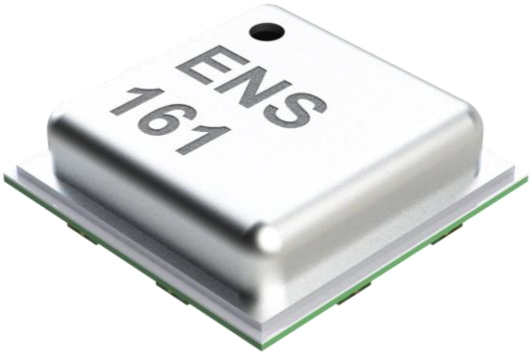


ENS161

Digital Metal-Oxide Multi-Gas Sensor
with permanent and low power operating modes

ENS161 datasheet

Version 1.1

Release Date: 2024-11-29

Document Status: Production

The ENS161 is a multi-gas sensor, based on metal oxide (MOX) technology with four sensor elements supporting isothermal and low-power operating modes plus an unrivaled wealth of fully processed output signals.

The independent hotplate control allows the detection of a wide range of volatile organic compounds (VOCs) including ethanol, toluene, hydrogen and oxidizing gases with superior sensitivity. The ENS161 supports intelligent algorithms to process raw sensor measurements on-chip. These algorithms calculate TVOC- and CO_2-equivalents, various air quality indices (AQIs) and perform humidity and temperature compensation, as well as baseline management, all on chip.

Raw sensor measurements can be read for further customization. The LGA-packaged device includes SPI and I^2C slave interfaces to communicate with a main host processor.

The ENS161 is a proven and maintenance-free technology, designed for high volume and reliability.

Key Features & Benefits

TrueVOC® air quality detection in compliance with worldwide IAQ[1] standards

- eCO_2[2],
- eTVOC[3],
- AQI-U[4],
- AQI-S[5],

Low power operating modes reducing power consumption down to 150µA.

Hassle-free on-chip heater drive control and data processing

➔ no need for external libraries

➔ no impact on MCU performance

Operating ranges

- temperature: -40 to +85°C
- humidity: 5 to 95%[6]
- V_{DD}: 1.71 to 1.98V
- V_{DDIO} 1.71 to 3.6V

Applications

- IoT devices
- Wearables / Mobiles
- Energy-critical applications in
  - Building Automation / HVAC[7]
    - Indoor air quality
    - Demand-controlled ventilation
  - Home appliances
    - Cooker hoods
    - Air cleaners / -purifiers

Properties

- 3x3x0.9mm LGA package
- Power consumption down to 0.3mW[8]
- Standard, fast and fast mode plus I^2C and SPI interfaces with separate V_{DDIO} up to 3.6V
- T&R packaged, reflow solderable

[1] IAQ = Indoor Air Quality

[2] eCO_2 = equivalent CO_2 values for compatibility with HVAC standards

[3] eTVOC = equivalent Total Volatile Organic Compounds values

[4] AQI-U = Air Quality Index (1 - 5) equivalent to UBA (German Federal Environmental Agency)

[5] AQI-S = relative Air Quality Index (0 - 500) according to ScioSense

[6] Non-condensing

[7] HVAC = Heat, Ventilation and Air Conditioning

[8] at Ultra Low Power mode and nominal V_{DD}

Table of Contents

1 Block diagram

The ENS161 digital multi-gas sensor consists of four independent heaters and gas sensor elements, based on metal oxide (MOX) technology, and a controller as shown in the functional block diagram below.

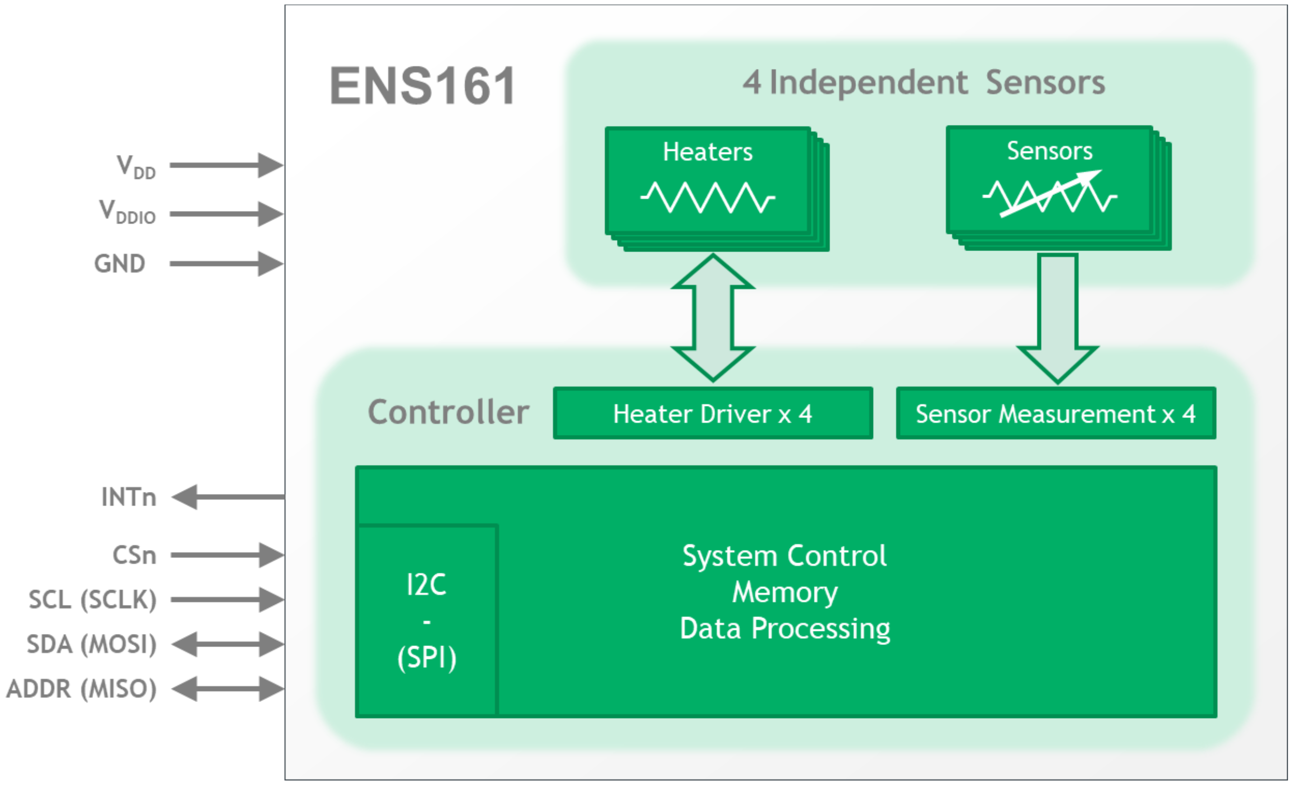


Figure 1: Functional Blocks

The *Heater Driver* controls the sensor operating modes and provides power to the *heaters* of each individual sensor element. During operation, the heater driver regulates the heaters to their individual set-points.

The *Sensor Measurement* block determines the value of the sensor resistance for each individual sensor element.

The *System Control* block processes the resistance values internally to output calculated eTVOC-, eCO_2-equivalents, AQIs and further signals on the digital interface.

The ENS161 includes a standard 2-wire digital *I^2C interface* (SCL, SDA) or 4-wire digital *SPI interface* (SCLK, MOSI, MISO, CSn) for communication to the main host processor.

2 Pin assignment

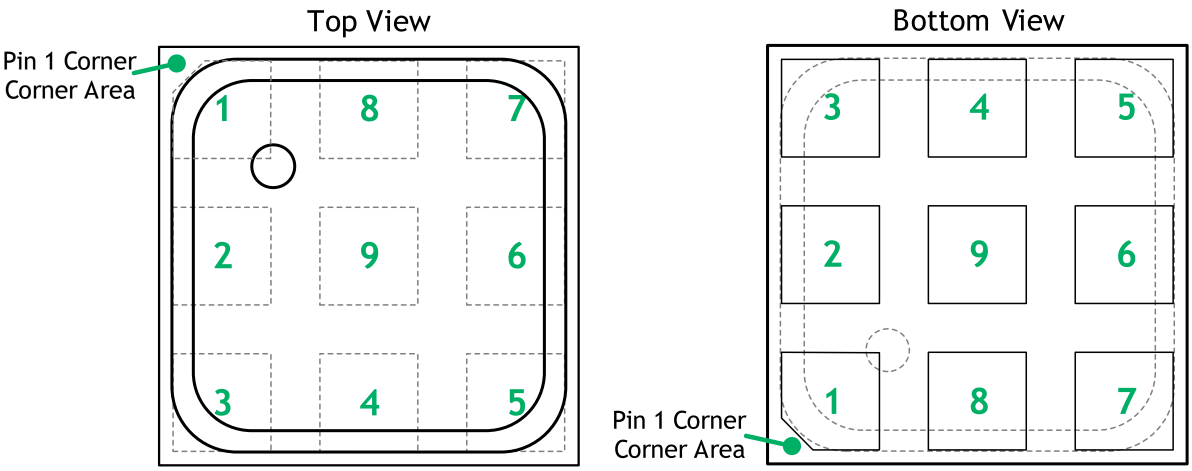


Figure 2: Pin diagram

Table 1: Pin description

Pins	Pin Name	Pin Type	Description
1	MOSI / SDA	Input / Output	SPI Master Output Slave Input / I²C Bus Bi-Directional Data
2	SCLK / SCL	Input	SPI Serial Clock / I²C Bus Serial Clock Input
3	MISO / ADDR	Input / Output	SPI Master Input Slave Output / I²C Address Select: I²C ADDR pin high -> 0x53 / ADDR pin low -> 0x52
4	V_{DD}	Supply	Main Supply Voltage
5	V_{DDIO}	Supply	Interface Supply Pins
6	INTn	Output	Interrupt to Host
7	CSn	Input	SPI Interface Select (CSn low -> SPI / CSn high -> I²C)
8, 9	V_{SS}	Supply	Ground Supply Voltage

Also see sections “I2C operation circuitry” and “SPI operation circuitry” for wiring.

3 Absolute maximum ratings

Table 2: Absolute Maximum Ratings

Symbol	Parameter	Min	Max	Units	Comments
Electrical Parameters					
V_{DD}	Supply Voltage	-0.3	1.98	V	
V_{DDIO}	I/O Interface Supply	-0.3	3.6	V	
V_{IO1}	MOSI/SDA, SCLK/SCL	-0.3	3.6	V	
V_{IO2}	MISO/ADDR, INTn, CSn	-0.3	V_{DDIO}+0.3	V	
V_{SS}	Input Ground	-0.3	0.3	V	
I_{SCR}	Input Current (latch-up immunity)	± 100		mA	JEDEC JESD78E
Electrostatic Discharge					
ESD_{HBM}	Electrostatic Discharge HBM	± 2000		V	JS-001-2014
ESD_{CDM}	Electrostatic Discharge CDM	± 750		V	JS-002-2014
Operating and Storage Conditions					
MSL	Moisture Sensitivity Level		1		Unlimited floor lifetime
T_{BODY}	Max. Package Body Temperature		260	°C	IPC/JEDEC J-STD-020
T_{STRG}	Storage Temperature	-40	125	°C	
RH_{STRG}	Storage Relative Humidity	5	95	%	Non-condensing
T_{AMB}[9]	Operating Ambient Temperature	-40	85	°C	
RH_{AMB}[13]	Operating Ambient Rel. Humidity	5	95	%	Non-condensing

Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only. Functional operation of the device at these or any other conditions beyond those indicated under Electrical Characteristics is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability and lifetime.

Note: The ENS161 is not designed for use in safety-critical or life-protecting applications.

[9] The ENS161 is electrically operable in this range, however its gas sensing performance might vary. Please refer to "Recommended Sensor Operation" for further information.

4 Electrical characteristics

The following figure details the electrical characteristics of the ENS161.

