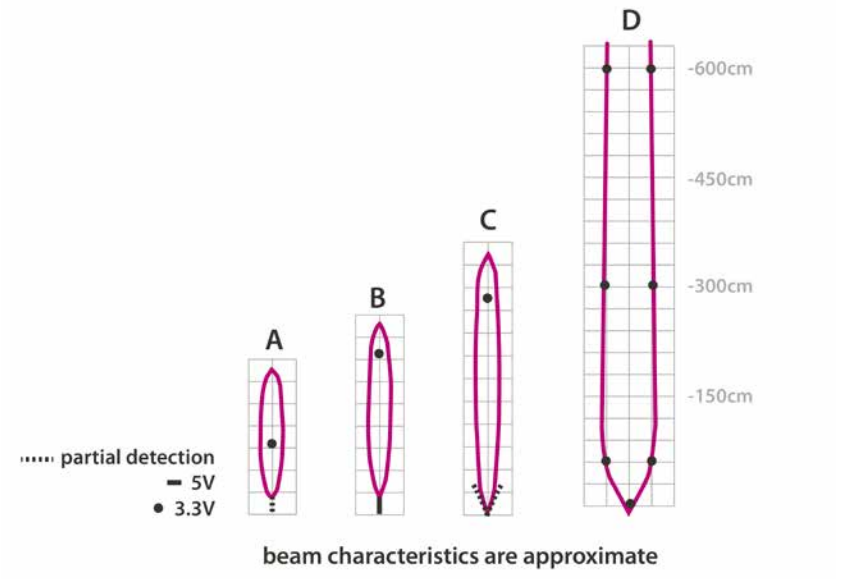


Figure: Diagram of the sensor beam extracted from the data sheet of the XL-MaxSonar®-WRA1™ sensor from MaxBotix

Figure: Image of configurations of the ultrasound sensor probe

As we see in the figure, the ultrasound sensor probe may be placed in different positions. The sensor can be focused directly to the point we want to measure.

11.4. Luminosity sensor probe (Luxes accuracy)

Sensor specifications (Luxes accuracy)

Dynamic range: 0.1 to 40000 Lux
Spectral range: 300 – 1100 nm
Voltage range: 2.7 – 3.6 V
Operating temperature: -30 ºC to +80 ºC
Typical consumption: 0.24 mA
Maximum consumption: 0.6 mA
Usage: Indoors and outdoors

Figure: Image of the Luminosity sensor probe (Luxes accuracy)

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.

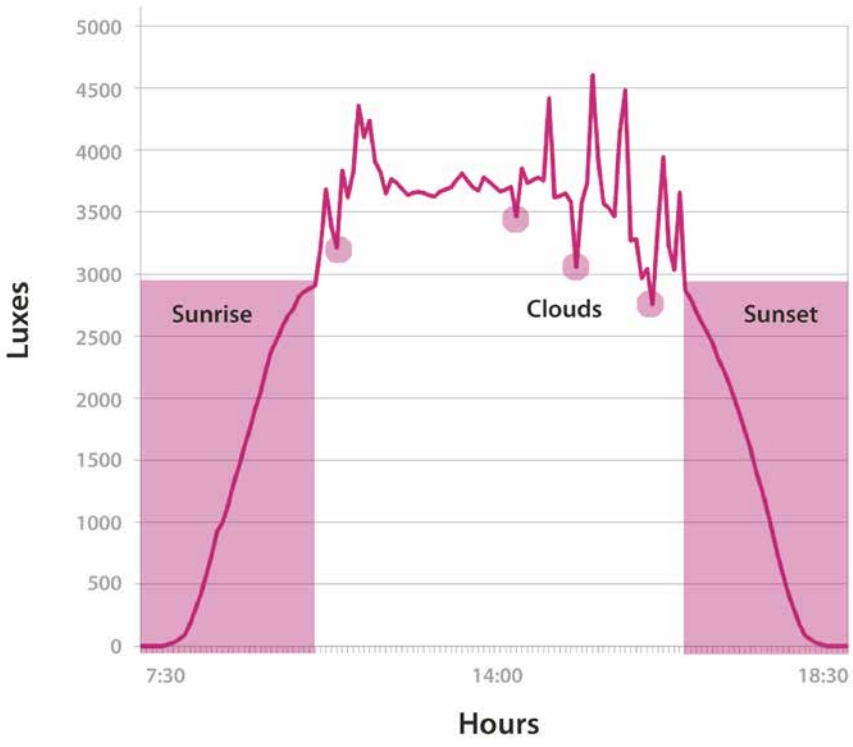


Figure: Image of the Luminosity sensor probe (Luxes accuracy)

11.5. Soil temperature (DS18B20) sensor probe

Sensor specifications (DS18B20)

Measurement range: [-55 ºC,+125 ºC]
Output voltage (0ºC): 500 mV
Resolution: 12 bits (0.0625 ºC)
Accuracy: ±0.5 ºC (range -10 ºC ~ +85 ºC)
Supply voltage: 3.0 ~ 5.5 V
Response time: 1.65 seconds (63% response from +30 to +125 °C)
Typical consumption: 1 mA
Conversion time: 750 ms

Figure: Image of the Soil Temperature sensor probe (DS18B20)

The DS18B20 is a temperature digital sensor which provides an accurate measurement and a high resolution (of up to 0.065 ºC) which communicates with the Waspmote's microcontroller through the 1-Wire bus. It has been encapsulated in a plastic seal that isolates it from humidity, thus allowing to use it in wet environments as long as for temperature measurement in soil or liquids.

11.6. Soil moisture sensor probe

Sensor specifications (Watermark)

Measurement range: 0 ~ 200 cb
Frequency range: 50 ~ 10000 Hz approximately

Diameter: 22 mm
Length: 76 mm
Terminals: AWG 20

Figure: Ecomatik DC3 sensor

Figure: Image of the Soil Moisture sensor probe (Watermark)

Figure: Ecomatik DD sensor

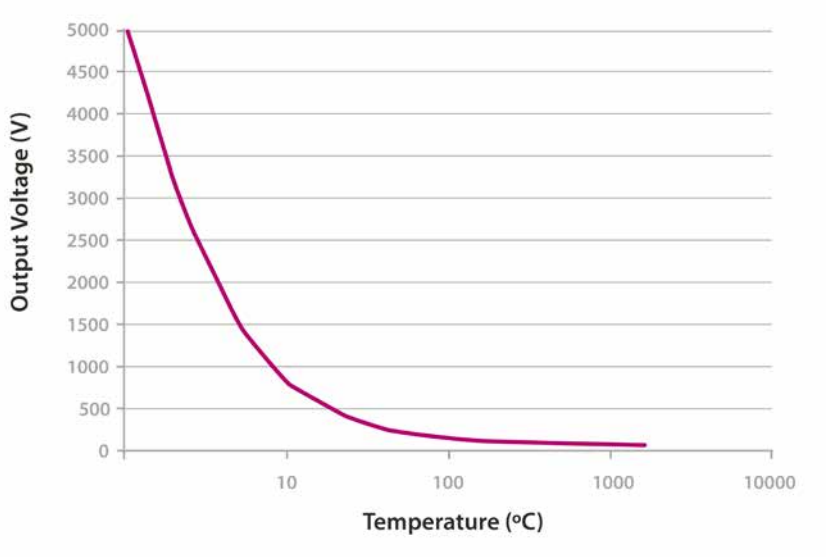


Figure: Output frequency of the Watermark sensor circuit with respect to the resistance of the sensor

The Watermark sensor by Irrometer is a resistive type sensor consisting of two electrodes highly resistant to corrosion embedded in a granular matrix below a gypsum wafer. The resistance value of the sensor is proportional to the soil water tension, a parameter dependent on moisture that reflects the pressure needed to extract the water from the ground. The function of the library `readValue` returns the frequency output of the sensor's adaptation circuit in Hertz (Hz), for more information about the conversion into soil water tension look at Appendix 1 of the Agriculture 3.0 Board technical guide.

11.7. Weather station WS-3000 probe

Sensor specifications (Anemometer)

Sensitivity: 2.4 km/h / turn
Wind Speed Range: 0 ~ 240 km/h
Height: 7.1 cm
Arm length: 8.9 cm
Connector: RJ11

The anemometer chosen for Waspmote consists of a Reed switch normally open that closes for a short period of time when the arms of the anemometer complete a turn, so the output is a digital signal whose frequency will be proportional to the wind speed in kilometers per hour (km/h).

Figure: Image of the Weather Station WS-3000 probe

Sensor specifications (Vane)

Height: 8.9 cm
Length: 17.8 cm
Maximum accuracy: 22.5º
Resistance range: 688 Ω ~ 120 kΩ

The wind vane consists of a basement that turns freely on a platform endowed with a net of eight resistances connected to eight switches that are normally open and are closed (one or two) when a magnet in the basement acts on them, which permits us to distinguish up to 16 different positions (the equivalent to a resolution of 22.5º). The equivalent resistance of the wind vane, along with a 10 kΩ resistance, form a voltage divider, powered at 3.3 V, whose output can be measured in an analog input of the microcontroller. The function of the library `readValue` also stores in variable `vane_direction` an 8 bits value which corresponds with an identifier of the pointing direction. Below, a table with the different values that the equivalent resistance of the wind vane may take is shown, along with the direction corresponding to each value:

Direction (Degrees)	Resistance (kΩ)	Voltage (V)	Identifier
0	33	2.53	SENS_AGR_VANE_N
22.5	6.57	1.31	SENS_AGR_VANE_NNE
45	8.2	1.49	SENS_AGR_VANE_NE
67.5	0.891	0.27	SENS_AGR_VANE_ENE
90	1	0.3	SENS_AGR_VANE_E
112.5	0.688	0.21	SENS_AGR_VANE_ESE
135	2.2	0.59	SENS_AGR_VANE_SE
157.5	1.41	0.41	SENS_AGR_VANE_SSE
180	3.9	0.92	SENS_AGR_VANE_S
202.5	3.14	0.79	SENS_AGR_VANE_SSW
225	16	2.03	SENS_AGR_VANE_SW
247.5	14.12	1.93	SENS_AGR_VANE_WSW
270	120	3.05	SENS_AGR_VANE_W

Direction (Degrees)	Resistance (kΩ)	Voltage (V)	Identifier
292.5	42.12	2.67	SENS_AGR_VANE_WNW
315	64.9	2.86	SENS_AGR_VANE_NW
337.5	21.88	2.26	SENS_AGR_VANE_NNW

Besides, it is recommended to use the function `getVaneFiltered` in order to perform a mean filtered measurement during a specified period of time. Thus, mechanical fluctuations will be avoided and a more accurate measurement will be done.

Sensor specifications (Pluviometer)

Height: 9.05 cm
Length: 23 cm
Bucket capacity: 0.28 mm of rain

The pluviometer consists of a small bucket that, once completely filled (0.28 mm of water approximately), closes a switch, emptying automatically afterwards. The result is a digital signal whose frequency is proportional to the intensity of rainfall in millimeters of rain per minute (mm/min). The sensor is connected directly to a Waspmote digital input through a pull-up resistance and to the interruption pin `TXD1`, allowing the triggering of an interruption of the microprocessor when the start of the rain is detected.

Tip: the user can apply a little of paraffin on the pluviometer's upper surface in order to help the rain drops to flow down to the inside of the sensor.

11.8. Leaf Wetness sensor probe

Sensor specifications (Leaf Wetness)
Resistance Range: 5 kΩ ~ >2 MΩ
Output Voltage Range: 1 V ~ 3.3 V
Length: 5.5 cm
Width: 4 cm

Figure: Image of the Leaf Wetness sensor probe

The leaf wetness sensor behaves as a resistance of a very high value (infinite, for practical purposes) in absence of condensation in the conductive combs that make it up, and that may fall down to about 5kΩ when it is completely submerged in water. The voltage at its output is inversely proportional to the humidity condensed on the sensor, and can be read at an analog input of Waspmote.

