HY-OPTIMA™ 5000 Series Hydrogen Sensor

Operating Manual

H2scan
ADVANCED HYDROGEN SENSING

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IMPORTANT NOTICES

Read and understand this operating manual before installing or using the unit.
If this equipment is used in a manner not specified by H2scan, the protection provided by this equipment may be impaired.

LIMITATION OF LIABILITY - seller shall under no circumstances be liable for any incidental, consequential, special, punitive, or other damages, including, but not limited to, loss of business or profit, promotional or manufacturing expenses, injury to reputation, or loss of customer, based on any alleged negligence, breach of warranty, strict liability, breach of contract, or any other legal theory arising out of the use, misuse, purchase, sale or possession of its goods or its performance of this contract to the extent that such liability extends seller's obligations beyond the price paid by buyer to seller for the item on which such claim is based. Seller advises buyer to perform acceptable tests on all hardware prior to deployment and to perform maintenance as described in the seller's instruction guide. Under no circumstances shall the equipment provided hereunder be used in a manner where it is the sole protective system for facilities, equipment, and personnel safety; the equipment is intended for use in conjunction with other appropriate protective systems.

LIMITED WARRANTY

H2scan Limited Warranty: Each hydrogen instrument ("Product") will conform, as to all substantial operational features, to the Product specifications set forth in this Manual and will be free of defects which substantially affect such Product's performance for twelve (12) months from the ship date for such Product.

Must Provide Notice of Defect: If you believe a Product that you believe is defective, you must notify H2scan in writing, within ten (10) days of receipt of such Product, of your claim regarding any such defect.

Return Product to H2scan for Repair, Replacement or Credit: If the Product is found defective by H2scan, H2scan's sole obligation under this warranty is to either (i) repair the Product, (ii) replace the Product, or (iii) issue a credit for the purchase price for such Product, the remedy to be determined by H2scan on a case-by-case basis.

Voided Warranty: H2scan's 12 Month Limited Warranty is void for any of the following:

- The unit is opened, and the manufacturing seal is broken.
- Unauthorized repair work performed at the customer's location or conducted by anyone other than H2scan's factory trained technicians.
- Equipment or parts that have been tampered with, misused, neglected, mishandled, improperly adjusted, or modified in any way without the written consent of H2scan.
- Equipment or parts that have been damaged due to shipping, misuse, accidents, mishandling, neglect, or problems with electrical power sources.
- Repair work performed during the warranty period does not prolong the warranty period past the original period.
- System operation in incorrect or inappropriate environments.
- Usage that is not in accordance with system guidelines or an operator's failure to follow manual instructions.

LIMITATION OF WARRANTY: THE ABOVE IS A LIMITED WARRANTY AS IT IS THE ONLY WARRANTY MADE BY H2SCAN. H2SCAN MAKES NO OTHER WARRANTY EXPRESS OR IMPLIED AND EXPRESSLY EXCLUDES ALL WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. YOUR SOLE REMEDY HEREUNDER IS REPAIR OR REPLACEMENT OF THE PRODUCT OR A CREDIT FOR THE PURCHASE PRICE FOR SUCH PRODUCT, THE PARTICULAR REMEDY TO BE DETERMINED BY H2SCAN ON A CASE-BY-CASE BASIS. H2SCAN SHALL HAVE NO LIABILITY WITH RESPECT TO ITS OBLIGATIONS UNDER THIS AGREEMENT FOR CONSEQUENTIAL, EXEMPLARY, OR INCIDENTAL DAMAGES EVEN IF IT HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. THE STATED EXPRESS WARRANTY IS IN LIEU OF ALL LIABILITIES OR OBLIGATIONS OF H2SCAN FOR DAMAGES ARISING OUT OF OR IN CONNECTION WITH THE DELIVERY, USE OR PERFORMANCE OF THE PRODUCTS.

Contents

1 Introduction

The HY-OPTIMA™ 5000 Series Hydrogen Sensors measure hydrogen concentration in mixed gases using H2scan's patented solid-state, non-consumable, hydrogen-specific sensing element. H2scan's patented technology provides a reliable, real-time, direct, hydrogen-specific measurement without cross sensitivities to common industrial gases such as hydrocarbons, carbon dioxide, inert gases, and limited concentrations of carbon monoxide and hydrogen sulfide. The robust design remains accurate over time without periodic calibration thereby reducing services cost.

This product series is ideal for real-time inline process applications to improve efficiency/yields and to provide safe and effective operations in petrochemical processing and hydrogen economy applications such as electrolyzers, fuel cells, and hydrogen distribution, blending and storage.

Based on H2scan's 5th generation electronics platform, the HY-OPTIMA™ 5000 Series Hydrogen Sensors report calibrated hydrogen readings through a digital interface. H2scan's solid-state hydrogen sensor and patented algorithms are combined in the HY-OPTIMA™ 5000 Series Hydrogen Sensors to provide continuous, maintenance free, dependable, and accurate hydrogen measurements.

The HY-OPTIMA™ 5000 Series Hydrogen Sensors have a single electrical connection to provide DC power and 2-wire, RS-485 communications using Modbus RTU protocol.

This document has been updated for use with firmware revision **3:5:A**.

2 Features

2.1 Sensor

The HY-OPTIMA™ 5000 Series Hydrogen Sensor hydrogen measurement is based on H2scan's state-of-the-art solid-state sensor. While H2scan cannot test every conceivable gas stream, for typical industrial streams under normal operation that follows the guidelines listed in this manual, the measurement algorithm can be expected to maintain the stated accuracy for the life of the device.

- The sensor measures and reports hydrogen as its partial pressure and therefore can measure hydrogen as a constituent of various gas mixtures.
- Periodic calibration is not required.
- The sensor does not require maintenance.
- The sensing element has a long life and is not consumed or degraded during operation.
- There are no moving parts to wear out.
- No background gas, carrier gas, or any other consumables required for operation.

2.2 Mechanical

The HY-OPTIMA™ 5000 Series Hydrogen Sensors have a rugged, waterproof mechanical assembly design for industrial applications. A ¾"-14 NPT fitting is provided for attachment of the sensor to a gas stream. The HY-OPTIMA™ 5000 Series Hydrogen Sensors are IP68 and saltwater corrosion rated for marine applications. (Exceeds C5M requirements)

Overall dimensions are shown in **Figure 1**.

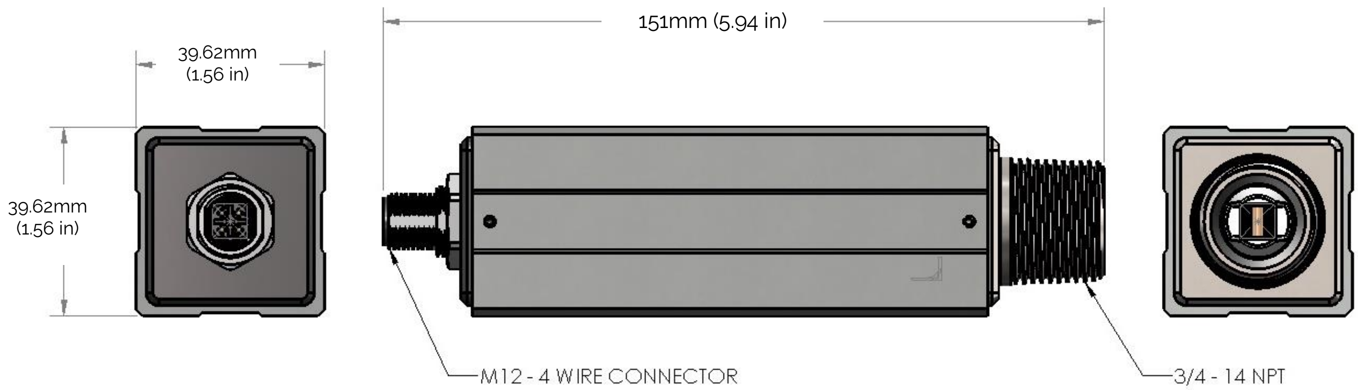


Figure 1: HY-OPTIMA™ 5000 Series Hydrogen Sensor Dimensions

2.3 Physical Barrier

A physical barrier exists between the hydrogen sensing element and the HY-OPTIMA™ 5000 Series Hydrogen Sensor electronics. This barrier includes a glass-to-metal feedthrough for electrical connections and gaskets to complete the hydrogen gas-tight seal.

2.4 Electrical Features

The HY-OPTIMA™ 5000 Series Hydrogen Sensor has a single 4-pin M12 connector for power and communications.

