FES SENSOR
TECHNOLOGY GMBH

www.fes-sensor.com

H2-CNI 0-10V-I *

Precision Hydrogen Sensor with Voltage Output for Industrial Applications

1. FEATURES

- Detection of hydrogen levels up to 100% LEL with 100 ppm resolution in air
- No sensitivity against typical catalyst poisons such as volatile siloxanes and carbon monoxide
- Fast response and recovery times
- No humidity-induced base line drift
- Applicable in relative humidity (rh) between 0 % to 100 %
- Industrial temperature range from -40 to +80 °C
- High mechanical stability
- Linear output up to 100 % LEL
- On-board instrumentation amplifier and voltage output
- I2C connectivity for sensor adjustment
- Supply voltage with reversed bias protection
- Designed for many years of operation time

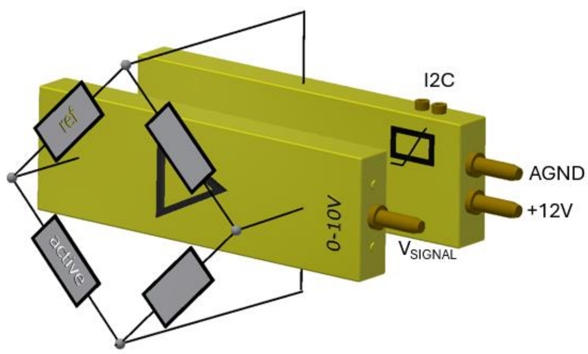
2. APPLICATION

Precision hydrogen meters

3. DESCRIPTION

H2-CNI 0-10V-I (see footnote *) is a pin-compatible replacement of previous models H2-CNI-0V-I, H2-CNI 0V-I ULTD, H2-CNI 0V WR sensors. It is a precise calorimetric hydrogen sensor with a catalytically highly active and siloxane-resistant sensor element and is based on a non-isothermal calorimetric operation principle. It contains on-board electronics to reduce the effect of ambient temperature changes on hydrogen sensitivity and to provide appropriate output signals. It is equipped with an additional I2C bus socket and a 0-10V output (like H2-CNI 0V WR). It is designed for use in a variety of applications which require accurate hydrogen determination in air. The sensor can be operated without connecting the I2C bus.

4. SIMPLIFIED SCHEMATIC



* H2-CNI 0-10V-I is the successor of the H2-CNI 0V-I, H2-CNI 0V-I ULTD, and H2-CNI 0V-WR sensors.

TABLE OF CONTENTS

5. REVISION HISTORY

Date	Rev.	
Mai 2, 2023	1.0	Initial version
Jan 2, 2024	1.1	Text of section 8 on page 6 changed, figure 4 and figure caption updated. Corrected figure 15 replaces figure 14. New section 8.9 on H2-CNI 0V WR sensors is added. Numbers of figures updated. Text of section 9 is changed.
Jan 16, 2024	1.2	Chapter 8.13 with figure 16 added
March 19, 2024	1.3	Figure 16 updated
June 4, 2024	1.4	Figure 16 updated
Sept 24, 2024	1.5	Table 6 and Figure 16 updated, Chapter 13 revised
April 14, 2025	2.1	New model H2-CNI 0-10V-I released, starting from serial number #416

6. PIN CONFIGURATION AND FUNCTION

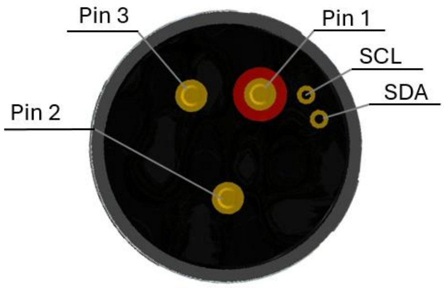


Figure 1: Bottom view

Table 1	
PIN NO.	DESCRIPTION
1 (red marking)	+12 V positive supply voltage with respect to ground
2	Sensor signal with respect to ground
3	Ground of the internal electronics. The pin is electrically not connected to the housing
SCL	Serial clock line of I2C bus, referenced to ground (pin 3)*
SDA	Serial data line of I2C bus, referenced to ground (pin 3)*
*The sensor can be operated without connecting the I2C bus. If connected, provide necessary pull-up resistors to SCL and SDA (e.g. 4.7 kOhm).	