11.9. Soil/Water Temperature (Pt-1000) sensor probe

Sensor specifications

Measurement range: 0 ~ 100 ºC
Accuracy: DIN EN 60751
Resistance (0 ºC): 1000 Ω
Diameter: 6 mm
Length: 40 mm
Cable: ~5 m

Figure: Image of the Soil/Water Temperature sensor probe

The resistance of the Pt-1000 sensor varies between approximately 920 Ω and 1200 Ω in the range considered useful in agriculture applications (-20 ~ 50 ºC approximately), which results in too low variations of voltage at significant changes of temperature for the resolution of the Waspmote's analog-to-digital converter. The temperature value is returned in Celsius degree (ºC).

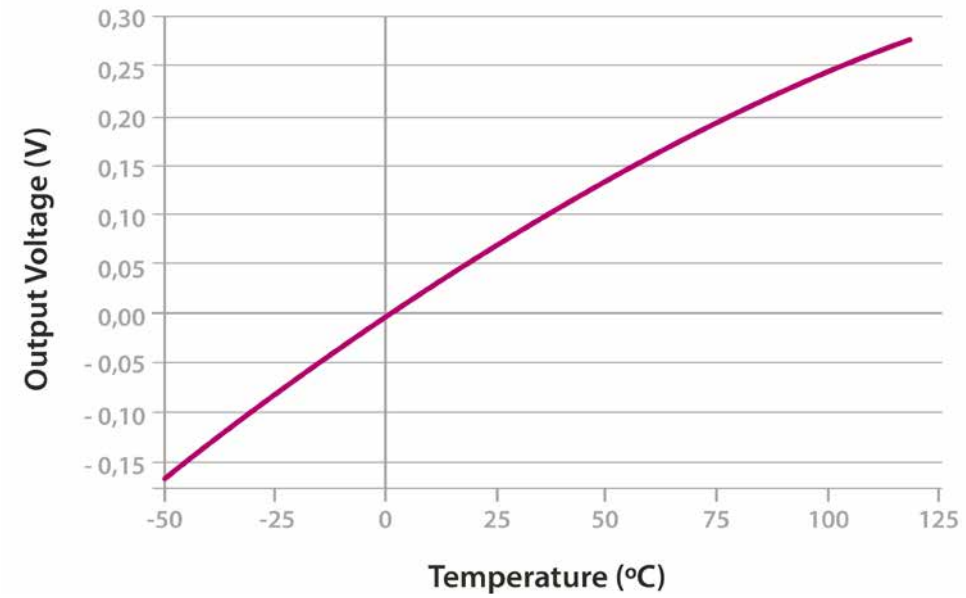


Figure: Output voltage of the PT-1000 sensor with respect to temperature

11.10. Solar Radiation sensor probe

Sensor specifications (SQ-110)

Sensibility: 0.200 mV / µmol·$m^{-2}s^{-1}$
Calibration factor: 5 µmol·$m^{-2}s^{-1}$ / mV
Non-linearity: < 1% (up to 4000 µmol·$m^{-2}s^{-1}$ / mV)
Non-stability (long-term drift): <2% per year
Spectral range: 410 ~ 655 nm
Accuracy: ±5%
Repeatability: <1%
Diameter: 2.4 cm
Height: 2.8 cm
Cable length: 5 m of shielded, twisted-pair wire
Operation temperature: -40 ~ 70 ºC
Operation humidity: 0 ~ 100% RH

Figure: Image of the Solar Radiation sensor probe

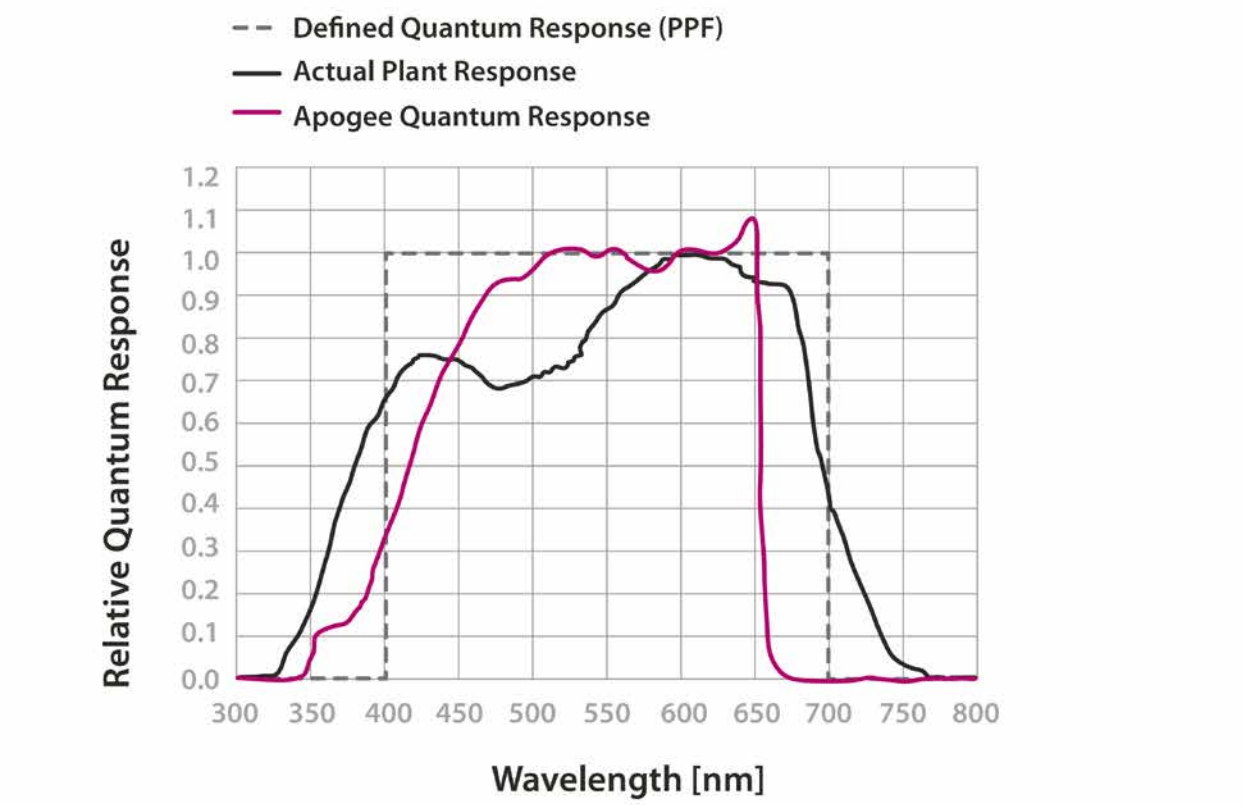


Figure: Graph of the spectral response of the SQ-110 sensor compared to the photosynthetic response of a plant

The SQ-110 sensor, specifically calibrated for the detection of solar radiation, provides at its output a voltage proportional to the intensity of the light in the visible range of the spectrum, a key parameter in photosynthesis processes. It presents a maximum output of 400 mV under maximum radiation conditions. In order to improve the accuracy of the reading, this is carried out through a 16 bits analog-to-digital converter that communicates with the microprocessor of the mote through the I2C.

Sensor specifications (SU-100)

Sensibility: 0.2 mV / µmol·m^{-2}s^{-1}
Calibration factor: 5.0 µmol·m^{-2}s^{-1} / mV
Non-stability (long-term drift): <3% per year
Non-linearity: <1% (up to 300 µmol·m^{-2}s^{-1})
Spectral range: 250 ~ 400 nm
Accuracy: ±10%
Repeatability: <1%
Diameter: 2.4 cm
Height: 2.8 cm
Cable length: 5 m shielded, twisted-pair wire
Operation temperature: -40 to 70 ºC

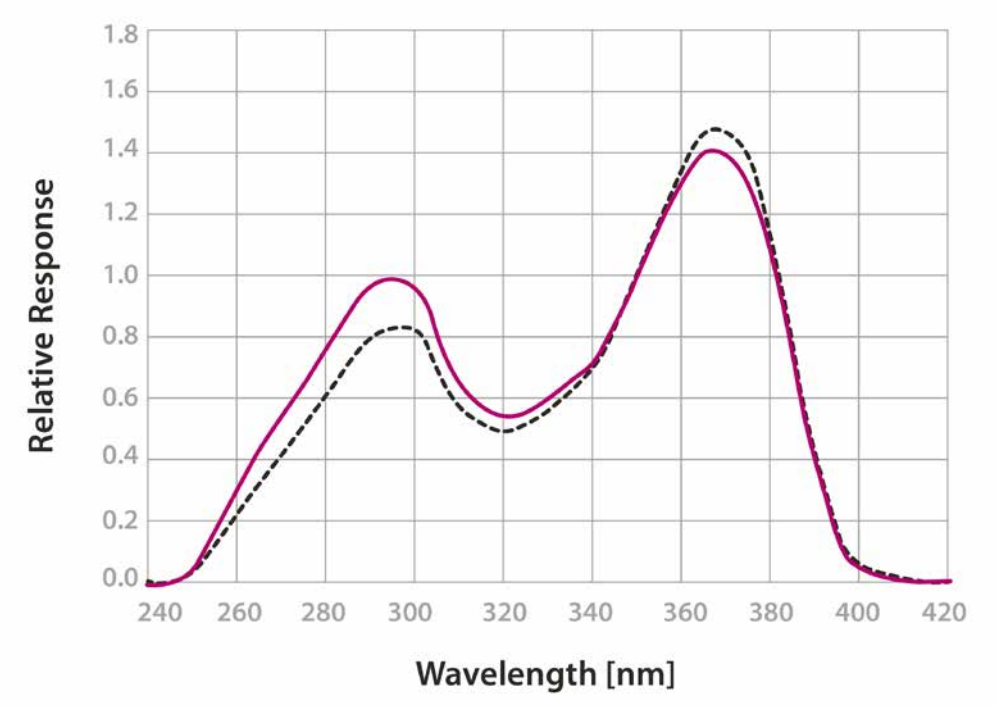


Figure: Graph of the spectral response of the SU-100 sensor compared to the photosynthetic response of a plant

The SU-100 sensor, complementary to the SQ-110 sensor, provides at its output a voltage proportional to the intensity of the light in the ultraviolet range of the spectrum. It presents a maximum output of 26 mV under maximum radiation conditions. This sensor is read by the mote through the same 16 bits analog-to-digital converter used with the SQ-110 sensor.

11.11. Dendrometer sensor probe

Figure: Image of the Dendrometer sensor probe

Sensor specifications (Trunk diameter)

Operation temperature: -30 ~ 40 ºC
Operation humidity: 0 ~ 100% RH
Trunk/branch diameter: from 5 cm
Accuracy: ±3.3 µm
Temperature coefficient: <1,4µm/K
Linearity: 0.7%
Output range: 0 ~ 20 kΩ
Range of the sensor: function of the size of the tree:

Tree Diameter (cm)	Measuring range in diameter (mm)
10	16.2
50	11.3
100	9.0

Note: The previous version of the DC3 Trunk diameter (the DC2) has been discontinued, but it is still available for replacements on demand. Contact your sales agent for more information.

