FDO2

Optical Oxygen Sensor

DATA SHEET

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The FDO2 is released by:

PyroScience GmbH
Hubertusstrasse 35
52064 Aachen
Germany

Phone	+49 (0)241 5183 2210
Fax	+49 (0)241 5183 2299
Email	info@pyroscience.com
Web	www.pyroscience.com

Registered: Aachen HRB 17329, Germany

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1 INTRODUCTION

The **FDO2** is an optical oxygen sensor for gas measurements based on luminescence quenching of a sensor dye. The dye is excited with red light, and the properties of the resulting luminescence are measured in the near infrared. The presence of molecular oxygen quenches the luminescence, changing its intensity and lifetime fully reversibly.

This principle is very robust. It shows virtually no interferences to other gases, has a very low drift, and the sensor is fully solid-state. It does not deplete over time, unlike galvanic oxygen sensors with their limited shelf life. Optics and electronics are hermetically sealed from the measured gas.

The sensor has a factory calibration that is sufficient for typical applications throughout the lifetime of the sensor. The **FDO2** features build in temperature compensation and a digital interface that provides oxygen partial pressure values. No additional signal conditioning is necessary. A mounting thread and a robust locking connector allow easy installation.

Features

- High-accuracy measurement
- Low drift
- Factory calibrated
- Long life
- Fast response ($t_{63}<2s$)
- Digital output of oxygen partial pressure
- Temperature compensation
- Low power consumption
- Lead free, ROHS compliant

Potential Applications

- Incubators
- Oxygen concentrators
- Inert gas processing chambers (glove boxes)
- Exhaust gas measurement
- Inert gas monitoring
- Portable equipment
- Monitoring fruit ripening and transport

2 SPECIFICATIONS

Analytical Performance

Measuring range Typical Maximum	in units of hPa 0-1000 hPa 0-2000 hPa	in units of %O2 * 0-100% O2 (gas)
Accuracy** @ 10°C – 40°C	±0.2 hPa at 10 hPa ±5 hPa at 200 hPa ±20 hPa at 1000 hPa	±0.02% O_2 at 1% O_2 ± 0.5% O_2 at 20% O_2 ± 2% O_2 at 100% O_2
Accuracy** @ -10°C – 60°C	±1 hPa at 10 hPa ±10 hPa at 200 hPa	±0.1% O_2 at 1% O_2 ± 1% O_2 at 20% O_2
Resolution	±0.1 hPa at 10 hPa ±1 hPa at 200 hPa ±5 hPa at 1000 hPa	±0.01% O_2 at 1% O_2 ±0.1% O_2 at 20% O_2 ±0.5% O_2 at 100% O_2
Detection limit	0.1 hPa	0.01% O_2
Response time (t_{63})	< 2 sec.	
Drift @ 25°C	typ. <1% O_2 / year at 20% O_2 *	
Minimum lifetime	>50,000,000 measurements	
Storage life	>5 years in darkness at 20°C	
Warm-up time	3 min (reduced accuracy during warm-up)	
Internal atmospheric pressure sensor measurement range	300 – 1100 mbar (measured through the venting capillary at the backside of the housing)	

* at 1013 mbar ambient gas pressure. Note, the FDO2 outputs oxygen partial pressure (hPa), the unit %O2 is given here only for convenience. If the air pressure at the oxygen sensing membrane is identical to the air pressure at the venting capillary on the backside of the housing, then the measurement of the internal pressure sensor can be used for converting the oxygen partial pressure (hPa) into units of %O2.

** given for factory calibration

Environment

Temperature range during operation	-10 to 60°C
Temperature range during storage	-40°C to 60°C
	Note: Exposure to temperatures >60°C might lead to increased drift of the oxygen measurement within the next weeks.
Humidity	Backside: Non-condensing Sensing Membrane: Dew point must not be within the membrane
Maximum absolute pressure	20 bar
Maximum differential pressure	3 bar

Interface

Supply Voltage	3.3 – 5.0 V DC
Standby / Peak Currents	ca. 8 mA / 40 mA ***
Energy Consumption per Measurement	ca. 1-2 mAs
Communication Interface	3.0 V UART (5 V tolerant)
Connector	Molex 560020-0420

*** in rush currents after power up can be higher

Mechanical

Dimensions	Ø 28,5 mm x 28 mm
Weight	10,5 g
Mounting Thread	M16 x 1
Housing Material	Polycarbonate
Conformity to RoHS directive	RoHS compliant, lead free

3 CROSS-SENSITIVITY AND CHEMICAL COMPATIBILITY

Due to the optical measurement principle, the **FDO2** has minimal cross sensitivity to other gases, unlike galvanic oxygen sensors. However, it is cross-sensitive to chlorine gas (Cl_2) and nitrogen dioxide (NO_2).

