ENS160

Digital Metal Oxide Multi-Gas Sensor

Digital Metal-Oxide Multi-Gas Sensor

The ENS160 is a digital multi-gas sensor solution, based on metal oxide (MOX) technology with four MOX sensor elements. Each sensor element has independent hotplate control to detect a wide range of gases e.g. volatile organic compounds (VOCs) including ethanol, toluene, as well as hydrogen and nitrogen dioxide with superior selectivity and accuracy. For indoor air quality applications, the ENS160 supports intelligent algorithms to digitally process raw sensor measurements on-chip. These algorithms calculate CO_2-equivalents, TVOC, various air quality indices (AQIs) and perform humidity and temperature compensation, as well as baseline management – all on chip! Moreover, a development option is available to digitally output raw sensor measurements from each sensor element for customization. The LGA packaged device includes an SPI or I^2C slave interface with separate VDDIO to communicate with a main host processor. The ENS160 is a proven and maintenance-free technology, designed for high volume and reliability.

Key Features & Benefits

TrueVOC air quality detection with industry-leading purity and stability, providing multiple outputs e.g. eCO_2[1], and TVOC in compliance with worldwide IAQ[2]-signal standards

Independent Sensor Heater Control for highest selectivity (e.g. to ethanol, toluene and acetone) and outstanding background discrimination

Immunity to humidity[3]

Hassle-free on-chip heater drive control and data processing – no need for external libraries – no mainboard-CPU performance impacts

Interrupt on Threshold for low-power applications

Wide operating ranges: temperature: -40 to +85°C; humidity: 5 to 95%[4]; V_{DD}: 1.71 to 1.98V; V_{DDIO} 1.71 to 3.6V

Applications

- Building Automation / Smarthome / HVAC[5]
  - Indoor air quality detection
  - Demand-controlled ventilation
  - Smart thermostats
- Home appliances
  - Cooker hoods
  - Air cleaners / purifiers
- Mobiles / Wearables
- IoT devices

Properties

- Small-3 x 3 x 0.9mm LGA package
- Design-flexibility through standard, fast and fast mode plus I^2C- and SPI-interfaces with separate VDDIO up to 3.6V
- T&R packaged, reflow-solderable[6]

1 eCO_2 = equivalent CO_2 values for compatibility with HVAC ventilation standards
2 IAQ = Indoor Air Quality
3 T/RH compensation via external T/RH-input
4 Non-condensing
5 HVAC = Heat, Ventilation and Air Conditioning
6 See section "Soldering Information" for further details

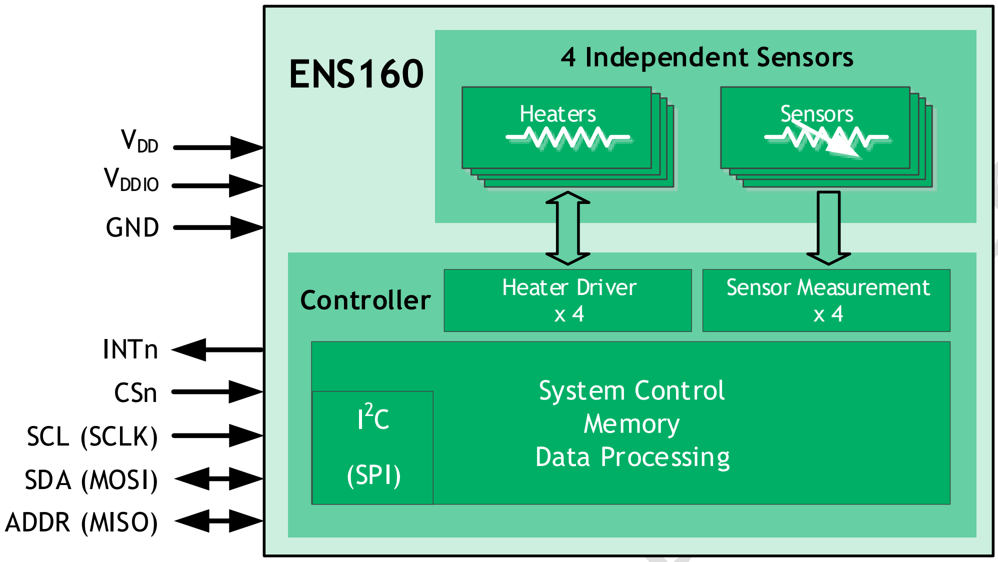
Add: 16/F, Bldg. #3, Zhongke Mansion, No.1 Hi-Tech S. Rd, Hi-Tech Park South, Shenzhen, Guangdong, 518067 P.R.China
Tel: + 86-755-83289036 Fax: + 86-755-83289052 E-mail: sales@isweek.com

Content Guide

1 Block Diagram

The ENS160 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 sensor resistance for each individual sensor element.

The *system control* block processes the resistance values internally to output calculated TVOC, CO_2-equivalents and further signals on the digital interface.

The ENS160 includes a standard 2-wire digital *I²C interface* (SCL, SDA) or 4-wire digital *SPI interface* (SCLK, MOSI, MISO, CSn) for communication to the main host processor.

On-chip memory is used to store calibration values.

2 Pin Assignment

The ENS160 pin assignment is described in the following figures.

Figure 2: Pin Diagram

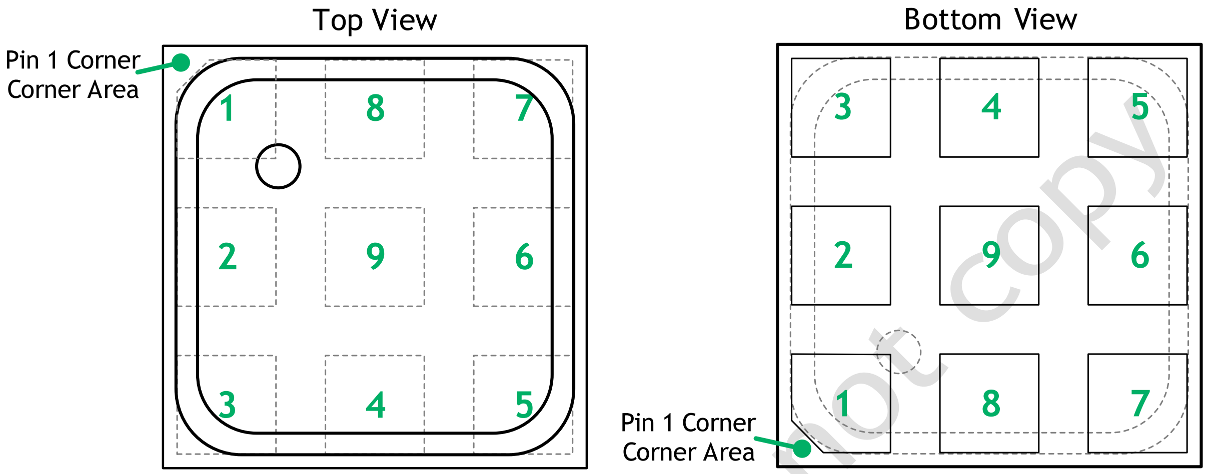


Table 1: Pin Description

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	AEC-Q100-004
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}[1]	Operating Ambient Temperature	-40	85	°C	
RH_{AMB}[1]	Operating Ambient Rel. Humidity	5	95	%	Non-condensing
L_T[2]	Product Lifetime	10		Years	

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: Although being able to detect potentially safety-relevant gases, the ENS160 is not designed for use in any safety-critical or life-protecting application.