- DC power input of 9 to 48 volts, 10 watts (commonly available 24 VDC or 48 VDC power supplies are recommended)
- 2-wire RS485 for Modbus RTU communications

3 Specifications

Sensor performance specifications are absolute and assume a dry process stream, an ambient temperature of 25˚C, 1 atmosphere absolute pressure, and are in addition to any errors in the calibration gases used. Accuracy and repeatability are defined as ± the values listed. For other operating pressures, see section 8.2 *Pressure Normalized Specifications* as it will affect the specifications listed in the tables below.

While the sensors can operate in gas containing no hydrogen, measurement performance specifications are valid only when the sensor is exposed to gas containing hydrogen above the Lower Detection Limit shown below.

Table 1: Product Selection

Model	H_2 Range		Lower Detection Limit (LDL)	CO Limit	H_2S Limit	Response Time T_{90} (sec) *	Accuracy	Repeatability
	Low	High						
5031	0%	10%	0.03%	100 ppm	20 ppm	< 90	See Table 2	See Table 2
5032	0%	5%	0.4%	0	0	< 60	0.3%	0.3%
5033	0%	100%	0.5%	100 ppm	1000 ppm	< 60	See Table 3	See Table 3
5034	0%	100%	0.5%	20%	3%	< 90	See Table 3	See Table 3

* For a more complete discussion on response time, please refer to section 8.5 *Response Time*

Table 2: Model 5031 Accuracy and Repeatability

H_2 Range	Accuracy (Absolute Error)	Repeatability (Absolute Error)
LDL – 0.5%	0.05%	0.05%
1% – 2%	0.10%	0.10%
2% – 5%	0.15%	0.15%
5% – 10%	0.20%	0.20%

Table 3: Model 5033/5034 Accuracy and Repeatability

H_2 Range	Accuracy (Absolute Error)	Repeatability (Absolute Error)
LDL – 10%	0.4%	0.2%
10% – 30%	0.7%	0.3%
30% – 70%	1.0%	0.4%
70% – 100%	1.2%	0.5%

Table 4: Absolute Maximum Operating Conditions

Parameter	Value			Units
	Minimum	Nominal	Maximum	
Environment – Gas Stream*				
Operating Temperature	-40		60	˚C
Pressure‡ (absolute)	0.1‡	1	10‡	atm abs.
Gas Flow Rate (1/4" tube)	0.1	1	10	slpm
Operating Humidity	< 95% RH (non-condensing)			
Environment – Ambient				
Operating Temperature	-40		70	˚C
Storage Temperature	-40		105	˚C
Ingress Protection	IP68; 25 feet water for 14 days (IEC 60529)			
Humidity	0 to 100% RH, condensing			
Corrosion Resistance	Class C5M Marine rated; salt-water condensing (IEC 60068-2-11 & DIN EN ISO 12944)			
Mechanical				
Vibration	3-axis Sinusoidal, Wideband and Random (IEC 60068-2-6 table C.2, IEC 60068-2-64 paragraph A.2, category no. 2, IEC 61373: 2010 Cat 1B section 9)			
Shock	30g, shock duration 18ms (IEC 60068-2-27)			
Weight	0.85 lbs. (387 grams)			
Electrical				
Voltage Input	8.1	24	52.8	VDC
Power Consumption			10	W

* Specific product models may have different limits.
‡ Operating at pressures above or below 1 atm abs. will affect the measurement accuracy. See 8.1 Effect of Pressure.

3.1 Certifications

CE

FC

IP68

3.2 Standards

- IEC 60068-2-2 & EN 50155 Section 13.4.4
- IEC 60068-2-11 & DIN EN ISO 12944
- IEC 60529
- IEC 60068-2-6 table C.2
- IEC 60068-2-64 paragraph A.2, category no. 2
- IEC 60068-2-27
- FCC Part 15
- EN 55011Class A Group 1
- IEC 61000-4-2, 61000-4-3, 61000-4-4, 61000-4-6, and 61000-4-8
- ANSI/UL/IEC/EN 61010-1
- IEC 61326-1

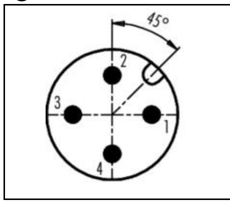
4 Electrical Interface

All electrical connections to the HY-OPTIMA™ 5000 Series Hydrogen Sensor are supplied through a single 4-pin M12 connector.

4.1 Connector

The key (notch) location and pin numbers are shown in **Table 5**.

Table 5: HY-OPTIMA™ 5000 Series Hydrogen Sensor Pin Out



Pin	Signal Name	Wire Color
1	DC power	Brown
2	DC ground	White
3	RS485 Data+	Blue
4	RS485 Data-	Black

> ***Note**: This view is looking at the connector on the HY-OPTIMA™ 5000 Series Hydrogen Sensor.*

4.2 Wiring Diagram

A wiring diagram is shown in **Figure 2**.

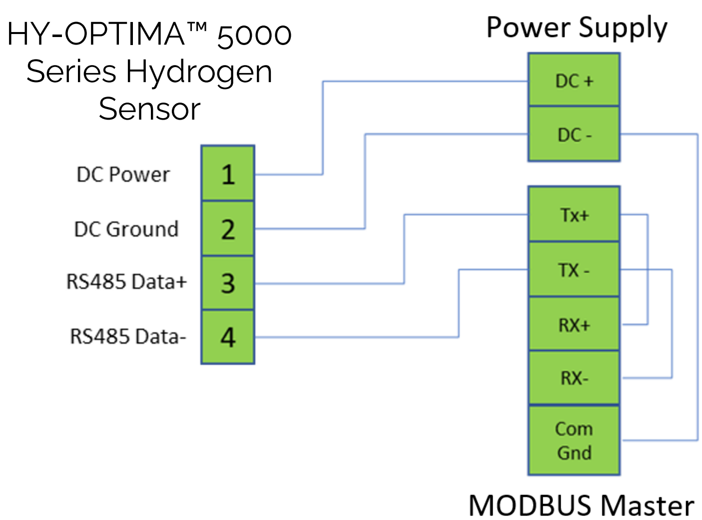


Figure 2: Connection to Modbus RTU Master

4.3 Cable

A suitably rated cable assembly is required for most field applications. A 5m cable is included as standard, all other lengths are custom orderable options.

Cable recommendations are:

- 4-pin M12 Female molded connector
- IP68 rated connector
- 4/18 AWG wire
- Shielded cable is recommended **(grounded at one end only)**

> ***Note**: H2scan is not responsible for issues arising from the use of cabling and connectors that are not suited for the environment.*

4.4 Power Supply

The HY-OPTIMA™ 5000 Series Hydrogen Sensors incorporate an internal isolated voltage regulator for operation in harsh electrical conditions. The DC ground line is electrically isolated from the metal case. The HY-OPTIMA™ 5000 Series Hydrogen Sensor enclosures are connected to earth ground through the mechanical connection.

Use an industrial grade, fixed-output power supply that meets the following specifications:

- DC voltage output
- Output Voltage: 12, 15, 24, 30, 36 or 48 VDC nominal (8.55 to 50.4 VDC)
- Output power: 10 watts minimum

***Note**: 24 VDC or 48 VDC Power Supply is recommended.*

A 24 VDC Power Supply is available as an orderable accessory from H2scan.

4.5 RS485

The RS485 input is galvanically isolated inside the HY-OPTIMA™ 5000 Series Hydrogen Sensors to improve noise immunity in harsh electrical environments.

The HY-OPTIMA™ 5000 Series Hydrogen Sensors do not include bias resistors for the Data lines which may need to be added at the SCADA end of the cable. A 120-Ohm termination resistor, between Data+ and Data-, is installed in the HY-OPTIMA™ 5000 Series Hydrogen Sensor.

The following communication settings are used for the RS485, 2-wire, half-duplex connection:

Baud Rate:	9,600
	14,400
	19,200 (Factory Default)
	38,400
	57,600
	115,200
Data bits:	8
Stop bits:	1 or 2 (Default 2)
Parity:	None
Flow Control:	None

5 Installation

5.1 Handling Precautions

The following precautions must be followed to ensure the sensor assembly is not damaged during handling:

- Ensure that nothing comes in contact with the sensor-end of the device.
- The protective cap should remain in place until the time of installation.
- Place a wrench on the metal housing closest to the threaded end when tightening. The HY-OPTIMA™ 5000 Series Hydrogen Sensors are designed to handle torque throughout the whole sensor assembly enclosure.
- Use standard torque for ¾" NPT fitting which is approximately 50 ft-lbs. Do not overtighten.

5.2 Mechanical Connection

Attach the sensor to a ¾"-14 NPT fitting. To adapt to sample streams with smaller ID pipe diameters such as ¼" NPT, a ¾"-14 NPT tee fitting can be used with ¾" Male NPT x ¼" Female NPT adapter bushings. It is recommended the sensor be mounted in the vertical position to prevent any potential accumulation of condensed fluids in the sensor cavity. Do not mount the sensor with the sensor cavity pointing upwards at any angle as shown in Figure 3.