Exposure of the sensor to organic solvent vapors or other volatile organic compounds (e.g. acetone, outgassing from adhesives or paints), or elevated temperatures, should be avoided since it can result in erroneous oxygen readings and enhanced drift. Please contact PyroScience for more information.

4 COMMUNICATION INTERFACE

The communication interface is a standard UART (3.0V levels, 5V tolerant). The default settings of the UART after power-up are:

- 19200 Baud Rate, 8 Data Bits, 1 Stop Bit, no Parity, no Handshake

The module needs ca. 1 sec. power up time before it responds to commands. If the module comes with an USB-adapter-cable, the "Simple FDO2 Logger" software (for PC with operation system "Windows") installs automatically a virtual serial port driver (COM-port), which is directly connected to the internal UART interface of the module. The virtual COM-port can be accessed by standard COM-port libraries in any programming language under Windows.

4.1 General Definitions

Every command sent from the "master" to the device must be terminated by a single carriage return (0x0D), or by a carriage return followed by a line feed (0x0D, 0x0A). This termination is indicated in the following by the symbol "↵". Values (numbers) are separated with spaces from each other and the command header. The command header is a unique string of characters. If the command with all values could be successfully interpreted by the device, the command is echoed **after completion of the requested task**, appended with requested values and terminated by **a single carriage return (0x0D) only**. Otherwise, the response begins with an error header followed by an error code. Italic letters represent placeholders for numbers, which are transmitted as ASCII-Strings (human readable). **The absolute maximum range of all values transmitted in the communication protocol is from -2147483648 to +2147483647**. The only exception is the command #IDNR which can return higher values.

4.2 Detecting communication errors and optional CRC

The protocol supports two levels of communication error handling. The first level is realized simply by the fact, that the device always echoes the complete command as it was received from the master. This way the master can compare the echo with the originally sent command. If there is a difference, then the master should send the command again.

However, the echoing of the command does not allow detecting potential communication errors within the returned values added by the device to the original command. For this purpose, it is possible to enable a cyclic redundancy check (CRC) based on the CRC16 definition as used for MODBUS protocols (CRC-16-IBM). The CRC is enabled by the command #CRCE (see below). Now every answer from the device to the master is terminated by the string ":␣*C*↵" where *C* is the CRC16 checksum represented as a decimal ASCII-string (human readable). The CRC is calculated for all ASCII-characters (unsigned bytes) from the very beginning of the returned string until the character just before the ":" proceeding the CRC16 checksum. Please note, that also spaces (ASCII code 32) are included in the CRC calculation.

The reminder of this document shows only examples with **disabled** CRC. So, the returned string from the device is only terminated by "↵", i.e. a single carriage return (0x0D).

4.3 Commands

Read Device Information:	#VERS ↵
Response	#VERS *D N R S* ↵

Returns general information about the device: *D* represents the device id, which is always *D*=8 for any **FDO2** module, *N* returns the number of oxygen channels which is *N*=1 for the **FDO2** module. *R* represents the firmware revision (e.g. *R*=328 designates firmware revision 3.28). *S* is a byte number indicating which sensor types are available. The bits refer to the following sensor types: bit 0: oxygen, bit 1: temperature within housing, bit 2: pressure within housing, bit 3: relative humidity within housing. If *S*=15 (default) then the module is equipped with all these sensor types.

Read Unique ID Number:	#IDNR ↵
Response	#IDNR *N* ↵

Returns an identification number *N* being unique for each single device, which is an unsigned 64 bit integer. Therefore, the decimal ASCII representation of this number can be up to 20 chars in length. Please note, that the unique ID number is not equivalent to the serial number off the device.

