Description

The ZMOD4410 Gas Sensor Module is designed for detecting total volatile organic compounds (TVOC), estimating CO_2, and monitoring indoor air quality (IAQ) in different smell based use cases. It is a 12-LGA assembly ($3.0 \times 3.0 \times 0.7$ mm) that consists of a gas sense element and a CMOS signal conditioning IC. The module's sense element consists of heater element on a Si-based MEMS structure and a metal oxide (MOx) chemiresistor. The signal conditioner controls the sensor temperatures and measures the MOx conductivity, which is a function of the gas concentration. The measurement results can be read via an I2C interface with the user's microprocessor, which processes the data.

The provided firmware enables different ZMOD4410 features based on traditional and machine learning algorithms with an embedded artificial intelligence (AI). This is used to determine the TVOC concentration, IAQ rating, and estimated carbon dioxide (eCO_2) level. Alternatively, depending on the operation mode, the ZMOD4410 algorithm can discriminate between sulfur-based odors or generate a control signal, which can trigger actions based on total odor levels. With its low operating current consumption in Low Power Operation Mode, the ZMOD4410 is an excellent choice for low-voltage and low power battery applications. Built-in nonvolatile memory (NVM) stores the module configuration and calibration data.

Typical Applications

- Indoor air monitoring
- Monitor home, office, personal, and bathroom environments for healthy conditions and comfort
- Detect hazardous materials and unhealthy conditions (e.g., fumes from construction materials)
- Automation based on indoor ambient air quality (HVAC, air purifiers, thermostats, kitchen hoods, etc.)
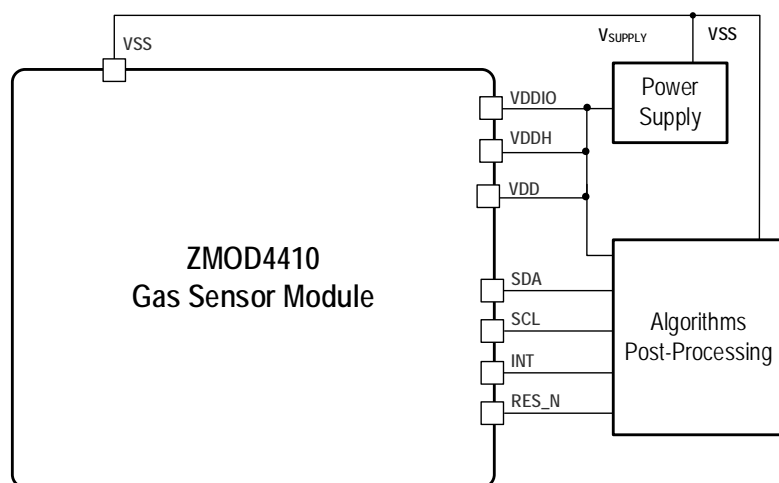
Available Support

- ZMOD4410 Evaluation Kit
- Manuals, application notes, blog, and white papers
- Instructional videos
- Programming libraries, example codes, and algorithm support to optimize performance
- Third-party certification for compliance with well-accepted international IAQ standards and best available technology for eCO2

Features

- Sensor output based on AI machine learning algorithmic:
  - Measurement of total organic compounds (TVOC) concentrations and indoor air quality (IAQ)
  - Module algorithm estimates carbon dioxide level (eCO_2)
  - Algorithm to set a control signal to trigger an external action based on IAQ and odor change
  - Algorithm to discriminate sulfur based odors
- Heater driver and regulation loop for constant resistance, minimizing effect of environmental temperature on signal
- Customization for mobile, industrial, and consumer applications
- Internal auto-compensated temperature sensor; not stress sensitive
- I2C interface: up to 400kHz
- Built-in nonvolatile memory (NVM) for module-specific data
- Very low average power consumption down to 1.5mW
- Excellent for low-voltage and low power battery applications
- No external trimming components required
- External reset pin (active-LOW)
- Siloxane resistant
- Supply voltage: 1.7V to 3.6V
- Package: 12-LGA
- RoHS compliant
- Assembly size: $3.0 \times 3.0 \times 0.7$ mm

ZMOD4410 Application Circuit

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1. Pin Assignments

Figure 1.   ZMOD4410 Pin Assignments for 12-LGA Module – Top View
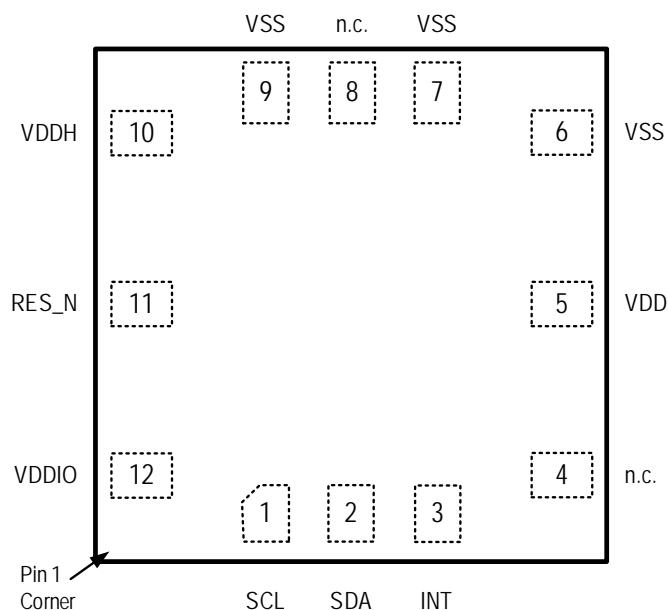
2. Pin Descriptions

Table 1.   Pin Descriptions

Pin Number	Name	Type	Description
1	SCL	Input	Serial clock for the I2C interface.
2	SDA	Input/Output	Serial data for the I2C interface. Default 7-bit slave address: 32$_{HEX}$.
3	INT	Output	Interrupt signal (push-pull): ▪ HIGH when a measurement is running ▪ LOW when a measurement has finished
4	n.c.	–	Do not connect.
5	VDD	Supply	Voltage supply for the ZMOD4410.
6	VSS	Ground	Ground reference for the ZMOD4410.
7	VSS	Ground	Ground reference for the ZMOD4410.
8	n.c.	–	Do not connect.
9	VSS	Ground	Ground reference for the ZMOD4410.
10	VDDH	Supply	Voltage supply for the integrated heater in the ZMOD4410.
11	RES_N	Input	ZMOD4410 reset; active low.
12	VDDIO	Supply	Voltage supply for I/O-interface in ZMOD4410.

3. Absolute Maximum Ratings

Note: The absolute maximum ratings are stress ratings only. The ZMOD4410 might not function or be operable below and above the recommended operating conditions given in Table 2. Stresses exceeding the absolute maximum ratings will change the sensor accuracy; lead to imprecision, and eventually cause irreversible damage to the device. In addition, extended exposure to stresses above the recommended operating conditions might affect device reliability. Renesas does not recommend designing to the "Absolute Maximum Ratings."

Table 2.   Absolute Maximum Ratings

Symbol	Parameter	Conditions	Minimum	Maximum	Units
V_{DD}, V_{DDH}, V_{DDIO}	Maximum Analog and I/O Supply Voltage		-0.4	3.63	V
V_{A_IO}, V_{D_IO}	Maximum Voltage at all Analog and Digital I/O Pins		-0.5	V_{DDIO} + 0.5	V
	Maximum Difference in Voltage between VDD and VDDH Pins		–	0.4	V
I_{IN}	Input Current into any Pin Except Supply Pins (Latch-Up Immunity)		-100	100	mA
V_{HBM1}	Electrostatic Discharge Tolerance – Human Body Model (HBM)		2000	–	V
V_{CDM}	Electrostatic Discharge Tolerance – Charged Device Model (CDM) on Packaged Module		750	–	V
$T_{OPERATION}$	Operation Temperature Range of MOx		100	450	°C
T_{STOR}	Storage Temperature		-50	125	°C

4. Operating Conditions

Note: The reference for all voltages is V_{SS}.