Sensor specifications (Stem diameter)

Stem/branch diameter: 0 ~ 20 cm
Range of the sensor: 11 mm
Output range: 0 ~ 20 kΩ
Accuracy: ±2 µm
Temperature coefficient: <0.1µm/K
Operation temperature: -30 ~ 40 ºC
Operation humidity: 0 ~ 100% RH
Cable length: 2 m

Sensor specifications (Fruit diameter)

Fruit diameter: 0 ~ 11 cm
Range of the sensor: 11 mm
Output range: 0 ~ 20 kΩ
Accuracy: ±2 µm
Temperature coefficient: <0.1 µm/K
Operation temperature: -30 ~ 40 ºC
Operation humidity: 0 ~ 100% RH
Cable length: 2 m

Figure: Ecomatik DC3 sensor

The operation of the three Ecomatik dendrometers, DC3, DD and DF, is based on the variation of an internal resistance with the pressure that the growing of the trunk, stem, branch or fruit exerts on the sensor. The circuit permits the reading of that resistance in a full bridge configuration through a 16 bits analog-to-digital converter whose reference is provided by a high precision 3 V voltage reference in order to acquire the most accurate and stable measurements possible, returning its value in mm.

12. Smart Agriculture Xtreme

12.1. General description

The Plug & Sense! Smart Agriculture Xtreme is an evolution of our Agriculture line with a new selection of high-end professional sensors. It allows to monitor multiple environmental parameters involving a wide range of applications, from plant growing analysis to weather observation. There are sensors for atmospheric and soil monitoring and plants health. Up to 19 sensors can be connected.

Figure: Smart Agriculture Xtreme 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 and D	Non-contact surface temperature measurement	9468-P
	Leaf and flower bud temperature	9467-P
	Soil oxygen level	9469-P
	Conductivity, water content and soil temperature 5TE	9402-P
	Conductivity, water content and soil temperature GS3	9464-P
	Soil temperature and volumetric water content	9460-P
	Soil water potentials	9465-P
	Vapor pressure, humidity, temperature, and atmospheric pressure in soil and air	9471-P
	Temperature, air humidity and pressure	9370-P
	Luxes	9325-P
	Ultrasound	9246-P
B	Non-contact surface temperature measurement	9468-P
	Leaf and flower bud temperature	9467-P
	Soil oxygen level	9469-P
	Conductivity, water content and soil temperature 5TE	9402-P
	Conductivity, water content and soil temperature GS3	9464-P
	Soil temperature and volumetric water content	9460-P
	Soil water potentials	9465-P
	Vapor pressure, humidity, temperature, and atmospheric pressure in soil and air	9471-P
	Leaf wetness Phytos 31	9466-P
	Shortwave radiation	9470-P
	Solar Radiation (PAR) for Smart Agriculture Xtreme	9251-PX
	Ultraviolet radiation	9257-PX
	4-20 mA type (generic)	-
C	Non-contact surface temperature measurement	9468-P
	Leaf and flower bud temperature	9467-P
	Soil oxygen level	9469-P
	Conductivity, water content and soil temperature 5TE	9402-P
	Conductivity, water content and soil temperature GS3	9464-P
	Soil temperature and volumetric water content	9460-P
	Soil water potentials	9465-P
	Vapor pressure, humidity, temperature, and atmospheric pressure in soil and air	9471-P
	Dendrometers	9252-PX, 9253-PX, 9254-PX
	Shortwave radiation	9470-P
	Solar Radiation (PAR) for Smart Agriculture Xtreme	9251-PX
	Ultraviolet radiation	9257-PX
E	Shortwave radiation	9470-P
	Solar Radiation (PAR) for Smart Agriculture Xtreme	9251-PX
	Ultraviolet radiation	9257-PX
	Wind and precipitations	9463-P

F	Shortwave radiation	9470-P
	Solar Radiation (PAR) for Smart Agriculture Xtreme	9251-PX
	Ultraviolet radiation	9257-PX
	RS-232 type (generic)	-
	4-20 mA type (generic)	-

Figure: Sensor sockets configuration for Smart Agriculture model

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

12.2. Non-contact surface temperature measurement sensor probe (Apogee SI-411)

The Non-contact surface temperature measurement sensor probe is able to measure the electromagnetic radiation that every object with a temperature above absolute zero emits, which is used to calculate surface temperature from a distance. Thanks to this, the temperature of the object surface is not altered in any way when measuring it.

Figure: The non-contact surface temperature measurement sensor probe (Apogee SI-411)

12.2.1. Specifications

- **Operating environment**: -45 to 80 ºC
- **Operation humidity**: 0 ~ 100% RH (non-condesing)
- **Calibration uncertainty (-20 to 65 ºC)**, when target and detector temperature are within 20 ºC: 0.2 ºC
- **Calibration uncertainty (-40 to 80 ºC)**, when target and detector temperature are different by more than 20 ºC: 0.5 ºC
- **Measurement repeatability**: less than 0.05 ºC
- **Stability** (Long-term drift): less than 2 % change in slope per year when germanium filter is maintained in a
- clean condition
- **Field of view**: 22º half angle

- **Spectral range**: 8 to 14 µm; atmospheric window
- **Dimensions**: 23 mm diameter; 60 mm length
- **Mass**: 190 g (with 5m of lead wire)
- **Cable**: 5 m

12.3. Leaf and flower bud temperature sensor probe (Apogee SF-421)

Frost events may happen in plants even though the ambient temperature is not 0 ºC or lower because the canopy temperature can be different than air temperature, this is called radiation frost. The Leaf and bud temperature sensor probe is designed to predict frost events.

Radiation frost occurs when there is a lack of air mixing by the wind near the surface and a negative net long wave radiation balance at the surface.

Figure: Leaf and bud temperature sensor probe (Apogee SF-421)

12.3.1. Specifications

- **Operating temperature**: -50 to 70 ºC
- **Operation humidity**: 0 ~ 100% RH
- **Measurement range**: -50 to 70 ºC
- **Measurement Uncertainty**:
  - 0.1 ºC (from 0 to 70 ºC)
  - 0.2 ºC (from -25 to 0 ºC)
  - 0.4 ºC (from -50 to -25 ºC)
- **Measurement repeatability**: less than 0.05 ºC
- **Stability** (Long-term drift): Less than 0.02 ºC per year
- **Equilibration time**: 10 s
- **Self-heating**: Less than 0.01 ºC
- **Dimensions**: 57 cm length, 2.1 cm pipe diameter, 7.0 cm disk diameter (see image below)
- **Mass**: 400 g
- **Cable**: 5 m

12.4. Soil oxygen level sensor probe (Apogee SO-411)

Oxygen is the second major constituent of Earth's atmosphere and it is crucial for the development of life. There are sensors which measures oxygen in 2 states: dissolved in a solution and in a gaseous state. The Soil oxygen level sensor probe measures gaseous oxygen.

The Soil oxygen level sensor probe consists of a galvanic cell type sensor and offers a measure of the percentage of the total number of molecules of oxygen in the air. This sensor is specially designed for use in soil or porous media.

Figure: Soil oxygen level sensor probe (Apogee SO-411)

Figure: SO-411 sensor with diffusion head AO-001

12.4.1. Specifications

- **Operating environment**: -20 to 60 ºC; 60 to 114 kPa
- **Operation humidity**: 0 ~ 100% RH (non-condensing)
- **Measurement range**: 0 to 100 % O_2
- **Measurement repeatability**: Less than 0.1 % of mV output at 20.95 % O_2
- **Non-linearity**: Less than 1 %
- **Long-term drift** (Non-stability): 1.0 mV per year
- **Oxygen consumption rate**: 2.2 µmol O_2 per day at 20.95 % O_2 and 23 ºC
- **Response time**: 60 s
- **Dimensions**: 32 mm diameter, 68 mm length
- **Mass**: 175 g
- **Cable**: 5 m

12.5. Shortwave radiation sensor probe (Apogee SP-510)

The Shortwave radiation sensor probe (Apogee SP-510) measures incoming global shortwave radiation from the Sun. Shortwave radiation is radiant energy with wavelengths in the visible (VIS), near-ultraviolet (UV), and near-infrared (NIR) spectra.

This sensor consists of a thermopile detector, acrylic diffuser, heater, and signal processing circuitry mounted in an anodized aluminum housing.

Figure: Shortwave radiation sensor probe (Apogee SP-510)

12.5.1. Specifications

General specifications

- Operating temperature: -50 to 80 ºC
- Operation humidity: 0 ~ 100% RH
- Sensitivity (variable from sensor to sensor, typical values listed): 0.057 mV per W m^{-2}
- Calibration factor (reciprocal of sensitivity): 17.5 W m^{-2} per mV
- Calibration uncertainty: ±5%
- Calibrated output range: 0 to 114 mV
- Measurement range: 0 to 2000 W m^{-2} (net shortwave radiation)
- Measurement repeatability: less than 1%
- Long-term drift (non-stability): less than 2% per year
- Non-linearity: less than 1%
- Detector response time: 0.5 s
- Field of view: 180º
- Spectral range (wavelengths where response is 50% of maximum): 385 to 2105 nm
- Directional (cosine) response: less than 30 W m^{-2} up to solar zenith angles of 80º
- Temperature response: less than 5% from -15 to 45 ºC
- Cable length: 5 m

12.6. Solar Radiation sensor probe

Sensor specifications (SQ-110)

Sensibility: 0.200 mV / µmol·$m^{-2}s^{-1}$
Calibration factor: 5 µmol·$m^{-2}s^{-1}$ / mV
Non-linearity: < 1% (up to 4000 µmol·$m^{-2}s^{-1}$ / mV)
Non-stability (long-term drift): <2% per year
Spectral range: 410 ~ 655 nm
Accuracy: ±5%
Repeatability: <1%
Diameter: 2.4 cm
Height: 2.8 cm
Cable length: 5 m of shielded, twisted-pair wire
Operation temperature: -40 ~ 70 ºC
Operation humidity: 0 ~ 100% RH

Figure: Image of the Solar Radiation sensor probe

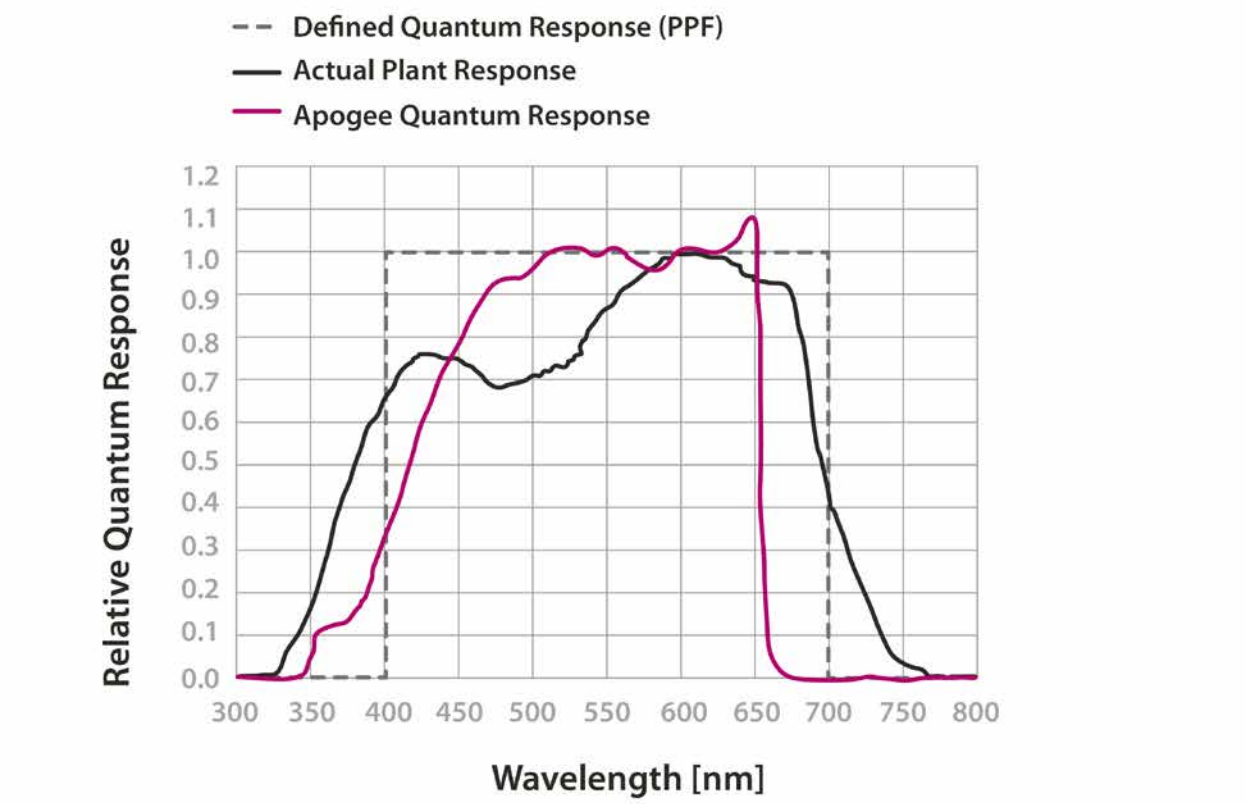


Figure: Graph of the spectral response of the SQ-110 sensor compared to the photosynthetic response of a plant

The SQ-110 sensor, specifically calibrated for the detection of solar radiation, provides at its output a voltage proportional to the intensity of the light in the visible range of the spectrum, a key parameter in photosynthesis processes. It presents a maximum output of 400 mV under maximum radiation conditions. In order to improve the accuracy of the reading, this is carried out through a 16 bits analog-to-digital converter that communicates with the microprocessor of the mote through the I2C.