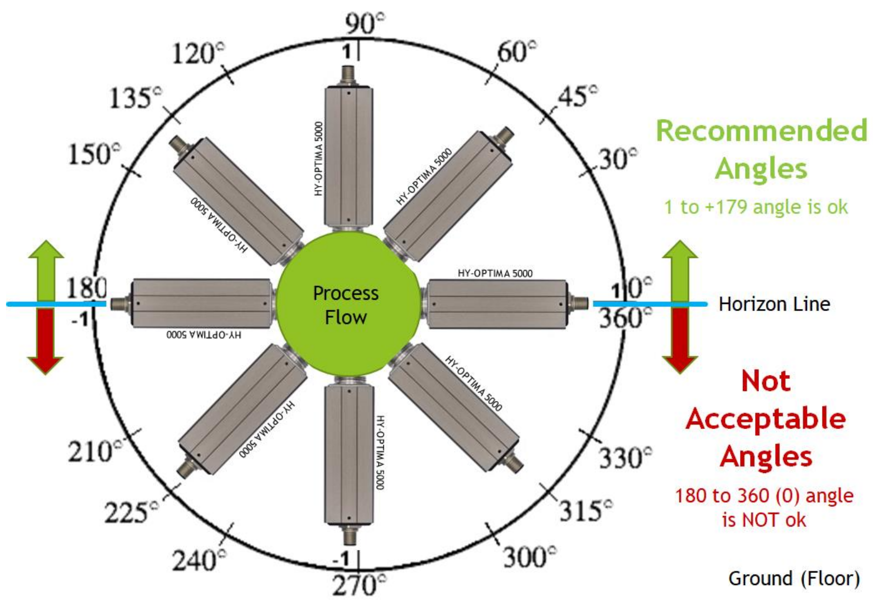


Figure 3: Acceptable and Unacceptable Mounting Orientations

WARNING: Mounting the sensor pointing upwards can cause the accumulation of condensed liquids in the sensor cavity and can cause issues with sensor operation and reporting and can void the limited warranty.

5.3 Electrical Connection

Before energizing the equipment:

- Install the cable between the HY-OPTIMA™ 5000 Series Hydrogen Sensor and the power/communication equipment
- Communication ground must be connected to DC ground
- Connect the cable to the power/communication equipment
- Connect the cable to the HY-OPTIMA™ 5000 Series Hydrogen Sensor

***Note**: The connector to the HY-OPTIMA™ 5000 Series Hydrogen Sensor must be fully tightened to ensure the IP68 rating.*

Turn on power and check Modbus communications. The default communication settings are:

- RS485, half-duplex, 19200 baud, 8 data bits, 2 stop bits, no parity
- Default Modbus ID is 1

5.4 Optional Accessories

H2scan offers accessories for the HY-OPTIMA™ 5000 Series Hydrogen Sensors to assist with integration and installation of the hydrogen sensor. For more information about these accessories, check the **h2scan.com** website and email **sales@h2scan.com**.

5.4.1 Grounding Lug

The ground lug provides a secure earth ground connection to HY-OPTIMA™ 5000 Series Hydrogen Sensor.

5.4.2 Mounting Bracket

The mounting bracket provides a method of attaching the HY-OPTIMA™ 5000 Series Hydrogen Sensor to a surface.

5.4.3 Conduit Adapter

The conduit adapter can be fixed to the end of the hydrogen sensor with the M12 connector, providing a feedthrough for the sensor cable through a 1/2" NPT conduit connection.

5.4.4 5902 HY-OPTIMA™ Analog Output Module

The analog output module converts the digital Modbus signal from the HY-OPTIMA™ 5000 Series Hydrogen Sensor into a 4-20mA analog signal.

5.4.5 Custom Sensor Cable Lengths

A standard 5 m cable is included with every HY-OPTIMA™ 5000 Series Hydrogen Sensor. If longer lengths are necessary, custom cables to 30 m can be ordered from H2scan.

6 Operation

> ***Note**: If operating at a pressure other than 1 atm absolute, the hydrogen reading will need to be compensated for pressure by performing a 2-point field calibration or by dividing the hydrogen reading by the known pressure in atm absolute.*

6.1 Startup

Power on the analyzer before flowing gas across the sensor by connecting the cable and turning on the power supply. The sensor will execute a startup sequence and will begin reporting hydrogen after 1 minute. During this period, the analyzer will:

- Perform a power on system self-test
- Restore configuration settings from non-volatile memory.

The Modbus status register **111** bit **15** will indicate **Ready** when the first valid hydrogen measurement is available. After the startup sequence completes, measurement data will be available in the Modbus registers.

If the analyzer has been powered off for more than one month, the real time clock may need to be set. See 7.2.11 Real time Clock.

If an error is reported, turn off power to the sensor; double check the electrical connections and power supply voltage before restoring power again. If the error condition persists, contact H2scan customer service for assistance at **technicalsupport@h2scan.com**.

6.2 Monitoring

During normal operation, the HY-OPTIMA™ 5000 Series Hydrogen Sensor measurements should be polled through the RS-485 interface periodically for a measurement reading. The time between readings can be from 1 second to several hours or days depending on user requirements. Each reading should include the following Modbus holding registers.

- **Status Register** (**111** bits **15** & **12**) – Bit 15 indicates that the hydrogen measurement is available. Bit 12 indicates that there is an error.
- **Error Status Registers** (**112**,**113**) – Indicates which error is detected. (These registers are active when register 111 bit 12 is high)
- **Hydrogen Registers** (**0**,**1**) – Provides the Hydrogen ppm values. Programming note: The high word (0) must be read to enable the low word (1) value to be available.

6.3 Shutdown

The following controlled shutdown procedure is recommended:

- Purge the system using gas with a hydrogen concentration of less than 5% H_2 or with 100% N_2 for 5 minutes.
  - **Note**: For the 5032 model, hydrogen-free gas such as air or inert gases such as nitrogen, argon, or helium can be used.
- Turn off all gas flow to the analyzer.
- Power off the analyzer.

6.4 Error/Exception Handling

The HY-OPTIMA™ 5000 Series Hydrogen Sensors are designed for continuous operation and will automatically recover from intermittent problems due to insufficient power, excessive electrical noise, or excessive internal PCB temperature.

If the sensor element is damaged and unable to operate, the HY-OPTIMA™ 5000 Series Hydrogen Sensor will shut down the measurement system and continue responding to Modbus for error reporting. This error will be reported via register **111** bit **12** and then details specified in register **112**,**113**. This type of error typically indicates a hardware fault that can only be repaired at H2scan. Power cycle the unit to attempt recovery. If the error condition persists, contact H2scan for repair at **technicalsupport@h2scan.com**.

7 Modbus

The HY-OPTIMA™ 5000 Series Sensors use Modbus RTU to communicate with external equipment. Modbus RTU is a popular industrial interface supported by many products.

7.1 Communication Settings

Modbus protocol communicates over RS485 and supports RTU packets. The HY-OPTIMA™ 5000 Series Hydrogen Sensor default Modbus ID is 1. The Modbus ID can be changed by writing to holding register **150**.

7.2 Protocol

The following tables comprise the list of Modbus packets, values, registers, and register definitions.

The maximum time for the sensor to respond to a Modbus command is 10 seconds. Therefore, the master's timeout should be set to 10,000 milliseconds or greater.

Table 6: Modbus Read Request Packet

Byte	Modbus Parameter	Range	Meaning
1	Slave address	1 – 247	Unit ID Address
2	Function Code	03	Read Holding Register
3	Starting Address Hi	0x00 – 0xFF	Holding Register Hi Byte
4	Starting Address Lo	0x00 – 0xFF	Holding Register Lo Byte
5	Number of registers Hi	0	Limited by Modbus spec V1.1b
6	Number of Registers Lo	1 – 125	Number of 16-bit registers Lo Byte
7	CRC Lo	0x00 – 0xFF	CRC Low Byte
8	CRC Hi	0x00 – 0xFF	CRC High Byte

Table 7: Modbus Read Response Packet

Byte	Modbus Parameter	Range	Meaning
1	Slave address	1 – 247	Unit ID Address
2	Function Code	03	Returning Holding Registers
3	Byte Count	7 – 255	Number of data bytes returned = N
4	1st Data Value Hi	0x00 – 0xFF	
5	1st Data Value Lo	0x00 – 0xFF	
6	2nd Data Value Hi	0x00 – 0xFF	
7	2nd Data Value Lo	0x00 – 0xFF	
...	...		
...	...		
2N+4	CRC Lo	0x00 – 0xFF	CRC Low Byte
2N+5	CRC Hi	0x00 – 0xFF	CRC High Byte
N is the number of bytes returned based on the number of registers requested. If N registers are requested, then 2N+5 bytes are returned.			