Table 3.   Operating Conditions

Symbol	Parameter	Min	Typ	Max	Unit
V_{DD}	Supply Voltage	1.7	–	3.6	V
T_{AMB}	Ambient Temperature Range for Sensor Operation	-40	–	65	°C

5. Electrical Characteristics

Values below are valid at operating conditions unless noted otherwise.

Table 4.   Electrical Characteristics

Symbol	Parameter	Conditions	Minimum	Typical	Maximum	Unit
	Average Power: IAQ 1st Gen	Continuous and Odor Operation Mode	–	23	–	mW
		Low Power Operation Mode	–	1.5	–	mW
	Average Power: IAQ 2nd Gen		-	6	-	mW
	Average Power: Odor Operation		-	23	-	mW
	Average Power: Sulfur Odor Discrimination		-	6	-	mW
I_{ACTIVE}	Supply Current, Active Mode including Heater Current for IAQ 1st Gen Continuous and Odor Operation Mode	At VDD = 1.8 V	-	13	-	mA
		At VDD = 3.3V	-	7	-	mA
I_{ACTIVE}	Supply Current, Active Mode including Heater Current for IAQ 2nd Gen and Sulfur Odor Discrimination	At VDD = 1.8 V	-	3.4	16.2	mA
		At VDD = 3.3V	-	2.4	10.3	mA
I_{SLEEP}	Supply Current, Sleep Mode ASIC, No Wake-up Timer Active	Does not include sensor heater current.	–	450	–	nA
PSRR	Power Supply Rejection Ratio	$V_{DD} \geq 2.0V$	–	30	–	dB
	Timing Accuracy (Valid for Measurements Only) (Sleep Timer is ±20%)	At room temperature; for timings derived from the internal clock.	-2	–	2	%
		Over-temperature range; for timings derived from the internal clock.	-0.1	–	0.1	%/K
r_{ADC}	ADC Resolution		10	–	16	Bit
t_{STA1}	Start-up Time: V_{DD} Ramp up to Interface Communication		–	–	1	ms
t_{STA2}	Start-up Time: V_{DD} Ramp up to Analog Operation		–	–	2.5	ms
t_{WUP1}	Wake-up Time for Sleep to Active Mode: Interface Communication		–	–	0.5	ms
t_{WUP2}	Wake-up Time for Sleep to Active Mode: Analog Operation		–	–	2	ms
$f_{C,I2C}$	I2C Clock Frequency		–	–	400	kHz
t_{VPP}	NVM Programming Time		–	6	16	ms
t_{RET_FTP}	Data Retention	85°C junction temperature	10	–	–	years
	NVM Programming Cycles		1000	–	–	cycles
	Default Communication Address	7-bit slave address	–	32_{HEX}	–	–
	Blocking Capacitor for Power Supply	Ceramic type; recommended to be placed close to gas sensor module	100	–	–	nF

6. Block Diagram

Note: See section 12 for definitions of abbreviations.

Figure 2.   Block Diagram
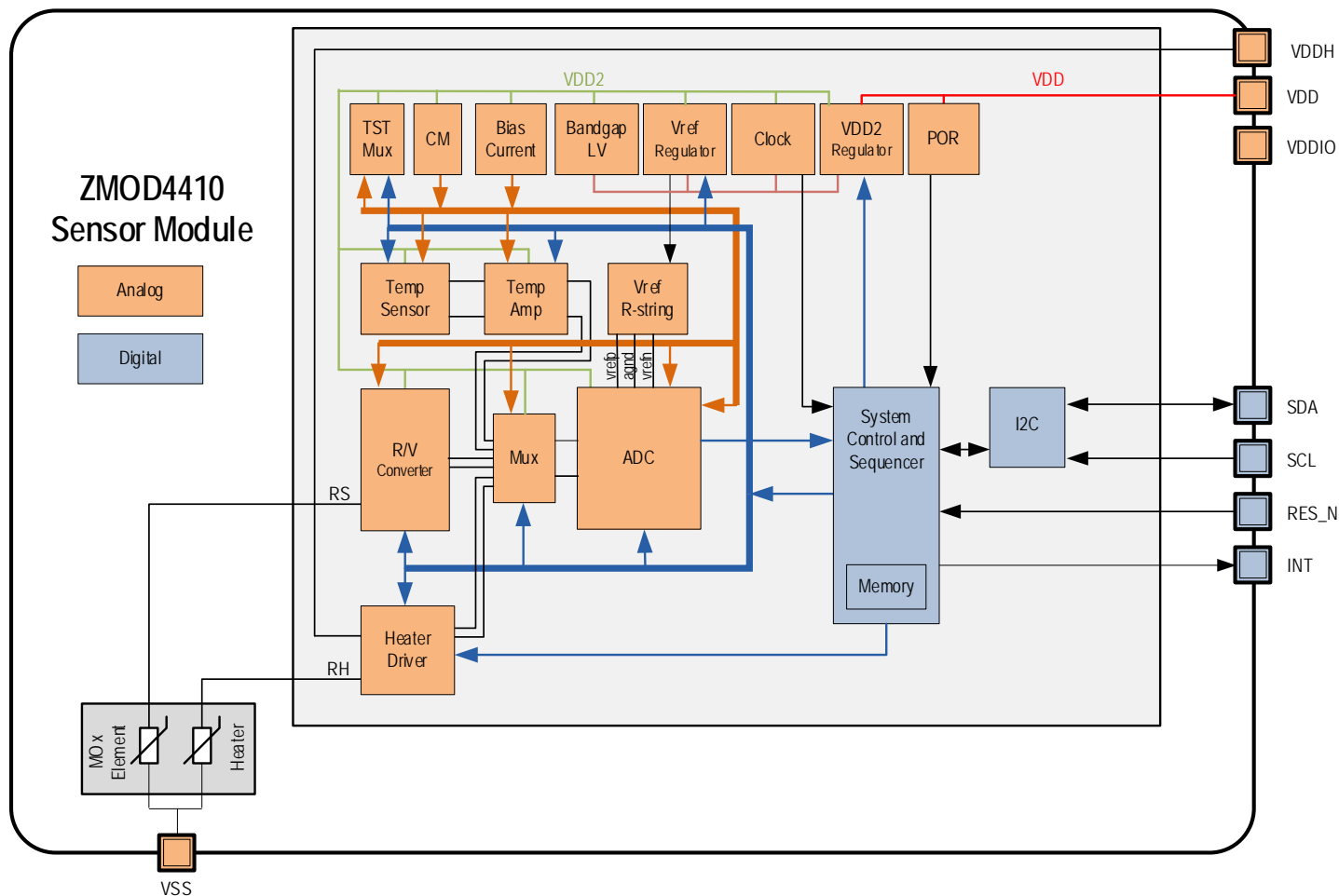
7. Sensor Module Characteristics

7.1 Gas Sensor Module

The ZMOD4410 Gas Sensor Module is designed to detect typical TVOC contaminations based on studies and international standards for indoor air quality. Characteristic module parameters are shown in Table 5. The response time for a gas stimulation is always within a few seconds, depending on the TVOC and its concentration. An active or direct airflow onto the sensor module is not necessary since diffusion of ambient gas does not limit the sensor response time.