Sensor specifications (SU-100)

Sensibility: 0.2 mV / µmol·m^{-2}s^{-1}
Calibration factor: 5.0 µmol·m^{-2}s^{-1} / mV
Non-stability (long-term drift): <3% per year
Non-linearity: <1% (up to 300 µmol·m^{-2}s^{-1})
Spectral range: 250 ~ 400 nm
Accuracy: ±10%
Repeatability: <1%
Diameter: 2.4 cm
Height: 2.8 cm
Cable length: 5 m shielded, twisted-pair wire
Operation temperature: -40 to 70 ºC

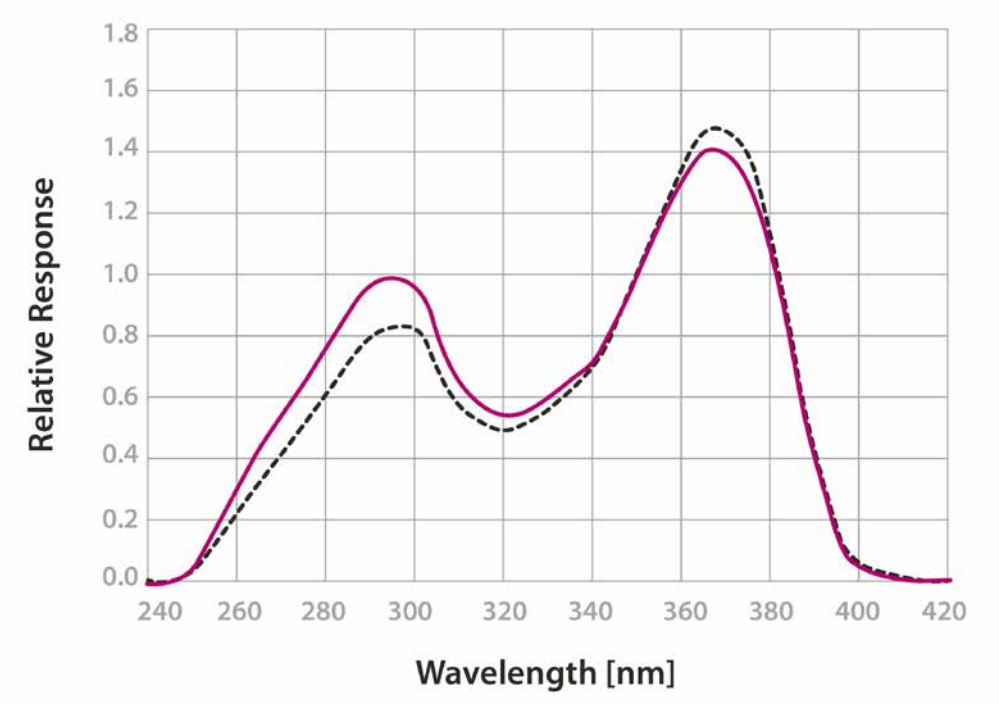


Figure: Graph of the spectral response of the SU-100 sensor compared to the photosynthetic response of a plant

The SU-100 sensor, complementary to the SQ-110 sensor, provides at its output a voltage proportional to the intensity of the light in the ultraviolet range of the spectrum. It presents a maximum output of 26 mV under maximum radiation conditions. This sensor is read by the mote through the same 16 bits analog-to-digital converter used with the SQ-110 sensor.

12.7. Ultraviolet radiation sensor probe for Smart Agriculture Xtreme (Apogee SU-100)

Ultraviolet (UV) radiation is typically defined as total radiation across a range from 100 to 400 nm and is subdivided into 3 wavelength ranges: UV-A (315 to 400 nm), UV-B (280 to 315 nm) and UV-C (100 to 280 nm). Much of the UV-B and all of the UV-C wavelengths from the sun are absorbed by the Earth's atmosphere.

The Ultraviolet radiation sensor probe for Smart Agriculture Xtreme (Apogee SU-100) detects UV radiation from 250 to 400 nm and is calibrated in photon flux units of micromoles per square meter per second ($\mu mol \cdot m^{-2} s^{-1}$). .

Figure: Ultraviolet radiation sensor probe for Smart Agriculture Xtreme (Apogee SU-100)

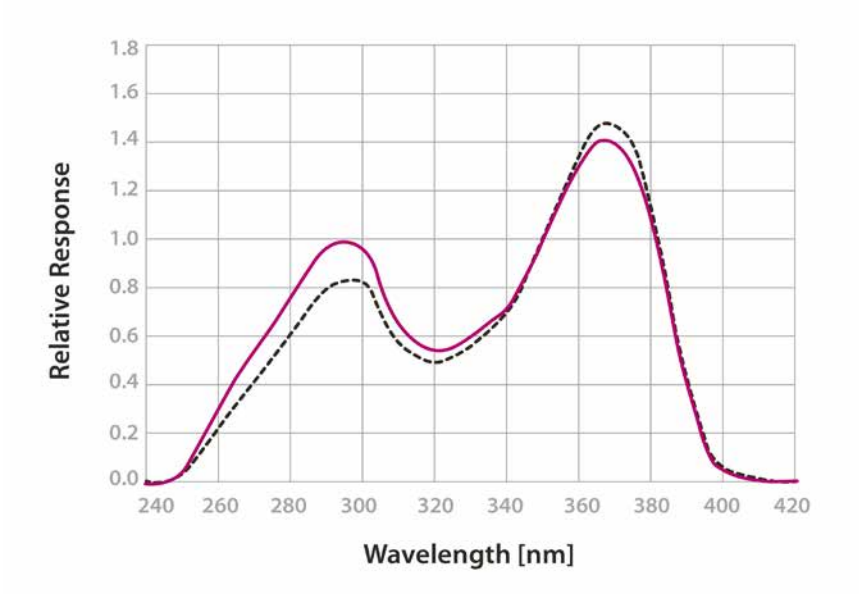


Figure: Graph of the spectral response of the SU-100 sensor probe compared to the photosynthetic response of a plant

12.7.1. Specifications

- **Operation temperature**: -40 to 70 ºC
- **Operation humidity**: 0 to 100 %
- **Sensitivity**: 0.2 mV / µmol·$m^{-2}s^{-1}$
- **Calibration factor** (reciprocal of sensitivity): 5.0 µmol·m-$m^{-2}s^{-1}$ / mV
- **Non-stability** (long-term drift): <3% per year
- **Non-linearity**: <1% (up to 300 µmol·$m^{-2}s^{-1}$)
- **Spectral range**: 250 ~ 400 nm
- **Repeatability**: <1%
- **Diameter**: 2.4 cm
- **Height**: 2.8 cm
- **Cable length**: 5 m

12.8. Temperature, Humidity and Pressure Sensor Probe

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

Specifications

Figure: Image of the Temperature, Humidity and Pressure Sensor Probe

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

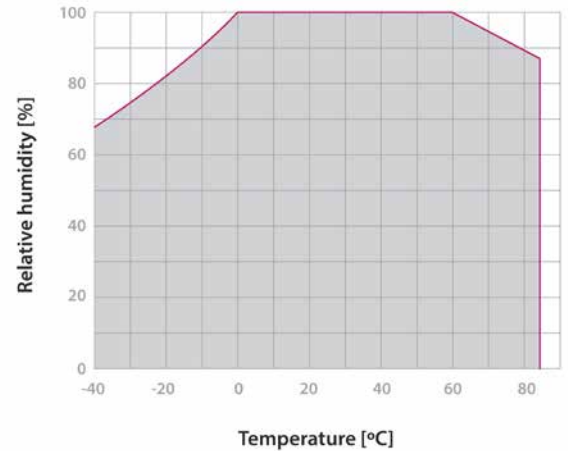


Figure: Humidity sensor operating range

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

12.9. Conductivity, water content and soil temperature GS3 sensor probe (Decagon GS3)

The Conductivity, water content and soil temperature sensor probe (Decagon GS3) can measure many types of growing media, specially in greenhouse applications where the probe can be inserted easily into different types of soilless substrates. The GS3 sensor determines volumetric water content (VWC) by measuring the dielectric constant (εa) of the medium using capacitance / frequency-domain technology, the temperature using a thermistor, and electrical conductivity using a stainless steel electrode array.

Figure: Conductivity, water content and soil temperature GS3 sensor probe (Decagon GS3)

12.9.1. Specifications

General specifications

- Operating temperature: -40 to 60 ºC
- Dielectric measurement frequency: 70 MHz
- Measurement time: 150 ms
- Dimensions: 9.3 x 2.4 x 6.5 cm
- Prong length: 5.5 cm
- Cable length: 5 m

Volumetric water content

- Accuracy: ε_a: ±1 ε_a (unitless) from 1 to 40 (soil range), ±15% from 40 to 80
- Resolution:
  - 0.1 ε_a (unitless) from 1 to 20
  - < 0.75 ε_a (unitless) from 20 to 80
  - 0.002 m^3/ m^3 (0.2% VWC) from 0 to 40% VWC
  - 0.001 m^3/ m^3 (0.1% VWC) > 40% VWC
- Range: Apparent dielectric permittivity (ε_a): 1 (air) to 80 (water)

Bulk electrical conductivity

- Accuracy: ±5% from 0 to 5 dS/m, ±10% from 5 to 23 dS/m
- Resolution: 0.001 dS/m from 0 to 23 dS/m
- Range: 0 to 25 dS/m (bulk)

Temperature

- Accuracy: ±1 ºC
- Resolution: 0.1 ºC
- Range: -40 to 60 ºC

12.10. Volumetric water content and soil temperature sensor probe (METER TEROS 11)

The Volumetric water content and soil temperature sensor probe (Meter TEROS 11) can measure many types of growing media, especially in greenhouse applications where the probe can be inserted easily into different types of soilless substrates. The TEROS 11 sensor determines volumetric water content (VWC) using capacitance / frequency-domain technology and the temperature using a thermistor.