Measure Oxygen and return the results:	#MOXY ↵
Response	#MOXY *O T S* ↵

Measures (1) the temperature, (2) the oxygen partial pressure (pO2), (3) the total pressure + humidity WITHIN the sensor housing, (4) ambient light and returns the results:

O: Oxygen partial pressure, signed 32 bit integer in units of 10^{-3} hPa
(O = 203456 corresponds to 203.456 hPa, typ. range 0-210 hPa)

T: Temperature, signed 32 bit integer in units of m°C
(T = 17892 corresponds to 17.892°C
T = -1965 corresponds to -1.965°C, typ. range 0 – 50°C)

S: Status (unsigned 32 bit integer) with warning and error bits, where bit(x)=1 means:
bit(0): WARNING, the detector amplification was automatically reduced in order to avoid saturation of the detector. The oxygen reading is still valid. This might happen at low temperatures together with low oxygen values causing high luminescent intensities of the oxygen indicator. Or the sensor might be exposed to excessive ambient light (e.g. sun light).
bit(1): FATAL ERROR, oxygen sensor signal intensity too low (<20mV)
bit(2): FATAL ERROR, oxygen sensor signal or ambient light too high
bit(3): FATAL ERROR, oxygen reference signal intensity too low (<20mV)
bit(4): FATAL ERROR, oxygen reference signal or ambient light too high (>2400mV)
bit(5): FATAL ERROR, failure of the temperature sensor
bit(6): reserved
bit(7): WARNING, the humidity within the sensor housing is >90%RH. This might lead to fatal electronic problems and therefore to a failure of the oxygen measurement.
bit(8): reserved
bit(9): ERROR, failure of the pressure sensor within the sensor housing, this has no direct influence on the measured oxygen partial pressure
bit(10): ERROR, failure of the humidity sensor within the sensor housing, this has no direct influence on the measured oxygen partial pressure

IMPORTANT: Under normal operation the status should be always S=0 or S=1 . In all other cases the oxygen (O) and the temperature (T) readings are or can be faulty, although this command is still returning values for O and T. It is on the users authority to check the status for each single measurement, in order to detect a faulty sensor operation. Especially the error bits marked with „FATAL ERROR“ will lead to incorrect oxygen readings.

Measure Partial Pressure Oxygen and Return Additional Raw Data: #MRAW ↲

Response #MRAW *O T S D I A P H* ↲

Measures (1) the temperature, (2) the oxygen partial pressure (pO2), (3) the total pressure + humidity WITHIN the sensor housing, (4) ambient light and returns the results including raw data:

O: refer to the command #MOXY
T: refer to the command #MOXY
S: refer to the command #MOXY
D: the phase shift „dphi“, signed 32 bit integer in units of m° (millidegrees)
(e.g. D = 24385 corresponds to 24.385°, typ. range 5°-60°)
I: the signal intensity of the oxygen sensor, signed 32 bit integer in units of µV
(e.g. I = 124072 corresponds to 123.072 mV, typ. range 100-500mV)
A: the ambient light entering the sensor, signed 32 bit integer in units of µV
(e.g. A = 12792 corresponds to 12.792 mV, typ. range 0 - ca. 100mV)
P: the ambient pressure at the BACKSIDE of the module, signed 32 bit integer in units of µbar
(e.g. P = 999734 corresponds to 999.734 mbar, typ. range 900-1100mbar)
H: the relative humidity inside the housing in units of m%RH
(e.g. H = 40365 corresponds to 40.365 %RH, typ. range 10-90%RH)

dphi (D). The fundamental raw data of the oxygen measurement is the phase shift „dphi“ (D) which is together with the temperature (T) internally converted into the oxygen reading (O).

Signal intensity (I). This represents the measured luminescent intensity of the oxygen sensor. The signal intensity can be used for checking the quality of the sensor. Please note, that the signal intensity is highly dependent on the actual oxygen level. Therefore, measured signal intensities can be only compared with each other, if they have been measured at similar oxygen levels. Typical signal intensities are 200-400 mV at oxygen levels of ca. 200 hPa at room temperature.

Ambient light (A). Immediately before each oxygen measurement, the device measures also the ambient light entering the oxygen detector. Considerable amounts of ambient light might enter the optoelectronics, if the sensor is exposed e.g. to direct sun light. This might lead to a saturation of the optical detector and to an invalid oxygen measurement (see parameter Status S). As a thumb of rule the sum of ambient light (A) and signal intensity (I) should not exceed ca. 2000 mV. If it exceeds this value, the sensor must be shaded from the external light source.