Important: The ZMOD4410 also can detect safety-relevant gases for indoor air, such as carbon monoxide (CO); however, the sensor is not designed to detect these interferants reliably and therefore it is not approved for use in any safety-critical or life-protecting applications. It must not be used in such applications, and Renesas disclaims all liability for any such use.

Table 5. Gas Sensor Module Specifications during Operation

Symbol	Parameter	Conditions	Minimum	Typical	Maximum	Unit [a]
	Resistance Measurement Range	Ethanol in air	0		1000	ppm
			0		1000000	ppb
	IAQ Specified Measurement Range*	Ethanol in air for IAQ 1st Gen	160		30000	ppb
		Ethanol in air for IAQ 2st Gen	160		10000	ppb
	Humidity Range	Non-condensing	0		90	% RH
S	Sensitivity over Lifetime	Resistance in Air / Resistance at 10ppm Ethanol (R_{Air}/R_{Gas})		5		Ω/Ω
T-80	Sensor Response Time [b]	Time to change to 80% of end value for IAQ 1st Gen		10		s

[a] The abbreviation ppm stands for "parts per million," and ppb is an abbreviation for "parts per billion." For example, 1 ppm equals 1000 ppb.

[b] Response times depend on TVOC gas and concentration.

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* Umweltbundesamt, *Beurteilung von Innenraumluftkontaminationen mittels Referenz- und Richtwerten*, (Bundesgesundheitsblatt - Gesundheitsforschung - Gesundheitsschutz, 2007).

8. Gas Sensor Module Operation Modes and Characteristics

The ZMOD architecture leverages different "Methods of Operation" which use time, temperature, and signatures from gases that enable unique signals from a highly trained machine learning system and makes use of embedded artificial intelligence (AI) technology. This section discusses the different operation modes of the ZMOD4410. At present, five operation modes are released.

Family of IAQ software releases:

- Operation Mode 1: IAQ 1st Generation: Continuous – Measurement of UBA levels for IAQ and eCO2
- Operation Mode 2: IAQ 1st Generation: Low Power – Measurement of UBA levels for IAQ and eCO2
- Operation Mode 3: IAQ 2nd Generation: Using AI for improved ppm TVOC, IAQ and eCO2 functionality (recommended for new designs)
- Operation Mode 4: Odor – Control signal based on Air Quality Change changes
- Operation Mode 5: Sulfur-based Odor Discrimination

By default, the IAQ 2nd Generation (Mode 3) operation should be used for new designs. In case of the need for a slightly faster sample rate and a larger VOC range (up to 30ppm), it is recommended to use the IAQ 1Gen algorithms.

In addition, details for sensitivity, reliability, sample rates, and sensor influences are explained in detail in the following sections. All graphs and information show the typical responses that are to be expected from the sensor module upon exposure to a variety of test conditions. Additional technical information on sensitivity, selectivity, and stability for all operation modes is available in Renesas' *ZMOD4410 Application Note – TVOC Sensing.* For more information, including application notes, white papers, blog, and manuals, visit www.idt.com/ZMOD4410.

8.1 Operation Modes 1–3

These operation modes are used for absolute measurements of indoor air quality (IAQ) according to UBA with eCO$_2$.

Note: Modes 1, 2, and 3 use the same output signal but have differences in power consumption and sample rate. In addition, the use of the IAQ 2nd Generation algorithm with embedded AI gives better consistency and accuracy compared to traditional gas sensor algorithms.

- Operation Mode 1: IAQ 1st Generation (Continuous) provides continuous data depending on the customer application and MCU polling.
- Operation Mode 2: IAQ 1st Generation (Low Power) has a fixed sampling interval of 6 seconds.
- Operation Mode 3: IAQ 2nd Generation has a fixed sampling interval of 3 seconds.

The following sections provide information on TVOC gases, concentrations, and thresholds given by the German Federal Environmental Agency (UBA) * and the US Environmental Protection Agency (EPA). These standards provide reliable information on indoor air quality and recommendations for air improvements if necessary.

8.1.1 Air Quality – UBA Levels

The algorithm provided by Renesas for the user's microprocessor uses the output from the ZMOD4410 to determine the relative level of TVOC gases present (see *ZMOD4410 Programming Manual – Read Me*; see also section 12). The algorithm features an automated baseline correction function, ensuring that the module can learn from its environment and distinguish elevated levels of TVOC under all conditions. The proprietary metal oxide (MOx) used in the sensor ensures the ability of the sensor module to respond effectively to changing TVOC levels during long-term operation.

Renesas has adopted the definition of TVOCs and their impact on user health and comfort proposed by the UBA (see Table 6). The ZMOD4410 can detect the presence of elevated TVOC levels as described in the UBA study.*

There are many sources of poor indoor air quality that can elevate TVOC levels in the typical home or office environments, and the types of TVOC that might be present can vary widely. Additional information on this topic is available in Renesas' *ZMOD4410 White Paper – Overview of TVOC and Indoor Air Quality.*

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* Umweltbundesamt, *Beurteilung von Innenraumluftkontaminationen mittels Referenz- und Richtwerten,* (Bundesgesundheitsblatt - Gesundheitsforschung - Gesundheitsschutz, 2007).

The ZMOD4410 can respond reliably to all of the types of organic compounds that are typically found in indoor environments. To assess the response of the gas sensor module to the levels described in the UBA study, the module has been tested using several TO-15/17 multi-component TVOC standards defined by the EPA. The ZMOD4410 response to the EPA standard with the TVOC levels from UBA is shown in Figure 3. A third-party report and certification from an independent research lab is available on the Renesas website that confirms the very good conformity for IAQ measurements with respect to the UBA study and EPA standard.
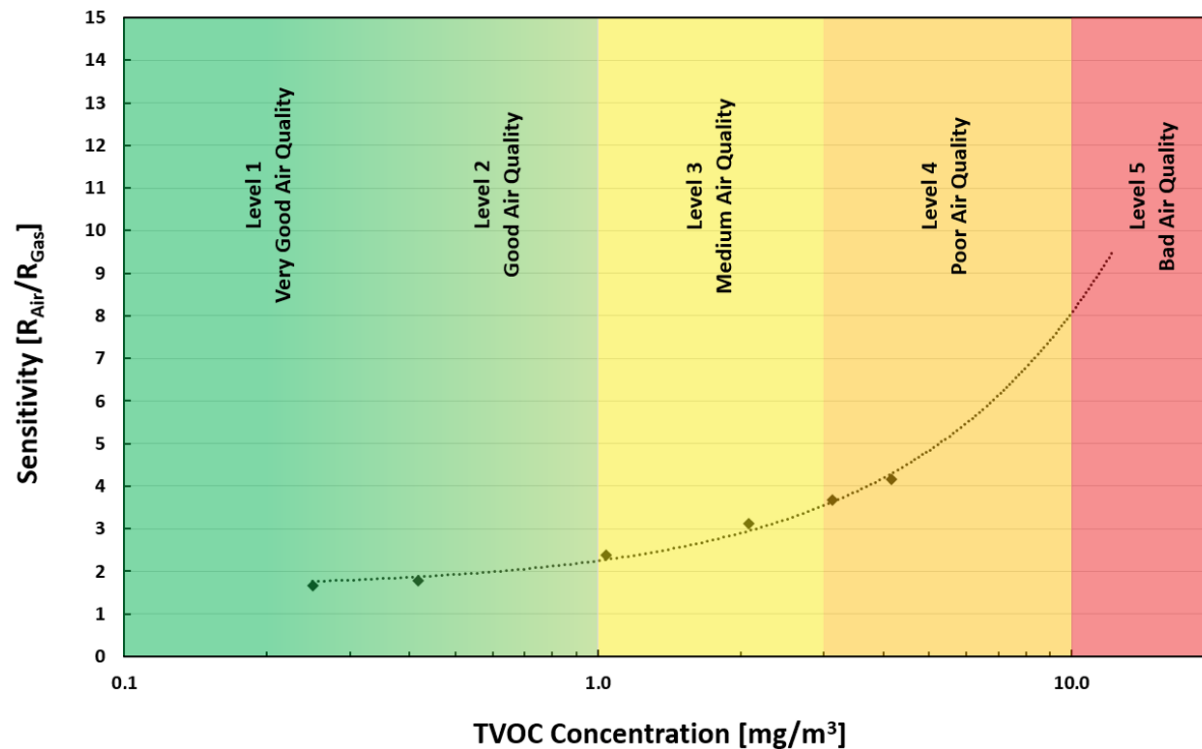
Table 6.   Level of Air Quality Based on TVOC Levels Described by UBA