7. SPECIFICATIONS

7.1. ABSOLUTE MAXIMUM RATINGS

Table 2	
Input supply voltage	+15 V at ambient temperature T_a = 20 °C.
Storage temperature	-40°C to 100 °C

7.2. ESD CAUTION

ESD (electrostatic discharge) sensitive device. Although this product features protection circuitry, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

7.3. HANDLING RATINGS

The sensor must not be subjected to severe shocks which might result from suddenly applied forces. They may cause permanent damage to the device.

7.4. RECOMMENDED OPERATING CONDITIONS

At ambient temperature T_a = 20 °C (unless otherwise noted).

Table 3

	MIN	NOM	MAX	UNIT
Input supply voltage	+9	+12	+15	V
Load resistor between pin 2 and pin 3		≥ 1		kΩ

7.5. MECHANICAL

Table 4

Housing material	Stainless steel (1.4404; SUS316L)
Potting	Epoxy
Base plane	FR4, flame retardant, according to UL-94
Weight	15 g
Maximum diameter	20.0 mm
Height (housing)	16.6 mm
Height (overall)	21.0 mm (pin-type)
Pins	Gold over nickel
Pin length	4.78 mm
Pin diameter	1.57 mm

7.6. ELECTRICAL

Table 5	
Supply Current at 20 °C	42 mA (typical)

7.7. ENVIRONMENTAL

Table 6	
Ambient temperature range during operation	-40 to +80 °C
Operation humidity	0 … 100 % r.h.

7.8. SENSOR PARAMETERS

Table 7	
Signal at 50% LEL	3 V (typical)
Resolution	< 0.25 % LEL or 100 ppm
Linearity	Typical value: 1.5 V/(25 % LEL) or 1.5 V/(1 vol-% H_2) at 20 °C
Response time	< 5 s
Thermal zero point drift	1 mV/°C (ULTD)

7.9. SENSOR CROSS SENSITIVITIES

Table 8

Gas / Vapor	Chemical Formula	Concentration Applied	Output $V_{Signal, Gas} - V_{Signal, air}$ (V)
Methane	CH_4	0 to 99.99 vol-%	0
Ethane	C_2H_6	0 to 99.95 vol-%	0
Propane	C_3H_8	0 to 30 vol-%	0
Butane	C_4H_{10}	0 to 70 vol-%	0
Ammonia	NH_3	0 to 5 vol-%	0
Chlorine	Cl_2	0 to 5 vol-%	0
Carbon dioxide	CO_2	1 vol-%	0
Carbon monoxide	CO	1500 ppm	0
Nitrogen dioxide	NO_2	5 ppm	0
Nitrogen monoxide	NO	15 ppm	0

7.10. EFFECT OF PRETREATMENTS OF THE SENSOR TO SILOXANES

OCTAMETHYLCYCLOTETRASILOXANE ($C_8H_{24}O_4SI_4$)

A laboratory beaker with 100 g $C_8H_{24}O_4Si_4$ (98%) is heated to 250 °C in a 2-liter glass together with the sensor for one hour. The sensor is tested with 2 vol-% H_2. A 12% decline of the sensor signal is found with respect to the initial signal.

HEXAMETHYLDISILOXANE ($C_6H_{18}OSI_2$)

A laboratory beaker with 40 ml $C_6H_{18}OSi_2$ is placed with in a 2-liter glass together with the sensor for one hour. The sensor is tested with 2 vol-% H_2. A 15% decline of the sensor signal is found with respect to the initial signal.