Table 8: Modbus Write Request Packet

Byte	Modbus Parameter	Range	Meaning
1	Slave address	1 – 247	Unit ID Address
2	Function Code	06	Write Holding Registers
3	Register Address Hi	0x00 – 0xFF	Unit Register Address Hi byte
4	Register Address Lo	0x00 – 0xFF	Unit Register Address Lo byte
5	Data Value Hi Byte	0x00 – 0xFF	
6	Data Value Lo Byte	0x00 – 0xFF	
7	CRC Lo	0x00 – 0xFF	CRC Low Byte
8	CRC Hi	0x00 – 0xFF	CRC High Byte

Table 9: Modbus Write Response Packet

Byte	Modbus Parameter	Range	Meaning
1	Slave address	1 – 247	Unit ID Address
2	Function Code	06	
3	Register Address Hi Byte	0x00 – 0xFF	Unit Register Address Hi byte
4	Register Address Lo Byte	0x00 – 0xFF	Unit Register Address Lo byte
5	Data Value Hi Byte	0x00 – 0xFF	
6	Data Value Lo Byte	0x00 – 0xFF	
7	CRC Lo	0x00 – 0xFF	CRC Low Byte
8	CRC Hi	0x00 – 0xFF	CRC High Byte

7.2.1 Exception Response

In a normal communications query and response due to a communication error, the master device sends a query to the slave device. Upon receiving the query, the slave processes the request and returns a response to the master device. An abnormal communication between the two devices produces one of four possible events:

1. If the slave does not receive the query due to a communications error, then no response is returned from the slave and the master device will eventually process a timeout condition for the query.
2. If the slave receives the query but detects a communication error (UART or CRC), then no response is returned from the slave and the master device will eventually process a timeout condition for the query.
3. If the slave receives the query without a communications error, and takes longer than the master's timeout setting, then no response is returned from the slave. The master device eventually processes a timeout condition for the query. To prevent this condition, the master timeout must be set longer than the maximum response time of the slave (10,000 milliseconds).
4. If the slave receives the query without a communications error but cannot process it due to reading or writing to a non-existent slave command register, then the slave returns an exception response message informing the master of the error.

The exception response message has two fields that differentiate it from a normal response. The first is the function code – byte 2. This code will have the high order bit set to a one (e.g., 0x83 for a read exception and 0x86 for a write exception). The second differentiating field is the exception code – byte 3. In addition, the total exception response length is 5 bytes rather than the normal message length.

Table 10: Exception Response Packet

Byte	Modbus Parameter	Range	Meaning
1	Slave Address	1 – 247	
2	Function Code	0x83 or 0x86	Read or Write
3	Exception Code	See Table Below	
4	CRC High	0x00 – 0xFF	
5	CRC Low	0x00 – 0xFF	

Table 11: Exception Response Codes

Code	Name	Description
1	Illegal Function Code	The function code received in the query is not an allowable action for the slave. This may be because the function code is only applicable to newer devices and was not implemented in the unit selected. It could also indicate that the slave is in the wrong state to process a request of this type, for example, it is not configured and is being asked to return register values.
2	Illegal Data Address	The data address received in the query is not an allowable address for the slave. More specifically, the combination of reference number and transfer length is invalid. For a controller with 100 registers, the PDU addresses the first register as 0, and the last one as 99. If a request is submitted with a starting register address of 96 and a quantity of registers of 4, then this request will successfully operate (address-wise at least) on registers 96, 97, 98, 99. If a request is submitted with a starting register address of 96 and a quantity of registers of 5, then this request will fail with Exception Code 0x02 "Illegal Data Address" since it attempts to operate on registers 96, 97, 98, 99 and 100, and there is no register with address 100.
3	Illegal Data Value	A value contained in the query data field is not an allowable value for slave. This indicates a fault in the structure of the remainder of a complex request, such as that the implied length is incorrect. It specifically does NOT mean that a data item submitted for storage in a register has a value outside the expectation of the application program, since the MODBUS protocol is unaware of the significance
4	Slave Device Failure	An unrecoverable error occurred while the slave was attempting to perform the requested action.

7.2.2 Modbus Command Register Definitions

The Command Register definitions for the HY-OPTIMA™ 5000 Series Hydrogen Sensors are identified in Table 12.

> ***Note**: When reading registers containing 32 or 64-bit integers the user must read the high order word first, then the lower order word(s). Reading of the high order word causes the low order word to be saved in a temporary location for the next register read. The second register is then automatically read from the temporary location by the firmware. Likewise, with a write, the high value is stored until the second value is received, at which time, both values are written to the instrument.*

Table 12: Command Register Locations

Register	Parameter	Function	Data Type	Data Range	Access
Measurements					
0	Hydrogen, ppm H_2 Note: To convert ppm to %, divide ppm reading by 10,000	High word	32-bit binary number	0 to 20,000,000	R
1		Low word			
2-6	Reserved for future use				
7	PCB Temperature, Celsius	x100 scale; 100 offset (T=V/100-100)	16-bit binary number	-100 to +200	R
8-30	Reserved for future use				

Register	Parameter	Function	Data Type	Data Range	Access
Information					
31-40	Model Number		ASCII String		R
41-50	Product Serial Number		ASCII String		R
51-60	Sensor Serial Number		ASCII String		R
61-70	Sensor Board Serial Number		ASCII String		R
71-80	Reserved for future use				
81	Manufacturing Date	high byte: Month low byte: Day	32-bit binary value		R
82		Year			
83	Factory Calibration Date	high byte: Month low byte: Day	32-bit binary value		R
84		Year			
85-86	Reserved for future use				
87	Field Calibration Date	high byte: Month low byte: Day	32-bit binary value		R
88		Year			
89-98	Firmware Revision		ASCII String		R
99-110	Reserved for future use				
Status/Error Information					
111	Status	Refer to section 7.2.3	16-bit binary flags	Table 13: Unit Status	R
112	Error Status	Refer to section 7.2.7.2 High word	32-bit binary flags	Table 14: Error Status	R
113		Low word			
114-120	Reserved for future use				

Register	Parameter	Function	Data Type	Data Range	Access
Calibration Functions					
121-125	Reserved for future use				
126	Calibration Gas 1, ppm H_2 Note: To convert % to ppm, multiply % value by 10,000	High word	32-bit binary number	0 to 1,000,000	R/W
127		Low word			
128	Calibration Complete/Date	High byte: Month Low byte: Day	32-bit binary value		R/W
129		Year			
130	Calibration Gas 2, ppm H_2 Note: To convert % to ppm, multiply % value by 10,000	High word	32-bit binary number	0 to 1,000,000	R/W
131		Low word			
132	Field Cal start command	Gas exposure duration (minutes)	16-bit binary number	60 to 1440	W
133	Field Cal abort command	Abort Field Cal or clear data	8-bit binary number	1: abort 2: clear	W
134	Field Cal get status command	High byte: Error code Low byte: Status	16-bit binary number	Table 22 and Table 23	R
135	Gas start command	Gas 1 or 2 started	8-bit binary number	1: gas 1 2: gas 2	W
Configuration Settings					
136-149	Reserved for future use				
150	Set Unit ID		8-bit binary number	1 to 247	R/W
151-158	Reserved for future use				
159	Stop Bit Selection		16-bit binary number	1 (stop bit = 1) 2 (stop bit = 2)	R/W
160	Baud Rate		8-bit binary number	1 = 9600 2 = 14400 3 = 19200 4 = 38400 5 = 57600 6 = 115200	R/W
161-174	Reserved for future use				

Register	Parameter	Function	Data Type	Data Range	Access
Diagnostics					
175	Month / Year	Date & Time; read register 175 first; order high-byte / low-byte; add 2000 to year (64-bit)	Two Bytes		R/W
176	Hour / Day		Two Bytes		R/W
177	Second / Minute		Two Bytes		R/W
178	Millisecond		16-bit binary number		R/W
179-200	Reserved for future use				
User Information					
201-210	User ID #1	Must start reading from low address; Must write low and high addresses to save string	ASCII String		R/W
211-220	User ID #2		ASCII String		R/W
221-230	User ID #3		ASCII String		R/W
231-255	Reserved for future use				

7.2.3 Hydrogen Measurement

The HY-OPTIMA™ 5000 Series Hydrogen Sensors report the most recent hydrogen **measurement** in registers 0-1. The 32-bit unsigned integer value is not scaled and reports the integer value of hydrogen in ppm H_2.

> ***Note***: *Read the device status in register 111 bit 15 to determine if the device is ready. The hydrogen value is zero until the ready bit is set.*

7.2.4 Temperature Measurement

The HY-OPTIMA™ 5000 Series Hydrogen Sensors monitor the internal electronics temperature. The temperature is reported as a scaled16-bit unsigned integer in degrees Celsius. Dividing the integer value by 100 and subtracting 100 will provide the measured temperature with 2 decimal places.