Table 3: Electrical characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{DD}	Positive supply		1.71[10]	1.8	1.98	V
V_{DDIO}	IO Supply Voltage		1.71		3.6	V
I_{DD}	Average[11] Supply Current[12]	DEEP SLEEP (OP_MODE 0x00)[13]		0.01		mA
		IDLE (OP_MODE 0x01)[11]		2	2.5	mA
		STANDARD (OP_MODE 0x02)		12		mA
		LOW POWER (OP_MODE 0x03)		0.7		mA
		ULTRA LOW POWER (OP_MODE 0x04)		0.15		mA
I_{DD_PK}	Peak Supply Current[14]	STANDARD (OP_MODE 0x02)		45 (<5ms)		mA
		LOW POWER (OP_MODE 0x03)		45 (<5ms)		mA
		ULTRA LOW POWER (OP_MODE 0x04)		45 (<5ms)		mA
V_{IH}	High-level input voltage		$0.7xV_{DDIO}$			V
V_{IL}	Low-level input voltage				$0.3xV_{DDIO}$	V
V_{OH}	High-level output voltage	MISO[15] [I_{OH}=5mA]	$0.8xV_{DDIO}$			V
		INTN [I_{OH}=2mA]	$0.65xV_{DDIO}$			V
V_{OL}	Low-level output voltage	MOSI/SDA, MISO [I_{OL}=5mA]			$0.2xV_{DDIO}$	V
		INTN [I_{OL}=2mA]			$0.35xV_{DDIO}$	V

[10] The minimum supply voltage VDD is 1.71V and must not drop below this value. Please refer to the recommended "I2C- or SPI-Operation Circuitry" in section 17.
[11] Averaged over the sequence
[12] Measured at V_{DD}-pin at ambient temperature of 35°C
[13] Not a gas sensing mode
[14] Initial (<5ms) current demand after device is switched from IDLE (OP_MODE 1) to STANDARD operation (OP_MODE 0x02) at nominal V_{DD}. Recurrent (<5ms every minute) current demand in LOW POWER operation (OP_MODE 0x03) and ULTRA LOW POWER (OP_MODE 0x04) operation at nominal V_{DD}.
[15] MOSI/SDA is open drain

5 Air quality signal characteristics

To satisfy a wide range of individual application requirements, the ENS161 offers a series of (indoor) air quality output signals that are derived from various international, as well as de-facto industry or proprietary standards. Table 4 provides a summary of such signals, that are further described in the following sections.

Table 4: Air quality signal output characteristics

Parameter	Range	Resolution	Unit	Comment
eTVOC	0 – 65,000	1	ppb	For requirements outside these specified ranges please contact us
eCO_2	400 – 65,000	1	ppm CO_2 equiv.	
AQI-UBA[16]	1 - 5	1	-	
AQI-S[17]	0 - 500	1	-	

5.1 eTVOC - equivalent Total Volatile Organic Compounds

More than 5,000 VOCs exist, and they are two to five times more likely to be found indoors than outdoors. Indoor VOCs are various types of hydrocarbons from mainly two sources: bio-effluents, i.e. odors from human respiration, transpiration and metabolism, and building material including furniture and household supplies. VOCs are known to cause eye irritation, headache, drowsiness or even dizziness – all summarized under the term Sick Building Syndrome (SBS). Besides industrial applications, comfort aspects (e.g. temperature, humidity), or building protection (mold, frost), VOCs are the main reason for ventilation.

Please refer to brochure “Intelligent Air Quality Beyond CO_2 for Indoor Air Quality” for further information on VOCs.

To group and classify VOCs, regional guidelines and industry preferences define a series of compounds and mixtures as reference, e.g. ethanol, toluene, acetone, combinations of the various groups of VOCs (e.g. ISO16000-29), and others.

Refer to “Registers” and “DATA_ETVOC (Address 0x22)” on how to obtain eTVOC values from the ENS161.

5.2 eCO_2 - equivalent CO_2

Due to the proportionality between airborne hydrogen and CO_2, generated by humans, CO_2-values historically served as an air quality indicator, reflecting the total amount of VOCs (=TVOC), produced by human respiration and transpiration. This law (first revealed by Max von Pettenkofer[18] in the 19th

[16] Classification of the eTVOC output signal according to the indoor air quality levels by the German Federal Environmental Agency (UBA, 2007)
[17] Relative Air Quality Index between 0 and 500
[18] Max von Pettenkofer (*1818 – †1901), German chemist and hygienist

century) and the unavailability of suitable VOC measurement technology made CO_2 the surrogate of inhabitant-generated air-pollution in confined living spaces of the past *and* the present, i.e. today's standard air quality reference for demand-controlled ventilation (DCV)– as adopted by most HVAC industry standards.

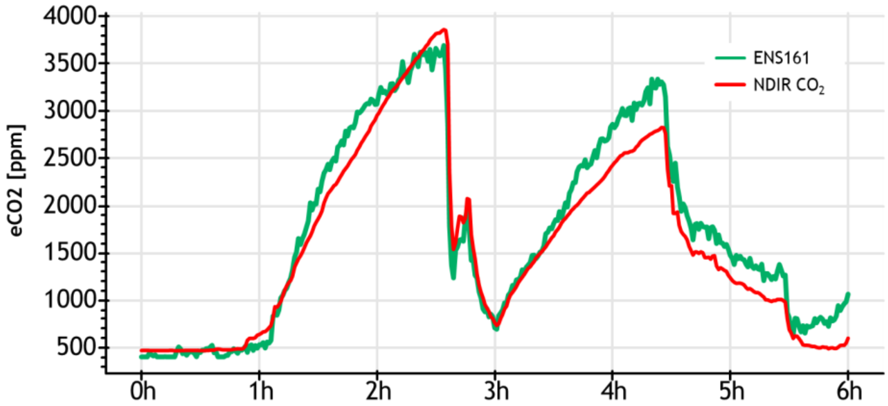


Figure 3: ENS161 equivalent CO_2 (eCO_2) output vs. NDIR CO_2 output during two meeting sessions

The ENS161 reverses the proportional correlation of VOCs and CO_2, by providing a standardized output signal in ppmCO_2-equivalents from measured VOCs plus hydrogen, thereby adhering to today's CO_2 standards, as shown in Figure 3.

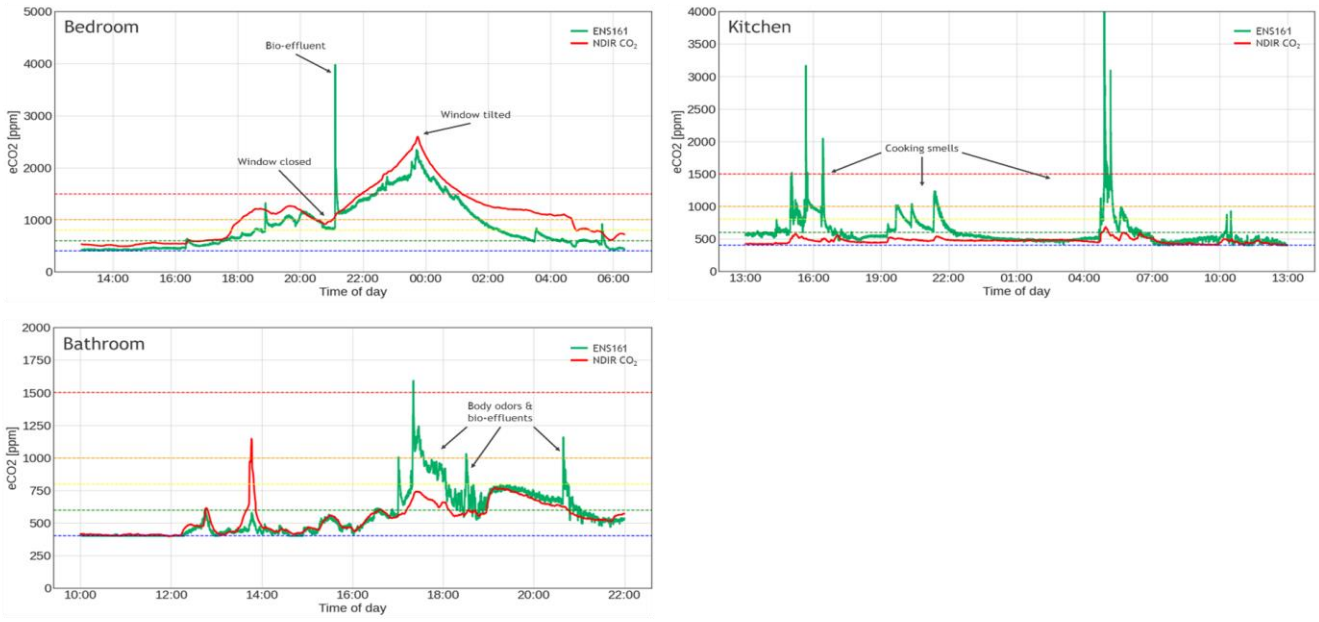


Figure 4: Added value of ENS161's eCO_2 outputs and typical cases of pure CO_2 sensors failing

A key advantage of the ENS161 is the capture of odors and bio-effluents that are completely invisible to CO_2-sensors. The diagrams in Figure 4 compare the ENS161's equivalent CO_2 output to an NDIR CO_2 sensor in typical indoor applications.

CO_2 sensors neither detect unpleasant odors and bio-effluents in bedroom or bathroom environments, nor cooking smells in kitchens or restaurants, whereas the ENS161 reliably reports such events.

Proven TrueVOC® control algorithms minimize sensor drift and ageing to provide reliable readings over lifetime, thereby making the ENS161's equivalent CO_2 output an affordable solution to complement or substitute real CO_2-based air quality sensors in the HVAC domain.

Table 5 shows a typical classification of (equivalent) CO_2 output levels.

Table 5: Interpretation of CO_2 and equivalent CO_2 values

Output		Comment / Recommendation
eCO_2 / CO_2	**Rating**	
>1500	Bad	Heavily contaminated indoor air / Ventilation required
1000 - 1500	Poor	Contaminated indoor air / Ventilation recommended
800 - 1000	Fair	Optional ventilation
600 - 800	Good	Average
400 - 600	Excellent	Target

Example: A CO_2- or eCO_2-controlled ventilation application would invoke its ventilation fan speeds 1, 2 and 3 at the upper three levels “Fair”, “Poor” and “Bad”, respectively.

See sections “Registers” and “DATA_ECO2 (Address 0x24)” on how to obtain equivalent CO_2-values from the ENS161.

5.3 AQI-UBA -Air Quality Index according to UBA

The AQI-UBA[19] air quality index is derived from a guideline by the German Federal Environmental Agency based on a TVOC sum signal. Although a local, German guideline, it is referenced and adopted by many countries and organizations.

Table 6: Air Quality Index of the UBA (German Federal Environmental Agency)[20]

AQI-UBA		TVOC		Hygienic Rating	Recommendation	Exposure Limit
#	**Rating**	**mg/m^3**	**ppm**			
5	Unhealthy	10 - 25	2.2 - 5.5	Situation not acceptable	Use only if unavoidable Intensified ventilation recommended	hours
4	Poor	3 - 10	0.65 - 2.2	Major objections	Intensified ventilation recommended Search for sources	<1 month
3	Moderate	1 - 3	0.22 - 0.65	Some objections	Increased ventilation recommended Search for sources	<12 months
2	Good	0.3 - 1	0.065 - 0.22	No relevant objections	Sufficient ventilation recommended	No limit
1	Excellent	<0.3	0 - 0.065	No objections	Target	No limit

See sections “Registers” and “DATA_AQI_UBA (Address 0x21)” on how to obtain AQI-UBA values from the ENS161.

[19] UBA = Umweltbundesamt - German Federal Environmental Agency
[20] Recommendation according to the UBA, Bundesgesundheitsblatt - Gesundheitsforschung Gesundheitsschutz 2007, 50:990–1005, DOI 10.1007/s00103-007-0290-y © Springer Medizin Verlag 2007

5.4 AQI-S - relative Air Quality Index according to ScioSense

The AQI-S is a relative and proprietary air quality output signal, classifying air quality in 500 steps between 0 and 500. It uses a reference output value of 100 for the average air quality of the past 24 hours.