8. TYPICAL PERFORMANCE CHARACTERISTICS

All data presented below are acquired in an automated gas mixing system with mass flow controllers and pressurized gas bottles with synthetic air (21 vol-% oxygen in nitrogen) and calibrated hydrogen mixtures (5 vol-% H_2 in nitrogen). For hydrogen volume fractions ≥4 vol-%, appropriate flows of pure oxygen replace synthetic air flows to achieve 21 vol-% oxygen in the test gas. For figures 12 and 14, pure hydrogen is used instead of 5 vol-% H_2 in nitrogen. Room temperature data are determined with the sensor attached to our test chamber TC 2x1/4". Ambient temperatures are adjusted in a cooled or heated test chamber. Data for figures 3 to 12 are collected with a 7 ½ digit precision multimeter with RS232 interface. For figures 4, 5 and 7 the evaluation kit PGA-ADC 3.4 and a stabilized 12 V power supply are used to provide very short electrical connections between the sensor and the amplifier and a constant 12 V operation voltage.

8.1. INITIAL WARM-UP PHASE

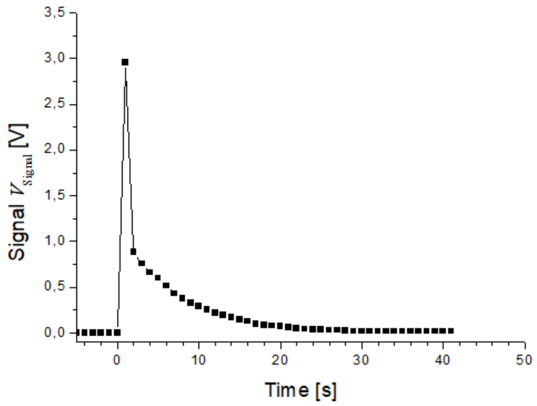


Figure 3. Typical signal characteristics (signal voltage at pin 2) of the sensor after applying the operational voltage of 12 V at time 0.

8.2. CALIBRATION CURVE AND LINEARITY

H2-CNI 0-10V-I are usually calibrated for the LEL range (0 to 4 vol-% H_2).

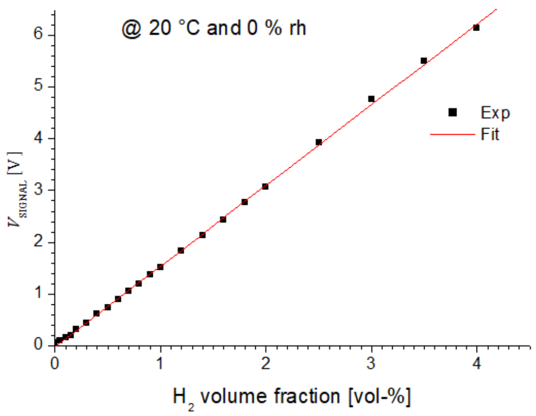


Figure 4. Typical values of the signal voltage V_{Signal} as a function of hydrogen volume fraction in synthetic dry air at 20 °C. Data (Exp) are determined for a total flow of 50 sccm/min. Red: Linear fit with a slope of 1,5 V/1 vol-%.

H2-CNI 0-10V-I can be adjusted to cover larger hydrogen ranges as shown in figure 12.

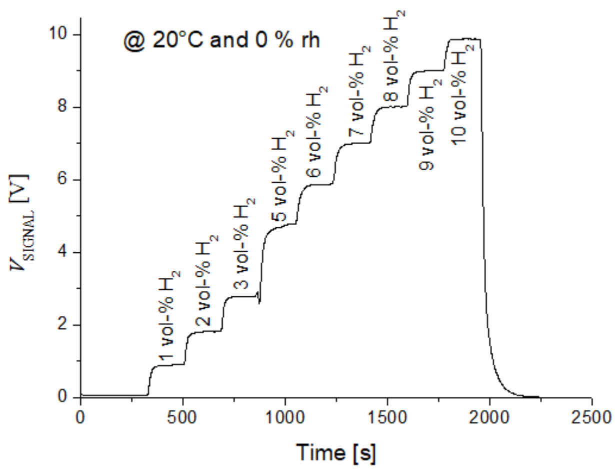


Figure 12. Sensor signal of H2-CNI 0-10V-I as a function of time for hydrogen volume fractions from 1 to 10 vol-% in air at a total flow of 50 sccm/min. Note that unlike the 0V and 0V ULTD sensors, this wide range WR type provides an output signal from 0 to 10 V.