Figure: Volumetric water content and soil temperature TEROS 11 sensor probe (Meter TEROS 11)

12.10.1. Specifications

General specifications

- Operating temperature: -40 to 60 ºC
- Dielectric measurement frequency: 70 MHz
- Measurement time: 150 ms
- Dimensions: 9.3 x 2.4 x 6.5 cm
- Prong length: 5.5 cm
- Cable length: 5 m

Volumetric water content

- Accuracy: ±0.03 m3/m3 typical in mineral soils that have solution electrical conductivity < 8 dS/m
- Resolution: 0.001 m3/m3
- Range: Mineral soil calibration: 0.00-0.70 m3/m3, Soilless media calibration: 0.0-1.0 m3/m3

NOTE: The VWC range is dependent on the media the sensor is calibrated to. A custom calibration will accommodate the necessary ranges for most substrates.

Temperature

- Accuracy: ±0.5 ºC from -40 to 0 ºC, ±0.3 ºC from 0 to 60 ºC
- Resolution: 0.1 ºC
- Range: -40 to 60 ºC

12.11. Conductivity, volumetric water content and soil temperature sensor probe (METER TEROS 12)

The Conductivity, volumetric water content and soil temperature sensor probe (Meter TEROS 12) can measure many types of growing media, specially in greenhouse applications where the probe can be inserted easily into different types of soilless substrates. The TEROS 12 sensor determines volumetric water content (VWC) using capacitance / frequency-domain technology, the temperature using a thermistor, and electrical conductivity using a stainless steel electrode array.

Figure: Conductivity, volumetric water content and soil temperature TEROS 12 sensor probe (Meter TEROS 12)

12.11.1. Specifications

General specifications

- Operating temperature: -40 to 60 ºC
- Dielectric measurement frequency: 70 MHz
- Measurement time: 150 ms
- Dimensions: 9.3 x 2.4 x 6.5 cm
- Prong length: 5.5 cm
- Cable length: 5 m

Volumetric water content

- Accuracy: ±0.03 m3/m3 typical in mineral soils that have solution electrical conductivity
- < 8 dS/m
- Resolution: 0.001 m3/m3
- Range: Mineral soil calibration: 0.00-0.70 m3/m3, Soilless media calibration: 0.0-1.0 m3/m3

Note: The VWC range is dependent on the media the sensor is calibrated to. A custom calibration will accommodate the necessary ranges for most substrates.

Bulk electrical conductivity

- Accuracy: ±5% from 0 to 10 dS/m, ±10% from 10 to 20 dS/m
- Resolution: 0.001 dS/m
- Range: 0 to 20 dS/m (bulk)

Temperature

- Accuracy: ±0.5 ºC from -40 to 0 ºC, ±0.3 ºC from 0 to 60 ºC
- Resolution: 0.1 ºC
- Range: -40 to 60 ºC

12.12. Conductivity, water content and soil temperature sensor probe (Decagon 5TE)

The Conductivity, water content and soil temperature sensor probe (Decagon 5TE) can measure volumetric water content, electrical conductivity, and temperature of soil. The sensor uses an oscillator running at 70 MHz to measure the dielectric permittivity of soil to determine the water content (VWC). A thermistor in thermal contact with the sensor prongs provides the soil temperature, while the screws on the surface of the sensor form a two-sensor electrical array to measure electrical conductivity.

Figure: Conductivity, water content and soil temperature 5TE sensor probe (Decagon 5TE)

12.12.1. Specifications

General specifications

- Operating temperature: -40 to 60 ºC
- Dielectric measurement frequency: 70 MHz
- Measurement time: 150 ms
- Dimensions: 10 cm x 3.2 cm x 0.7 cm
- Prong length: 5.2 cm
- Cable length: 5 m

Volumetric water content

- Range: Apparent dielectric permittivity (εa): 1 (air) to 80 (water)
- Resolution:
  - 0.1 ε_a (unitless) from 1 to 20,
  - < 0.75 ε_a (unitless) from 20 to 80
  - 0.0008 m^3/ m^3 (0.08% VWC) from 0 to 50% VWC
- Accuracy: ε_a : ±1 ε_a (unitless) from 1 to 40 (soil range), ±15% from 40 to 80 (VWC)

Bulk electrical conductivity

- Range: 0 to 23 dS/m (bulk)
- Resolution: 0.01 dS/m from 0 to 7 dS/m, 0.05 dS/m from 7 to 23 dS/m
- Accuracy: ±10% from 0 to 7 dS/m

Temperature

- Range: −40 to 60 ºC
- Resolution: 0.1 ºC
- Accuracy: ±1 ºC

12.13. Soil temperature and volumetric water content sensor probe (Decagon 5TM)

The Soil temperature and volumetric water content sensor probe (Decagon 5TM) sensor can measure volumetric water content and temperature of soil. The sensor uses an oscillator running at 70 MHz to measure the dielectric permittivity of soil to determine the water content (VWC). A thermistor in thermal contact with the sensor prongs provides the soil temperature.

Figure: Soil temperature and volumetric water content sensor probe (Decagon 5TM)

12.13.1. Specifications

General specifications

- Operating temperature: -40 to 60 ºC
- Dielectric measurement frequency: 70 MHz
- Measurement time: 150 ms
- Dimensions: 10 cm x 3.2 cm x 0.7 cm
- Prong length: 5.2 cm
- Cable length: 5 m

Volumetric water content

- Range: Apparent dielectric permittivity (ε_a): 1 (air) to 80 (water)
- Resolution:
  - 0.1 ε_a (unitless) from 1 to 20,
  - < 0.75 ε_a (unitless) from 20 to 80
  - 0.0008 m^3/ m^3 (0.08% VWC) from 0 to 50% VWC
- Accuracy: ε_a : ±1 εa (unitless) from 1 to 40 (soil range), ±15% from 40 to 80 (VWC)

Temperature

- Range: −40 to 60 ºC
- Resolution: 0.1 ºC
- Accuracy: ±1 ºC

12.14. Soil water potential sensor probe (TEROS 21)

There are 2 basic parameters that describe the state of water in soil: one is soil water content, or the amount of water per unit of soil, and the other is soil water potential, or the energy state of water in the soil. Although water content is useful when trying to describe the water balance of a soil, i.e. how much water is moving in, out, or being stored, water potential is often preferred over water content because it determines how water moves in a soil or from the soil to the plant. In addition, you can use water potential to determine plant availability of water, schedule irrigation, or determine the mechanical stress state of soil.

The Soil water potential sensor probe (Teros 21) measures the water potential and temperature of a wide range of soil and other porous materials without user maintenance and factory calibration. Its extended range makes this sensor ideal for measuring the water potential in natural systems or other drier systems. The added temperature measurements can be used to determine approximate soil water potential in frozen soils.

Figure: Soil water potential sensor probe (Teros 21)

Note: The Meter TEROS 21 was previously named Decagon MPS-6.

12.14.1. Specifications

General specifications

- Operating temperature: -40 to 60 ºC (no water potential measurement below 0 ºC)
- Operation humidity: 0 ~ 100% RH
- Dielectric measurement frequency: 70 MHz
- Measurement time: 150 ms
- Dimensions: 9.6 cm (L) x 3.5 cm (W) x 1.5 cm (D)
- Sensor diameter: 3.2 cm
- Cable length: 5 m

Water potential

- Range: -9 to -2000 kPa*
- Resolution: 0.1 kPa
- Accuracy: ±(10% of reading + 2 kPa) from −9 to −100 kPa

Temperature

- Range: −40 to 60 ºC
- Resolution: 0.1 ºC
- Accuracy: ±1 ºC

** TEROS 21 sensors with serial numbers up to T21-00009999 have a water potential range of −9 to −100,000 kPa.*

12.15. Vapor pressure, temperature, barometric pressure and relative humidity sensor (Decagon VP-4)

The VP-4 sensor probe is an accurate tool to measure air temperature, relative humidity (RH), vapor pressure, and barometric pressure in soil and in air. A microprocessor within the sensor calculates vapor pressure from the RH and temperature measurements. The sensor uses a sensor chip to measure both air temperature and RH and a secondary chip to measure barometric pressure.

Despite this sensor can be installed in dry soils with a good performance, it is not recommended for saturated soils. The humidity measurements could saturate and could give a drift. Moreover, if the soil is completely saturated, it will not make sense to measure barometric pressure because there will not be air in the soil.

Figure: Vapor pressure, humidity, temperature and pressure in soil and air sensor probe (Decagon VP-4)

Figure: VP-4 sensor inside radiation shield

12.15.1. Specifications

General specifications

- Operating temperature: −40 to 80 ºC
- Measurement time: 300 ms
- Dimensions: 1.96 cm (dia) x 5.4 cm (h)
- Cable length: 5 m

Vapor pressure

- Range: 0 to 47 kPa
- Resolution: 0.001 kPa
- Accuracy: see diagram below

Vapor Pressure Accuracy [%RH]

Humidity [%RH]	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C
100%	±0.05	±0.09	±0.16	±0.29	±0.49	±0.81	±1.30	±2.62	±6.32
95%	±0.05	±0.09	±0.14	±0.24	±0.41	±0.68	±1.08	±2.26	±5.27
90%	±0.05	±0.07	±0.09	±0.15	±0.33	±0.54	±1.06	±2.23	±5.20
85%	±0.05	±0.07	±0.08	±0.15	±0.33	±0.53	±1.05	±2.19	±5.13
80%	±0.04	±0.07	±0.08	±0.15	±0.32	±0.53	±0.83	±1.84	±4.07
75%	±0.04	±0.07	±0.08	±0.14	±0.31	±0.52	±0.82	±1.80	±4.00
70%	±0.04	±0.07	±0.08	±0.14	±0.31	±0.51	±0.81	±1.77	±3.97
65%	±0.04	±0.07	±0.08	±0.13	±0.30	±0.50	±0.79	±1.73	±3.86
60%	±0.04	±0.05	±0.07	±0.13	±0.22	±0.36	±0.57	±1.38	±3.30
55%	±0.04	±0.04	±0.07	±0.13	±0.22	±0.35	±0.56	±1.34	±3.23
50%	±0.03	±0.04	±0.07	±0.12	±0.21	±0.34	±0.55	±1.31	±3.16
45%	±0.03	±0.04	±0.07	±0.12	±0.20	±0.33	±0.53	±1.27	±2.60
40%	±0.03	±0.03	±0.07	±0.12	±0.20	±0.33	±0.52	±1.24	±2.53
35%	±0.03	±0.05	±0.06	±0.11	±0.19	±0.32	±0.50	±1.20	±2.46
30%	±0.03	±0.05	±0.06	±0.11	±0.19	±0.31	±0.49	±1.17	±2.39
25%	±0.03	±0.04	±0.06	±0.10	±0.18	±0.30	±0.48	±1.14	±2.32
20%	±0.03	±0.06	±0.06	±0.10	±0.25	±0.41	±0.67	±1.10	±2.25
15%	±0.03	±0.05	±0.05	±0.10	±0.24	±0.40	±0.85	±1.39	±2.67
10%	±0.05	±0.07	±0.08	±0.14	±0.31	±0.52	±0.84	±1.67	±4.08
5%	±0.05	±0.10	±0.12	±0.22	±0.38	±0.64	±1.03	±1.96	±5.00
0%	±0.08	±0.15	±0.12	±0.22	±0.45	±0.75	±1.22	±3.21	±5.92

Temperature [°C]

Figure: Vapor pressure accuracy chart

Temperature

- Range: −40 to 80 ºC
- Resolution: 0.1 ºC
- Equilibration time: < 400 s
- Long term drift: < 0.04 ºC/year typical
- Accuracy: see diagram below