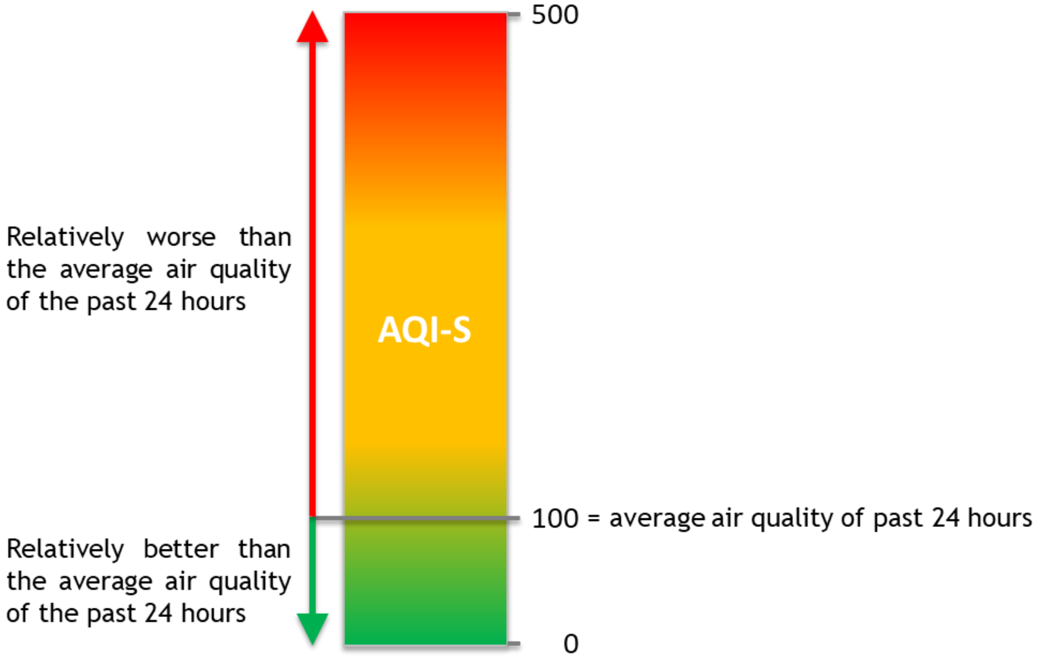


Figure 5: Functional description of the AQI-S air quality index

The following examples help interpreting AQI-S output values (also refer to Figure 4):

- A value of <100 means relatively better air quality than the average air quality of the past 24 hours.
- A value of >100 means relatively worse air quality than the average air quality of the past 24 hours.

Due to the nature of this relative air quality index, output values below 100 do not guarantee good air quality. It simply means that the present air quality is better than the average air quality of the past 24 hours. As AQI-S does not predict absolute output values (like eTVOC or eCO_2), the signal will align with said reference value after a longer period of time without excitation.

6 Single gas signal characteristics[21]

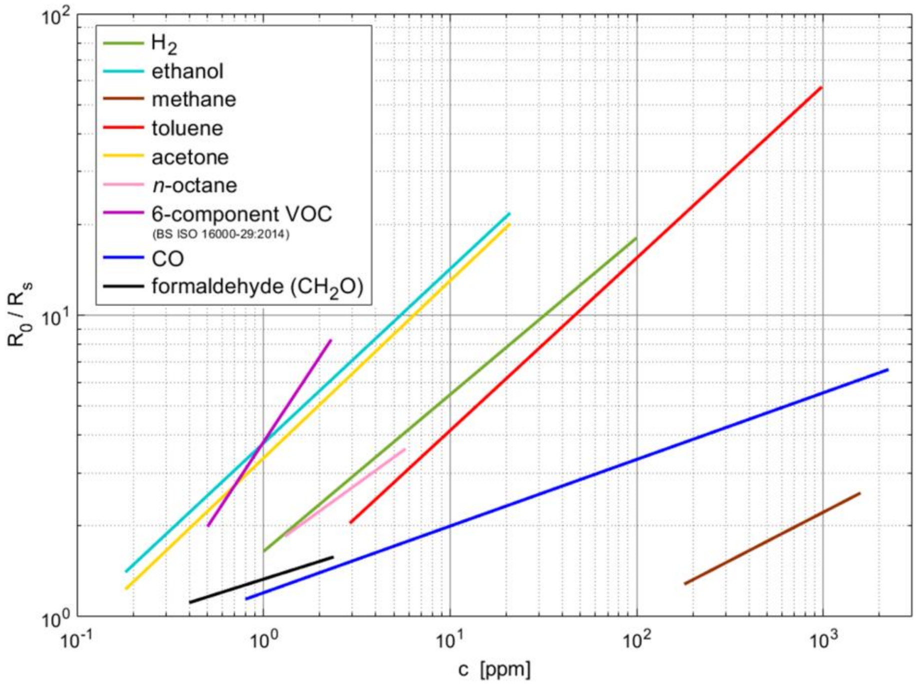


Figure 6: Harmonized, typical response of the ENS161 to various gases

Since metal oxide sensors exhibit a broadband sensitivity to both, reducing and oxidizing gases, their raw output signals represent the resulting sum of the entire gas mixture, present. Such sum-signals are beneficial when it comes to broadband TVOC- or AQI-applications, but unsatisfactory for the detection of single gases.

Figure 6 shows the ENS161's response to a variety of indoor gases that have been characterized in a gas mixing system in Standard mode of operation, whereas Table 7 provides ranges of such gases.

Table 7: Single Gas Signal Characteristics

Target Gas	Specified Range	Measurement Range	Unit	Register	Comment
Ethanol	0 to 20	0 to 450	ppm	DATA_ETOH (0x22) = DATA_ETVOC	Dedicated Register
Hydrogen	0 to 100	0 to 1,000	ppm	$R4_{raw}$ = GPR_READ[6:7]	R_{iraw} = raw resistance values that need to be calibrated to target gas. See text below.
Acetone	0 to 20	0 to 450	ppm	$R4_{raw}$ = GPR_READ[6:7]	
Carbon Monoxide	0 to 900	0 to 900	ppm	$R4_{raw}$ = GPR_READ[6:7]	
Toluene	0 to 450	0 to 450	ppm	$R4_{raw}$ = GPR_READ[6:7]	

[21] All values have been determined by tests in clean, partially synthetic air in a climate chamber-with stated environmental conditions, suitable reference analytics and sensor preconditioning of at least 24h in standard/isothermal mode of operation, which may not reflect real-life environments. Unless otherwise noted, the accuracy statements have been carried out at 25°C and 50% relative humidity, applying a MOX-sensor-specific calibration scheme.

Measurement values for individual gases can be obtained from dedicated device registers or calculated from sensor raw resistance values as specified in above table. See sections "Registers" and "Gas sensor raw resistance signals" for further information.

7 Gas sensor raw resistance signals

For one of its sensing elements the ENS161 provides an individual output of the raw sensor value.

Table 8: Gas sensor raw resistance signals

Sensor	Raw Value	Range	Unit	Gen. Purpose Register	Comment
4	$R3_{raw}$	[0..65535]	-	GPR_READ[6:7]	Arbitrary logarithmic units - no resistance values. R_{iraw} require conversion to corresponding resistance value R_{ires} [Ω] (see below) Note: Raw sensor index starts with 0. 1st sensor is R0; 4th sensor is R3

Gas sensor raw values R_{iraw} can be obtained from the ENS161 General Purpose Read Register (GPR_READ) for customer-specific signal post-processing.

Prior to use, R_{iraw} values require conversion to resistance values, using the following formula:

$$R_{ires}[\Omega] = 2^{\frac{R_{iraw}}{2048}}$$

See section "Registers" and "GPR_READ (Address 0x48)" on how to obtain AQI values from the ENS161.

8 Signal conditioning

Chemical gas sensors are relative sensors that are susceptible to changes in their chemical and physical environments. Typical drivers are changes of the target gas(es), of the interfering background gas mixture and changes of the physical environment (air pressure, humidity, etc.).

In the following sections TrueVOC® signal conditioning technology comes into play for enhanced output signal ruggedness and resilience.

8.1 Baselining

As part of the TrueVOC® technology the ENS161 deploys a unique automatic baseline correction, featuring compensation for oxidizing gases such as ozone.

8.2 Humidity compensation

Extreme humidity conditions outside the range between 20% and 80% relative humidity can influence the output signal, especially when very accurate or single gas measurements are required. To overcome such impacts, the ENS161 is equipped with a temperature and humidity compensation algorithm, relying on data from an external temperature- and humidity-sensor (the ENS161 works well with ScioSense's ENS21x family of temperature and humidity sensors as both share the same data format), that can be regularly updated to an internal register for processing.

Note: The humidity compensation discussed in this section works per default for all output signals except for sensor raw signals.

See sections "Registers", "TEMP_IN (Address 0x13)" and "RH_IN (Address 0x15)" for further information.

8.3 Ozone compensation

Backed up by its TrueVOC® technology, the ENS161 deploys an effective ozone compensation algorithm to maintain solid eCO_2-, eTVOC- and AQI-output signals.

9 Output signal accuracy

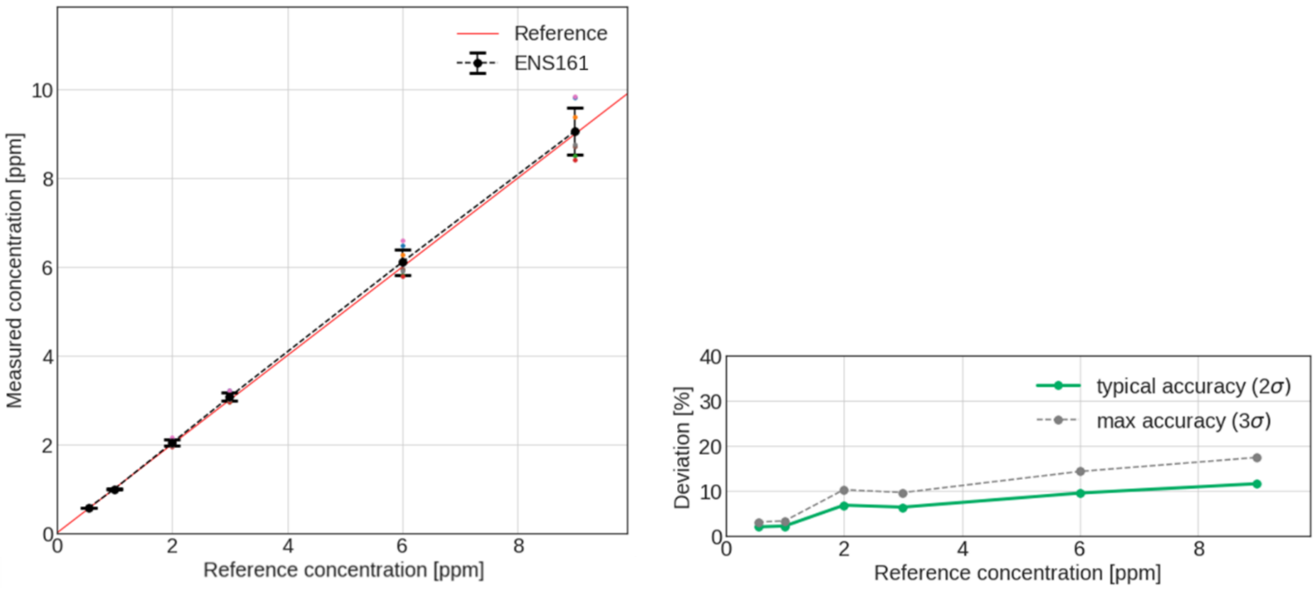


Figure 7: Example output signal accuracy for hydrogen

Figure 7 shows the non-linearity of several devices (left) and typical and maximum accuracies (bottom) for various hydrogen concentrations[22]. A typical error of <12% of the measured value can be stated. The ENS161 exhibits excellent measurement accuracies[23] and device-to-device variation.

10 Start-Up and response times

Table 9: Initial Start-up and Warm-up times

Parameter	Condition	Typical Times	Comment
Initial Start-up	Standard mode	1 hour	See 10.1 and 10.2 for further details
	Low Power modes	3 – 24 hours	
Warm-up	Standard mode	3 minutes	
	Low Power modes	5 - 60 minutes	
Immediate response[24]	Standard mode	1 second	Immediate response of sensor
	Low Power modes	60 – 320 seconds	

[22] In this document use of the term "Concentration" in ppm (= parts per million) and ppb (= parts per billion) means volume fractions of the respective gases in air: 1 ppm = 1 mL/m³ = 1000 ppb = 1000 µL/m³.
[23] All values have been determined by tests in clean, partially synthetic air in a climate chamber-with stated environmental conditions, suitable reference analytics and sensor preconditioning of at least 24h in standard/isothermal mode of operation, which may not reflect real-life environments. Unless otherwise noted, the accuracy statements have been carried out at 25°C and 50% relative humidity, applying a MOX-sensor-specific calibration scheme.
[24] Long-term drift of response time: approx. 1s/a; depending on environmental conditions and sensor history.