8.3. LOW DETECTION LIMIT AND RESOLUTION

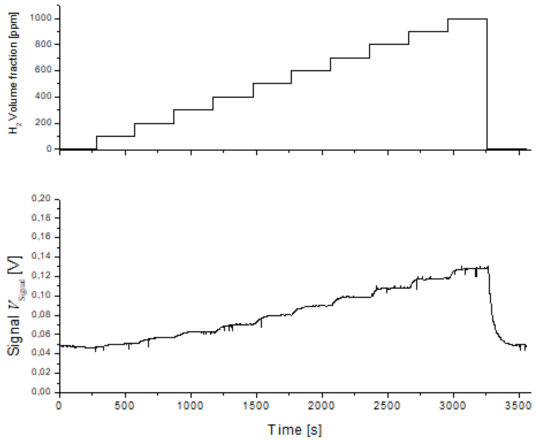


Figure 5. Bottom: Sensor signal as a function of the time (top) in dry air at 20 °C at low volume fractions of hydrogen between 100 and 1000 ppm. Offset of the signal voltage is 50 mV. Total flow 100 sccm/min. Top: Corresponding changes of H_2 volume fractions.

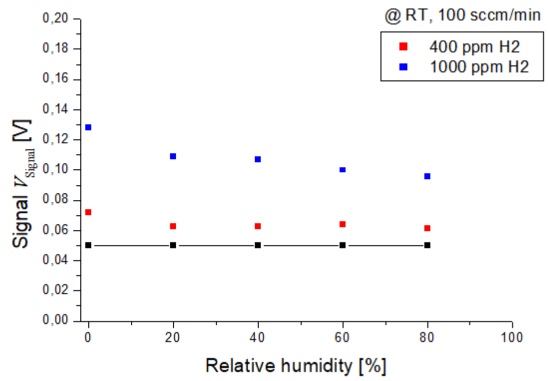


Figure 6 Bottom: Sensor signal as a function of humidity (0, 20, 40, 60, and 80% at 20 °C at low volume fractions of hydrogen.

8.4. TEMPERATURE-DEPENDENCE

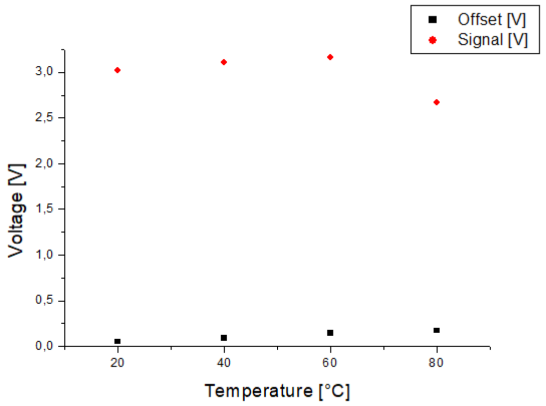


Figure 7. Red: Sensor signal for a hydrogen volume fraction of 2 vol% at temperatures of 20 °C, 40 °C, 60 °C, and 80 °C. Black: Offset voltage at 0 vol% H_2.