Ambient pressure (P). This gives the ambient air pressure measured at the BACKSIDE of the housing (i.e. the side where the electrical connector is positioned).

Relative humidity (H). The relative humidity measured inside the housing including the optoelectronics. The inner volume of the housing is connected via a thin channel to the BACKSIDE of the housing (connector side). Therefore, the humidity will be in the long run influenced by the humidity present at the BACKSIDE of the housing. A rel. humidity > 90% will lead to a warning in the status (S).

Indicate Logo: #LOGO ↵

Response #LOGO ↵

The status LED of the device flashes 4 times (total duration ca. 1 second). This command can be used to identify which device belongs to which interface port, if several devices are operated in parallel.

Enable or disable CRC checksum: Note WARNING below! * `#CRCE K ↵`

Response `#CRCE K ↵`

K = 0: Disable the CRC checksum (default)
K = 1: Enable the CRC checksum
The current status is automatically saved in the flash memory, so the status is persistent even after a power cycle.

Read User Memory: `#RDUM R N ↵`

Response `#RDUM R N Y1 … YN ↵`

The device offers a user memory of altogether 64 signed 32bit integer numbers (range -2147483648 to 2147483647) which is located in the flash memory and is therefore retained even after power cycles. This read command returns *N* (*N*=1…64) consecutive values Y_1 … Y_N from the user memory starting at the user memory address *R* (*R*=0…63). Note, that *N*+*R* must be <=64.

Write User Memory: `#WRUM R N Y1 … YN ↵`

Response `#WRUM R N Y1 … YN ↵`

This command writes the *N* (*N*=1…64) values Y_1 … Y_N consecutively starting at the user memory address *R* (*R*=0…63). Note, that *N*+*R* must be <=64.
IMPORTANT: This command must be used economically, because the flash memory is designed for typ. max. 20000 flash cycles. Each time this command is executed, it will trigger a flash cycle.

Set Baud Rate: `#BAUD R ↵`

Response `#BAUD R ↵`

Changes the current baud rate of the UART interface to R. Supported baud rates are 1200, 2400, 4800, 9600, 14400, *19200*, 28800, 38400, 56000, 57600, 115200. The default baud rate after a power cycle is always 19200. If the command was successfully interpreted, the response string is sent back by using the old baud rate and afterwards the baud rate is changed. For highest reliability it is recommended to use the default baud rate of 19200.

Calibrate Oxygen Sensor at 0% oxygen: Note WARNING below! * `#CALO ↵`

Response `#CALO ↵`

Execution of this command will result in a loss of the factory calibration!
Calibrates the oxygen sensor at 0% oxygen, giving the lower calibration point of a two-point oxygen calibration. The sensor should be measuring (with the application specific sample interval) for at least 5 min. under steady state conditions, before this command is executed. This command needs up to 10 seconds for completion, before the response is returned. The new calibration is automatically stored in the flash memory and kept even after a power cycle.
Note: This command might be locked (disabled) for specific customer versions. In this case this commands returns the error code "#ERR -12".

Calibrate Oxygen Sensor at given partial pressure oxygen: Note WARNING below! * #CAHI *P* ↲

Response #CAHI *P* ↲

Execution of this command will result in a loss of the factory calibration!
P: Oxygen partial pressure in the given calibration standard, signed 32 bit integer in units of 10^{-3} hPa (P = 203456 corresponds to 203.456 hPa)
Calibrates the oxygen sensor at a given calibration standard (not equal 0% oxygen!), giving the upper calibration point of a two-point oxygen calibration. The sensor should be measuring (with the application specific sample interval) for at least 5 min. under steady state conditions, before this command is executed. This command needs up to 10 seconds for completion, before the response is returned. The new calibration is automatically stored in the flash memory and kept even after a power cycle.
Note: This command might be locked (disabled) for specific customer versions. In this case this commands returns the error code "#ERR -12".

Enable/Disable Broadcast Mode: Note WARNING below! * #BCST *T* ↲

Response #BCST *T* ↲

Enables or disables the broadcast mode, and stores the actual status always in the flash memory, so the actual status is persistent even after a power cycle.
T = 0: Broadcast mode is disabled (default).
T = 100..10000: Broadcast mode is enabled with the time interval of T ms. So time intervals between 0.1s and 10s are possible. In broadcast mode the modules triggers itself periodic measurements and returns the results via the UART interface as given by the answer string of the #MRAW command. Note, that the time interval is only an approximated value, as the duration of the actual oxygen measurement and the transmission of the UART response must be added to this interval.