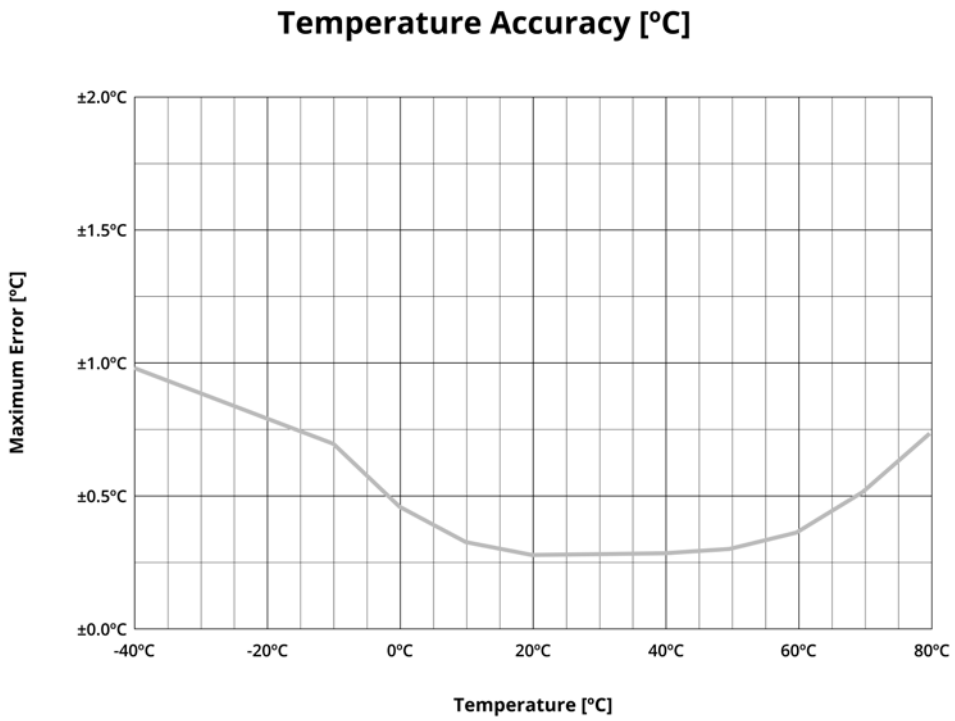


Figure: Temperature accuracy chart

Barometric pressure

- Range: 49 to 109 kPa
- Resolution: 0.01 kPa
- Accuracy: 0.4 kPa

Relative humidity

- Range: 0 to 100% RH
- Resolution: 0.1% RH
- Equilibration time: <40 s
- Hysteresis: <1% RH typical
- Long term drift: <0.5% RH/year typical
- Accuracy: see diagram below

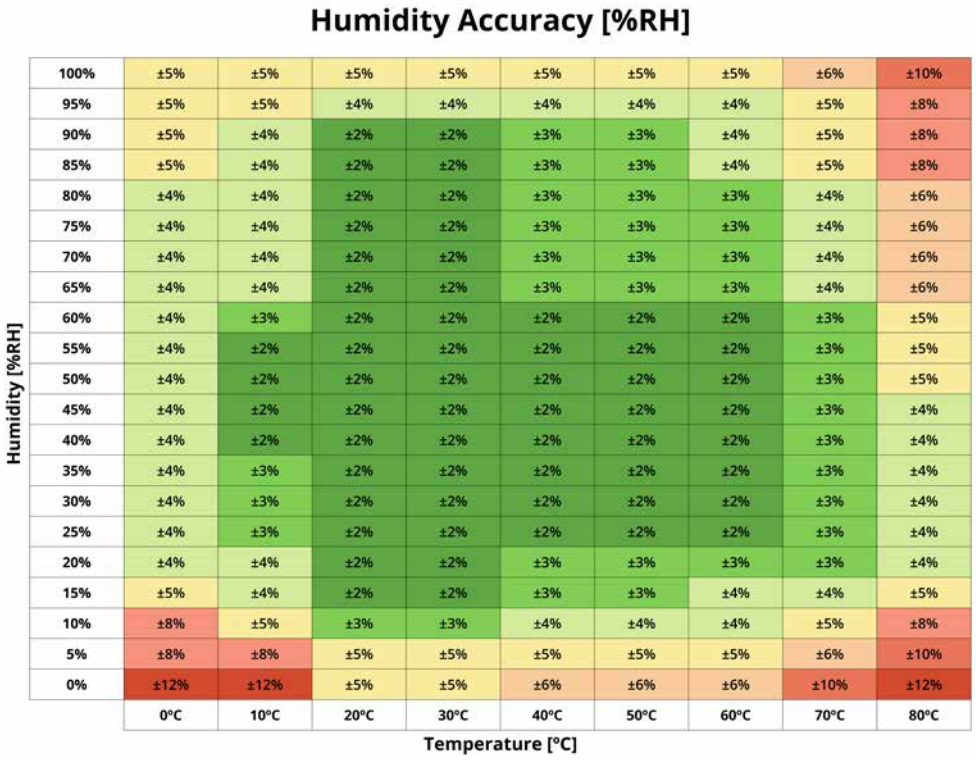


Figure: Humidity accuracy chart

12.16. Leaf wetness Phytos 31 sensor probe (Decagon Phytos 31)

The Leaf wetness Phytos 31 sensor probe (Decagon Phytos 31) measures leaf surface wetness by measuring the dielectric constant of the sensor's upper surface. This sensor has very high resolution, which gives you the ability to detect very small amounts of water (or ice) on the sensor surface. Water on the sensor surface does not need to bridge electrical traces to be detected, as is common with resistance-based surface wetness sensors.

Figure: Leaf wetness Phytos 31 sensor probe (Decagon Phytos-31)

12.16.1. Specifications

- **Operating temperature:** -20 to 60 ºC
- **Measurement time**: 10 ms
- **Probe dimensions**: 11.2 cm x 5.8 cm x .075 cm
- **Cable length**: 5 m

12.17. Dendrometer sensor probes for Smart Agriculture Xtreme (Ecomatik DC3, DD-S and DF)

Dendrometers are highly precise instruments for the continuous measurement of changes in plant diameter (i.e. growth dynamic, diurnal diameter changes). Dendrometer signals document the response of plants to their environment in high temporal resolution.

This type of sensors do not measure the total diameter of the trunk or fruit, but the micro variations in diameter. That is a great tool to study how well the plant grows, absorbs and transpires water, its hydrological stress, possible diseases, etc.

Figure: Dendrometer sensor (Ecomatik DF)

12.17.1. Ecomatik DC3 specifications (Trunk diameter)

- **Operation temperature:** -30 ~ 40 ºC
- **Operation humidity:** 0 ~ 100% RH
- **Trunk/branch diameter:** from 5 cm
- **Accuracy:** ±3.3 µm
- **Temperature coefficient:** <1,4µm/K
- **Linearity:** 0.7%
- **Output range:** 0 ~ 20 kΩ
- **Range of the sensor:** function of the size of the tree:

Tree Diameter (cm)	Measuring range in diameter (mm)
10	16.2
50	11.3
100	9.0

12.17.2. Ecomatik DD-S specifications (Stem diameter)

- **Operation temperature**: -30 ~ 40 ºC
- **Operation humidity**: 0 ~ 100% RH
- **Stem/branch diameter**: 0 ~ 20 cm
- **Range of the sensor**: 11 mm
- **Output range**: 0 ~ 20 kΩ
- **Accuracy**: ±2 µm
- **Temperature coefficient**: <0.1µm/K
- **Cable length**: 2 m

12.17.3. Ecomatik DF specifications (Fruit diameter)

- **Operation temperature**: -30 ~ 40 ºC
- **Operation humidity**: 0 ~ 100% RH
- **Fruit diameter**: 0 ~ 11 cm
- **Range of the sensor**: 11 mm
- **Output range**: 0 ~ 20 kΩ
- **Accuracy**: ±2 µm
- **Temperature coefficient**: <0.1 µm/K
- **Cable length**: 2 m

12.18. Weather station sensor probes (Gill Instruments MaxiMet series)

The Plug & Sense! Smart Agriculture Xtreme model offers the possibility of connecting any of the MaxiMet weather stations provided by Gill Instruments.

The MaxiMet series offers a compact solution for weather forecast. The user can choose easily the best configuration thanks to the modularity that they offer, keeping the robustness, easy installation and low maintenance features. In other words, any of the different weather sensors can be combined in a custom model.

Parameters related with wind, precipitation, solar radiation, dew point, air temperature, air humidity or atmospheric air pressure can be measured with these weather station probes.

In the next subsections, all the available models are described briefly to allow the user selecting the best for each application. However, a feature table is also provided below:

Weather station	Wind and compass	Precipitation	Temperature, relative humidity and pressure	Solar radiation	GPS
GMX-100 (PO)		X (Optical)			
GMX-101 (R)				X	
GMX-200 (W)	X				Optional
GMX-240 (PO-W)	X	X (Optical)			Optional
GMX-300 (T-H-AP)			X		
GMX-301 (T-H-AP-R)			X	X	
GMX-400 (PO-T-H-AP)		X (Optical)	X		
GMX-500 (W-T-H-AP)	X		X		Optional
GMX-501 (W-T-H-AP-R)	X		X	X	Optional
GMX-531 (W-PT-T-H-AP-R)	X	X (Tipping bucket)	X	X	Optional
GMX-541 (W-PO-T-H-AP-R)	X	X (Optical)	X	X	Optional
GMX-550 (W-x-T-H-AP)	X	Optional (Tipping bucket)	X		Optional
GMX-551 (W-x-T-H-AP-R)	X	Optional (Tipping bucket)	X	X	Optional
GMX-600 (W-PO-T-H-AP)	X	X (Optical)	X		Optional

According to Libelium's nomenclature:

- PO: Includes a Precipitation sensor (Optical type)
- PT: Includes a Precipitation sensor (Tipping bucket type)
- x: This item accepts a Precipitation sensor (tipping bucket type), needs to be ordered apart
- W: Includes a Wind sensor
- T-H-AP: Includes air Temperature, air Humidity and Atmospheric air Pressure sensors
- R: Includes a Radiation sensor

As seen, the weather stations capable of metering wind, can accept a GPS accessory (available on demand, needs to be ordered specially).

The precipitation parameter can be measured with 2 different sensors: the optical one and the traditional tipping bucket (Gill's Kalyx rain gauge). The tipping bucket is included by default in the GMX-531, but it needs to be ordered as an accessory for the GMX-550 and GMX-551 (available on demand).

12.18.1. MaxiMet GMX-100 (PO) sensor probe

The MaxiMet GMX-100 sensor probe provides accurate information about precipitation (optical method).

An integrated optical rain gauge that senses water hitting its outside surface provides measurements based on the size and number of drops.

The optical rain gauge has no moving parts so possible mechanical problems are avoided.

Figure: MaxiMet GMX-100 sensor probe

12.18.2. MaxiMet GMX-300 (T-H-AP) sensor probe

The MaxiMet GMX-300 sensor probe provides accurate information about air temperature, air humidity and atmospheric air pressure.

This model is basically a solar shield with no moving parts which allows high performance over large time periods.

Figure: MaxiMet GMX-101 sensor probe

12.18.3. MaxiMet GMX-200 (W) sensor probe

The MaxiMet GMX-200 sensor probe provides accurate information about wind.

Three ultrasonic sensors provide wind speed and direction measurements and the addition of an electronic compass provides apparent wind measurement. Average speed and direction together with WMO averages and gust data are also provided.

In addition, this model has a compass and an optional GPS.

Figure: MaxiMet GMX-200 sensor probe

12.18.4. MaxiMet GMX-240 (W-PO) sensor probe

The MaxiMet GMX-240 is a weather station that provides accurate meteorological information about wind and precipitation (optical method).