1 The ENS160 is electrically operable in this range, however its gas sensing performance might vary. Please refer to "Recommended Sensor Operation" for further information.
2 At normal, non-poisonous, non-aggressive/non-acidic air and typical environmental conditions i.e. 25°C, 50% RH. Please refer to "Recommended Sensor Operation" for further information.

4 Electrical Characteristics

The following figure details the electrical characteristics of the ENS160.

Table 3: Electrical Characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{DD}	Positive supply		1.71	1.8	1.98	V
V_{DDIO}	IO Supply Voltage		1.71		3.6	V
I_{DD}	Average[1] Supply Current[2]	Mode 0 (DeepSleep)[3]		10		µA
		Mode 1 (IDLE)[3]		2	2.5	mA
		Mode 2 (single hotplate)		10		mA
		Mode 2 (4 hotplates)		33		mA
		Mode 3 (pulse1)				mA
		Mode 4 (pulse2)				mA
I_{DD_PK}	Peak Supply Current[2] [4]	Mode 2 (single hotplate)		36 (<5ms)		mA
		Mode 2 (4 hotplates)		85 (<5ms)		mA
		Mode 3 (pulse1)[1]				mA
		Mode 4 (pulse2)[1]				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[5] [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

1 Averaged over the sequence
2 Measured at V_{DD}-pin at ambient temperature of 35°C and V_{DD} = 1.98V
3 Not a gas sensing mode
4 Initial (<5ms) current demand from VDD after the sensor is switched from IDLE (Mode 1) to operation (Mode 2)
5 MOSI/SDA is open drain

5 Air Quality Signal Characteristics

To satisfy a wide range of individual application requirements, the ENS160 offers a series of (indoor) air quality output signals that are derived from various national and international, as well as de-facto standards. Table 4 provides a summary of such signals, with further description in the following sections.

Table 4: Air Quality Signal Output Characteristics

Parameter	Range	Resolution	Unit	Comment
TVOC	0 - 65'535	1	ppb	For requirements outside these specified ranges please contact us
eCO_2	400 - 65'535	1	$ppmCO_2$ equivalents	

5.1 TVOC - Total Volatile Organic Compounds

About 5,000 to 10,000 different VOCs exist. 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. VOCs are known to cause eye irritations, headache, drowsiness or, even dizziness, all summarized under the term SBS[1]. Besides industrial applications, comfort aspects (e.g. temperature), or building protection (humidity), VOCs are the one and only root cause for the need to ventilate. Please refer to our "Air Quality Solutions" brochure 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 representatives of the various groups of VOCs (e.g. ISO16000-29), and more, to mention a few.

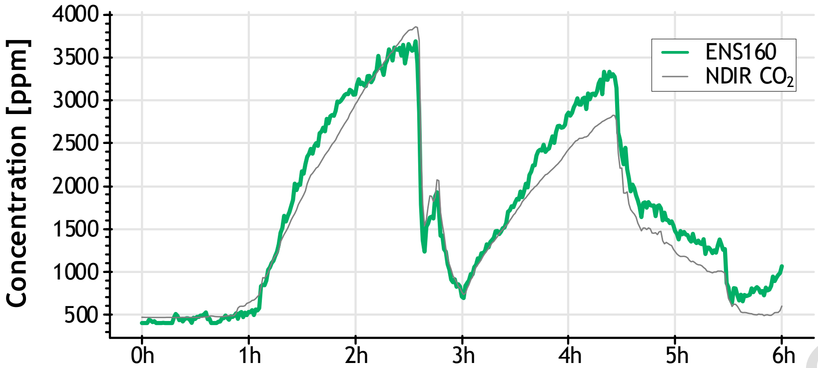
The ENS160 supplies calibration to ethanol for best, most balanced TVOC-results.

5.2 eCO_2 - Equivalent CO_2

Due to the proportionality between VOCs and -CO_2 generated by humans, CO_2-values historically served as an air quality indicator, reflecting the total amount of VOCs (=TVOCs) produced by human respiration and transpiration. This law (as first revealed by Max von Pettenkofer[2] in the 19^{th} 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 – as adopted by most HVAC industry standards.

1 SBS = Sick Building Syndrome
2 Max von Pettenkofer (*1818 – †1901), German chemist and hygienist

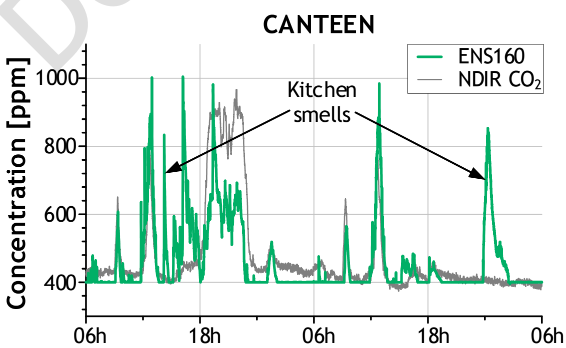
Figure 3: ENS160-based equivalent CO_2 (eCO_2) vs. NDIR-based CO_2 during two meeting sessions

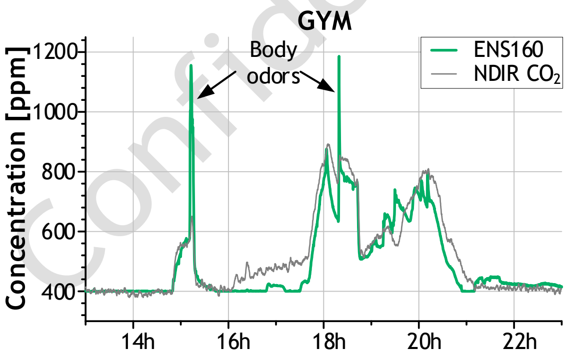


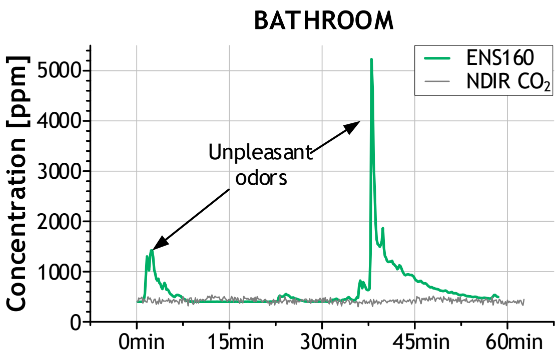
Taking advantage of its RMR[1]-technology, today, the ENS160 reverses the proportional correlation of VOCs and CO_2, by providing a standardized output signal in ppmCO_2-equivalents from measured VOCs plus hydrogen, thus ad-hering to today's CO_2-standards, as the diagram on the left testifies: ENS160-based equivalent CO_2 estimate vs. CO_2, detected by an NDIR-sensor during two consecutive meeting sessions, interrupted by a lunch-break.