7.2.4.1 PCB Temperature

PCB temperature is reported in register 7. This is the internal temperature of the electronics enclosure which must not exceed 105˚C.

This is a good register to read during installation and communication testing because the value is always valid and frequently changes.

7.2.5 ASCII Strings

HY-OPTIMA™ 5000 Series Hydrogen Sensor information is available as ASCII strings terminated with a zero byte (0x00). Each string can be up to 19 characters long with 2 characters per Modbus register. Use the read holding register function and read ten registers, each byte is an ASCII character.

7.2.5.1 Model Number

The model number is in registers 31-40.

7.2.5.2 Product Serial Number

The product serial number is in registers 41-50.

7.2.5.3 Sensor Serial Number

The sensor serial number is in registers 51-60.

7.2.5.4 Sensor Board Serial Number

The sensor board serial Number is in registers 61-70.

7.2.5.5 Firmware Revision

The firmware revision is in registers 89-98, using format x:y:z; example 3:5:A

- x is the major revision
- y is the minor revision
- z is the product designator

7.2.6 Date Register Format

Registers that report a date value are encoded as follows.

- High word, high byte is the Month
- High word, low byte is the Day
- Low word is the Year

7.2.6.1 Manufacturing Date

Original manufacturing date is in registers 81,82

7.2.6.2 Factory Calibration Date

Last factory calibration date is in registers 83,84

7.2.7 Status and Error Information

The HY-OPTIMA™ 5000 Series Hydrogen Sensors provide status and error information for the user to determine if it is operating normally.

7.2.7.1 Unit Status

Unit status information is maintained in Modbus register 111. The bit map for this status word is described below:

Table 15: Unit Status

Bit #	Description
15	Unit Ready, hydrogen readings are valid
14	New measurement data available, auto clear after register read
13	Unlisted bits are not used and may be 0 or 1.
12	Error, indicates an unrecoverable error occurred, read Reg 112,113 for more information
0-11	Unlisted bits are not used and may be 0 or 1.

7.2.7.2 Error Status

When the error flag (bit 12) of the Unit Status register 111 is set, the 32-bit register 112,13 has more information about what is causing the error. The bit map is shown below.

Table 16: Error Status

Bit #	Hex Value	Description
31	0x8000 0000	Sensor – Heater fault
30	0x4000 0000	Sensor – Temperature Sensor Fault
29	0x2000 0000	Sensor – Hydrogen Sensor Fault
3-28	0x1000 0000 - 0x0000 0008	Unlisted bits are not used and may be 0 or 1.
2	0x0000 0004	PCB Temperature greater than 105C
1	0x0000 0002	Required data not available
0	0x0000 0001	Configuration data not valid

7.2.8 Set Unit ID

The Modbus ID is reported or set in register 150. Reading this register is used to confirm that the selected ID is in use. Writing the desired ID to register 150 will set the unit to the specified ID. The device ID can range from 1 to 247 or as limited by the Modbus master. Note that if the current device ID is unknown then writing the desired ID to device 0 will broadcast the ID to all connected HY-OPTIMA™ 5000 Series devices.

Preparing multiple units to share a common RS485 bus is accomplished by connecting one unit at a time to a Modbus controller and writing the desired ID for that unit to register 150 at device ID 0.

For PC-based configuration, use ComTest Pro from www.BaseBlock.com for a Modbus controller. The device must be power cycled for the new ID to take effect. It is recommended that each device is labeled with the new device ID.

A simple procedure to configure multiple units is as follows:

1) Disconnect all units from the RS485 cable
2) Connect first unit to the RS485 cable
3) Use the Modbus Controller to write a single holding register (function 6) to register 150, device 0, with the desired ID for the connected unit
4) Wait up to 10 seconds for the Modbus response
5) Disconnect this unit and connect the next one to the RS485 cable
6) Repeat steps 3, 4, and 5 until all units are configured
7) Attach all units to the RS485 cable and read register 150 from each of the configured devices

7.2.9 Stop Bit Selection

To select which stop bit to use in the RS485 communication port settings, write a 1 or 2 to Modbus register **159** (default selection is **1**). **Note**: If changing to **2**, you **may** need to write a **3** to register **160** (baud rate – 19,200) as well and power-cycle the HY-OPTIMA™ 5000 Series Hydrogen Sensor.

7.2.10 Baud Rate

The HY-OPTIMA™ 5000 Series Hydrogen Sensor RS485 baud rate can be modified from the default 19,200 baud by writing to Modbus register 160 with the number corresponding to the desired value in the table below. The device must be power cycled for the new baud rate to take effect.

Table 17: Baud Rate

Number	Description
1	9,600 baud
2	14,400 baud
3	19,200 baud
4	38,400 baud
5	57,600 baud
6	115,200 baud

7.2.11 Real time Clock

HY-OPTIMA™ 5000 Series Hydrogen Sensors have an internal real time clock with backup power provided by a super capacitor. Depending on temperature, the backup power will last a few months in storage. During installation, the real time clock should be set to the current date and time.

To set the date and time, write to registers 175, 176, 177, then 178; the time is saved when register 178 is written.

To get the date and time, read registers 175, 176, 177, then 178; the time is captured when register 175 is read.

7.2.11.1 Month / Year

The month and year are in register 175; month in the high byte, year (from 2000) is in the low byte.

7.2.11.2 Hour / Day

The hour and day are in register 176; hour (24-hour format) in the high byte, day in the low byte.

7.2.11.3 Second / Minute

The second and Minute are in register 177; second in the high byte, minute in the low byte.

7.2.11.4 Millisecond

Milliseconds are in register 178.

7.2.12 User Information

The HY-OPTIMA™ 5000 Series Hydrogen Sensors provide three ASCII strings that the user can program to indicate the where the sensor is installed. Each string can be up to 20 characters including null termination.

7.2.12.1 User ID #1

The user string #1 is saved in registers 201 through 210.

7.2.12.2 User ID #2

The user string #2 is saved in registers 211 through 220.

7.2.12.3 User ID #3

The user string #3 is saved in registers 231 through 230.

8 Principles of Operation

8.1 Effect of Pressure

The HY-OPTIMA™ 5000 Series Hydrogen Sensors are hydrogen specific and measures the partial pressure of only hydrogen in a gas stream. Changes in gas pressure will affect the hydrogen partial pressure and therefore the measured output as well.

Example: At 1.0 atmosphere absolute, a 50% H_2/N_2 mixture will be reported as 50% by the analyzer. At 1.1 atmospheres absolute the reading will increase to 55% and 2.0 atmospheres absolute will result in a reading of 100%. Some models, such as the HY-OPTIMA™ 5033 and HY-OPTIMA™ 5034, can measure multiple atmospheres of hydrogen, and readings above 100% H_2 are interpreted as hydrogen pressures above 1.0 atmosphere absolute. For example, a reading of 150% H_2 means 1.5 times the hydrogen pressure of a 100% H_2 concentration at 1.0 atmosphere absolute.

The analyzers are factory calibrated at 1.0 atmosphere absolute. If the operating pressure is different than 1.0 atmosphere absolute but is constant, a 2-point field calibration can be performed upon installation to ensure the H_2 reading provides the correct volumetric concentration of H_2. (Refer to section 9 for detailed instructions.) If the pressure is known or actively measured by a pressure sensor, the volumetric H_2 concentration can be calculated using equation (1) below:

$$H_{2_{vol}} = \frac{H_{2_{read}}}{P_{ata}} \tag{1}$$

Where P_{ata} is the known or measured pressure in atmospheres absolute and $H_{2_{read}}$ is the H_2 reading from the analyzer, under the assumption the analyzer is using the factory calibration at 1.0 atmosphere absolute. It is important to note that any error in the pressure measurement will translate as error in the H_2 concentration measurement. This effect is especially significant when the analyzer is measuring high hydrogen concentrations. For example, if an analyzer is measuring 100% H_2 at 1.00 atmospheres absolute and a pressure sensor is used to actively compensate the reading for pressure but has a relative error of 1% (0.01 atmospheres), then the analyzer will have a measurement error of 1% H_2.

Another important consideration of using a pressure sensor to actively compensate the analyzer's hydrogen reading for changes in pressure is the differences in response times between the hydrogen sensor and the pressure sensor. Typically, pressure sensors can respond very quickly to changes in pressure. The hydrogen sensor, however, will have a time constant that is measured on the order of seconds. If a step change in pressure were to occur with the hydrogen concentration remaining constant, a pressure compensated hydrogen measurement would instantaneously adjust for the pressure change (as indicated by the pressure sensor), but the actual hydrogen response of the hydrogen sensor would gradually be introduced into the equation. The result would be an erroneous transient in the pressure compensated hydrogen measurement that would reduce to zero once the hydrogen sensor returned to equilibrium with the gas. This effect can be partially mitigated by artificially reducing the response time of the pressure sensor to match that of the hydrogen sensor using a low pass filter, but there will likely always be some residual error.