Three ultrasonic sensors provide wind speed and direction measurements and the addition of an electronic compass provides apparent wind measurement. Average speed and direction together with WMO averages and gust data are also provided.

An integrated optical rain gauge that senses water hitting its outside surface provides measurements based on the size and number of drops.

The optical rain gauge and the wind ultrasonic sensors have no moving parts so possible mechanical problems are avoided.

Figure: MaxiMet GMX-240 sensor probe

12.18.5. MaxiMet GMX-300 (T-H-AP) sensor probe

The MaxiMet GMX-300 sensor probe provides accurate information about air temperature, air humidity and atmospheric air pressure.

This model is basically a solar shield with no moving parts which allows high performance over large time periods.

Figure: MaxiMet GMX-300 sensor probe

12.18.6. MaxiMet GMX-301 (T-H-AP-R) sensor probe

The MaxiMet GMX-301 sensor probe provides accurate information about air temperature, air humidity, atmospheric air pressure and solar radiation.

This model is basically a solar shield with no moving parts which allows high performance over large time periods. On the top of the solar shield, an integrated pyranometer protected by a single glass measures the solar radiation. In addition, an inclinometer is also included to allow a precise installation.

Figure: MaxiMet GMX-301 sensor probe

12.18.7. MaxiMet GMX-400 (PO-T-H-AP) sensor probe

The MaxiMet GMX-400 sensor probe provides accurate information about precipitation (optical method), air temperature, air humidity and atmospheric air pressure.

This model is basically a solar shield with no moving parts which allows high performance over large time periods. On the top of the solar shield, an integrated optical rain gauge senses water hitting its outside surface, providing measurements based on the size and number of drops.

Figure: MaxiMet GMX-400 sensor probe

12.18.8. MaxiMet GMX-500 (W-T-H-AP) sensor probe

The MaxiMet GMX-500 sensor probe provides accurate information about wind, air temperature, air humidity and atmospheric air pressure.

This model is basically a solar shield with no moving parts which allows high performance over large time periods. On the top of the solar shield, three ultrasonic sensors are placed to provide wind speed and direction measurements. Besides, an electronic compass provides apparent wind measurement. Average speed and direction together with WMO averages and gust data are also provided.

Figure: MaxiMet GMX-500 sensor probe

12.18.9. MaxiMet GMX-501 (W-T-H-AP-R) sensor probe

The MaxiMet GMX-501 sensor probe provides accurate information about wind, air temperature, air humidity, atmospheric air pressure and solar radiation.

This model is basically a solar shield with no moving parts which allows high performance over large time periods. On the top of the solar shield, three ultrasonic sensors are placed to provide wind speed and direction measurements. Besides, an electronic compass provides apparent wind measurement. Average speed and direction together with WMO averages and gust data are also provided. Additionally, an integrated pyranometer protected by a single glass measures the solar radiation. Finally, an inclinometer is also included to allow a precise installation.

Figure: MaxiMet GMX-501 sensor probe

12.18.10. 12.17.10 MaxiMet GMX-531 (W-PT-T-H-AP-R) sensor probe

The MaxiMet GMX-531 sensor probe provides accurate information about wind, precipitation (tipping bucket method), air temperature, air humidity, atmospheric air pressure and solar radiation.

This model is basically a solar shield with no moving parts which allows high performance over large time periods. On the top of the solar shield, three ultrasonic sensors are placed to provide wind speed and direction measurements. Besides, an electronic compass provides apparent wind measurement. Average speed and direction together with WMO averages and gust data are also provided. Additionally, an integrated pyranometer protected by a single glass measures the solar radiation. Finally, an inclinometer is also included to allow a precise installation.

On top of that, a tipping bucket rain gauge is provided to measure precipitation, with excellent performance in tropical or heavy precipitation locations. The Kalyx rain gauge is connected using a 20 m cable.

Figure: MaxiMet GMX-531 sensor probe

12.18.11. MaxiMet GMX-541 (W-PO-T-H-AP-R) sensor probe

The MaxiMet GMX-541 sensor probe provides accurate information about wind, precipitation (optical method), air temperature, air humidity, atmospheric air pressure and solar radiation.

This model is basically a solar shield with no moving parts which allows high performance over large time periods. On the top of the solar shield, three ultrasonic sensors are placed to provide wind speed and direction measurements. Besides, an electronic compass provides apparent wind measurement. Average speed and direction together with WMO averages and gust data are also provided. Additionally, an integrated pyranometer protected by a single glass measures the solar radiation. Finally, an inclinometer is also included to allow a precise installation.

On top of that, an optical gauge is provided to measure precipitation. It senses water hitting its outside surface, providing measurements based on the size and number of drops. The optical rain gauge is connected using a 20 m cable.

Figure: MaxiMet GMX-541 sensor probe

12.18.12. MaxiMet GMX-550 (W-x-T-H-AP) sensor probe

The MaxiMet GMX-550 sensor probe provides accurate information about wind, precipitation (with an accessory), air temperature, air humidity and atmospheric air pressure.

This model is basically a solar shield with no moving parts which allows high performance over large time periods. On the top of the solar shield, three ultrasonic sensors are placed to provide wind speed and direction measurements. Besides, an electronic compass provides apparent wind measurement. Average speed and direction together with WMO averages and gust data are also provided. Finally, an inclinometer is also included to allow a precise installation.

On top of that, an integrated connector allows the user to connect a tipping bucket rain gauge to measure precipitation.

Figure: MaxiMet GMX-550 sensor probe

12.18.13. MaxiMet GMX-551 (W-x-T-H-AP-R) sensor probe

The MaxiMet GMX-551 sensor probe provides accurate information about wind, precipitation (with an accessory), air temperature, air humidity, atmospheric air pressure and solar radiation.

This model is basically a solar shield with no moving parts which allows high performance over large time periods. On the top of the solar shield, three ultrasonic sensors are placed to provide wind speed and direction measurements. Besides, an electronic compass provides apparent wind measurement. Average speed and direction together with WMO averages and gust data are also provided. Additionally, an integrated pyranometer protected by a single glass measures the solar radiation. Finally, an inclinometer is also included to allow a precise installation.

On top of that, an integrated connector allows the user to connect a tipping bucket rain gauge to measure precipitation.

Figure: MaxiMet GMX-551 sensor probe

12.18.14. MaxiMet GMX-600 (W-PO-T-H-AP) sensor probe

The MaxiMet GMX-600 sensor probe provides accurate information about wind, precipitation (optical method), air temperature, air humidity and atmospheric air pressure.

This model is basically a solar shield with no moving parts which allows high performance over large time periods. On the top of the solar shield, three ultrasonic sensors are placed to provide wind speed and direction measurements. Besides, an electronic compass provides apparent wind measurement. Average speed and direction together with WMO averages and gust data are also provided. Moreover, an integrated optical rain gauge senses water hitting its outside surface, providing measurements based on the size and number of drops. Finally, an inclinometer is also included to allow a precise installation.

Figure: MaxiMet GMX-600 sensor probe

12.18.15. Specification for each weather station sensor

General specifications

- Operating temperature: -40 to 70 ºC
- Operation humidity: 0 ~ 100% RH
- Weight (approximate, depends on models): 0.5 kg
- Dimensions (approximate, depends on models): 141 x 209.5 mm
- Protection Class: IP66

Wind speed

- Range: 0.01 m/s to 60 m/s
- Accuracy: ±3% to 40 m/s; ±5% above 40 and up to 60 m/s
- Resolution: 0.01 m/s
- Threshold: 0.01 m/s

Wind direction

- Range: 0-359º
- Accuracy: ±3º to 40 m/s; ±5º above 40 and up to 60 m/s
- Resolution: 1º
- Starting threshold: 0.05 m/s

Compass

- Range: 0-359º
- Accuracy: ±3º
- Resolution: 1º

Precipitation: optical method

- Range: 0 to 300 mm/h
- Precipitation resolution: 0.2 mm
- Repeatability: 3%

Precipitation: mechanical, tipping bucket method (Kalyx rain gauge)

- Range: 0-1000 mm/hr
- Precipitation resolution: 0.2 mm
- Accuracy: 2%

Air temperature and dew point

- Range: -40 °C to +70 °C
- Resolution: 0.1 °C
- Accuracy: ± 0.3 °C @ 20 °C

Air humidity

- Range: 0 - 100%
- Resolution: 1%
- Accuracy: ± 2% @ 20 °C (10%-90% RH)

Atmospheric air pressure

- Range: 300 to 1100 hPa
- Resolution: 0.1 hPa
- Accuracy: ± 0.5 hPa @ 25 °C

Global solar radiation

- Wavelength sensitivity: 300 to 3000 nm
- Range: 0 to 1600 W/m2
- Resolution: 1 W/m2
- DIN standard: ISO 9060 Second Class

12.19. Solar radiation and temperature Datasol MET probe (Atersa Datasol MET)

The Datasol MET is a precision device that allows to visualize and acquire solar radiation, peak sun hours (PSH), temperature of the cell and the ambient temperature. The radiation measurement of the Datasol MET incorporates compensation with the temperature of the cell.

This sensor is especially focused on owners of a photovoltaic system looking for maximum performance.

Figure: Solar radiation and temperature Datasol MET probe

12.19.1. Specifications

General specifications

- **Operating temperature:** -20 to 50 ºC
- **Weight:** 1.2 kg
- **Dimensions:** 266 x 266 x 35 mm
- **Protection Class:** IP54

Temperature

- **Range:** -20 °C to +100 °C
- **Accuracy:** ±0.8 °C

Radiation

- **Range:** 0 to 1400W/m2
- **Intrinsic measurement error:** ±0.2%
- **CIEMAT reference standard measurement error:** ±2%
- **Maximum relative error:** ±2.2%

12.20. Luminosity sensor (AMS TSL2561)

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.

Figure: Luminosity sensor probe (AMS TSL2561)

12.20.1. Specifications

- **Operating temperature:** -30 ºC to +80 ºC
- **Dynamic range**: 0.1 to 40000 Lux
- **Spectral range**: 300 – 1100 nm
- **Usage**: Indoors and outdoors

Figure: Luminosity sensor graphic

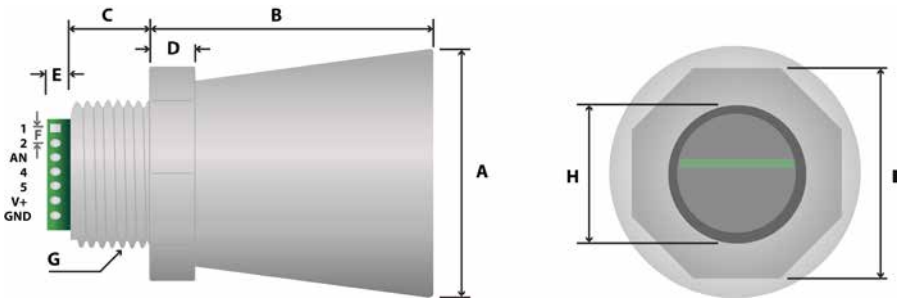
12.21. Ultrasound sensor probe (Maxbotix MB7040)

The Ultrasound sensor probe (MaxBotix MB7040) has high acoustic power output along with real-time auto calibration for changing conditions (voltage and acoustic or electrical noise) that ensure users receive the most reliable ranging data for every reading taken in air.

Figure: Ultrasound sensor (Maxbotix MB7040)

12.21.1. Specifications

- Operation frequency: 42 kHz
- Maximum detection distance: 765 cm
- 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: Ultrasound sensor dimensions

13. Ambient Control

13.1. General description

This model is designed to monitor the main environment parameters easily. Only three sensor probes are allowed for this model, as shown in next table.

Figure: Ambient Control Waspmote Plug & Sense! model

Sensor sockets are configured as it is shown in figure below.