* WARNING:

The commands #CALO, #CAHI, #CRCE, and #BCST automatically trigger that the internal configuration and calibration registers of the FDO2 are saved into its internal flash memory (“flash cycle”), in order to make the changes persistent even after power cycles. Note, the FDO2 supports max. ca. 20,000 flash cycles triggered by these commands. If the power supply is interrupted during a flash cycle, then the FDO2 flash memory might be corrupted. There would be no reasonable oxygen readings anymore, which cannot be repaired by consecutive calibration attempts.

SAFETY MEASURES

• Use the commands #CALO, #CAHI, #CRCE, and #BCST economically, i.e. do not use them more frequently than really needed.

• Ensure a stable power supply when executing these commands.

• Always evaluate the response sent back by these commands. After these commands have been executed, the FDO2 will send back the identical command string as an acknowledgement. If you do not receive this answer, the flash memory might be corrupted.

4.4 Error Codes

If a command triggered an internal error or could not be interpreted correctly an error string is sent back instead of the default echo. An error string always begins with the error header followed by an error number and a carriage return termination.

#ERRO *E* ↵

Table 1: Error Codes

E	*Error Type*	Description
-1	*General*	A non-specific error occurred.
-2	*Channel*	The requested channel does not exist.
-11	*Register Access*	Register access violation either caused by a not existing requested register, or by an out of range address of the requested value.
-12	*Register Lock*	The requested command or register is locked.
-13	*Register Flash*	An error occurred while saving the registers permanently in the flash memory of the device.
-14	*Register Erase*	An error occurred while erasing the flash memory region for the registers.
-15	*Register Inconsistent*	The registers in the RAM memory are inconsistent with the permanently stored registers in the flash memory of the device.
-21	*UART Parse*	An error occurred while parsing the command string. The last command should be repeated. Check the command syntax!
-22	*UART Rx*	The command string was not received correctly (e.g. device was not ready, last command was not terminated correctly). Repeat the last command.
-23	*UART Header*	The command header could not be interpreted correctly (must contain only characters from A-Z). Repeat the last command.
-24	*UART Overflow*	The command string could not be processed fast enough to prevent an overflow of the internal receiving buffer. In principle the command length is not limited as it is processed on the fly, however, it can happen that the device is too slow to processing the command. Requests shorter than 64 characters should never cause overflow errors.
-25	*UART Baudrate*	The requested baudrate is not supported. No baudrate change took place.
-26	*UART Request*	The command header does not match any of the supported requests.

-27	*UART Start Rx*	The device was waiting for incoming data, however, the next event was not triggered by receiving a command.
-30	*I2C SPI Transfer*	There was an error transferring data on the internal I2C or SPI bus.
-40	*Temp Sensor*	The internal communication with the temperature sensor was not successful.
-41	*Periphery No Power*	The requested periphery (e.g. oxygen or temperature sensor) was not powered up.
-42	*Power Up Lock*	The device is locked by the powerUpLock. The requested command is not executed until the device is unlocked.

5 CHANGES IN THE FIRMWARE REVISIONS

Changes in firmware revision 3.41

- New feature “broadcast mode” was added. New register #10 in the settings registers.
- New command #BCST for enabling or disabling the broadcast mode.
- The status of the command #CRCE is now automatically stored in the flash memory and is therefore persistent even after a power cycle. This way the checksum functionality can be enabled permanently and used also during the broadcast mode.

Changes in firmware revision 3.30 - 3.40

- There are no changes in the command interface between revision 3.40 and 3.30.

Changes in firmware revision 3.29

- the results.status register got a new warning bit. If bit(0) is set to 1, this indicates that an automatic amplification reduction was activated. This might happen at low temperatures together with low oxygen values causing high luminescent intensities of the oxygen indicator. Or the sensor might be exposed to excessive ambient light (e.g. sun light).
  In earlier firmware versions the error bit(2) (=FATAL ERROR) was set in this case. This was misleading, because an activated automatic amplification reduction is not a fatal error, the oxygen reading is still valid.

Changes in firmware revision 3.28

- the commands #RDUM and #WRUM were added for reading and writing a new user flash memory region comprising 64 signed 32bit integers
- the last status of the command #CRCE is not anymore automatically stored in the flash memory.