Because of the effects described above, it is strongly recommended to condition the gas stream at the analyzer to have a stable operating pressure and constant flow. Further, even if the system is designed to operate at 1.0 atmospheres absolute, for best measurement accuracy (especially if measuring high hydrogen concentrations), a 2-point field calibration is recommended upon installation to remove any measurement error due to small offsets in pressure. Once the calibration is complete, keep the system at that operating pressure and do not adjust the pressure regulation to ensure the normal operating conditions match the field calibration conditions as closely as possible.

8.2 Pressure Normalized Specifications

Because the sensing element is sensitive to the partial pressure of hydrogen , the operating pressure of the analyzer can significantly affect its measurement accuracy. The reported hydrogen is given as a volumetric concentration and the pressure is assumed to be constant. The specifications listed in section 3 Specifications are given as volumetric concentrations at 1 atmosphere absolute.

As described in section 8.1 there is a simple physical relationship between volumetric concentration and partial pressure. A gas containing 10% hydrogen by volume at 1 atmosphere absolute can be thought of instead as having a partial pressure of 0.1 atmospheres absolute of hydrogen, and 10% hydrogen by volume at 2 atmospheres absolute would correspond to 0.2 atmospheres absolute of hydrogen. (For more information on the subject refer to Dalton's Law.)

The table below describes the specifications for each product in units of atmospheres absolute. These specifications assume a dry process stream, an ambient temperature of 25˚C, and are in addition to any errors in the calibration gases used.

Table 18: Partial Pressure Limits

Model	H_2 Range		Lower Detection Limit (LDL)	CO Limit	H_2S Limit
	Low	High			
5031	0	0.1	0.0003	0.0001	0.00002
5032	0	0.05	0.004	0	0
5033	0	3	0.005	0.0001	0.001
5034	0	3	0.005	0.2	0.03

Units: atmospheres absolute (ata)

Example: A gas stream containing up to 70% H_2 and 1% H_2S by volume can be monitored by a HY-OPTIMA™ 5034 at up to 3 atmospheres absolute. At this operating pressure, the analyzer would see up to 2.1 atmospheres absolute of H_2 and 0.03 atmospheres absolute of H_2S, both of which are within the limits listed in the table above. However, if the operating pressure were to be raised to 4 atmospheres absolute, while the partial pressure of H_2 is still within the limit at 2.8 atmospheres absolute, the H_2S would exceed the limit at 0.04 atmospheres absolute.

The uncertainty of the measurement must also be scaled with pressure. The accuracy specifications listed in section 3 Specifications are given as maximum errors as an absolute volumetric concentration of H_2. For the various models these accuracy specifications are further broken down by hydrogen range. However, this is done for simplicity and only applies for an operating pressure of 1 atmosphere absolute. The uncertainty can be expanded generally across the full partial pressure of hydrogen operating range (above the LDL) as described by equation (2) below.

$$\%H_{2_{error}} = 100 \cdot \left(\left(\sqrt{P_{H2_{ata}}} + \frac{K_{acc}}{1000} \right)^2 - P_{H2_{ata}} \right) \quad (2)$$

Where $\%H_{2_{error}}$ is the maximum expected volumetric hydrogen concentration error as reported by the analyzer in units of "% H_2", $P_{H2_{ata}}$ is the partial pressure of hydrogen in absolute atmospheres, and K_{acc} is the model-specific uncertainty factor. The values for this factor are shown in the table below:

Table 19: Uncertainty Factors

Model	K_{acc}
5031	3.147
5032*	7.694
5033	5.982
5034	5.982

*Sensors operated in gas streams containing oxygen and no hydrogen may experience temporary higher uncertainty levels upon initial exposure to hydrogen. See section 8.3.2 for more information.

Example: A HY-OPTIMA™ 5033 reading 70% H_2 at an operating pressure of 1 atmosphere absolute ($P_{H2_{ata}} = 0.7$) would have an expected uncertainty of ±1.0% H_2 in the measurement. If the operating pressure was raised to 2 atmospheres absolute the analyzer would read 140% H_2. Performing a 2-point field calibration at the new operating pressure would return the reading to 70% H_2. However, with $P_{H2_{ata}} = 1.4$ the expected uncertainty in the measurement would now be ±1.42% H_2.

8.3 Sensor Behavior

H2scan provides two different types of sensors employed in process analyzer models. This includes sensors calibrated for continual H_2 exposure (H_2 measurement applications), and sensors calibrated for uncommon H_2 exposure (H_2 detection applications).

An internal algorithm is utilized to maintain long term measurement accuracy of the sensors and remove the need for periodic field calibrations. For this algorithm to run properly the analyzers must be powered on continuously. If the analyzer is powered only for short durations (<2 hours), the algorithm will not function properly, and the accuracy of the sensor may not meet the product specifications.

8.3.1 H_2 Measurement

The sensors in the HY-OPTIMA™ models 5031, 5033 and 5034 are designed for continual H_2 exposure, i.e., H_2 measurement applications. The standard range of measurement for these models is 0.5% to 100% H_2 by volume for the 5033 and 5034 or 0.1% to 10% for the model 5031.

Because these sensors are designed to continually see H_2, if they are left on for periods of time in a gas containing oxygen with no H_2 present (or very little H_2, typically when the concentration of O_2 is greater than 30 times the concentration of H_2), an oxygen offset will occur. The more oxygen that is exposed to the sensor, the faster and stronger the offset will be. Oxygen offset varies by sensor. This physical offset will not appear in the reported H_2 because an internal algorithm will remove the effect, but when the sensor is exposed to H_2

after the oxygen offset is formed there may be temporarily reduced accuracy and a delayed response time.

Reducing atmospheres: Even small amounts of H_2 (1000ppm, for example) should ensure no offset takes place even in atmospheres containing oxygen (tested in air, up to 20% O_2. Higher oxygen contents may require higher amounts of H_2 to prevent oxidation).

If oxygen were to cause an offset to the sensor, it can be reversed by purging the sensor with H_2 and allowing time for the algorithm to automatically correct for any offset that occurred. The time it takes for this to occur depends on the magnitude of the oxidation offset, the concentration of the hydrogen removing the offset, and the stability of the system. Generally, two hours in a constant H_2 concentration is sufficient. Higher H_2 concentrations will remove the oxygen offset faster but be sure to not exceed the maximum specified H_2 concentration for the given model. For example, a 1-hour exposure to forming gas (5% H_2/95% N_2) at 1 atmosphere absolute will achieve this, but even low concentrations such as 1000ppm H_2/99.9% N_2 over 2+ hours will work.

8.3.2 H_2 Detection

The sensor in the HY-OPTIMA™ 5032 is designed for H_2 exposure of less than a few hours at a time, e.g., leak detection applications. While the sensor is capable of continuous H_2 exposure, doing so may result in a temporary reduction in accuracy 3 to 6 hours after the start of the continuous H_2 exposure. When H_2 is exposed to this sensor for these extended periods, it will bond with the oxygen (on the sensor surface) and the H_2 measured by the sensor will be less than the H_2 present. Once the O_2 on the sensor is completely depleted (a process that can take several hours, depending on the H_2 concentration), an internal algorithm will correct the measurement and allow the sensor to measure accurately in the continuous H_2. However, for best measurement accuracy it is recommended to limit the H_2 exposure.

It is important to note that the sensors should be *powered on* in a hydrogen-free environment containing oxygen (such as air) for most of their operation. If the sensors are only powered on during periods of hydrogen measurement, their measurement accuracy will be degraded. To restore measurement accuracy, power the sensor in a hydrogen-free environment containing oxygen for at least 24 hours then perform a 2-point field calibration.

8.3.2.1 Non-reducing and Non-oxidizing Atmospheres

If the sensor is left powered on in a gas that contains no hydrogen and no oxygen for periods of days or longer it will experience drift. An internal algorithm will ensure the reported H_2 remains at 0. However, when the sensor is eventually exposed to hydrogen (above the lower detection limit), the initial response may be inaccurate. An internal algorithm will restore the accuracy if exposed to any constant hydrogen concentration (within the range of the model) for at least 4 hours.

8.4 Diurnal Effect

Temperature changes throughout the day may induce small changes to the H_2 reading of the analyzer. As explained in section 8.1 Effect of Pressure, the sensor is sensitive to the partial pressure of hydrogen which means pressure changes (brought on by temperature fluctuations) can create minor fluctuations in the reported H_2 concentration. While the sensor is not directly sensitive to fluctuations in gas temperature, any resulting fluctuations in pressure may affect the measurement accuracy.