Renesas IAQ Rating	Reference Level*	Air Information	TVOC (mg/m³) [a]	Air Quality
≤ 1.99	Level 1	Clean Hygienic Air (target value)	< 0.3	Very Good
2.00 to 2.99	Level 2	Good Air Quality (if no threshold value is exceeded)	0.3 to 1.0	Good
3.00 to 3.99	Level 3	Noticeable Comfort Concerns (not recommended for exposure > 12 months)	1.0 to 3.0	Medium
4.00 to 4.99	Level 4	Significant Comfort Issues (not recommended for exposure > 1 month)	3.0 to 10.0	Poor
≥ 5.00	Level 5	Unacceptable Conditions (not recommended)	> 10.0	Bad

[a]   Conversion from mg/m³ to ppm for most common TVOC is by the factor approximately 0.5; for example, 10mg/m³ equals approximately 5ppm. Conversion from ppm to ppb is by the factor 1000; for example, 0.1ppm equals 100ppb.

Figure 3.   Typical ZMOD4410 Response to Levels of TVOC Described by UBA using EPA Std. Mixture

Note: TVOC is a subset comprising 25 of the EPA's TO-15/17 certified mixtures.

8.1.2 Air Quality – Estimated Carbon Dioxide Correlation (eCO₂)

A very reliable correlation can be made based on TVOC levels for situations where an elevated carbon dioxide (CO_2) concentration is caused by human occupancy, although the sensor module is not directly responsive to CO_2. Renesas has developed a robust, patent pending, correlation between elevated VOCs and CO_2 attributable to human occupancy in a wide variety of living spaces, including homes and offices. The correlation can predict the CO_2 level as shown in Figure 4. Additional details for Renesas' CO_2 correlation are available in the *ZMOD4410 Application Note – Estimating Carbon Dioxide.*

Table 7.   Measurement of Estimated CO₂ Levels (eCO₂)

Symbol	Parameter	Conditions	Minimum	Typical	Maximum	Unit
eCO₂	Estimated CO₂ Range	Human occupied space (home, office, etc.)	400		5000	ppm
	Estimated CO₂ Accuracy	Versus reference nondispersive Infrared (NDIR) reference instrument		±25		%

Figure 4.   Typical Graph of CO₂ Correlation
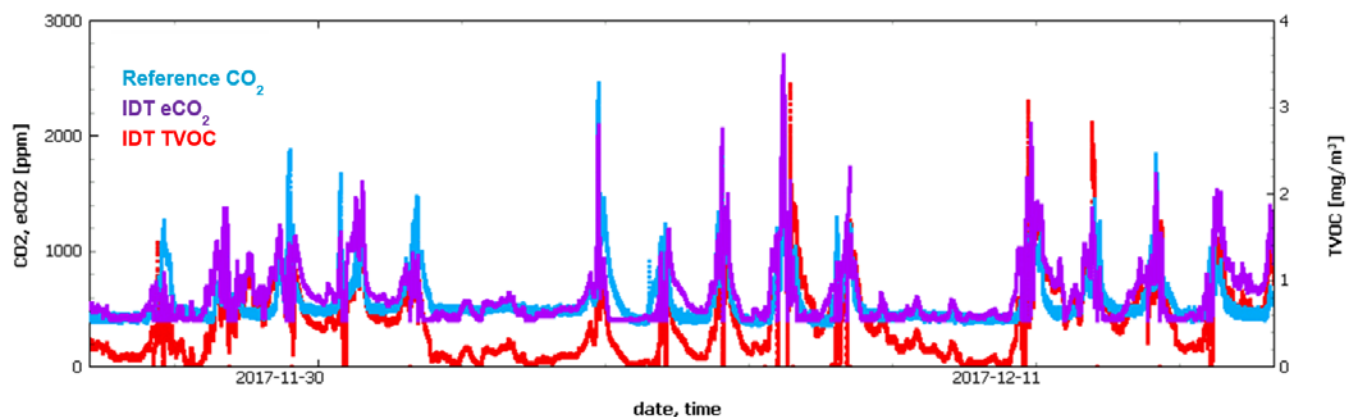
8.2   Operation Mode 4: Odor

Operation Mode 4 can be used to control an external device, such as a fan or ventilation system, based on changes in Air Quality.

Renesas provides firmware and algorithms, which allow the ZMOD4410 to learn its environment. The gas sensor module will only respond to changes in the ambient conditions by detecting changes in the relative ambient TVOC concentration. When a user-defined threshold is exceeded, an I/O control signal (trigger) based on the algorithm output may control an external device. Recommendation: Activate the external device for at least a few minutes (stop delay time) to ensure air quality improvement and avoid an on-off activation at the threshold limit.

Table 8.   Control Parameters for Odor Operation

Parameter	Conditions	Typical Value	Unit
Learning Time Environment	Typical value valid for sample rate of 2 seconds	60	min
Sensor Response Time	Sample rate dependent, typically 1 to 3 samples	5	s
Threshold Trigger	Change of raw sensor signal; recommended difference: 30%	1.3	–
Stop Delay	Stop delay for external device; defines minimum activation time	2	min

When using the ZMOD4410 Evaluation Kit, the AD5 pin (GPIO) on connector K3 on the ZMOD4410 HiCom Communication Board is the trigger control signal output that is set to HIGH/LOW for Operation Mode 4. For more information, see the *ZMOD4410 Evaluation Kit User Manual.*

8.3   Operation Mode 5: Sulfur based Odor Discrimination

Operation Mode 5 can be used to identify if a sulfur-smelling odor is present. When the target gas families have been defined through analysis, a sweeping method allows for chemical discrimination. A machine learning embedded artificial intelligence (AI) algorithm makes use of a MOx surface temperature array to get to a selectivity approach.

This operation mode classifies the odors in "sulfur" (sulfur based) and "acceptable" (organic based) and shows an intensity level of the smell. Acceptable odors are for example coming from air refreshers, soaps, perfumes etc., while bad smelling sulfur based odors come from personal odors in bathrooms. Because impression of smell is very unique, there might be overlaps with how people perceive odors. To bring this in an algorithm, a highly trained Neural Network is using typical chemical signatures from Hydrogen sulfide (H_2S) and Dimethyl sulfide (DMS, C_2H_6S). A range of organic sulfur compounds are considered from the low ppb to the ppm range.

This sulfur-based odor discrimination firmware was developed based on known commercially available products that represent both bad and acceptable odors. Other places with unknown chemical signatures can lead to wrong algorithm results. Training the sensor and developing the discrimination for other gases and applications may be considered for future releases.