10.1 Initial Start-Up

Initial Start-Up is the time the ENS161 needs to exhibit reasonable air quality readings after its very first power-on.

The ENS161 sensor raw resistance signals and sensitivities will change upon first power-on. The change in resistance is greatest in the first 48 hours of operation. Therefore, the ENS161 employs a start-up algorithm, allowing eCO_2, eTVOC and AQI output signals to be used from first power-on after 1 hour in Standard- and after 3 to 24 hours of in the Low Power modes of operation[25].

10.2 Warm-Up[26]

Further to "Initial Start-up" the conditioning or "Warm-up" period is the time required to achieve adequate sensor stability before measuring VOCs after idle periods or power-off.

Typically, the ENS161 requires 3 minutes of warm-up in Standard mode of operation until reasonable air quality readings can be expected[27]. In the low power modes this may take up to 60 minutes.

11 Gas sensor status and signal rating

The status flag is an additional feature assessing the current operational mode and the reliability of the output signals. It aids the application obligation to manage timings efficiently, in particular during initial start-up or after re-powering. Furthermore, a simple signal quality assessment and a system self-check is provided.

Table 10: ENS161 Status and Signal Rating (Validity Flag)

Flag	Meaning	Implementation approach
0	Operating ok	Standard operating mode.
1	Warm-up[28]	Active during Warm-Up phase after power-on: Standard mode: 2min Low Power mode: 4min Ultra Low Power mode: 40min
2	Reserved	Not used
3	No valid output	Signals give unexpected values (very high or very low). sensor out of range.

See "Validity Flag" in section "DEVICE_STATUS (Address 0x20)" for further information.

[25] Slightly reduced signal accuracy may be encountered in early phase, thereafter.
[26] Valid for eCO_2, eTVOC and AQI-U. Values may deviate for AQI-S due to nature of its design.
[27] Values have been determined by tests in clean, partially synthetic air in a climate chamber-with stated environmental conditions, suitable reference analytics and sensor preconditioning of at least 24h, which may not reflect real-life environments. Unless otherwise noted, accuracy statements have been carried out at 25°C and 50% relative humidity.
[28] Given times may vary by ±10% due to clock variations

12 Recommended sensor operating conditions

For best performance, the sensor shall be operated in normal indoor air in the range -5 to 60°C (typical: 25°C); relative humidity: 20 to 80%RH (typical: 50%RH), non-condensing with no aggressive or poisonous gases present. Prolonged exposure to environments outside these conditions can affect performance and lifetime of the sensor.

Please also refer to the "ENS16x Design Guidelines and Handling Instructions" document for further information on handling and optimal integration of the ENS161. The guidelines outlined in this document shall be followed for optimal sensor performance and maximum lifetime.

Important Note: The ENS161 is not designed for use in safety-critical or life-protecting applications.

13 Recommended sensor storage conditions

The guidelines under "Recommended sensor operating conditions" also apply to sensor storage.

14 Host communication

The ENS161 is an I²C or SPI Slave device.

If the CSn is held high, the interface behaves as an I²C slave. At power-up the condition of the MISO/ADDR pin is used to determine the LSB of the I²C address. The I²C slave address is 0x52 (MISO/ADDR low) or 0x53 (MISO/ADDR high).

If the CSn pin is asserted (low) the interface behaves as an SPI slave. This condition is maintained until the next Power-on Reset.

Both the SPI and I²C slave interfaces use the same register map for communication.

14.1 I2C specification

14.1.1 I2C description

The ENS161 is an I²C slave device with a fixed 7-bit address 0x52 if the MISO/ADDR line is held low at power-up or 0x53 if the MISO/ADDR line is held high.

The I²C interface supports standard (100kbit/s), fast (400kbit/s), and fast plus (1Mbit/s) mode. Details on I²C protocol is according to I²C-bus specifications [UM10204, I²C-bus specification and user manual, Rev. 6, 4 April 2014].

The device applies all mandatory I²C protocol features for slaves: START, STOP, Acknowledge and 7-bit slave address. None of the other optional features (10-bit slave address, general call, software reset or Device ID) are supported, nor are the master features (Synchronization, Arbitration, START byte).

The Host System, as an I²C master, can directly read or write values to one of the registers by first sending the single byte register address. The ENS161 implements "auto increment" which means that it is possible to read or write multiple bytes (e.g. read multiple DATA_X bytes) in a single transaction.

14.1.2 I2C I/O and timing information

Table 11: ENS161 I²C I/O parameters

Parameter	Symbol	Standard		Fast		Fast Mode Plus		Unit
		Min	Max	Min	Max	Min	Max	
Low level input voltage	V_{IL}	-0.5	$0.3xV_{DDIO}$	-0.5	$0.3xV_{DDIO}$	-0.5	$0.3xV_{DDIO}$	V
High level input voltage	V_{IH}	$0.7xV_{DDIO}$	2.39	$0.7xV_{DDIO}$	2.39	$0.7xV_{DDIO}$	2.39	V
Hysteresis of Schmitt trigger inputs	V_{hys}	-	-	$0.05xV_{DDIO}$	-	$0.05xV_{DDIO}$	-	V
Low-level output voltage @ 2mA sink current	V_{OL2}	-	-	0	$0.2xV_{DDIO}$	0	$0.2xV_{DDIO}$	V
Low-level output current @ 0.4V	I_{OL}	3		3		20		mA
Output fall time from V_{IHmin} to V_{ILmax}	t_{OF}		250	$20xV_{DDIO}$ / 5.5	250	$20xV_{DDIO}$ / 5.5	250	ns
Input current each I/O pin	I_i	-10	10	-10	10	-10	10	µA

Table 12: ENS161 I²C timing parameters[29]

Parameter	Symbol	Standard		Fast		Fast Mode Plus		Unit
		Min	Max	Min	Max	Min	Max	
SCLK clock frequency	f_{SCLK}	0	100	0	400	0	1000	kHz
Hold time (repeated) START condition. After this period, the first clock pulse is generated	t_{HD_STA}	4	-	0.6	-	0.26	-	µs
LOW period of the SCLK clock	t_{LOW}	4.7	-	1.3	-	0.5	-	µs
HIGH period of the SCLK clock	t_{HIGH}	4.0	-	0.6	-	0.26	-	µs
Set-up time for a repeated START condition	t_{SU_STA}	4.7	-	0.6	-	0.26	-	µs
Data set-up time	t_{SU_DAT}	250	-	100 [30]	-	50 [2]	-	ns

[29] All values referred to V_{IHmin} and V_{ILmax} levels.
[30] A fast mode I²C bus device can be used in Standard mode I²C bus systems, but the requirement t_{SU_DAT} >= 250ns must then be met. This will automatically be the case if the device does not stretch the LOW period of

Data hold-time	t_{HD_DAT}	0 [31]	3.45 [32]	0 [3]	0.9 [4]	0 [3]	-	µs
Rise time of SDA and SCLK signals	t_r	-	1000	20	300	20	120	ns
Fall time of SDA and SCLK signals	t_f	-	300	$20xV_{DDIO}$ / 5.5	300	$20xV_{DDIO}$ / 5.5	120	ns
Set-up time for STOP condition	t_{SU_STO}	4.0	-	0.6	-	0.26	-	µs
Bus free time between a STOP and START condition	t_{BUF}	4.7	-	1.3	-	0.5	-	µs
Capacitive load for each bus line	C_b	-	400	-	400	-	550	pF
Noise margin at the LOW level	V_{nL}	$0.1xV_{DDIO}$	-	$0.1xV_{DDIO}$	-	$0.1xV_{DDIO}$	-	V
Noise margin at the HIGH level	V_{nH}	$0.2xV_{DDIO}$	-	$0.2xV_{DDIO}$	-	$0.2xV_{DDIO}$	-	V

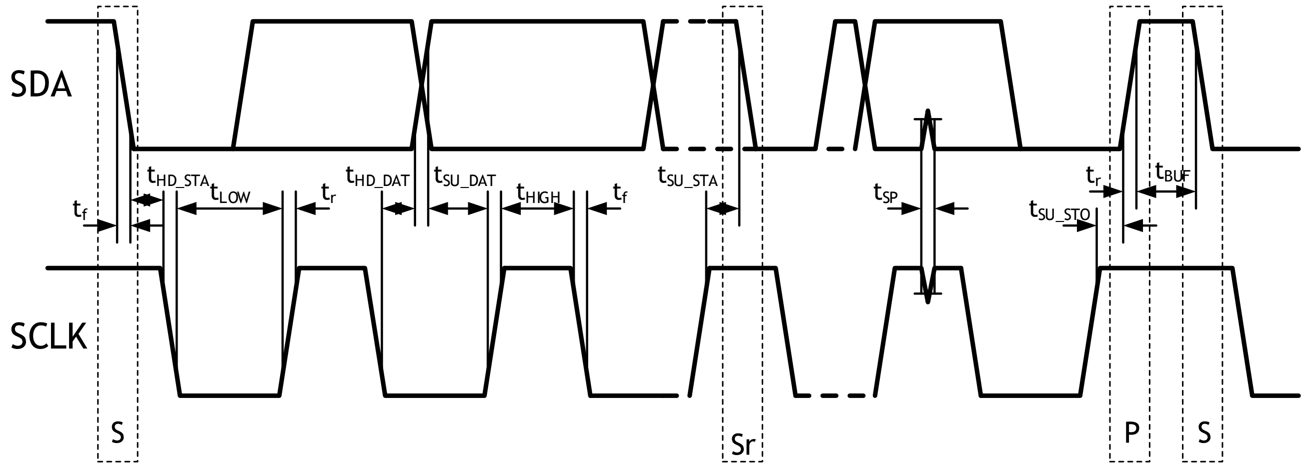


Figure 8: Definition of I²C timing parameters

the SCL signal. If such a device does stretch the LOW period of the SCL signal, it must output the next data bit to the SDA line t_{rmax}. t_{SU_DAT}= 1000 + 250 = 1250ns (according to standard mode I²C bus specification) before the SCL line is released.

[31] This device internally provides a hold time of at least 300ns for the SDA signal to bridge the undefined region of the falling edge of the SCL.

[32] The maximum t_{HD_DAT} has only to be met if the device does not stretch the LOW period (t_{LOW}) of the SCLK signal.

14.1.3 I2C read operation

After the START condition, in the first transaction:

- The I²C Master sends the 7-bit slave address and 0 into the R/W bit (the byte sent would be 0xA4 or 0xA6 dependent on the power-up value of MISO/ADDR).
- The I²C Master then sends the address of the first register to read.

Then either after a RESTART condition (i.e. STOP followed by START)

- The I²C Master sends the 7-bit slave address and 1 into the R/W bit (the byte sent would be 0xA5 or 0xA7 dependent on the power-up value of MISO/ADDR).
- The I²C Master then reads 1-n data bytes from sequential registers (if valid) until the transaction is concluded with a STOP condition.