Sensor Socket	Sensor probes allowed for each sensor socket	
	Parameter	**Reference**
A	Humidity + Temperature (Sensirion)	9247-P
B	Luminosity (LDR)	9205-P
C	Luminosity (Luxes accuracy)	9325-P
D, E and F	Not used	-

Figure: Sensor sockets configuration for Ambient Control model

As we see in the figure below, thanks to the directional probe, the Luminosity (Luxes accuracy) sensor probe may be placed in different positions. The sensor can be focused directly to the light source we want to measure.

Figure: Configurations of the Luminosity sensor probe (luxes accuracy)

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

13.2. Temperature, Humidity and Pressure Sensor Probe

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

Specifications

Figure: Image of the Temperature, Humidity and Pressure Sensor Probe

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

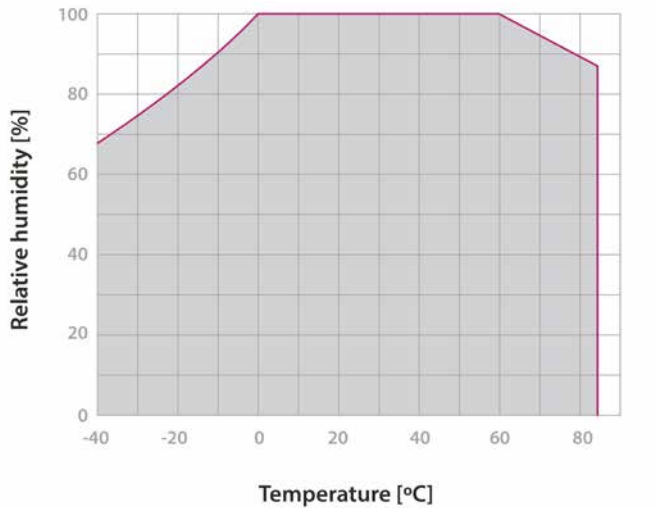


Figure: Humidity sensor operating range

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

13.3. Luminosity (LDR) sensor probe

Sensor specifications (LDR)

Resistance in darkness: 20 MΩ
Resistance in light (10lux): 5 ~ 20 kΩ
Spectral range: 400 ~ 700 nm
Operating temperature: -30 ºC ~ +75 ºC

Figure: Image of the Luminosity sensor probe (LDR)

This is a resistive sensor whose conductivity varies depending on the intensity of light received on its photosensitive part. The measurable spectral range (400 nm – 700 nm) coincides with the human visible spectrum so it can be used to detect light/darkness in the same way that a human eye would detect it.

Note: *The Luminosity sensor probe used in Ambient Control is different from the probe used in the other Plug & Sense! Applications, so they are not interchangeable.*

13.4. Luminosity sensor probe (Luxes accuracy)

Sensor specifications (Luxes accuracy)

Dynamic range: 0.1 to 40000 Lux
Spectral range: 300 – 1100 nm
Voltage range: 2.7 – 3.6V
Operating temperature: -30ºC to +80ºC
Typical consumption: 0.24mA
Maximum consumption: 0.6mA
Usage: Indoors and outdoors

Figure: Image of the Luminosity sensor probe (Luxes accuracy)

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.

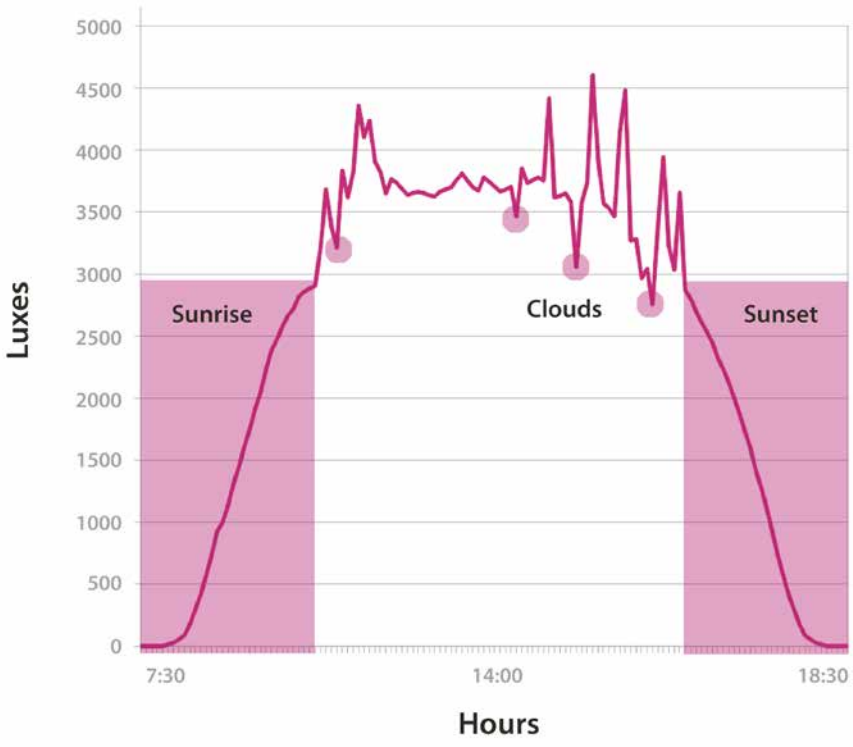


Figure: Image of the Luminosity sensor probe (Luxes accuracy)

Figure: Image of configurations of the Luminosity sensor probe (Luxes accuracy)

As we see in the figure, the luminosity sensor probe may be placed in different positions. The sensor can be focused directly to the light source we want to measure.

If you want to focused it directly to the light source, be sure that it (the sun, a spotlight...) emits less light than the maximum value allowed by the sensor. If we try to measure a higher value the sensor will saturate.

13.5. Comparative between Light and Luminosity sensor

As it is shown in the graph below, the Luminosity sensor probe (LDR) can measure the presence of a light source below or above a certain threshold. Different from the Luminosity sensor probe (Luxes accuracy) that can measure the exact quantity of the light in luxes. It allows us to appreciate different values along the time.

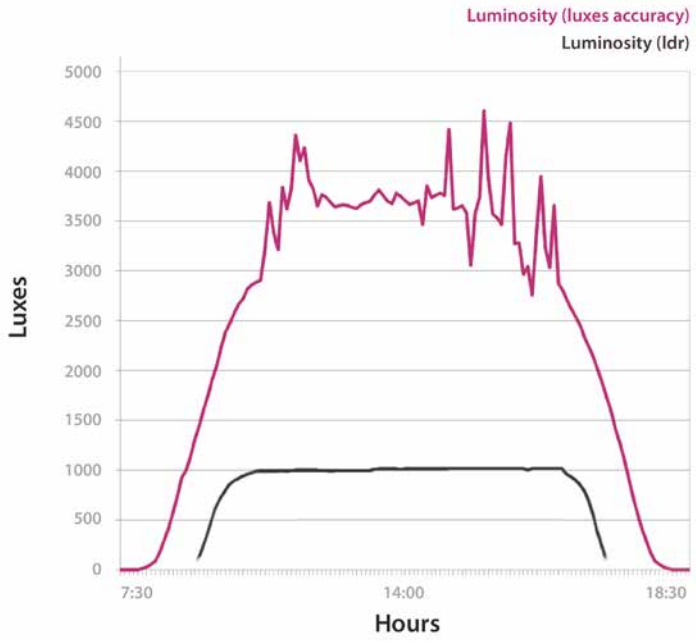


Figure: Comparison of the responses of the Luminosity sensor probe (Luxes accuracy) and the Luminosity sensor probe (LDR)

14. 4-20 mA Current Loop

The applications for this Plug & Sense! model are focused on adding wireless connectivity to 4-20 mA devices and connecting them to the Cloud.

Figure: 4-20 mA Current Loop Waspmote Plug & Sense! model

Sensor sockets are configured as shown in the figure below.

Sensor Socket	Sensor probes allowed for each sensor socket	
	Board channel	**Reference**
A	Channel 1 (type 2 and type 3)	9270-P, DB9-P
B	Channel 2 (type 2 and type 3)	9270-P, DB9-P
C	Channel 3 (type 2 and type 3)	9270-P, DB9-P
D	Channel 4 (type 4)	9270-P, DB9-P

Figure: Sensor sockets configuration for 4-20 mA Current Loop model

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

14.1. Terminal box probe

To provide access to the 4-20 mA current loop board signals on the Waspmote Plug & Sense! encapsulated line, a waterproof terminal block junction box is available as a probe, making the connections on industrial environments or outdoor applications easier.

It consists of 2 cable glands and 6 terminal block connectors with screw. The junction box can be easily opened by removing the four external screws and the cover. Then, the user is able to make the necessary connections using the terminal block connectors. Finally, the cable glands should be adjusted and the junction box should be closed properly to avoid water ingress.

Figure: Terminal box probe

Note: Please double check the terminal block connections to avoid wrong wirings or short circuits between poles. The Waspmote Plug & Sense! Unit can be seriously damaged. Besides, ensure that the junction box is properly closed to avoid damaged in outdoor applications. Libelium warranty will not cover damages caused by a wrong installation.

14.2. DB9 probe

The DB9 connector is commonly used in many applications with data transmission on industrial ambients. Libelium provides this probe with a standard DB9 female connector and a length of 1.5 meters.

Figure: DB9 probe

15. Documentation changelog

From v8.1 to v8.2

- Added references to the new Radar level VEGAPULS C21 sensor probe
- Renamed the MPS-6 sensor probe to TEROS 21 sensor probe

From v8.0 to v8.1

- Added references to the new TEROS 11 sensor probe
- Added references to the new TEROS 12 sensor probe
- Added references to the new Total coliform bacteria, TLF, turbidity and temperature Proteus sensor probe
- Added references to the new StacSense sensor probe
- Added references to the new sensors for the Manta probe: Rhodamine, Crude Oil, Refined Oil, Fluorescein, Tryptophan, Optical Brighteners, Bromide and Total Dissolved Gas (TGD)
- Deleted references to the discontinued Radiation Control model

From v7.9 to v8.0

- Updated info for the DC3 dendrometer sensor, evolution of the discontinued DC2

From v7.8 to v7.9

- Added changes related to the new version of Smart Parking
- Deleted references to the discontinued H2, HCl, HCN, PH3, ETO and Cl2 sensors for Gases PRO and Smart Cities PRO

From v7.7 to v7.8

- Added changes related to the new version of Smart Parking
- Deleted references to the discontinued H2, HCl, HCN, PH3, ETO and Cl2 sensors for Gases PRO and Smart Cities PRO

From 7.6 to v7.7

- Added section for the new Solar radiation and temperature Datasol MET probe

From v7.5 to v7.6

- Added references to the new OPC-N3 sensor (OPC-N2 evolution)
- Deleted references to the discontinued Calcium (Ca2+) sensor probe for the Single model of Smart Water Ions
- Deleted references to the discontinued Carbon Monoxide (CO) for high concentrations sensor probe

From v7.4 to v7.5

- Added chapter for the new Smart Water Xtreme line
- Added 13 new Gill weather stations

From v7.3 to v7.4

- Added chapter for the new Smart Agriculture Xtreme line

- The length of the Pt-1000 sensor probe cable was updated

From v7.2 to v7.3

- The lengths of the cables of the sensors of Smart Water and Smart Water Ions were updated

From v7.1 to v7.2

- Added notes to discontinued sensors probes in Smart Environment PRO
- Added references to new sensor probes for Smart Environment PRO and Smart Cities PRO
- Updated information for the Ozone (O3) Gas Sensor Probe [Calibrated]
- Errata correction for the PAR and Ultraviolet sensor probes
- Added info about the Smart Water Ions PRO line

From v7.0 to v7.1:

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

16. 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