8.4   Conditioning and Stability

The ZMOD4410 will respond to TVOC immediately upon start-up; however, a conditioning period of 48 hours in an ambient environment is recommended to improve stability and obtain maximum performance. Best results are achieved with continuous operation because the module algorithm can learn about the environment over time.

Figure 5 shows the ZMOD4410 sensor module's raw data response to clean air with 30%RH and its response to 5ppm, 10ppm, and 20ppm ethanol mixed in clean air. The result is a very stable, fast changing, and repeatable sensor signal with a high sensitivity. Signal stability even at high TVOC indoor air quality contaminations is shown in Figure 6.

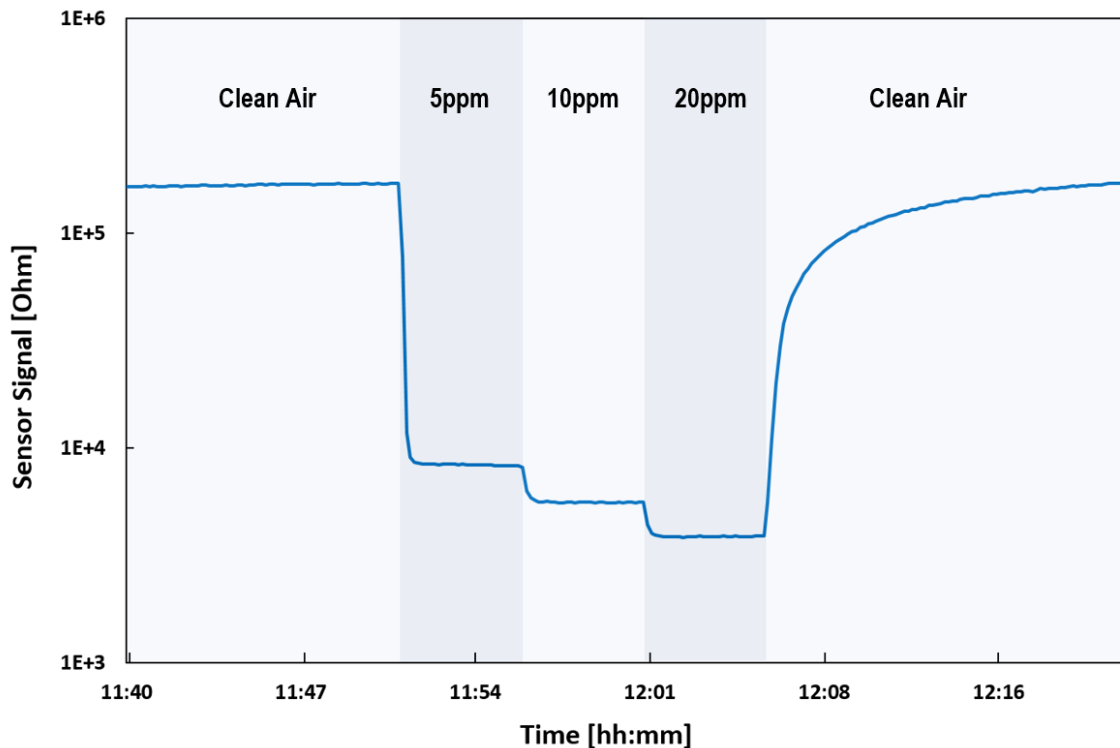**Figure 5.   ZMOD4410 Typical Response Time and Signal Stability for TVOC Exposure**
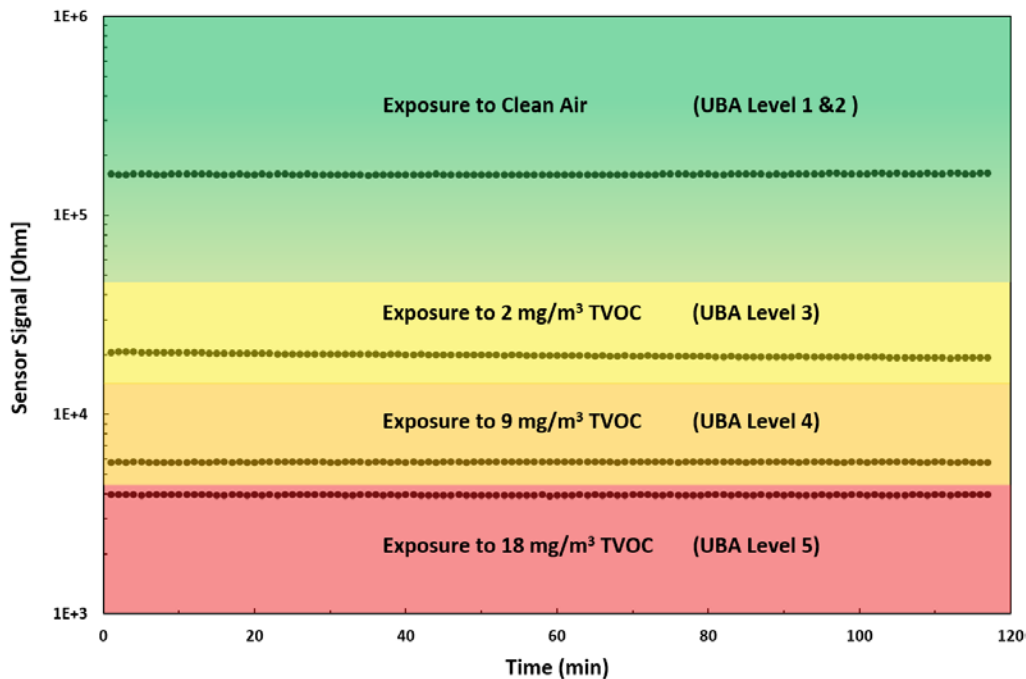
Figure 6.   Sensor Module Response to Exposures at Different TVOC Concentrations for 2 Hours Each

8.5   Environmental Temperature and Humidity

Although the ZMOD4410 sensor module is tested, qualified, and functional in the range of -40°C to +65°C, the best performance according to its calibration is achieved in the temperature range of 0°C to +40°C. Figure 7 shows the module's response to variations in the range from 15% to 65% relative humidity for ethanol concentrations mentioned in section 8.3.

Figure 7.   Humidity Influence at Three Different VOC Concentrations
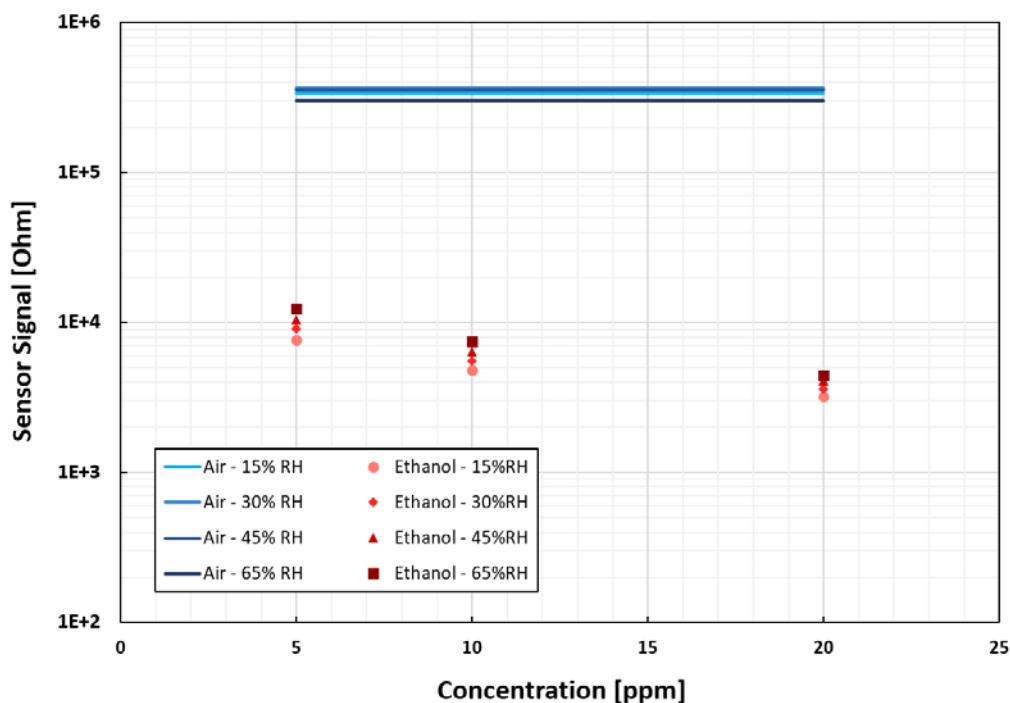
8.6   Accuracy and Consistency