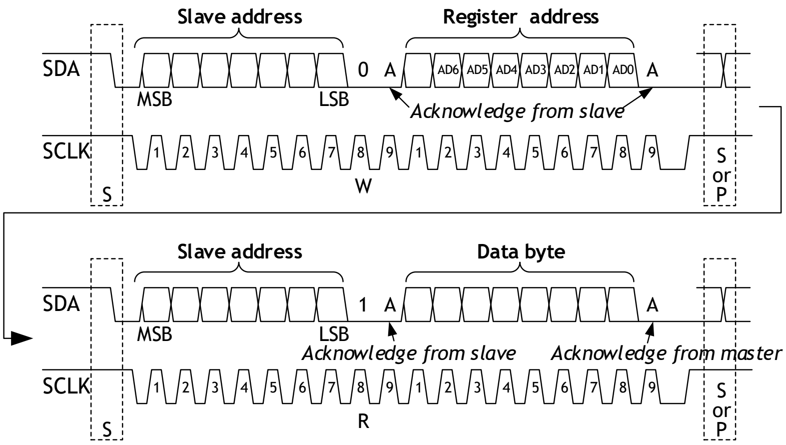


Figure 9: I²C Read operation

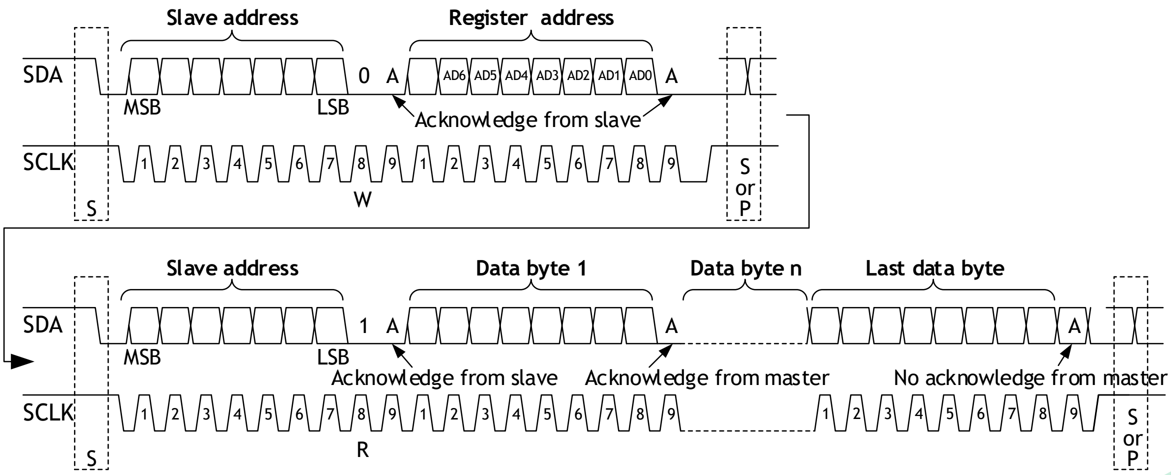


Figure 10: I²C Auto-increment read operation

14.1.4 I2C write operation

After the START condition, in a single continuous transaction:

- The I²C Master sends the 7-bit slave address and 0 into the R/W bit (the byte sent would be 0xA4 or 0xA6 dependent on the power-up value of MISO/ADDR).
- The I²C Master then sends the address of the first register to write.
- The I²C Master then sends 1-n data bytes which are written into sequential registers (if valid) until the transaction is concluded with a STOP condition.

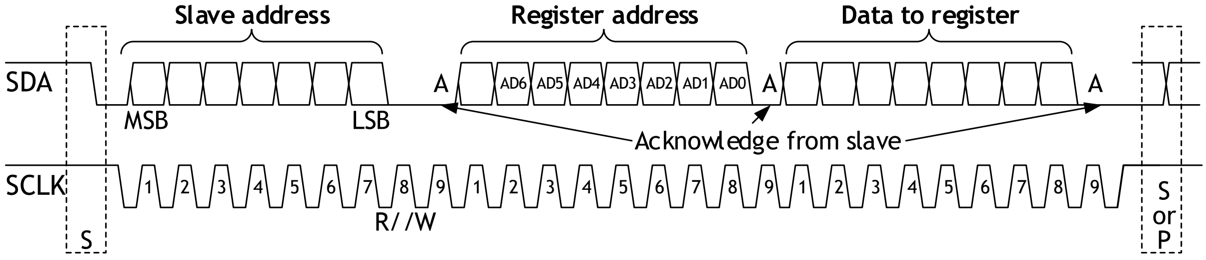


Figure 11: I2C Write operation

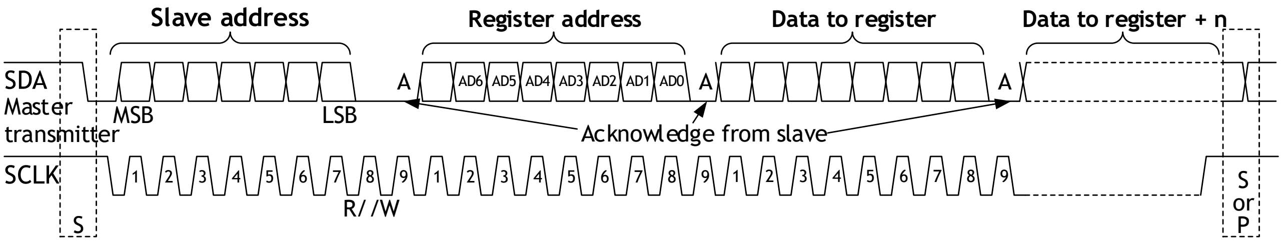


Figure 12: I²C Auto-increment write operation

14.2 SPI specification

14.2.1 SPI description

The SPI interface is a slave bus operating up to 10 MHz clock-frequency.

It shares pins with the I²C interface. SPI is selected and SPI transfer initiated by asserting the CSn line low. Once the CSn line has been asserted low the ENS161 will not accept I²C transactions until the next Power-On Reset.

Data is clocked in on the rising edge of SCLK; most significant bit first.

14.2.2 SPI timing information

Table 13: SPI Timings

Parameter	Symbol	Condition	Min	Typ	Max	Unit
SPI Clock (SCLK) Frequency	FSCLK				10	MHz
CSn falling to MISO Enabled	TEN	25pF load			20	ns
CSn rising to MISO Disable	TDIS	25pF load			20	ns
MOSI Setup Time before SCLK	TSUPI		15			ns
MOSI hold time after rising SCLK	THLDI		15			ns
CSn low to first rising SCLK	TLEAD		20			ns
Last SCLK low to CSn high	TLAG		20			ns
SCLK High Time	TSCLKH		40			ns
SCLK Low Time	TSCLKL		40			ns
SCLK falling to MISO Valid	TVALID	25pF load			40	ns

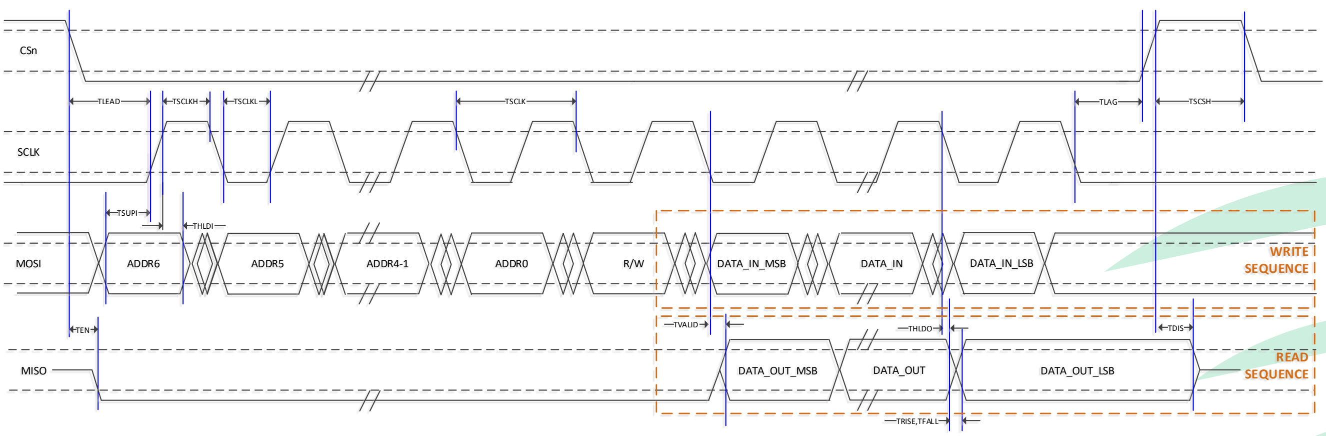


Figure 13: SPI Timings Reference

14.2.3 SPI read operation

During a Read operation, data is clocked out on the falling edge of SCLK so it is stable for the following riding edge.

MISO stays in high impedance mode until the device is selected (CSn low). Data on MISO is only valid on a Read operation.

A transaction starts with the target address and R/W control bit in the first byte followed by the read or write data.

In a Read operation Auto-increment of the address enables multiple registers to be read in sequence. CSn de-asserting (to high) terminates the Read sequence.

A Read SPI frame is composed as follows:

Table 14: Read SPI frame

Byte	Bit	Name	Description
0	7:1	AD[6:0]	On MOSI: Address of the register to Read
0	0	RW	On MOSI: 1: bytes are to be read, starting from AD[6:0].
1	7:0	RDATA[7:0]	Output on MISO; MOSI ignored
n	7:0	RDATA[7:0]	Output on MISO; MOSI ignored

14.2.4 SPI write operation

In a Write operation, the address does not Auto-increment. Multiple writes can be performed by alternating Address and Data bytes. CSn de-asserting (to high) terminates the Write sequence.

A Write SPI frame is composed as follows:

Table 15: Write SPI frame

Byte	Bit	Name	Description
0	7:1	AD[6:0]	On MOSI: Address of the register to Write
0	0	RW	On MOSI: 0: bytes are to be written at AD[6:0].
1	7:0	WDATA[7:0]	Input on MOSI; MISO Dummy Data
even	7:1	AD[6:0]	On MOSI: Address of the register to Write
even	0	RW	On MOSI: 0: bytes are to be Written, at AD[6:0].
odd	7:0	WDATA[7:0]	Input on MOSI; MISO Dummy Data

15 Operation

The ENS161 state diagram is depicted in Figure 14. At power-up, the ENS161 configures itself from a reset state and prepares for commands over the serial bus via either I^2C or SPI Protocols.

The default state is OPMODE 0x01, which is an IDLE condition that enables the ENS161 so that it may respond to several commands. In this mode it is not operating as a gas sensor.

OPMODE 0x00 is a very low power standby state, called DEEP SLEEP.

Active OPMODEs are described further in the OPMODE Register section.

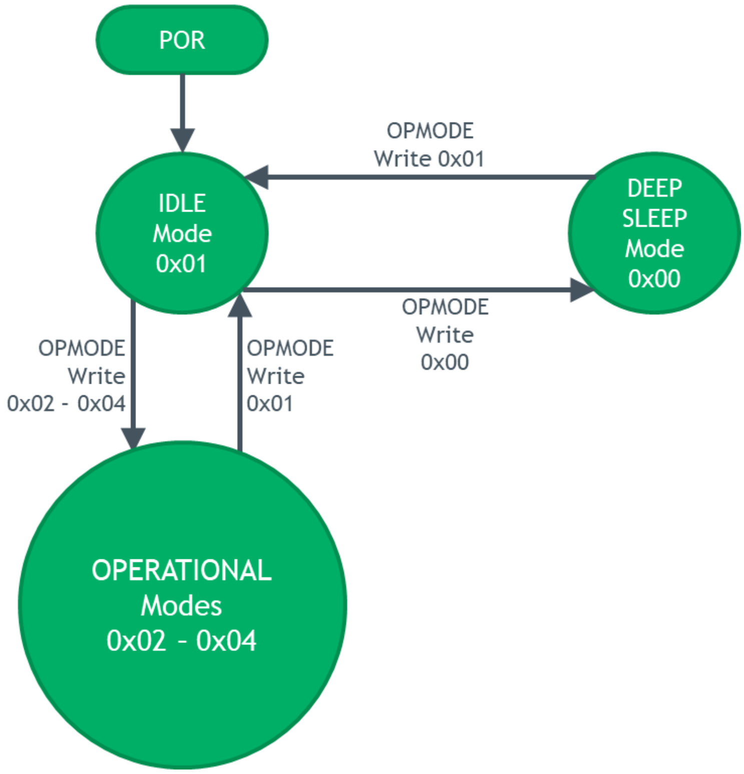


Figure 14: ENS161 state diagram

Note: When the active gas sensing OPMODE (e.g. 0x02 = STANDARD) is running, new data is notified either via the interrupt (INTn; must be enabled, see CONFIG) or by polling the DEVICE_STATUS register. The output of the gas sensing OPMODEs are presented in the DATA_XXX registers which can be read at any time.

16 Registers

This section describes the registers of the ENS161 which enable the host system to

- Identify the device and version information
- Configure the ENS161 and set the operating mode
- Read back STATUS information, the calculated gas concentrations and Air Quality Index

16.1 Register overview

Note that some registers are spread over multiple addresses. For example, PART_ID at address 0 is spread over 2 addresses (its "Size" is 2). Registers are stored in little endian so the LSB of PART_ID is at address 0 and the MSB of PART_ID is at address 1.