Changes in firmware revision 3.27

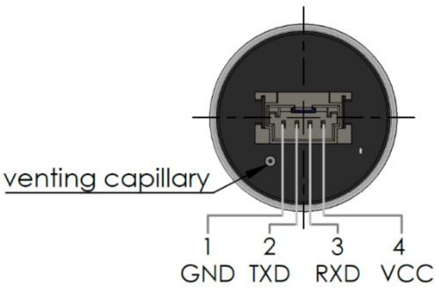
- the command MMM was removed again
- new commands #MOXY, #MRAW, #CALO, #CAHI, #CRCE

Changes in firmware revision 3.26

- new command MMM was added, efficient command for triggering measurements of all sensors and reading out all results
- the register Results.status got an additional warning bit for indicating high humidity levels (>90%RH) within the optoelectronics

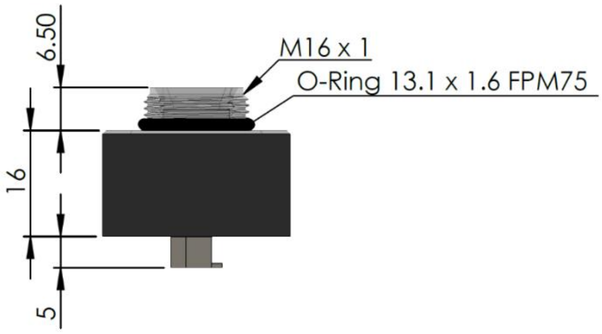
- the register Results.status got additional error bits for indicating a failure of the sensor for “pressure”, “humidity”, “internal (case) temperature”, and “sample (external) temperature”

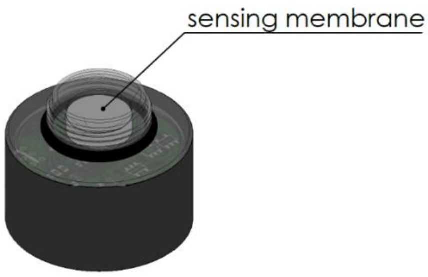
6 MECHANICAL DIMENSIONS AND ELECTRICAL INTERFACE

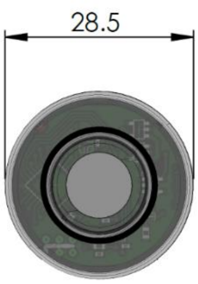


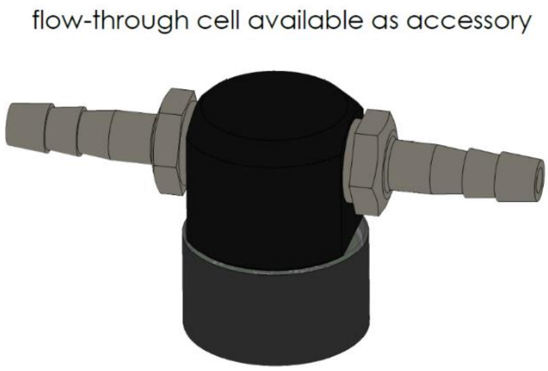
Pin	Name	Function	Description
1	GND	Power	Ground
2	TXD	Digital output 3.0 V levels	Data transmission line of the UART interface
3	RXD	Digital input 3.0 V levels (3.3 V & 5 V tolerant)	Data receive line of the UART interface
4	VCC	Power	Power supply min. 3.3 VDC max. 5.0 VDC

Connector: Molex 560020-0420









All units given in millimeter (mm).

7 WARNINGS

Do not use these products in safety critical devices or in any other application where failure of the product could result in loss of life, personal injury, or damaged property.

This device and the sensors are not intended for aerospace, medical, breath control, diving, military or other safety-relevant applications.

Avoid all sources of ignition especially if the sensors are used in pure oxygen or oxygen enriched atmospheres.

The product information and specifications in this document are subject to change without prior notice.

The data contained in this document is for guidance only. Customers should test under their own conditions, to ensure that the sensors are suitable for their own requirements.

CONTACT

PyroScience GmbH
Hubertusstraße 35
52064 Aachen
Deutschland

Tel.: +49 (0)241 5183 2210
Fax: +49 (0)241 5183 2299
info@pyroscience.com
www.pyroscience.com