8.5 Response Time

The response of the sensor to a change in hydrogen follows a typical "s-curve", 1st order system responsel in most cases. As a change in the partial pressure of hydrogen around the sensor die interacts with the sensing element, its electrical properties change immediately. If the sensor is not oxidized, this change will be reflected in the analyzer's hydrogen output within a few seconds.

For applications where the sensor is exposed to a gas containing oxygen and no hydrogen (or less than ~500ppm of hydrogen), an oxide layer will form on the surface of the sensor. This oxide layer will be quickly removed in the presence of hydrogen, but it must be fully removed before the sensor will begin showing a response to the hydrogen. The duration of this process depends on how long the sensor was exposed to oxygen before the initial hydrogen exposure as well as the hydrogen concentration.

In general, sensors are considered fully oxidized after being powered on in a gas containing oxygen (and no hydrogen) for more than a week. As mentioned previously, the time it takes to remove this oxide layer in order to respond to the hydrogen depends on the hydrogen concentration. Assuming an operating pressure around 1 atmosphere absolute, a fully oxidized sensor being exposed to 2% hydrogen should have its oxide layer removed (and thus begin showing a change in the reported H_2) within 30 seconds and be 90% through the transition within 60 seconds. If, however, the fully oxidized sensor was exposed to 0.4% hydrogen, the oxide layer may take over 60 seconds to be fully removed and start reporting an increase in H_2. A response to 4% H_2 (the LEL) will remove the oxide layer in just a few seconds.

If the gas contains oxygen but small amounts of hydrogen such as 500ppm, this may be enough to prevent the formation of an oxide layer and will allow the sensor to respond more quickly to an increase in hydrogen.

When a fast response time is critical or when measuring response time, it is important to understand that the sensor can only respond to the gas at the sensor. A transition from a first condition to a second may be instantaneous at the source, but there is always some transport time before the gas reaches with the sensor.

When considering the mixture of gas in a system during a transition, a general rule is that each standard volume turnover will achieve 90% of the transition. For example, if the total system volume (including plumbing) is 1 standard liter and the flow rate is 1 slpm, then 1 minute after the transition start the gas would be estimated to comprise 10% the first condition and 90% the second. After 2 minutes this becomes 1% and 99%, and so on and so forth. The hydrogen measurement of the sensor is a function of the gas mixture *at the sensor*, so minimizing the response time can be achieved by:

- Minimizing the standard volume of gas between the source and the sensor by:
    - Using a small diameter pipe
    - Minimizing the length of pipe
    - Reducing the gas pressure to (or near to) the desired operating pressure early in the flow path

> ***Note:*** *The recommended operating pressure is 1 atmosphere absolute. Deviating from this operating pressure will affect the measurement accuracy of the analyzer. See section 8.1 Effect of Pressure.*

- Increasing the volumetric gas flow rate

> ***Note:*** *A high flow rate in a system with small diameter pipe, small diameter pipe bends, changes in orifice size, etc., can affect the pressure or cause turbulent flow. The recommended flow rate is 1 slpm to limit these effects.*

It is up to the end user to understand the principles of sample stream conditioning and to determine the ideal plumbing for the application. A constant, stable pressure and laminar, steady flow at the sensor is ideal.

9 2-Point Field Calibration

The HY-OPTIMA™ 5000 Series Hydrogen Sensors support a 2-point field calibration. By applying two known gas concentrations, the sensor system will calculate and apply a gain and offset to its measurements to match its hydrogen reading with the known gas concentrations. If the pressure is constant, this can be used as one method to normalize the hydrogen reading when operating the sensor at a pressure other than 1 atmosphere absolute. For more methods, see section 8.1 Effect of Pressure.

9.1 Calibration Gases

WARNING: DO NOT use gases with a hydrogen concentration exceeding 10% at 1.0 atm for the 5031 or 5% at 1.0 atm for the 5032.

Two gases are required. Primary standard (±0.02%) tolerance is recommended. The given accuracy specification of the analyzer does not include the error of the calibration gas certification and is only valid with an exposure time of at least 60 minutes per gas.

For best results, use a calibration gas concentration just below the lowest expected reading and just above the highest expected reading. For example, if the process stream is expected to operate between 61% and 78% H_2, then calibration gases of 60% and 80% H_2 would be ideal. It is not necessary to use an expensive custom blend, just use whatever is readily commercially available, keeping in mind that the better the accuracy of the calibration gas the better the accuracy of the calibration will be.

Table 20: Calibration Gas Limits

Model	Minimum Cal Gas	Maximum Cal Gas
5031	0.03%	10%
5032	0.4%	5%
5033	0.5%	100%
5034	0.5%	100%

Note: The concentrations listed above assume 1.0 atm absolute pressure.

The recommended flow rate is **1.0** ± 0.2 slpm.

For the model 5032 the recommended gases are 1% H_2 in air and 2% H_2 in air. A verification/calibration kit is available from H2scan.

Gases are applied to the analyzer through user's plumbing. Make sure the system allows for the calibration gases to be applied at the same pressure as the analyzer sees during normal operation.

9.2 Background Gases

For an analyzer operated in hydrogen with an inert gas background (models 5031, 5033, 5034), the following background gases are safe:

- N_2
- Hydrocarbons (Alkanes / Alkenes / Alkynes)
- CO_2
- He, Ar, etc. (Noble)

For an analyzer operated where hydrogen may be present in air or oxygen (model 5032), the calibration can be performed using hydrogen in an air background or the backgrounds listed above.

9.3 Field Calibration Procedure

***Note**: The exposure time per gas is a minimum of 60 minutes per exposure. Exposures shorter than 60 minutes can generate erroneous calibration data.*

***Two** calibration hydrogen gas standards are required: one high and one low.*

Do NOT use gases exceeding the H_2 concentration limit specified for the model as this will damage the sensor (See: Table 20).

Do NOT use 100% air, 100% N_2, or any gas with an H_2 concentration below the LDL of the product model (See: Table 20.

***Note**: The calibration can be aborted at any time (See: 9.4 Abort Field Calibration)*

Table 21: 2-Point Field Calibration Registers

Register	Parameter	Function	Data Type	Data Range	Access
126	Calibration Gas 1, ppm H_2*	High word	32-bit binary number	0 to 10,000,000	R/W
127		Low word			
128	Calibration Complete/Date	High byte: Month Low byte: Day	32-bit binary value		R/W
129		Year			
130	Calibration Gas 2, ppm H_2*	High word	32-bit binary number	0 to 10,000,000	R/W
131		Low word			
132	Field Cal start command	Gas exposure duration (minutes)	16-bit binary number	60 to 1440	W
133	Field Cal abort command	Abort Field Cal or clear data	8-bit binary number	1: abort 2: clear	W
134	Field Cal get status command	High byte: Error code Low byte: Status	16-bit binary number	Table 22 and Table 23	R
135	Gas start command	Gas 1 or 2 started	8-bit binary number	1: gas 1 2: gas 2	W

*Note: To convert % to ppm, multiply % reading by 10,000.

The status and error codes should be read from register **134** after each write to the field calibration registers. Once the calibration is initiated, the status code should read '**1**' (in-progress) and the error code should read '**0**' (no errors detected) after register write until the procedure is completed. Once completed, the status code should read '**0**' (success) and the error code should read '**0**' (no errors detected). Refer to 9.6 Calibration Status and Errors if an unexpected code appears.

1. Initiate the calibration by writing the duration per gas exposure in minutes to register **132** (the minimum time is 60 minutes per gas with longer being better up to 1440 minutes).
2. Apply the first gas to the unit at 1 slpm.
3. If necessary, adjust the gas pressure at the sensor to match the intended operating pressure.

> ***Note**: Ideally, the calibration gases are flowed through the same pressure regulation system as the measured gas stream and require no adjustment.*

4. Indicate that the first gas is flowing, by writing '**1**' to register **135**.
5. Wait the exposure time.
6. Write the first gas concentration in **ppm** to registers **126**, **127**.

   Tip: To convert % to ppm, multiply % value by 10,000.
7. Apply the second gas at 1 slpm.
8. Ensure the gas pressure at the sensor has not changed, making any adjustments if necessary.
9. Indicate that the second gas is flowing by writing '**2**' to register **135**.
10. Wait the exposure time.
11. Write the second gas concentration in **ppm** to registers **130**, **131**.
12. Finish the field calibration with the current date, by writing to registers **128**, **129**.

> ***Note**: If the entered calibration date does not match the current date in the unit, the field calibration will not complete. The unit's current date can be found in registers 175, 176. See Table 12 for formatting details.*

13. The unit will automatically reboot.

9.4 Abort Field Calibration

If a field calibration is in progress but needs to be aborted, this can be performed by either power cycling the unit or writing '1' to register 133.