Figure 4: Added value of ENS160's eCO_2 Outputs -where plain CO_2 sensors fail

The major advantage of the ENS160 is the ability to capture odors and bio-effluents that are completely invisible to CO_2-sensors. The below diagrams, compare the ENS160's equivalent CO_2 output to an NDIR CO_2 sensor in various typical environments: CO_2 sensors did not detect any of the unpleasant odors, bio-effluents or kitchen smells in a bathroom environment, gym- or restaurant-application whereas the ENS160 reliably reports such events.







Proven control-algorithms minimize sensor drift and ageing to provide reliable readings over lifetime, thereby making the ENS160's equivalent CO_2 output an affordable solution to truly substitute real CO_2-based air-quality sensors in the HVAC domain. Please refer to our "Air Quality Solutions" brochure for further information.

1 RMR = Reverse Metabolic Rule, reversing the "Pettenkofer law" to achieve signal compatibility between eCO2 and CO2

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

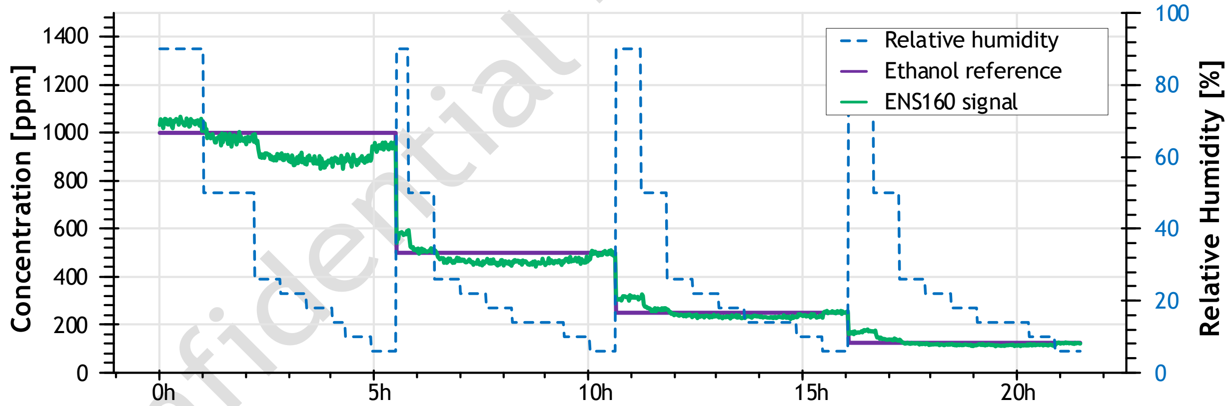
The above table shows a typical classification of (equivalent) CO_2 output levels.

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 section “Registers” and “DATA_ECO2 (Address 0x24)” on how to obtain equivalent CO_2-values from the ENS160.

6 Humidity Compensation

Figure 5: Ethanol Response at Various Humidity Levels

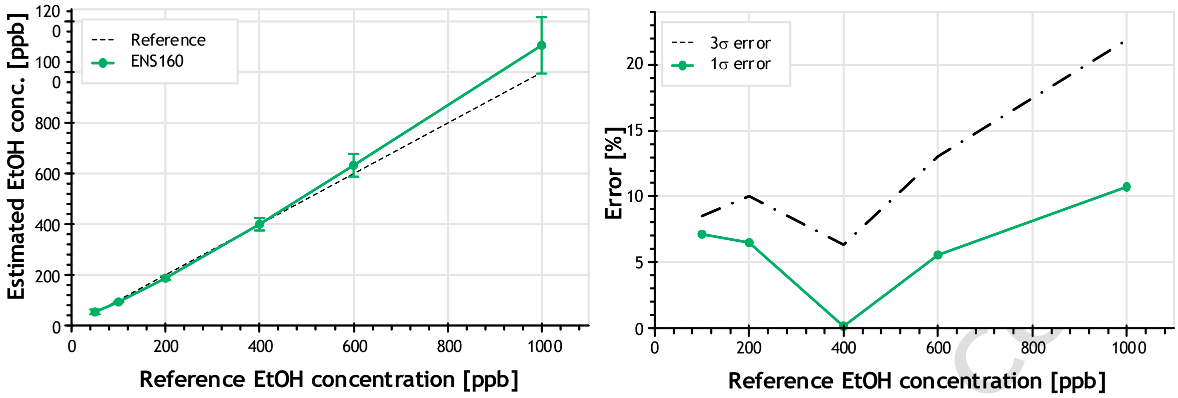


Extreme humidity conditions (<20% and >80% RH) or sudden, significant changes, thereof may influence the output signals. To overcome such impacts, the ENS160 is equipped with a temperature and humidity compensation algorithm, relying on data from an external temperature and humidity-source, that can be regularly updated to an internal register for processing (See section “Registers” for further information). The diagram on the left shows the ENS160’s response to various ethanol concentrations[1] while impacted by significant humidity changes.

1 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

7 Output Signal Accuracy[1]

Figure 6: Output Signal Accuracy for Ethanol



The diagrams show the typical and maximum (3σ) accuracies of the ethanol signal. A typical error of maximum 10% of the measured value can be derived.

8 Initial Start-Up and Warm-Up

Table 6: Initial Start-Up and Warm-Up Timings

Parameter	Maximum Time	Comment
Initial Start-Up	60 minutes	See below for further details
Warm-Up	5 minutes	See below for further details

8.1 Initial Start-Up

The ENS160 performance in terms of sensor raw resistance signals and sensitivities will change upon its first power-on. This change in resistance is greatest over the first 48 hours of operation. Therefore, the ENS160 comprises an initial start-up algorithm, allowing its output signals (e.g. eCO_2 and TVOC) to be used from first power-on after 60 minutes of operation in any of the relevant gas sensing modes[2].

8.2 Warm-Up

Besides "Initial Start-Up" the conditioning or "Warm-Up" period is the time required to achieve adequate sensor stability before measuring VOCs after long idle periods or power-off. The ENS160 requires a minimum of 5 minutes warm-up before accurate readings can be expected[1].

1 All results derived from 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, the accuracy statements have been carried out at 25°C and 50% relative humidity.