8.5. EFFECT OF RELATIVE HUMIDITY ON THE BASE LINE

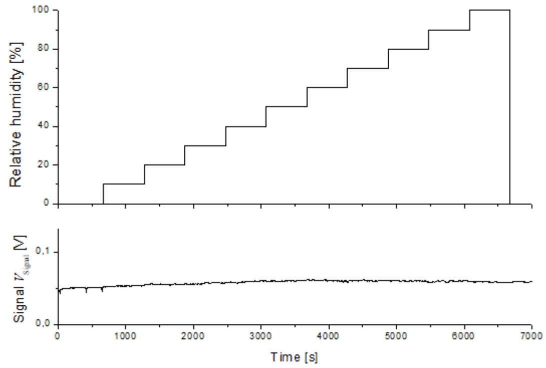


Figure 8. Top: Sensor signal as a function of time at different levels of relative humidity from dry air to 100 % at 20 °C (total flow = 50 sccm/min). Bottom: Corresponding changes of the relative humidity in the test chamber as a function of time.

8.6. EFFECT OF RELATIVE HUMIDITY ON THE SIGNAL

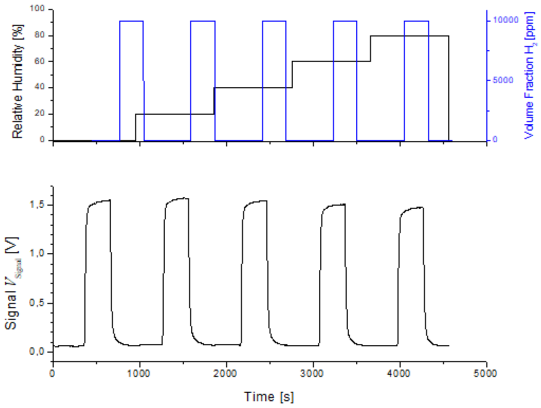


Figure 9. Sensor signal at 1 vol-% H_2 in air of varying relative humidity at 20 °C (total flow = 50 sscm/min).

8.7. EFFECT OF FLOW RATES ON THE BASE LINE

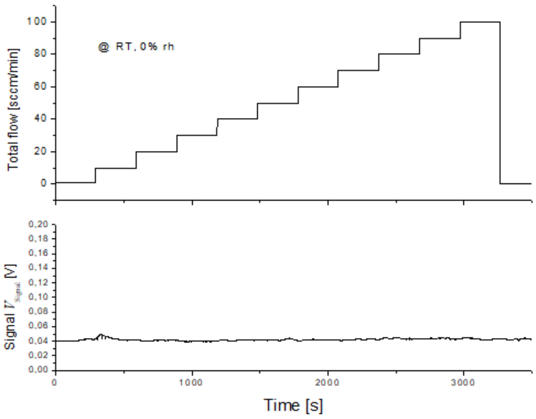


Figure 10. Sensor signal as a function of the total flow in dry air at 20 °C.

8.8. EFFECT OF FLOW RATES ON THE SIGNAL

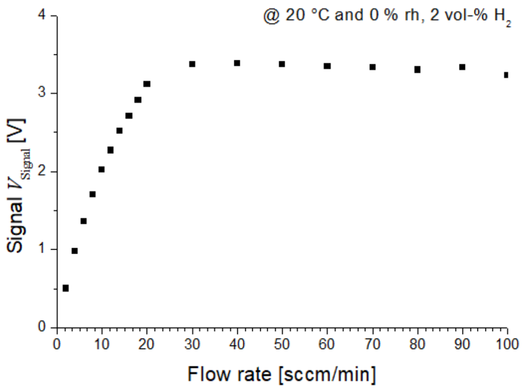


Figure 11. Sensor signal as a function of the total flow for 2 vol-% H_2 in dry air at 20 °C. Because of the catalytic sensing principle and the hydrogen-to-water oxidation, a steady-state signal cannot be generated at a zero-flow rate.