Register	Parameter	Function	Data Type	Data Range	Access
133	Field Cal abort command	Abort Field Cal or clear data	8-bit binary number	**1: abort** 2: clear	W

9.5 Clear Field Calibration

Clearing a field calibration removes the active field calibration. To clear the field calibration, write '**2**' to register **133**.

> ***Note**: An analyzer operating without an active field calibration will measure hydrogen using the factory calibration. Unless a special factory calibration was requested, this is performed at an operating pressure of 1 atmosphere absolute. If*

the analyzer is operated at any other pressure the hydrogen measurement will need to be compensated. See section 8.1 Effect of Pressure.

Register	Parameter	Function	Data Type	Data Range	Access
133	Field Cal abort command	Abort Field Cal or clear data	8-bit binary number	1: abort **2: clear**	W

9.6 Calibration Status and Errors

To see calibration status and errors, read from Register **134**.

Register	Parameter	Function	Data Type	Data Range	Access
134	Field Cal get status command	High byte: Error code Low byte: Status	16-bit binary number	Table 22 and Table 23	R

Table 22: Field Calibration Status

Code	Description	Notes
0	Success	The calibration completed successfully.
1	In-progress	The calibration process is on-going.
2	Fail	The calibration stopped due to errors.
3	Abort	The calibration was cancelled by the user.
4	Clear	The calibration corrections have been removed.
5	Bad Input	The most recent command was not executed. See the error code for more details.

Table 23: Field Calibration Errors

Code	Description	Notes
0	No errors	No errors detected
2	Field calibration already in-progress	The command to start a field calibration was given but a field calibration is already in progress. The field calibration in progress must first be aborted.
3	Bad gas exposure time	The entered time is outside the exposure time limits. Ensure the time was entered in minutes and within the limits of the product (minimum of 60 minutes with more being better).
4	Timer error	There was an internal problem with the unit; power cycle and try again. Contact H2scan if this problem persists.
5	N/A	This code is used for diagnostic purposes only.
6	Gain error	The calculated calibration gain is outside the limits. Check that the gas was flowing, and the gas concentrations were entered in ppm and match the respective gases.
7	Bad gas concentration	The entered gas concentration is outside the limits for the product. Ensure the gas concentration is entered in ppm, and within the range of the product model.
8	Bad gas number	The command to start Gas 2 was received before Gas 1 completed.
9	Data not ready	A command to finish the calibration was received before both calibration points were completed.
10	Calculation failed	The calibration could not complete based on the measured data. Retry the calibration and contact H2scan if the error persists.
11	Calibration date mismatch	The entered date must match the date stored in the unit to the day. Note that the unit's date stored in registers 175, 176 is in a different format than that expected in registers 128, 129. See Table 12 for details.
12	Bad result	The calculated gain and/or offset are outside the limits. Check that the gas was flowing, and the gas concentrations were entered in ppm and match the respective gases.
13	Bad state	A step was skipped in the calibration process.
14	Exposure not done	The gas exposure was not completed. Retry the command once the full exposure time has elapsed. If an incorrect gas exposure time was entered, abort the field calibration, and start over.

10 Appendix

10.1 Firmware Upgrade

The HY-OPTIMA™ 5000 Series Hydrogen Sensor firmware is field-upgradable. Instructions and PC software will be provided by H2scan as needed.

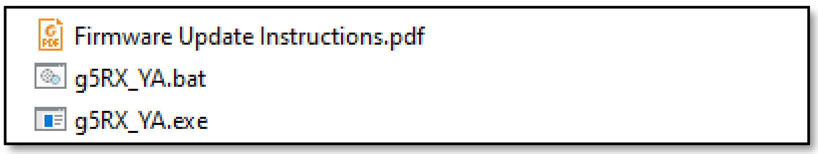
Copy the firmware upgrade files to a directory on the PC. (**NOTE**: The latest available firmware will be made available)

- **g5RX_YA.exe** – sensor firmware binary file
- **g5RX_YA.bat** – batch file

Example: g5R3_5A.exe and g5R3_5A.bat

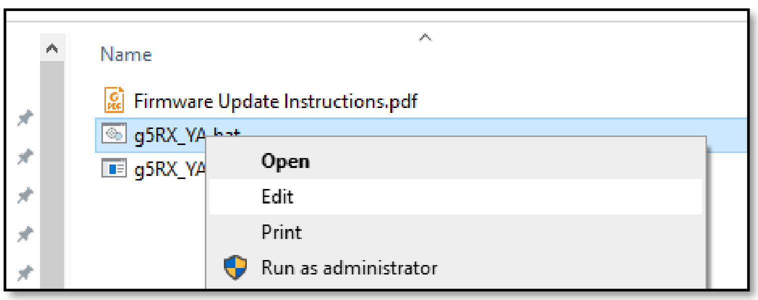
7-Step procedure to upgrade firmware:

1) Copy the files below to your local directory.



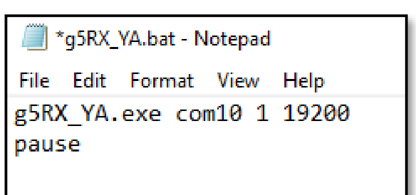
2) Connect the HY-OPTIMA™ 5000 Series Hydrogen Sensor to your PC using a USB to RS485 adapter.

3) Right-click on g5RX_YA.bat and then select Edit.



4) You will see the port information below. Update the com port, the device address, and the baud rate you are using to connect to the HY-OPTIMA™ 5000 Series Hydrogen Sensor. Save the file.

ComPort	= comX	→ change to the com port being used
Device Address	= 1	→ default address is 1
Device Baud Rate	= 19200	→ default baud rate is 19200



5) Double-click on g5RX_YA.bat. You will see the following information as the firmware is being upgraded.

```
C:\Windows\system32\cmd.exe

C:\Users\jgoodheart\Desktop\Firmware\Gen5\3.5.A (hex -333A 353A 4100)>g5R3_5A.exe com4 1 19200

 Gen5 SFU Utility Software Version 2.00
\\.\com4, baudrate = 19200, devID = 1, size=3ffc8, crc=f7a3
1. Open Serial Comm Port.
nothing read
2. Check if Gen5 is in Modbus or CLI mode.

*Gen5 is in Modbus mode.
3. Switching to CLI mode.

*FW=3:5:A, PORRST>
got prompt!
FW=3:5:A,4. Ready for code download. Begin.

*
*
*aaa 3ffc8 f7a3

*abb 8000 df7e

....
*abb 8000 df7e


*abb 8000 23c2
```

6) The upgrade process is complete when you see the window below.

```
C:\Windows\system32\cmd.exe
....
*abb 8000 e6f8


*abb 8000 8151

....
*abb 8000 8151


*abb 8000 85fd

....
*abb 8000 85fd


*abb 7fc8 e0aa

....
*abb 7fc8 e0aa

6. Code download is done

*acc 3ffc8 f7a3

SUCCESS: final size = 0x3ffc8, crc = 0xf7a3
7. Close Serial Comm Port.

C:\Users\jgoodheart\Desktop\Firmware\Gen5\3.5.A (hex -333A 353A 4100)>pause
Press any key to continue . . .
```

7) To complete the process, please power cycle the HY-OPTIMA™ 5000 Series Hydrogen Sensor.

10.2 General Troubleshooting

Here are some general questions to answer if problems are encountered with the analyzer.

1. Verify the analyzer is reporting H_2.
    - Check all connections and flow paths.
    - Reduce process or calibration gas stream pressure to 1.0 atm and power cycle the analyzer.
2. Verify the pressure and flow is stable.
    - Unstable pressure or flow can cause the analyzer to behave erratically. Ensure the process gas stream is properly regulated. The analyzer is less sensitive to changes in flow but a flow rate of 1.0 slpm is recommended.
3. Check the stability of the sensor output.
    - Expose the analyzer to a calibration gas (40-100% H_2, but not exceeding 10% H_2 in the model 5031 or 5% H_2 in the model 5032) overnight while recording the H_2 reading.
    - Plot the H_2 reading. (You may use spreadsheet software such as Microsoft Excel). Assuming a constant pressure, temperature, and flow rate, the H_2 line for the most recent data should be flat with no perturbations outside the defined specifications for the analyzer. If it is not yet stable, leave the analyzer exposed to the calibration gas for another 24 hours or until stability is observed.
    - Once the sensor is stable, perform a 2-point field calibration (see section 9).
    - If the sensor does not stabilize, contact H2scan for support.
4. Has the sensor been exposed to substances that may have damaged it?
    - Exposure to liquids, acids, bases, or levels of H_2S or CO that exceed the product limits will damage the sensor.
    - Exposure to H_2 partial pressures that exceed the product limits will damage the sensor.

If you have any questions, please contact us at the address below:

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