2 Slightly reduced signal accuracy may be encountered in early phase, thereafter

9 Recommended Sensor Operation

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

Important Note: Although being able to detect potentially safety-relevant gases, the ENS160 is not designed for use in any safety-critical or life-protecting application.

10 Recommended Sensor Storage

The guidelines under "Recommended Sensor Operation" also apply for its storage.

11 Host Communication

The ENS160 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.

11.1 I²C Specification

11.1.1 I²C Description

The ENS160 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 May 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 ENS160 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.

11.1.2 I²C I/O and Timing Information

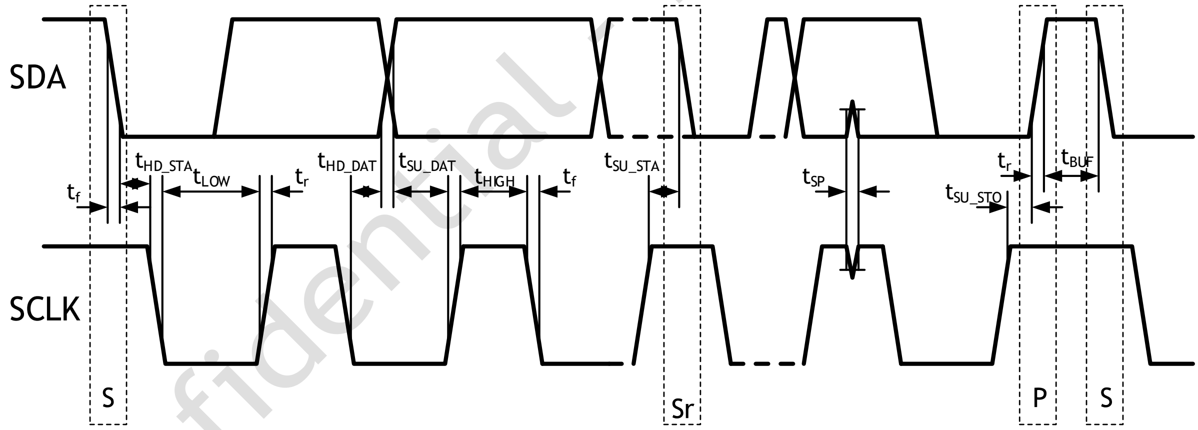
Table 7: ENS160 I²C I/O Parameters

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 8: ENS160 I^2C Timing Parameters[1]

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 [2]	-	50 [2]	-	ns
Data hold-time	t_{HD_DAT}	0 [3]	3.45 [4]	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 7: Definition of I^2C Timing Parameters



[1] All values referred to V_{IHmin} and V_{ILmax} levels
[2] A fast mode I^2C bus device can be used in Standard mode I^2C bus system, 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 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 I^2C bus specification) before the SCL line is released.
[3] 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
[4] 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

11.1.3 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 8: I²C Read Operation

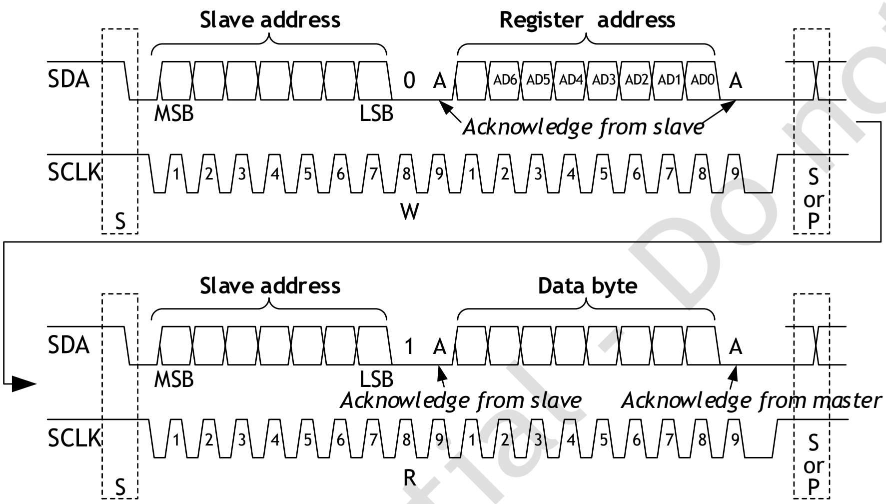
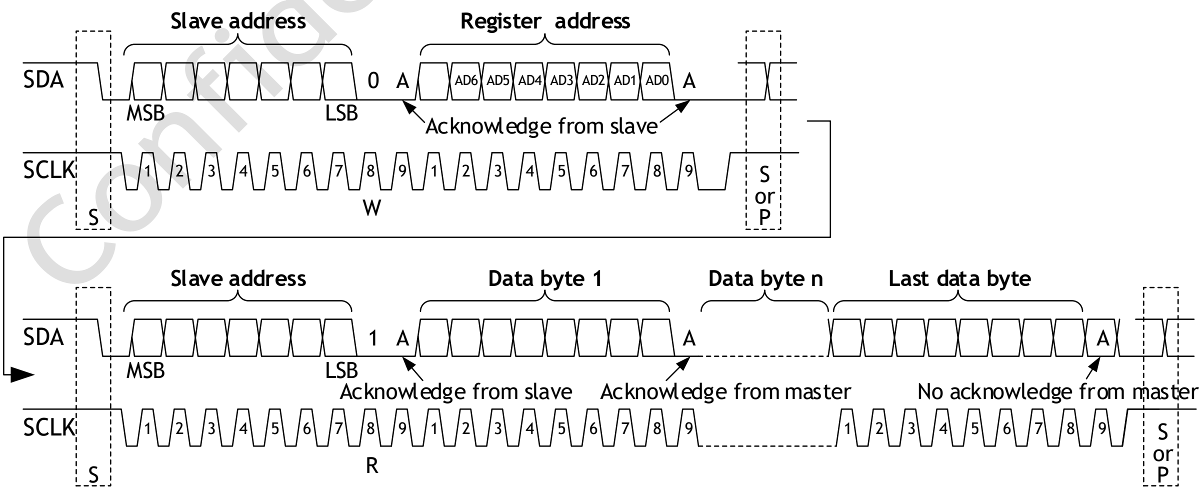


Figure 9: I²C Auto-Increment Read Operation



11.1.4 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 10: I²C Write Operation