Table 16: Register Overview

Address	Name	Size	Access	Description
0x00	PART_ID	2	Read	Device Identity 0x61, 0x01
0x10	OPMODE	1	Read / Write	Operating Mode
0x11	CONFIG	1	Read / Write	Interrupt Pin Configuration
0x12	COMMAND	1	Read / Write	Additional System Commands
0x13	TEMP_IN	2	Read / Write	Host Ambient Temperature Information
0x15	RH_IN	2	Read / Write	Host Relative Humidity Information
0x17 – 0x1F	-	1	-	Reserved
0x20	DEVICE_STATUS	1	Read	Operating Mode
0x21	DATA_AQI_UBA	1	Read	Air Quality Index according to UBA
0x22	DATA_ETVOC	2	Read	Equivalent TVOC Concentration (ppb)
0x24	DATA_ECO2	2	Read	Equivalent CO_2 Concentration (ppm)
0x26	DATA_AQI_S	2	Read	Relative Air Quality Index according to ScioSense
0x28	-	2	-	Reserved
0x2A	-	2	Read	Reserved
0x2C – 0x2F	-	1	-	Reserved
0x30	DATA_T	2	Read	Temperature used in calculations
0x32	DATA_RH	2	Read	Relative Humidity used in calculations
0x34 – 0x37	-	1	-	Reserved
0x38	DATA_MISR	1	Read	Data Integrity Field (optional)
0x40	GPR_WRITE[0:7]	8	Read/Write	General Purpose Write Registers
0x48	GPR_READ[0:7]	8	Read	General Purpose Read Registers

16.2 Detailed register description

16.2.1 PART_ID (Address 0x00)

This 2-byte register contains the part number in little endian of the ENS161.

The value is available when the ENS161 is initialized after power-up.

Table 17: Register PART_ID

Address 0x00		PART_ID		
Bits	**Field Name**	**Default**	**Access**	**Field Description**
0:7	PART_ID_LSB	0x61	read	Lower Byte of Part ID
8:15	PART_ID_MSB	0x01	read	Upper Byte of Part ID

16.2.2 OPMODE (Address 0x10)

This 1-byte register sets the Operating Mode of the ENS161. The Host System can write a new OPMODE at any time.

Any current operating mode will terminate, and the new operating mode will start.

Table 18: Register OPMODE

Address 0x10		OPMODE		
Bits	**Field Name**	**Default**	**Access**	**Field Description**
7:0		0x01	R/W	Operating mode: 0x00: DEEP SLEEP mode (low-power standby) 0x01: IDLE mode (low power) 0x02: STANDARD gas sensing mode 0x03: LOW POWER gas sensing mode 0x04: ULTRA LOW POWER gas sensing mode 0xF0: RESET

0x00 (**DEEP SLEEP**) ENS161 has limited functionality but will respond to OPMODE IDLE.

0x01 (**IDLE**) is intended for configuration before running an active sensing mode.

0x02 (**STANDARD**) is an active gas sensing mode to indicate the levels of air quality or for specific gas detection at 1 sample/second.

0x03 (**LOW POWER**) is an active power-saving gas sensing mode, indicating the levels of air quality at 1 sample/minute.

0x04 (**ULTRA LOW POWER**) is an active power-saving gas sensing mode, indicating the levels of air quality at 1 sample/5 minutes. Limited output signal performance may be expected due to 5 minute cycles; particularly short gas events may get lost. If capturing of such events is required, use STANDARD or LOW POWER mode instead.

Notes:

- Before toggling between active operating modes (0x02 – 0x04), always include an interim IDLE step (0x01) as depicted in figure 14.
- It is not advisable to frequently toggle between active operating modes (0x02 – 0x04) as this will cause algorithms to restart the warm-up or start-up behavior.

16.2.3 CONFIG (Address 0x11)

This 1-byte register configures the action of the INTn pin which allows the ENS161 to signal to the host system that data is available.

The INTn pin can be (de-)asserted (polarity configurable) when ENS161 updates GPR_Read registers, or when it updates DATA registers, or when a certain threshold is reached (set through COMMAND mode).

A typical setting 0x23 would enable an active low interrupt (no pull-up required) when new output data is available in the DATA registers.

Table 19: Register CONFIG

Address 0x11		CONFIG		
Bits	**Field Name**	**Default**	**Access**	**Field Description**
7	-	0b0	-	Reserved
6	INTPOL	0b0	R/W	INTn pin polarity: 0: Active low (Default) 1: Active high
5	INT_CFG	0b0	R/W	INTn pin drive: 0: Open drain 1: Push / Pull
4	-	0b0	-	Reserved
3	INTGPR	0b0	R/W	INTn pin asserted when new data is presented in the General Purpose Read Registers
2	-	0b0	-	Reserved
1	INTDAT	0b0	R/W	INTn pin asserted when new data is presented in the DATA_XXX Registers
0	INTEN	0b0	R/W	INTn pin is enabled for the functions above

16.2.4 COMMAND (Address 0x12)

This 1-byte register allows some additional commands to be executed on the ENS161. This register can be written at any time, but commands will only be actioned in IDLE mode (OPMODE 0x01).

The COMMAND register allows multiple interactions with the system where data needs to be passed between the user/host and the ENS161.

Typically, a request for data (e.g. GetHWVer, GetFWVer) will result in the requested data being placed in the General Purpose READ Registers and an input of data (e.g. set alarm threshold) would first be stored in the General Purpose WRITE Registers at address 0x40-47.

Below is a list of valid commands for the ENS161.

Table 20: Register COMMAND

Address 0x12		COMMAND		
Bits	Field Name	Default	Access	Command
7:0	Command	0x00	R/W	0x00: ENS16x_COMMAND_NOP 0x0E: ENS16x_COMMAND_GET_APPVER – Get FW Version 0xCC: ENS16x_COMMAND_CLRGPR Clears GPR Read Registers

16.2.4.1 ENS16x_COMMAND_GET_APPVER

After issuing ENS16x_COMMAND_GET_APPVER, the firmware version of the ENS161 will be placed in General Purpose Registers according to table 21. The NEWGPR bit in DEVICE_STATUS will be set and the INTn asserted if configured to react to NEWGPR.

Table 21: GPR_READ settings for ENS16x_COMMAND_GET_APPVER command

Register	7	6	5	4	3	2	1	0
GPR_READ4	Version (Major)							
GPR_READ5	Version (Minor)							
GPR_READ6	Version (Release)							

16.2.4.2 ENS16x_COMMAND_CLRGPR

After issuing ENS16x_COMMAND_CLRGPR all GPR Read registers are cleared.

16.2.5 TEMP_IN (Address 0x13)

This 2-byte register allows the host system to write ambient temperature data to ENS161 for compensation. The register can be written at any time. TEMP_IN_LSB should be written first as the update is recognized on a write to TEMP_IN_MSB.

Table 22: Register TEMP_IN

Address 0x13		TEMP_IN		
Bits	**Field Name**	**Default**	**Access**	**Field Description**
0:7	TEMP_IN _LSB	0x00	R/W	Lower Byte of TEMP_IN
8:15	TEMP_IN_MSB	0x00	R/W	Upper Byte of TEMP_IN

The format of the temperature data is the same as the format used in the ENS21x (family of ScioSense temperature and humidity sensors) as shown below.

Table 23: Format of Temperature Data

Byte 0x14								Byte 0x13							
7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
TEMP_IN Integer Part (Kelvin)								TEMP_IN Fractions							

The ENS161 required input format is: temperature in Kelvin * 64 (with Kelvin = Celsius + 273.15).

Example: For 25°C the input value is calculated as follows: (25 + 273.15) * 64 = 0x4A8A.

16.2.6 RH_IN (Address 0x15)

This 2-byte register allows the host system to write relative humidity data to ENS161 for compensation. The register can be written at any time. RH_IN_LSB should be written first as the update is recognized on a write to RH_IN_MSB.

Table 24: Register RH_IN

Address 0x15		RH_IN		
Bits	**Field Name**	**Default**	**Access**	**Field Description**
0:7	RH_IN _LSB	0x00	R/W	Lower Byte of RH_IN
8:15	RH_IN_MSB	0x00	R/W	Upper Byte of RH_IN

The format of the relative humidity data is the same as the format used in the ENS21x as shown below:

Table 25: Format of Relative Humidity Data

Byte 0x16								Byte 0x15							
7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
RH_IN Integer Part (%)								RH_IN Fractions							

The ENS161 required input format is: relative humidity in %rH * 512.

Example: For 50% rH the input value is calculated as follows: 50 * 512 = 0x6400.

16.2.7 DEVICE_STATUS (Address 0x20)

This 1-byte register indicates the current status of the ENS161.

Table 26: Register DEVICE_STATUS

Address 0x20		DEVICE_STATUS		
Bits	**Field Name**	**Default**	**Access**	**Field Description**
7	STATAS	0b0	-	High indicates that an OPMODE is running
6	STATER	0b0	R	High indicates that an error is detected. E.g. Invalid Operating Mode has been selected.
5	-	0b0	R	Reserved
4	-	0b0	R	Reserved
2-3	VALIDITY FLAG	0b00	R	Status 0: Normal operation 1: Warm-Up phase 2: Not used 3: Invalid output
1	NEWDAT	0b0	R	High indicates that a new data is available in the DATA_x registers. Cleared automatically at first DATA_x read.
0	NEWGPR	0b0	R	High indicates that a new data is available in the GPR_READx registers. Cleared automatically at first GPR_READx read.

During operation, Bit 6 (STATER) of DEVICE_STATUS is asserted if an error has occurred.

The meaning of the errors may be different, depending on the operation being undertaken.

16.2.8 DATA_AQI_UBA (Address 0x21)

This 1-byte register reports the calculated Air Quality Index according to the UBA.

Table 27: Register DATA_ AQI_UBA

Address 0x21		DATA_AQI_UBA		
Bits	**Field Name**	**Default**	**Access**	**Field Description**
0:2	AQI_UBA	0x01	R	Air Quality Index according to UBA [1..5]
3:7	AQI_UBA	0x00	R	Reserved

See section "AQI-UBA -Air Quality Index" for further information.

16.2.9 DATA_ETVOC (Address 0x22)

This 2-byte register reports the calculated equivalent TVOC concentration in ppb.

Table 28: Register DATA_ETVOC

Address 0x22		DATA_ETVOC		
Bits	**Field Name**	**Default**	**Access**	**Field Description**
0:7	ETVOC_LSB	0x00	R	Lower Byte of DATA_ETVOC
8:15	ETVOC _MSB	0x00	R	Upper Byte of DATA_ETVOC

See section "eTVOC - equivalent Total Volatile Organic Compounds" for further information.

16.2.10 DATA_ETOH (Address 0x22)

This 2-byte register reports the calculated ethanol concentration in ppb.

Table 29: Register DATA_ETH

Address 0x22		DATA_ETOH		
Bits	**Field Name**	**Default**	**Access**	**Field Description**
0:7	ETH_LSB	0x00	R	Lower Byte of DATA_ETH
8:15	ETH_MSB	0x00	R	Upper Byte of DATA_ETH

16.2.11 DATA_ECO2 (Address 0x24)

This 2-byte register reports the calculated equivalent CO_2-concentration in ppm, based on the detected VOCs and hydrogen.

Table 30: Register DATA_ECO2

Address 0x24		DATA_ECO2		
Bits	**Field Name**	**Default**	**Access**	**Field Description**
0:7	ECO2_LSB	0x00	R	Lower Byte of DATA_ECO2
8:15	ECO2_MSB	0x00	R	Upper Byte of DATA_ECO2

See section "eCO2 - equivalent CO2" for further information.

16.2.12 DATA_AQI-S (Address 0x26)

This 2-byte register reports the calculated relative Air Quality Index, proprietary to ScioSense, in arbitrary units between 0 and 500.

Table 31: Register DATA_AQI_S

Address 0x26		DATA_AQI_S		
Bits	**Field Name**	**Default**	**Access**	**Field Description**
0:7	AQI_S_LSB	0x00	R	Relative Air Quality Index according to ScioSense [0..500]
8:15	AQI_S_MSB	0x00	R	

See section "AQI-S - relative Air Quality Index according to ScioSense" for further information.

16.2.13 DATA_T (Address 0x30)

This 2-byte register reports the temperature used in its calculations (taken from TEMP_IN, if supplied).

Table 32: Register DATA_T

Address 0x30		DATA_T		
Bits	**Field Name**	**Default**	**Access**	**Field Description**
0:7	DATA_T _LSB	0x8A	R	Lower Byte of DATA_T
8:15	DATA_T _MSB	0x4A	R	Upper Byte of DATA_T

The format of the temperature data is the same as the format used in the ENS21x.