All Renesas gas sensor modules come with electrical and chemical factory calibration with data stored in the module's nonvolatile memory (NVM). Using the software provided by Renesas and the calibration coefficients in the NVM will lead to stable measurement of the UBA level discussed in section 8.1.1 with a maximum deviation of ±1 category over the module's lifetime.

Typical accuracy and consistency without additional calibration are displayed in Table 9 and in Figure 8. Users who require an absolute measurement with the maximum achievable accuracy are advised to re-calibrate the sensor with a known organic compound to enable an absolute accuracy of up to ±15%. For some environments, an interference response to siloxanes is of concern; however, the ZMOD4410 has proven to be resistant against siloxanes. A maximum potential lifetime exposure has been simulated in all ZMOD4410 operation modes by applying the chemicals D4 (octamethylcyclotetrasiloxane) and D5 (decamethylcyclopentasiloxane) in high concentration for several hundred hours. For more information on test conditions and results, see *ZMOD4410 Application Note – TVOC Sensing.*

Table 9.   Typical ZMOD4410 Sensor Module Accuracy Achievable with Calibration

Parameter	Conditions	Minimum	Typical	Maximum	Unit
Accuracy for TVOC	Without additional calibration		±25		%
	With additional calibration		±15		%
Accuracy for IAQ	Without additional calibration		±10		%
Consistency	Part-to-Part Variation		±25		%
Durability to Siloxanes	Change in sensitivity		±5		%

Figure 8.   Accuracy and Consistency for Eight Sensor Modules

Same Data Set Used for TVOC (Left Plot) and IAQ Levels according to UBA (Right Plot)
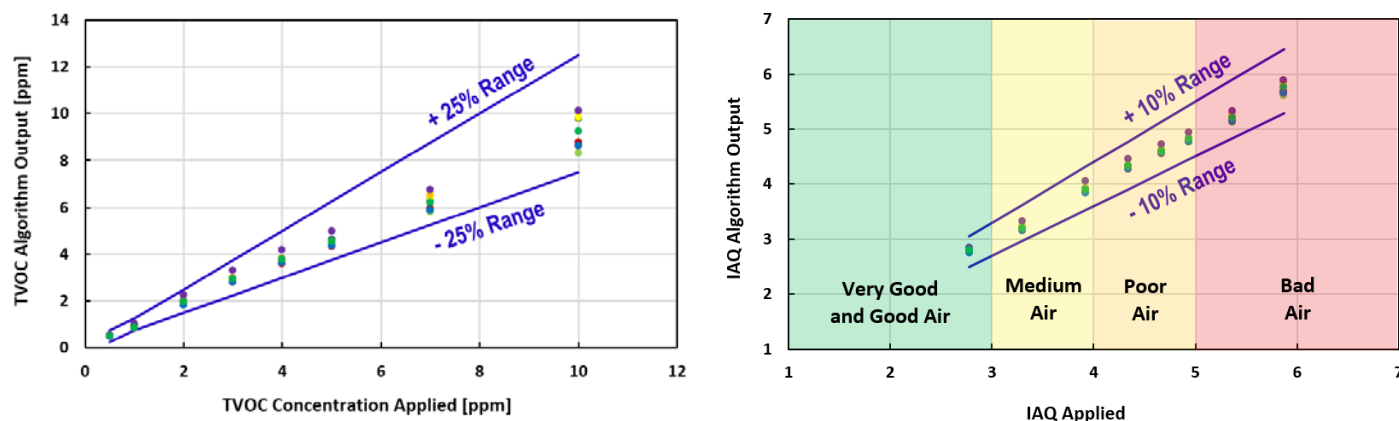
9. Assembly Restrictions, Operation, Integration Notes, and Storage

When implementing the ZMOD4410 in electrical circuit boards a gas sensor module might react to chemicals during the assembly process and to outgassing components, such as resins from the printed circuit board (PCB) assembly. A standard soldering profile can be used to assemble the ZMOD4410 on the user's PCB and should fulfill the IPC/JEDEC J-STD-020C Standard ("Moisture/Reflow Sensitivity Classification for Non-hermetic Solid State Surface Mount Devices"). A typical lead-free reflow solder profile is shown in Figure 9. After assembly, an outgassing of the PCB and electronic components must be considered, especially when operating the sensor module at elevated temperatures. This will ultimately influence the sensor signal and may dominate the air quality reading. A PCB heat treatment before assembling the ZMOD4410 is recommended. After the gas sensor module assembly, no coating, cleaning, or ultrasonic bath should be applied to the PCB. Also, in case sensor module parts are contaminated during assembly or storage, it can be cleaned by operating at 450°C for 10 minutes after assembly to remove any contamination of solder vapor from the MOx surface.

Store the sensor in an antistatic metallic bag with a low VOC background after the sensor module is removed from its original packaging or the assembled PCB is populated. The optimal storage conditions are < 1 ppm TVOC, 10°C to 50°C, and humidity levels within 20% to 80%RH. If the sensor is stored outside of these conditions for extended periods of time, the sensor readings can exhibit a temporary offset. The sensor can be reconditioned and brought back to its calibration state by operation for 24 hours to 48 hours in clean air.

To operate the ZMOD4410, the software and libraries provided by Renesas can be used. For implementing the sensor module in a customer-specific application, detailed information on the programming is available. The recommended requirements for the host MCU are 16kB flash for ZMOD4410 related firmware code, 1kB RAM for ZMOD4410 related operations, and the capability to perform I2C communication, timing functions, and floating-point instructions. The *ZMOD4410 Programming Manual - Read Me* explains documentation, libraries for supported controllers and compilers, and code examples in C, for an easy integration (see section 12).