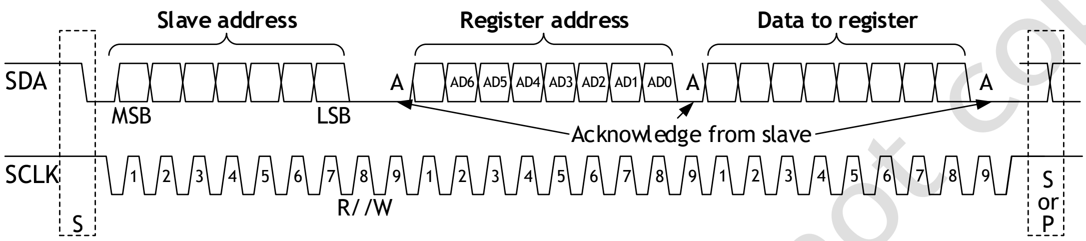
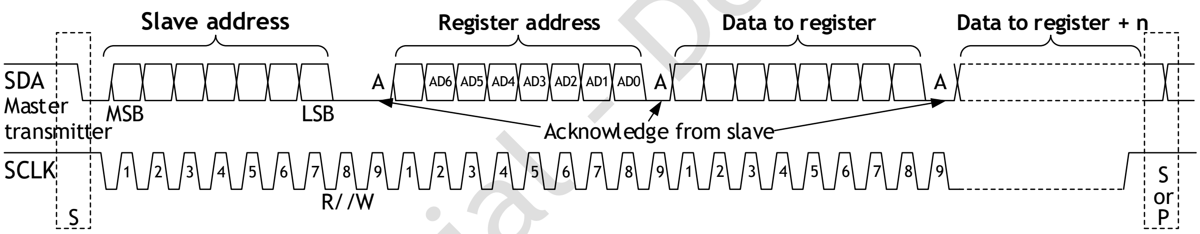


Figure 11: I²C Auto-Increment Write Operation



11.2 SPI Specification

11.2.1 SPI Description

The SPI interface is a slave bus that can operate with up to 10MHz 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 ENS160 will not accept I²C transactions until the next Power-On Reset.

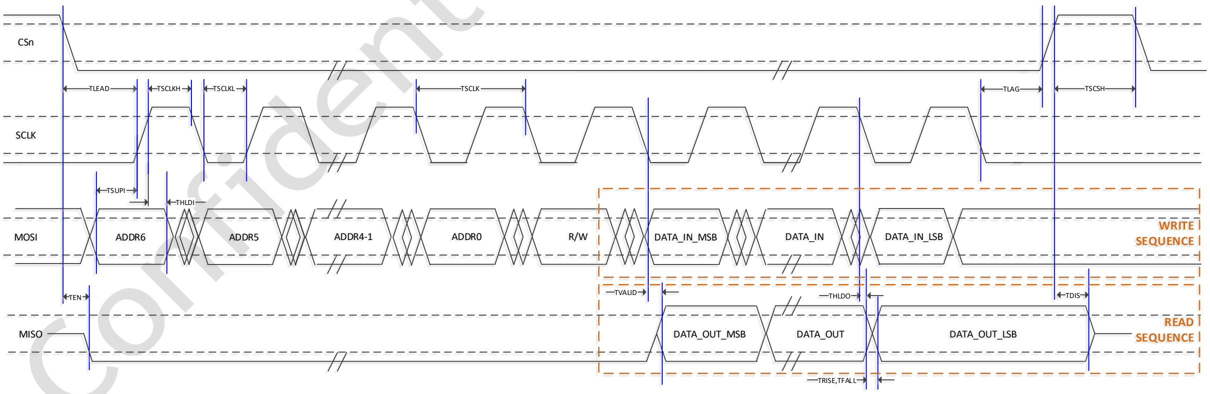
Data is clocked in on the rising edge of SCLK; most significant bit first.

11.2.2 SPI Timing Information

Table 9: 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 12 SPI Timings Reference



11.2.3 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 10: 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

11.2.4 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 11: 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

12 Functional Description

Please refer to first pages for functional description.

13 Operation

At power-up, the ENS160 configures itself from a reset state and prepares for commands over the serial bus via either I^2C or SPI Protocols.

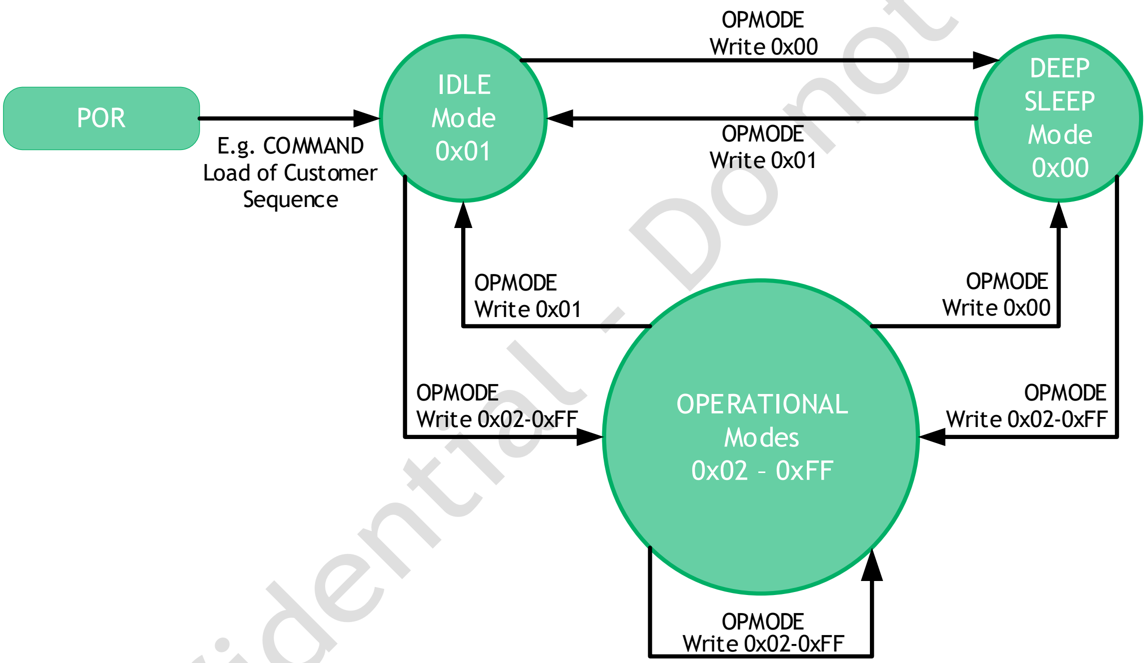
The default state is OPMODE 1, which is an IDLE condition that enables ENS160 so that it may respond to several commands. In this mode it is not operating as a gas sensor.

OPMODE 0 is a very low power standby state. ENS160 exits from the standby state when the user asks to execute a different OPMODE.

Active OPMODEs are described further in the OPMODE Register section.

When active gas sensing OPMODEs are running, new data is notified either via the interrupt (INTn) or by polling the DATA_STATUS register. The output of the gas sensing OPMODEs are presented in the DATA_XXX registers which can be read at any time.