Table 33: Format of temperature data

Byte 0x30								Byte 0x31							
7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
TEMP_IN Integer Part (Kelvin)								TEMP_IN Fractions							

The DATA_T storage format is: temperature in Kelvin * 64 (with Kelvin = Celsius + 273.15).

Example: For a stored DATA_T value of 0x4A8A the temperature in °C is calculated as follows: 0x4A8A / 64 - 273.15 = 25°C.

See section "TEMP_IN (Address 0x13)" for further information.

16.2.14 DATA_RH (Address 0x32)

This 2-byte register reports the relative humidity used in its calculations (taken from RH_IN if supplied).

Table 34: Register DATA_RH

Address 0x32		DATA_RH		
Bits	**Field Name**	**Default**	**Access**	**Field Description**
0:7	DATA_RH _LSB	0x00	R	Lower Byte of DATA_RH
8:15	DATA_RH_MSB	0x64	R	Upper Byte of DATA_RH

The format of the relative humidity data is the same as the format used in the ScioSense ENS21x product family.

Table 35: Format of relative humidity data

Byte 0x32								Byte 0x33							
7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
RH_IN Integer Part (%)								RH_IN Fractions							

The DATA_RH storage format is: relative humidity in %rH * 512.

Example: For a stored DATA_RH value of 0x6400 the relative humidity in % is calculated as follows: 0x6400 / 512 = 50%rH.

See section "RH_IN (Address 0x15)" for further information.

16.2.15 DATA_MISR (Address 0x38)

This 1-byte register reports the calculated checksum of the previous DATA_* read transaction (of n-bytes). It can be read as a separate transaction, if required, to check the validity of the previous transaction. The value should be compared with the number calculated by the host system on the incoming data.

Table 36: Register DATA_MISR

Address 0x38		DATA_MISR		
Bits	Field Name	Default	Access	Field Description
0:7	DATA_MISR	0x00	R	Calculated checksum of the previous transaction

Example: C-code to calculate MISR on the received DATA, to compare with DATA_MISR:

```
// The polynomial used in the CRC computation in DATA_MISR
//                      76543210 bit weight factor
#define POLY 0x1D // 0b00011101 = x^8+x^4+x^3+x^2+x^0 (x^8 is implicit)
// The hardware register DATA_MISR is updated with every read from a
// register in the range 0x20 to 0x37, using a CRC polynomial (POLY).
// For every register read, call `misr_update()` to keep the software
// variable `misr` in sync with the hardware register.
static uint8_t misr = 0; // Mirror of DATA_MISR (0 is hardware default)
uint8_t misr_update(uint8_t data) {
  uint8_t misr_xor= ( (misr<<1) ^ data) & 0xFF;
  if( misr&0x80==0 )
    misr= misr_xor;
  else
    misr= misr_xor ^ POLY;
}
// Typically, when an I2C/SPI transaction is completed, read DATA_MISR,
// and compare it with the software `misr`. They should equal. If not
// there is a CRC error: one or more bytes were corrupted in the transfer.
uint8_t misr_set(void) {
  return misr;
}
// Once the CRC is wrong, or transactions have been executed without
// calling update() the software `misr` is out of sync with DATA_MISR.
// Read DATA_MISR and call `misr_set()` to bring back in sync.
void misr_set(uint8_t * val) {
  misr= val;
}
```

16.2.16 GPR_WRITE (Address 0x40)

This 8-byte register is used by several functions for the Host System to pass data to the ENS161. Writes to these registers are not valid when the ENS161 is in DEEP SLEEP or during a low power portion of an operating mode. Writes should only be done during IDLE mode (OPMODE 0x01).

Table 37: Register GPR_WRITE

Address 0x40			GPR_WRITE0-7		
Address	**Bits**	**Field Name**	**Default**	**Access**	**Field Description**
0x40	0:7	GPR_WRITE0	0x00	R/W	General Purpose WRITE Register 0
0x41	0:7	GPR_WRITE1	0x00	R/W	General Purpose WRITE Register 1
0x42	0:7	GPR_WRITE2	0x00	R/W	General Purpose WRITE Register 2
0x43	0:7	GPR_WRITE3	0x00	R/W	General Purpose WRITE Register 3
0x44	0:7	GPR_WRITE4	0x00	R/W	General Purpose WRITE Register 4
0x45	0:7	GPR_WRITE5	0x00	R/W	General Purpose WRITE Register 5
0x46	0:7	GPR_WRITE6	0x00	R/W	General Purpose WRITE Register 6
0x47	0:7	GPR_WRITE7	0x00	R/W	General Purpose WRITE Register 7

16.2.17 GPR_READ (Address 0x48)

This 8-byte register is used by several functions for the ENS161 to pass data to the host system. When NEW_GPR_DATA is available the NEW_GPR bit of the DEVICE_STATUS register will be set and the INTn pin asserted (if configured).

Table 38: Register GPR_READ

Address 0x48			GPR_READ0-7		
Address	**Bits**	**Field Name**	**Default**	**Access**	**Field Description**
0x48	0:7	GPR_READ0	0x00	R	General Purpose READ Register 0
0x49	0:7	GPR_READ1	0x00	R	General Purpose READ Register 1
0x4A	0:7	GPR_READ2	0x00	R	General Purpose READ Register 2
0x4B	0:7	GPR_READ3	0x00	R	General Purpose READ Register 3
0x4C	0:7	GPR_READ4	0x00	R	General Purpose READ Register 4
0x4D	0:7	GPR_READ5	0x00	R	General Purpose READ Register 5
0x4E	0:7	GPR_READ6	0x00	R	General Purpose READ Register 6
0x4F	0:7	GPR_READ7	0x00	R	General Purpose READ Register 7

17 Application information

17.1 I2C operation circuitry

The recommended application circuit for the ENS161 I^2C interface operation is shown in Figure 15.

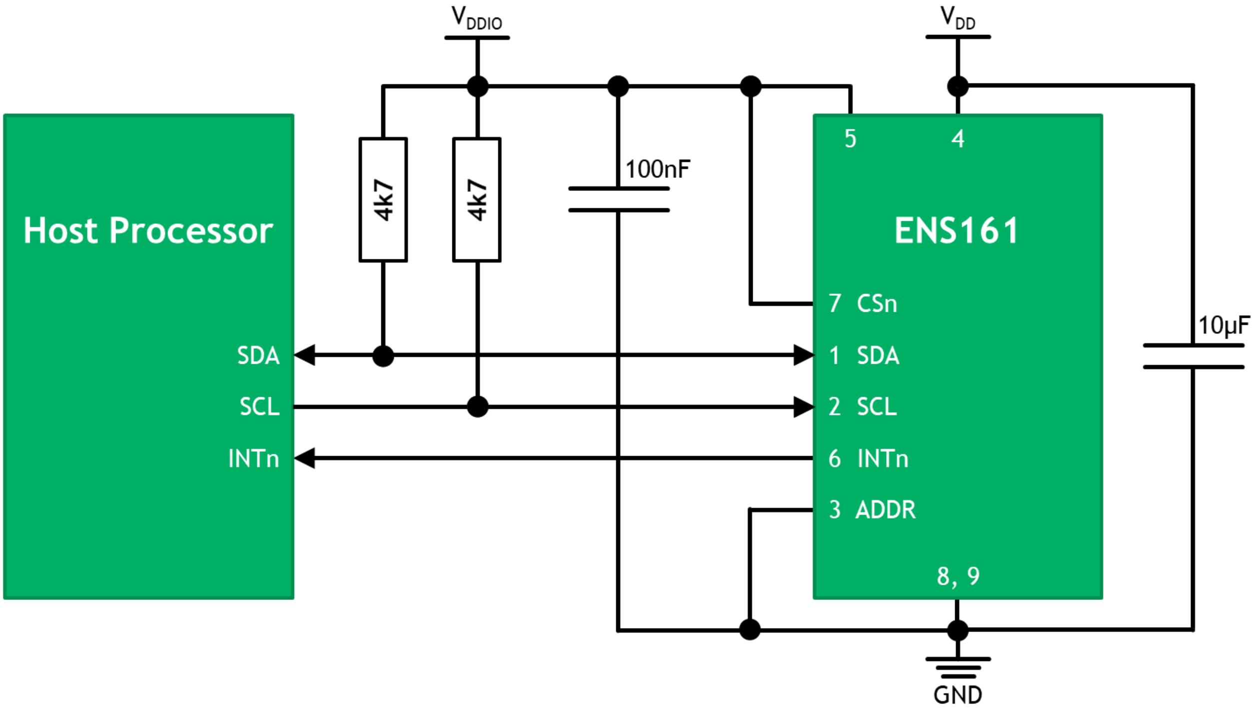


Figure 15: Recommended application circuit (I^2C operation)

Note(s):

1. **The minimum supply voltage V_{DD} is 1.71V and must not drop below this value for reliable device operation. Decoupling capacitors must be placed close to the V_{DD} (Pin 4) and V_{DDIO} (Pin 5) supply pins of the ENS161.**
2. CSn must be pulled high (directly to V_{DDIO}) to ensure I^2C interface is selected.
3. MISO/ADDR should be pulled low or high to specify the LSB of the address.
4. Pull-up resistors.
   The above recommendation for pull-up resistance values applies to I^2C standard mode only. Pull-up resistors for SCL and SDA are assumed to be part of the host system and should be selected dependent on the intended I^2C data rate and individual bus architecture.

17.2 SPI operation circuitry

The recommended application circuit for the ENS161 for SPI interface is shown in Figure 16.

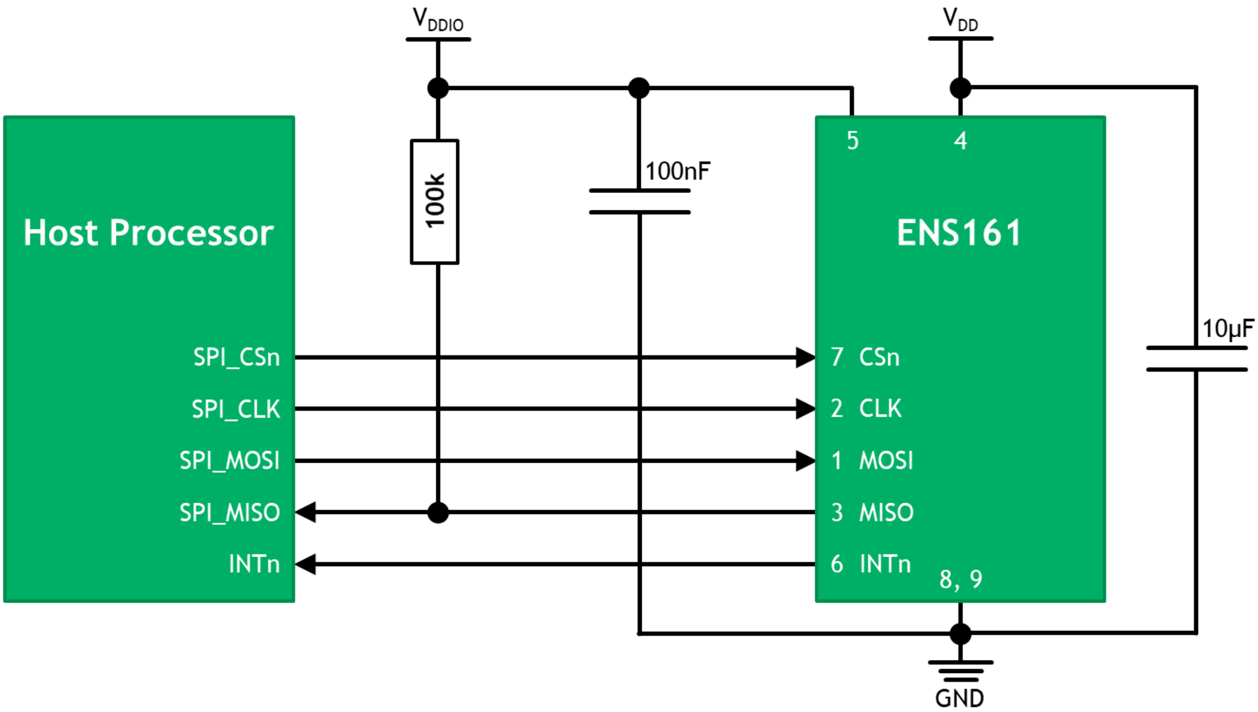


Figure 16: Recommended application circuit (SPI operation)

Note(s):

1. **The minimum supply voltage V_{DD} is 1.71V and must not drop below this value for reliable device operation. Decoupling capacitors must be placed close to the V_{DD} (Pin 4) and V_{DDIO} (Pin 5) supply pins of the ENS161.**
2. Weak pull-up resistor may be required for MISO to define the level when tri-stated.
3. Decoupling capacitors must be placed close to the V_{DD} (Pin 4) and V_{DDIO} (Pin 5) supply pins of the ENS161.