8.9. RESPONSE AND DECAY TIMES

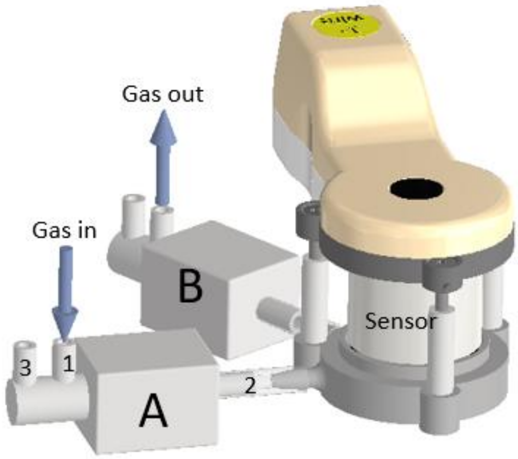


Figure 13. Special setup to determine the response and decay time of the sensor. Here, the evaluation kit PGA-ADC 3.4 is used to apply the 12 V voltage and to determine the signal voltage V_{SIGNAL} of the sensor. A flow of 2 vol-% H_2 in air with 50 sccm/min flows into the system at the "gas in" through port 1 of valve A. The valve can be switched electrically to pass the flow through port 3 to the ambient air or port 2 to the sensor, attached to a small test chamber. Valve B is operated together with valve A and cut off the test chamber from the outlet if A is switched into the 1-3 position.

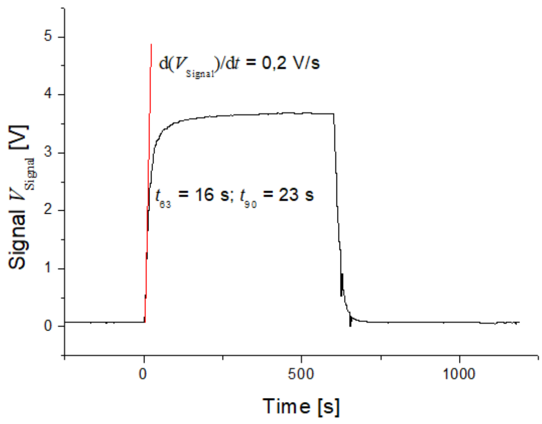


Figure 14. Sensor signal as a function of time after applying 2 vol-% H_2 in dry air at 20 °C. The sensor signal reaches a steady-state signal with a t_{64} response time of 16 s and a t_{90} response time of 44 s. The slope dVSignal/dt is approx. 0,2 V/s, i.e., a 1-Volt change of the signal is found after 5 s. After re-directing the test gas to the port "Out 1", the signal decays to zero due to an oxidation and consumption of the hydrogen molecules at the sensor´s catalytic layer.

8.10. CALIBRATION PROCEDURE

The sensor contains a 12 bit digital-analog converter with non-volatile memory for adjusting the offset voltage of the Wheatstone bridge, and a nonvolatile 256-position digital potentiometer to adjust the output signal for a constant hydrogen volume fraction. It is usually not necessary to make any changes of the settings. Refer to section 10 for further information.

8.11. MECHANICAL TESTS

The electronic board of the sensor has been tested in shock tests with the sensor placed on a vibrating plate (50 Hz) and on a alternating acceleration test stand with 8 G.

8.12. EFFECT OF THERMAL SURROUNDING

As with all devices based on calorimetric concepts, the hydrogen sensor H2-CNI 0-10V-I is sensitive against changes of its thermal surrounding. This gives rise to noticeable variations of the base line of such devices. H2-CNI 0-10V-I has precisely adjusted sensor and reference elements that operate at virtually identical temperatures when a voltage is connected between pins 1 and 3. The best assembly place for the sensor should provide a constant thermal surrounding to minimize variations of the signal´s base line which can be lower than 100 mV under good conditions. Consider a vertical upside or upside-down direction of the sensor if possible.

8.13. STABILITY OF CALIBRATION OVER TIME

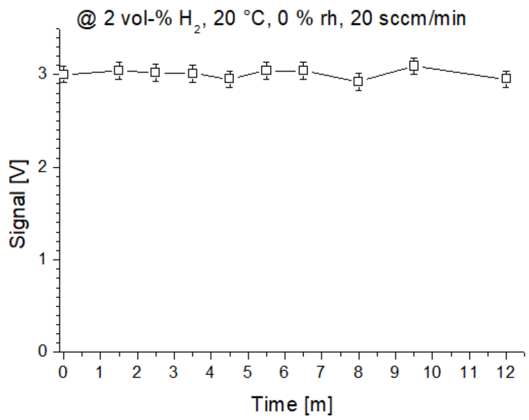


Figure 16. Results of repeated hydrogen exposure tests with a sensor that is continously powered with 12 V over one year.