Figure 13: Operating Modes



14 Registers

This section describes the registers of the ENS160 which enable the host system to

- Identify the Device and version information
- Configure the ENS160 and set the operating mode
- Read back STATUS information, the calculated gas concentrations and Air Quality Indices

14.1 Register Overview

Note that some registers are actually 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 12: Register Overview

Address	Name	Size	Access	Description
0x00	PART_ID	2	Read	Device Identity 0x01, 0x60
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	-	1	Read	Reserved
0x22	DATA_TVOC	2	Read	TVOC Concentration (ppb)
0x24	DATA_ECO2	2	Read	Equivalent CO_2 Concentration (ppm)
0x26	-	2	Read	Reserved
0x28	-	2	Read	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

Add: 16/F, Bldg. #3, Zhongke Mansion, No.1 Hi-Tech S. Rd, Hi-Tech Park South, Shenzhen, Guangdong, 518067 P.R.China
Tel: + 86-755-83289036 Fax: + 86-755-83289052 E-mail: sales@isweek.com

14.2 Detailed Register Description

14.2.1 PART_ID (Address 0x00)

This 2-byte register contains the part number in little endian of the ENS160.

The value is available when the ENS160 is initialized after power-up.

Table 13: Register PART_ID

Address 0x00				PART_ID
Bits	Field Name	Default	Access	Field Description
0:7	PART_ID_LSB	0x60	read	Lower Byte of Part ID
8:15	PART_ID_MSB	0x01	read	Upper Byte of Part ID

14.2.2 OPMODE (Address 0x10)

This 1-byte register sets the Operating Mode of the ENS160. The Host System can write a new OPMODE at any time including when the ENS160 is in DEEP SLEEP.

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

Table 14: Register OPMODE

Address 0x10				OPMODE
Bits	Field Name	Default	Access	Field Description
7:0		0x00	R/W	Operating mode: 0x00: Deep sleep mode (low power standby) 0x01: Idle mode (low-power) 0x02 – 0xFF: Gas Sensing Modes (except 0x0F) 0x0F: Software reset (full system reset)

In Deep sleep mode, ENS160 has limited functionality but will respond to an OPMODE write.

Idle Mode is intended for configuration before running an active sensing mode.

0x02-0xFF (except 0x0F) are active gas sensing operating modes.

Note: Only OPMODE 0x02 can currently be used as standard gas sensing mode.

14.2.3 CONFIG (Address 0x11)

This 1-byte register configures the action of the INTn pin which allows the ENS160 to signal to the host system that particular data is available.

The INTn pin can be (de-)asserted (polarity configurable) when ENS160 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 15: 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	INTTH	0b0	R/W	INTn pin asserted when previously configured thresholds are reached
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

14.2.4 COMMAND (Address 0x12)

This 1-byte register allows some additional commands to be executed on the ENS160. This register can be written at any time, however, 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 ENS160.

Typically, a request for data (e.g. GetVer) 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 ENS160.

Table 16: Register COMMAND

Address 0x12				COMMAND
Bits	**Field Name**	**Default**	**Access**	**Field Description**
7:0	Command	0x00	R/W	List of commands 0x01: GETVER – Get ENS160 Version

(1) GETVER

After issuing GetVer, the version of the ENS160 will be placed in General Purpose Registers GPR_READ0 and GPR_READ1. The NEWGPR bit in DATA_STATUS will be set and the INTn asserted if configured to react to NEWGPR.

Table 17: GPR_READ Settings for GETVER Command

Register	7	6	5	4	3	2	1	0
GPR_READ0	Release				Version			
GPR_READ1	Sub-Version							

14.2.5 TEMP_IN (Address 0x13)

This 2-byte register allows the host system to write ambient temperature data to ENS160 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 18: 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 as shown below:

Table 19: Format of Temperature Data

Temperature in Kelvin * 64. Kelvin = Celsius + 273.15. 0x4A8A is equivalent to 25 Celsius.

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					

14.2.6 RH_IN (Address 0x15)

This 2-byte register allows the host system to write relative humidity data to ENS160 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 20: 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 21: Format of Relative Humidity Data

Relative Humidity * 512.

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								

14.2.7 DATA_STATUS (Address 0x20)

This 1-byte register indicates the current STATUS of the ENS160.

Table 22: Register DATA_STATUS

Address 0x20				DATA_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	THRESH	0b0	R	High means that the threshold (for xxx, if previously set) has been reached.
3	-	0b0	R	Reserved
2	-	0b0	R	Reserved
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 DATA_STATUS is asserted if an error has occurred.

Further information regarding the error can be read from the GPR_READ registers.

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

14.2.8 DATA_TVOC (Address 0x22)

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

Table 23: Register DATA_TVOC

Address 0x22				DATA_TVOC
Bits	Field Name	Default	Access	Field Description
0:7	TVOC_LSB	0x00	R	Lower Byte of DATA_TVOC
8:15	TVOC _MSB	0x00	R	Upper Byte of DATA_TVOC

14.2.9 DATA_ECO2 (Address 0x24)

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

Table 24: 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

14.2.10 DATA_T (Address 0x30)

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

Table 25: 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 26: Format of Temperature Data

Temperature in Kelvin * 64. Kelvin = Celsius + 273.15. 0x4A8A is equivalent to 25 Celsius.

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					

14.2.11 DATA_RH (Address 0x32)

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

Table 27: 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 ENS21x.

Table 28: Format of Relative Humidity Data

Relative Humidity * 512. 0x6400 is equivalent to 50%RH.