18 Soldering information

The ENS161 uses an open LGA package. This package can be soldered using a standard reflow process in accordance with IPC/JEDEC J-STD-020D (Figure 17).

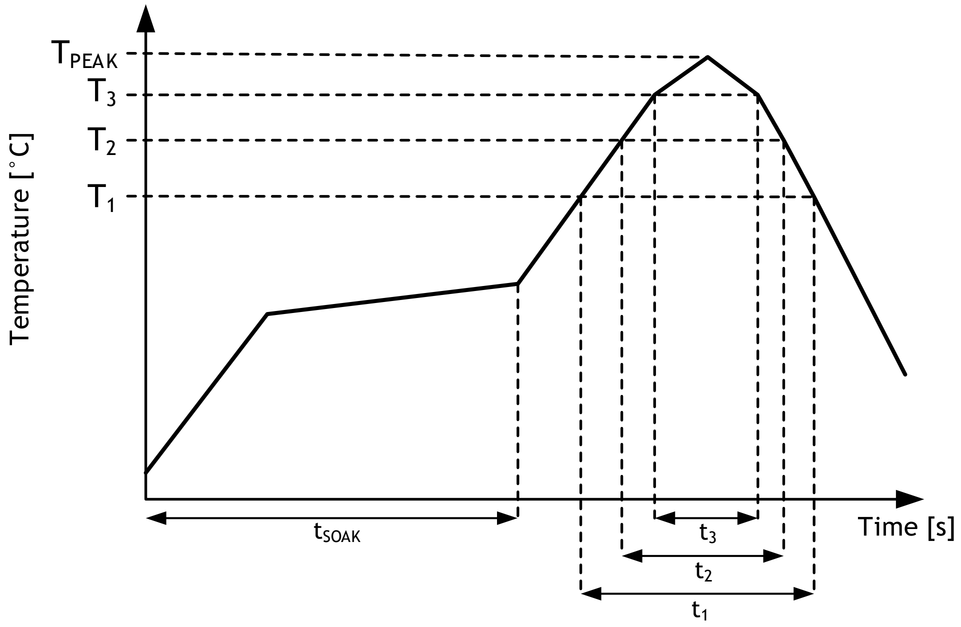


Figure 17: Solder reflow profile graph

The detailed settings for the reflow profile are shown in Table 39.

Table 39: Solder Reflow Profile

Parameter	Reference	Rate / Unit
Average temperature gradient in preheating		2.5K/s
Soak time	t_{SOAK}	2..3 min
Soak temp range	Ts max	200°C
	Ts min	150°C
Time above 217°C (T1)	t_1	Max. 60s
Time above 230°C (T2)	t_2	Max. 50s
Time above TPEAK -10°C (T3)	t_3	Max. 10s
Peak temperature in reflow	T_{PEAK}	260°C
Temperature gradient in cooling		Max. -5K/s

It is recommended to use a no-clean solder paste. There should not be any board wash processes, to prevent cleaning agents or other liquid materials contacting the sensor area.

19 Package drawings & markings

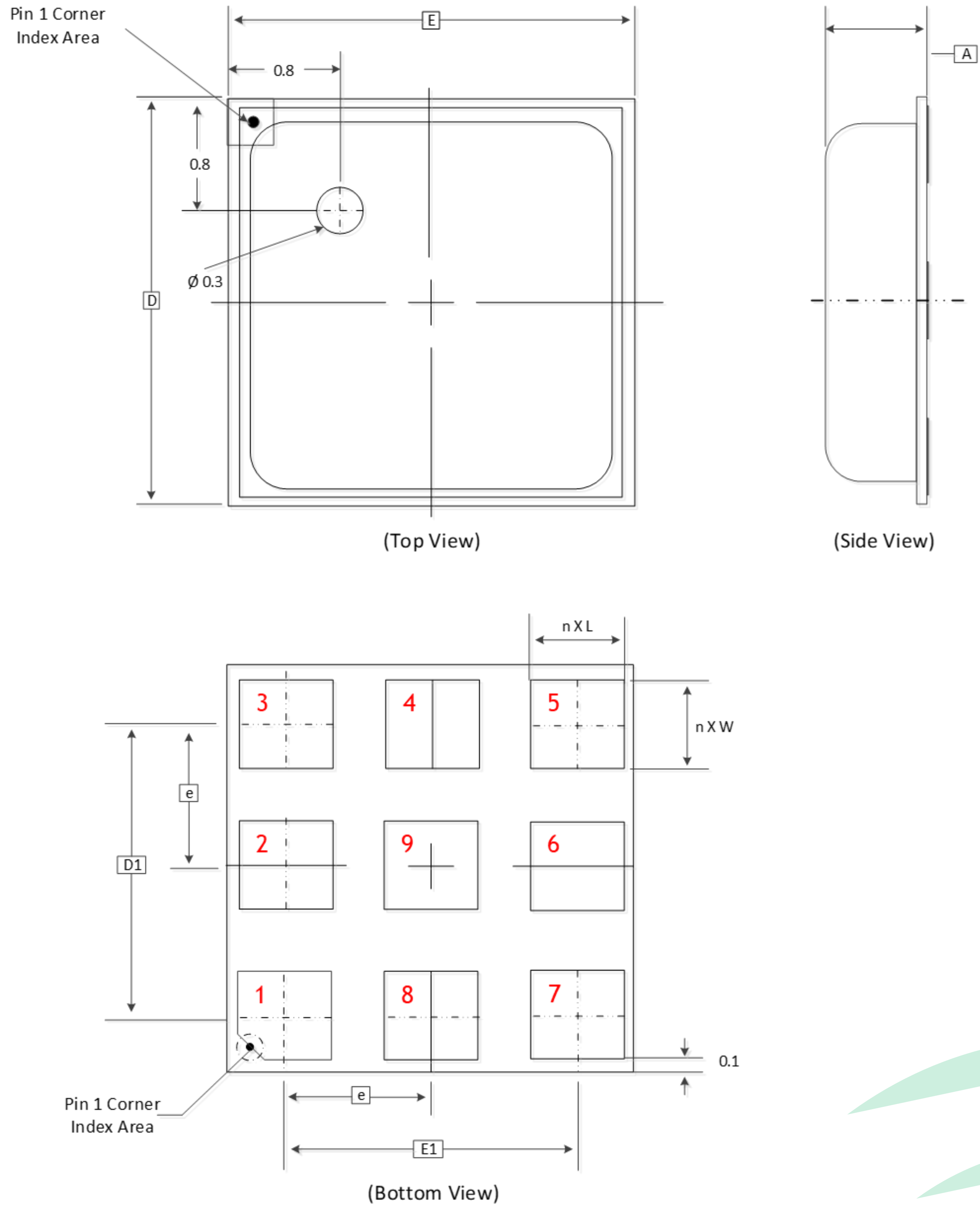
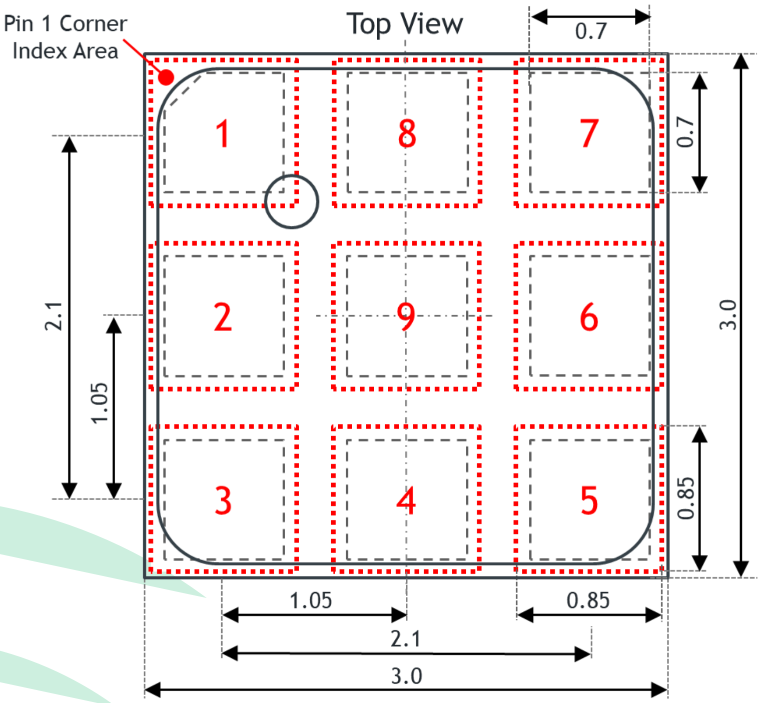


Figure 18: LGA package drawing

Table 40: LGA package dimensions

Parameter	Symbol	Dimensions		
		Min	Nominal	Max
Total thickness	A	-	0.83	0.9
Body Size	D		3.0	BSC
	E		3.0	BSC
Lead Width	W	0.65	0.7	0.75
Lead Length	L	0.65	0.7	0.75
Lead Pitch	e		1.05	BSC
Lead Count	n		9	
Edge Lead Centre to Centre	D1		2.1	BSC
	E1		2.1	BSC
Note: All dimensions are in mm				



Note(s):

1. All dimensions are in mm.
2. PCB land pattern are shown as red dotted lines.
3. Add 0.05mm all around the nominal lead width and length for the PCB land pattern.

Figure 19: Recommend LGA Land Pattern for ENS161

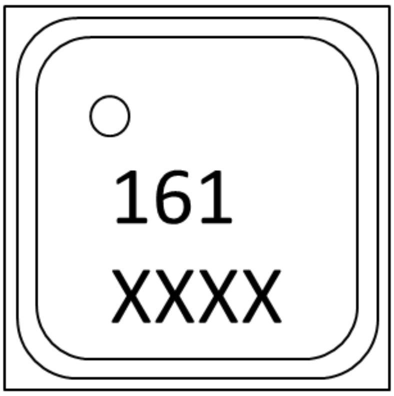


Figure 20: LGA package marking

20 Ordering information

Table 41: Ordering information

Ordering Code	Material ID	Package	Delivery Form	Delivery Quantity
ENS161-BLGM LGA9 T&R 500	507890002	9-pin LGA	Tape & reel	500 pcs
ENS161-BLGT LGA9 T&R 1k5	507890001	9-pin LGA	Tape & reel	1,500 pcs
ENS161-LG_EK_ST V1	507890004	PCB	box	1 pc

21 Support

Find code resources and drivers on: https://github.com/sciosense

22 RoHS Compliance & ScioSense Green Statement

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24 Document status

Table 42: Document status

Document Status	Product Status	Definition
Product Preview	Pre-Development	Information in this datasheet is based on product ideas in the planning phase of development. All specifications are design goals without any warranty and are subject to change without notice.
Preliminary Datasheet	Pre-Production	Information in this datasheet is based on products in the design, validation or qualification phase of development. The performance and parameters shown in this document are preliminary without any warranty and are subject to change without notice.
Datasheet	**Production**	**Information in this datasheet is based on products in ramp-up to full production or full production which conform to specifications in accordance with the terms of ScioSense B.V. standard warranty as given in the General Terms of Trade.**
Datasheet (Discontinued)	Discontinued	Information in this datasheet is based on products which conform to specifications in accordance with the terms of ScioSense B.V. standard warranty as given in the General Terms of Trade, but these products have been superseded and should not be used for new designs.

25 Revision information

Table 43: Revision history

Revision	Date	Comment	Page
1.1	2024-11-29	Remove ENS161-BLGR (5k pcs reel) from ordering information, which is EOL	43
1.0	2023-09-15	Initial release	All

Note(s) and/or Footnote(s):

1. Page and figure numbers for the previous version may differ from page and figure numbers in the current revision.
2. Correction of typographical errors is not explicitly mentioned.

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