Figure 9.   Typical Solder Profile
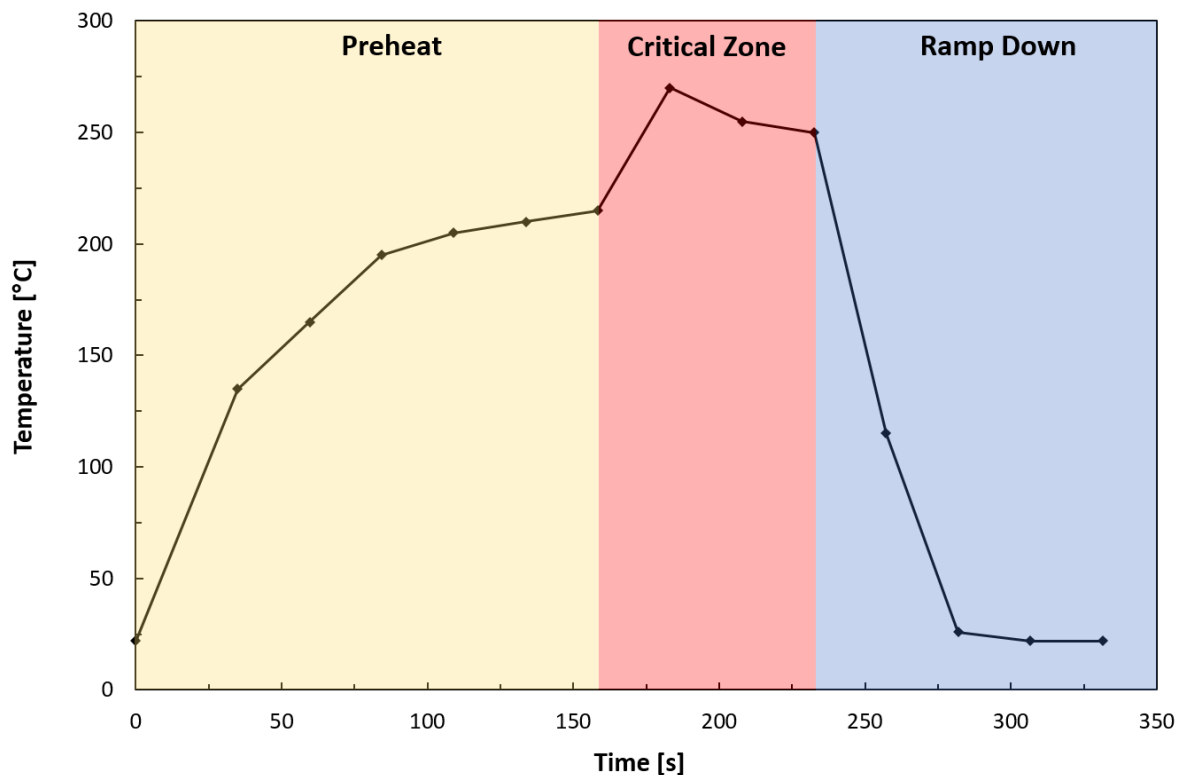
10. Test and Calibration

As a unique feature, all sampled gas sensor modules are fully tested during Renesas' final test. The final test parameters in Table 10 are applied for each ZMOD4410. All sensor modules are pre-stabilized in the final test although the user might see a small change in the module's raw signal during an initial warm-up phase during the first operation. The gas sensor module qualification is based on JEDEC (JESD47) and its subsequent standard (JESD22, JESD78 etc.); it has been tested for a lifetime of 5 years. Renesas has proven a MOx lifetime of over 15+ years in actual continuous operation in conditions without exposures to stressful environments.

Table 10.   Final Test Parameters

Test	Test Object	Parameters	Test Results Saved in NVM?
Electrical	ASIC	Voltages, current consumption, frequencies, scan pattern	No
Electrical	Module	Calibration conditions, tracking ID, resistances	Yes
Gas	Module	Sensitivity parameters (slope and intercept) at stimulation with different gas concentrations	Yes
Gas	Module	Pre-stabilization	No

11. I2C Interface and Data Transmission Protocol

The I2C slave device interface supports various bus speeds: Standard Mode (≤ 100kHz) and Fast Mode (≤ 400kHz).
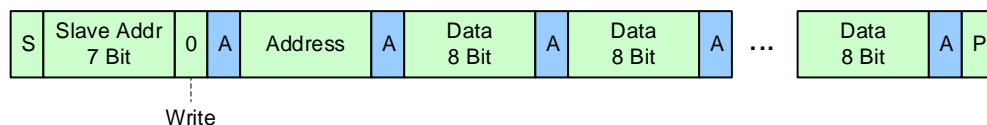
By default, the 7-bit slave address for the serial I2C data interface is set to 32_{HEX}. The implemented data transmission protocol is similar to the one used for conventional EEPROM devices. The register to read/write is selected by a register address pointer. This address pointer must be set during an I2C write operation. After transmission of a register, the address pointer is automatically incremented. An increment from the address FF_{HEX} rolls over to 00_{HEX}.

For an example of the I2C data transmission protocol, see Figure 10. For information on I2C bus timing, see Figure 11. For I2C bus characteristics, see Table 11, which explains how to set up the interface. Although the ZMOD4410 has an I2C interface, the user is not intended to modify any registers because a configuration change will affect the sensor's performance, reliability, and accuracy. The API provided with the downloadable firmware package on the website manages all necessary sensor communication.

To validate the general MCU-specific I2C read/write driver without the use of Renesas libraries, it is possible to write random values to registers 0x88 to 0x8B and read them afterwards. After register testing, reset the device by disconnecting the power support; otherwise the device may not operate properly.

Figure 10. I2C Data Transmission Protocol

WRITE Access RAM

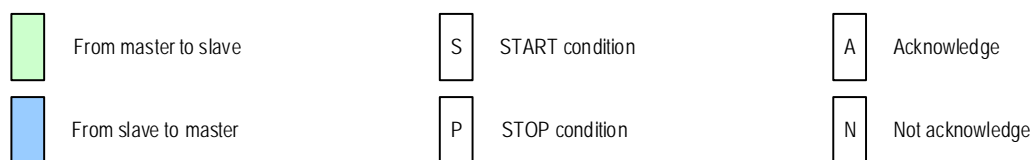| S | Slave Addr 7 Bit | 0 | A | Address | A | Data 8 Bit | A | Data 8 Bit | A | ... | Data 8 Bit | A | P |

Write

READ Access NVM and RAM

| S | Slave Addr 7 Bit | 0 | A | Address 8 Bit | A | S | Slave Addr 7 Bit | 1 | A | Data 8 Bit | A | Data 8 Bit | A | ... | Data 8 Bit | N | P |

Write   Read

| | From master to slave | | S | START condition | | A | Acknowledge |
| | From slave to master | | P | STOP condition | | N | Not acknowledge |

Figure 11. Bus Timing
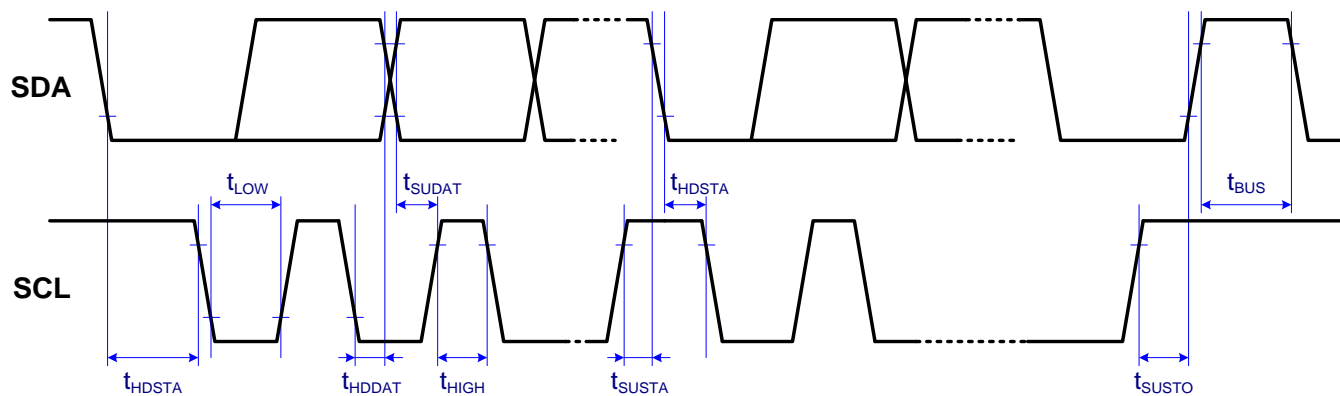
Table 11.   Bus Timing Characteristic