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							

14.2.12 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 29: 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 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;
}
```


Add: 16/F, Bldg. #3, Zhongke Mansion, No.1 Hi-Tech S. Rd, Hi-Tech Park South, Shenzhen, Guangdong, 518067 P.R.China
Tel: + 86-755-83289036 Fax: + 86-755-83289052 E-mail: sales@isweek.com

14.2.13 GPR_WRITE (Address 0x40)

This 8-byte register is used by several functions for the Host System to pass data to the ENS160.

Writes to these registers are not valid when the ENS160 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 30: 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

14.2.14 GPR_READ (Address 0x48)

This 8-byte register is used by several functions for the ENS160 to pass data to the Host System.

When New GPR_DATA is available the NEW_GPR bit of the DATA_STATUS register will be set and the INTn pin asserted (if configured).

Table 31: Register GPR_READ

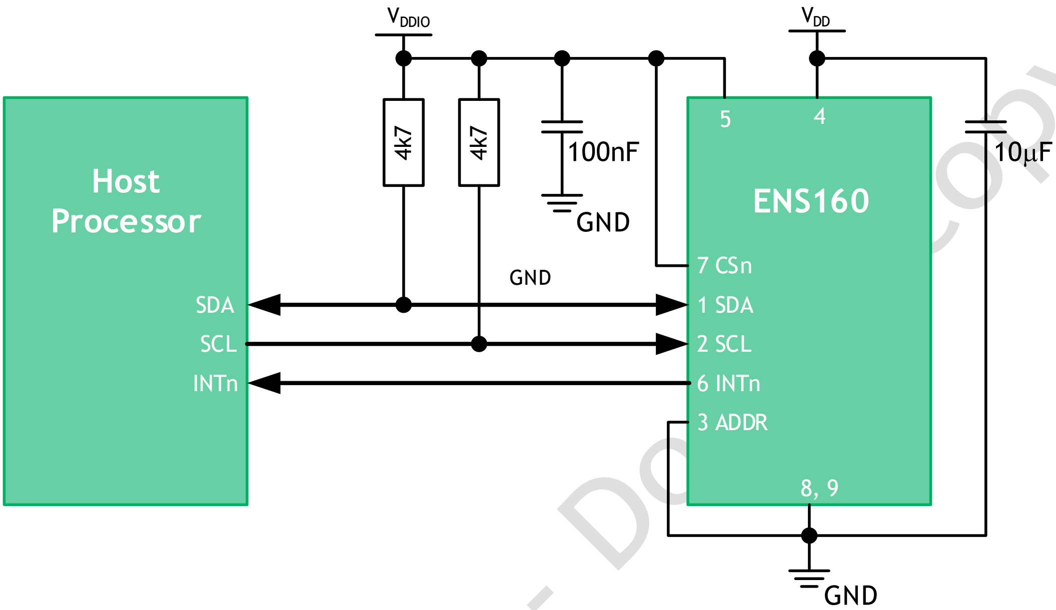
Address 0x48			GPR_READ0-7		
Address	Bits	Field Name	Default	Access	Field Description
0x48	0:7	GPR_READ0	0x00	R	General Purpose READ Register 0
0x49	0:7	GPR_READ1	0x00	R	General Purpose READ Register 1
0x50	0:7	GPR_READ2	0x00	R	General Purpose READ Register 2
0x51	0:7	GPR_READ3	0x00	R	General Purpose READ Register 3
0x52	0:7	GPR_READ4	0x00	R	General Purpose READ Register 4
0x53	0:7	GPR_READ5	0x00	R	General Purpose READ Register 5
0x54	0:7	GPR_READ6	0x00	R	General Purpose READ Register 6
0x55	0:7	GPR_READ7	0x00	R	General Purpose READ Register 7

15 Application Information

15.1 I²C Operation Circuitry

The recommended application circuit for the ENS160 I²C interface operation is shown below:

Figure 14: Recommended Application Circuit (I²C Operation)



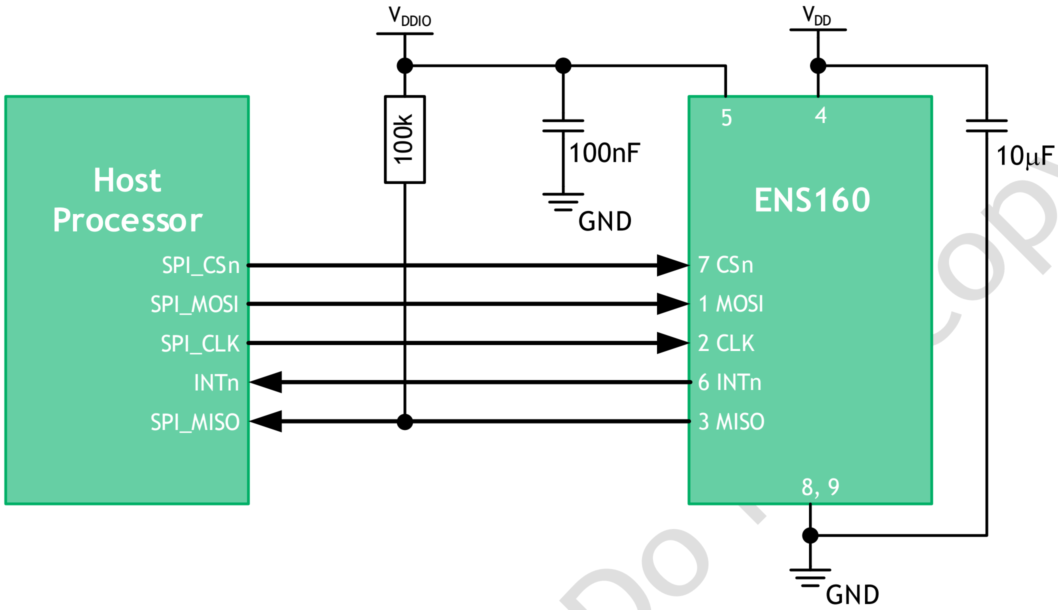
Note(s):

1. CSn must be pulled high (directly to V_{DDIO}) to ensure I²C interface is selected
2. MISO/ADDR should be pulled low or high to specify the LSB of the address
3. Pull-up resistors
   The above recommendation for pull-up resistance values applies to I²C 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 I²C data rate and individual bus architecture.
4. Decoupling capacitor must be placed close to the V_{DD} (Pin 4) and V_{DDIO} (Pin 5) supply pins of the ENS160

15.2 SPI Operation Circuitry

The recommended application circuit for the ENS160 for SPI interface is shown below:

Figure 15: Recommended Application Circuit (SPI Operation)



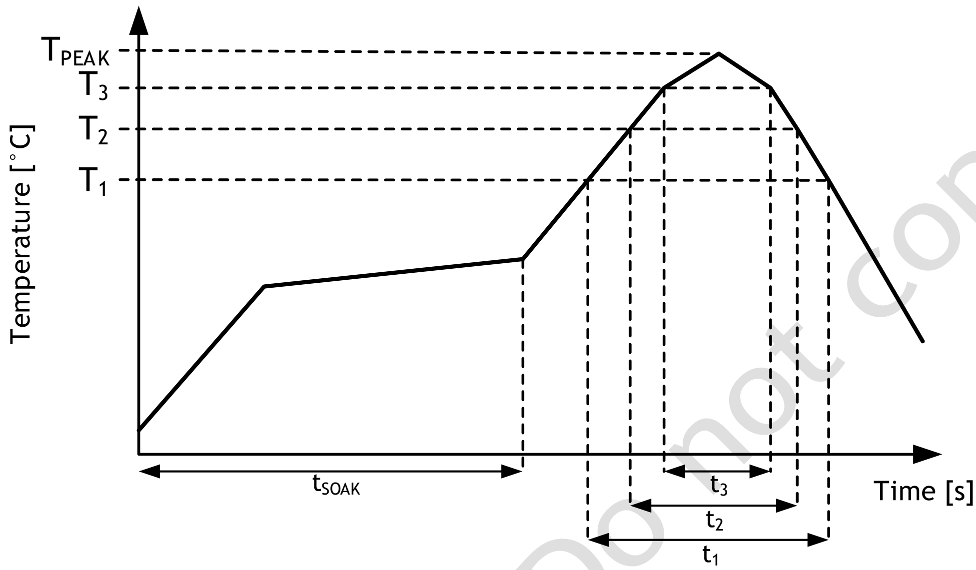
Note(s):

1. Weak pull-up resistor may be required for MISO to define the level when tri-stated
2. Decoupling capacitors must be placed close to the V_{DD} (Pin 4) and V_{DDIO} (Pin 5) supply pins of the ENS160

16 Soldering Information

The ENS160 uses an open LGA package. This package can be soldered using a standard reflow process in accordance with IPC/JEDEC J-STD-020D.

Figure 16: Solder Reflow Profile Graph



The detailed settings for the reflow profile are shown in the table below.

Table 32: 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 (T_1)	t_1	Max. 60s
Time above 230°C (T_2)	t_2	Max. 50s
Time above T_{PEAK} -10°C (T_3)	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.

17 Package Drawings & Markings

Figure 17: LGA Package Drawing

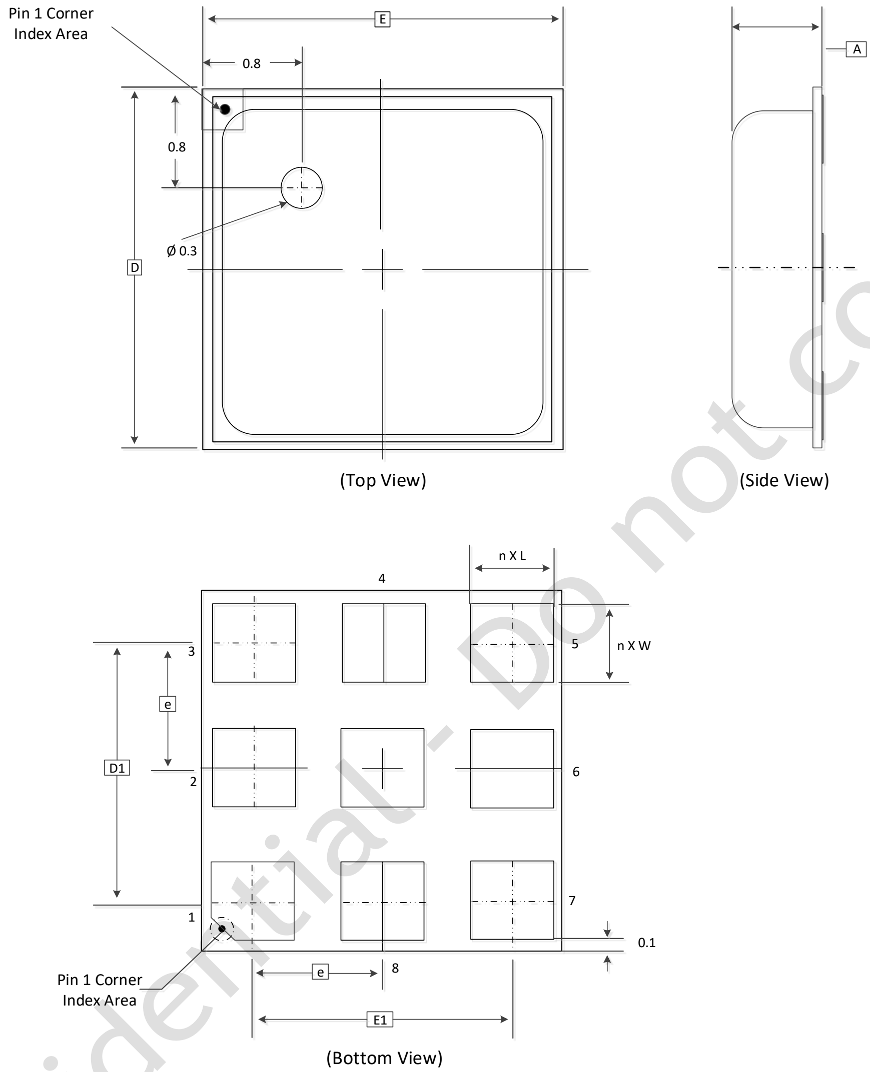
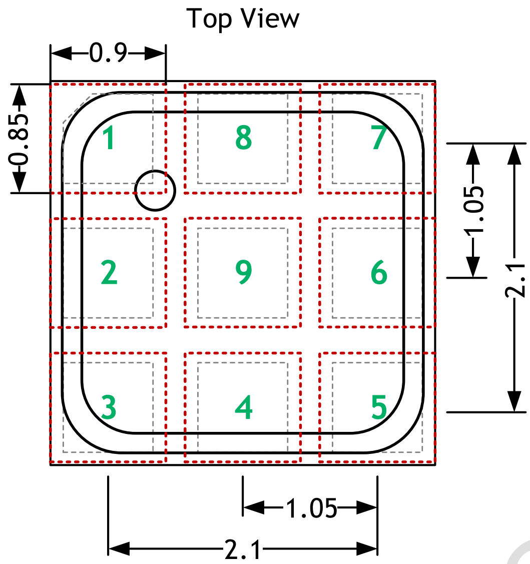


Table 33: LGA Package Dimensions

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				

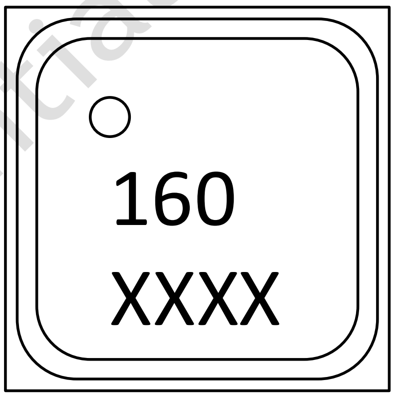
Figure 18: Recommend LGA Landing Pattern for ENS160



Note(s):

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

Figure 19: LGA Package Marking



The package has a marking with TC_4 trace-code according to Cspec 507870020.

18 Ordering & Contact Information

Table 34: Ordering Information

Ordering Code	Package	Marking	Delivery Form	Delivery Quantity
ENS160	LGA	160	Tape & Reel	5k TBD

19 RoHS Compliance & ScioSense Green Statement

RoHS: The term RoHS compliant means that ScioSense B.V. products fully comply with current RoHS directives. Our semiconductor products do not contain any chemicals for all 6 substance categories, including the requirement that lead does not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, RoHS compliant products are suitable for use in specified lead-free processes.

ScioSense Green (RoHS compliant and no Sb/Br): ScioSense Green defines that in addition to RoHS compliance, our products are free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material).

Important Information: The information provided in this statement represents ScioSense B.V. knowledge and belief as of the date that it is provided. ScioSense B.V. bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. ScioSense B.V. has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. ScioSense B.V. and ScioSense B.V. suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

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21 Document Status

Table 35: 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.

22 Revision Information

Table 36: Revision History

Revision	Date	Comment	Page
0.9	2019-12-11	Initial Version	

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.