Parameter	Symbol	Standard Mode	Fast Mode	Units
Maximum SCL clock frequency	f_{SCL}	100	400	kHz
Minimum START condition hold time relative to SCL edge	t_{HDSTA}	4		µs
Minimum SCL clock low width	t_{LOW}	4.7		µs
Minimum SCL clock high width	t_{HIGH}	4		µs
Minimum START condition setup time relative to SCL edge	t_{SUSTA}	4.7		µs
Minimum data hold time on SDA relative to SCL edge	t_{HDDAT}	0		µs
Minimum data setup time on SDA relative to SCL edge	t_{SUDAT}	0.1	0.1	µs
Minimum STOP condition setup time on SCL	t_{SUSTO}	4		µs
Minimum bus free time between stop condition and start condition	t_{BUS}	4.7		µs

12. Related Websites and Software

Visit the ZMOD4410 and ZMOD4410 Evaluation Kit (ZMOD4410-EVK) product pages on the Renesas website to download software and the latest version of related documents, such as application notes, white papers, product briefs, and third-party reports.

Note that some documents require logging in with a free customer account, which can be set up under the "LOG IN" button on www.IDT.com. Some downloads require an additional step to complete a request form that appears when the link is clicked.

Product	Web Page
ZMOD4410	www.IDT.com/ZMOD4410
ZMOD4410-EVK	www.IDT.com/ZMOD4410-EVK

If additional support is needed for downloading, contact Renesas via the contact information on the last page.

13. Glossary

Term	Description
ADC	Analog-to-Digital Converter
AI	Artificial Intelligence
CDM	Charged Device Model
CM	Common Mode Generator
HBM	Human Body Model
IAQ 1st Gen	Indoor Air Quality algorithm using traditional computing methods
IAQ 2nd Gen	Indoor Air Quality algorithm using machine learning AI
LGA	Land Grid Array
LV	Low Voltage
MOx	Metal Oxide
MSL	Moisture Sensitivity Level
Mux	Multiplexer
n.a.	Not Applicable
NVM	Nonvolatile Memory
POR	Power-On Reset
SDA	Serial Data
SCL	Serial Clock
SSC	Sensor Signal Conditioner
TST	Test
TVOC	Total Volatile Organic Compounds
UBA	Umweltbundesamt (German Federal Environmental Agency)

14. Package Outline Drawings

The package outline drawings are appended at the end of this document and are accessible from the link below. The package information is the most current data available.
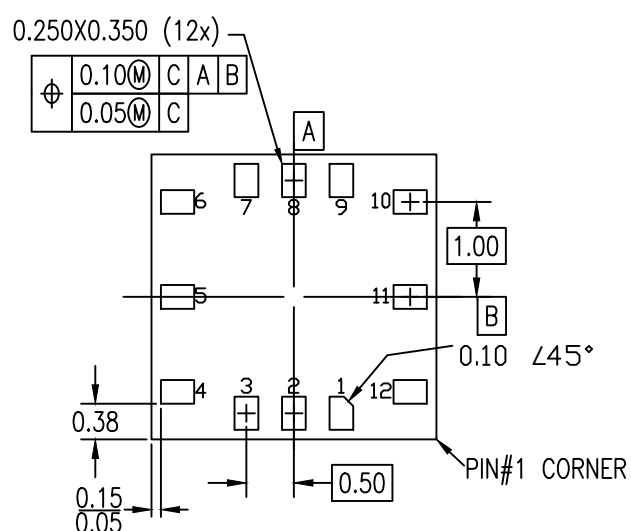
https://www.idt.com/document/psc/12-lga-package-outline-drawing-30-x-30-x-07-mm-body-05-x-10-mm-pitch-lgg12d1

15. Ordering Information

Orderable Part Number	Description and Package	MSL Rating	Carrier Type	Temperature
ZMOD4410AI1V	ZMOD4410 Sensor Module, 3.0 × 3.0 × 0.7 mm 12-LGA	3	Tray	-40°C to +65°C
ZMOD4410AI1R	ZMOD4410 Sensor Module, 3.0 × 3.0 × 0.7 mm 12-LGA	3	Reel	-40°C to +65°C
ZMOD4410-EVK-HC	ZMOD4410 Evaluation Kit including the ZMOD4410 Sensor Board, ZMOD4410 HiCom Communication Board (USB Interface), and Micro-USB Cable. (The ZMOD4410 Evaluation Software is available for download free of charge on www.IDT.com/ZMOD4410-EVK.)			

16. Revision History

Revision Date	Description of Change
June 3, 2020	▪ Completed minor edits.
June 1, 2020	▪ Changed to Renesas layout ▪ Added RoHS compliance ▪ Updated NVM data space ▪ Updated with Operation Mode for IAQ 2nd Gen ▪ Updated with Operation Mode for Sulfur based odor discrimination
July 30, 2019	▪ MSL rating corrected in the Ordering table.
May 9, 2019	▪ Addition of storage conditions. ▪ Improved programming description for customer-specific applications. ▪ Improved pin description for INT. ▪ Addition of lifetime for qualification. ▪ Addition of the "Related Website and Software" section.
March 12, 2019	▪ Update to add I2C specification. ▪ Update figure for humidity influence. ▪ Update to add disclaimer for safety-related applications in section 7.1. ▪ Minor edits.
November 2, 2018	▪ Update with Low Power Operation Method.
September 24, 2018	▪ Update for operation methods for trigger/control signal option. ▪ Update for power consumption and minor update in electrical characteristics. ▪ Update references.
September 1, 2018	Initial release.

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TOP VIEW

3.00

2.80 REF

0.70

0.075 C

A

0.75

∅0.30

3.00

2.80 REF

B

PIN#1 CORNER

R0.13 REF
R0.24 REF

BOTTOM VIEW

0.250X0.350 (12x)

| ⊕ | 0.10 Ⓜ | C | A | B |
| | 0.05 Ⓜ | C | | |

A

6 7 8 9 10

1.00

5 11 B

0.10 ∠45°

4 3 2 1 12

0.38

0.15
0.05

0.50

PIN#1 CORNER

SIDE VIEW

R0.20 REF

// 0.10 C

(0.13)

0.77
0.63

C

NOTES:

1. ALL DIMENSIONING AND TOLERANCING CONFORM TO ANSI Y14.5M–1982

2. ALL DIMENSION ARE IN MILLIMETERS.

RENESAS

12-LGA, Package Outline Drawing
3.0 x 3.0 x 0.7 mm Body, 0.5 x 1.0 mm Pitch
LGG12D1, PSC-4685-01, Rev 02, Page 2

RECOMMENDED LAND PATTERN DIMENSION

NOTES:
1. ALL DIMENSION ARE IN MM. ANGLES IN DEGREES.
2. TOP DOWN VIEW. AS VIEWED ON PCB.
3. LAND PATTERN RECOMMENDATION PER IPC-7351B GENERIC REQUIREMENT
   FOR SURFACE MOUNT DESIGN AND LAND PATTERN.

Package Revision History		
Date Created	Rev No.	Description
Sept 12, 2019	Rev 01.	Add Dimension on Gal Inlet Hole
Dec 17, 2019	Rev 02	Add Location Dimension Gal Inlet

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