9. THEORY OF OPERATION

The hydrogen sensor H2-CNI 0-10V-I comprises two temperature-sensitive transducers that form a Wheatstone bridge arrangement together with precision resistors R_2 and R_3. One transducer (the so-called active sensor element R_{active}) is covered with an advanced catalytic layer that promotes the hydrogen-to-water oxidation while the second transducer (the so-called inactive sensor element R_{ref}) is used as a reference to compensate variations of the out-of-balance voltage with changing ambient temperatures. The out-of-balance voltage is set to zero by means of a 12 bit digital-analog converter, connected to one arm of the Wheatstone bridge by R_5. Exposure of the sensor to hydrogen and oxygen containing atmospheres results in the generation of a chemical reaction heat that causes a temperature change and hence a resistance change of the active sensor element R_{active}. This leads to a non-zero out-of-balance voltage of the bridge, an adjustable fraction of it is amplified by means of a built-in instrumentation amplifier. The amplified signal is lead out at pin 2. The Wheatstone bridge voltage can be adjusted in a limited range to optimize the sensor properties for the desired application.

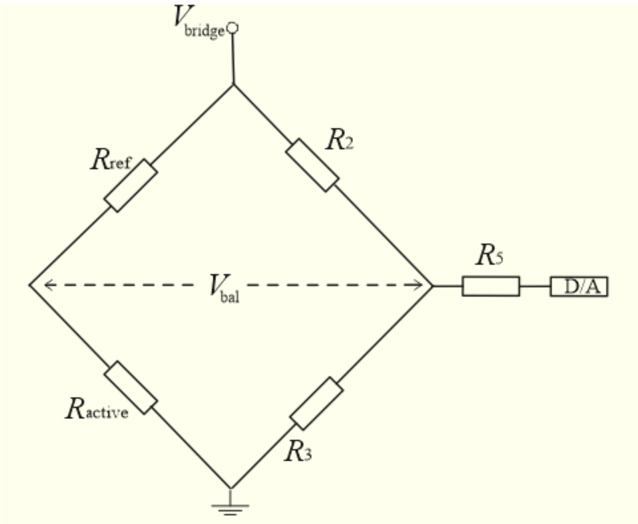


Figure 17. Wheatstone bridge with active and reference sensor element (schematic).

10.APPLICATION AND IMPLEMENTATION

After connecting the sensor to the supply voltage, all sensor adjustments, stored in the non-volatile memories of the internal integrated circuits, are set automatically. A zero-voltage signal is generated at an ambient temperature of T_a = 20 °C. The device contains a special circuitry that reduces the effect of ambient temperature changes on the sensor sensitivity in the range of -40 to 80 °C.

10.1. I²C BUS

Two pull-up resistors are required to ensure that the SCL and SDA lines of the I²C bus are at high potential.

The following 7bit addresses are used in the H2-CNI 0-10V-I sensors:

Table 9: 7bit Addresses

Binary code	Hexadecimal code	IC
1010000	x50	1K bit serial electrically erasable PROM
1100000	X60	12-Bit digital-to-analog converter used for offset adjustment
0101110	x4E	Nonvolatile 256-position digital potentiometer used to adjust the amplification
0101000	x28	Nonvolatile 256-position digitally controlled variable resistor used to adjust the programmable voltage source

All command and data information is transferred with the Most-Significant Bit (MSB) first.

10.1. EEPROM

The EEPROM is organized as a single block of 128 x 8-bit memory. The following table indicates the information, kept under the different word addresses. The word addresses 0x00 to 0x03, 0x05 and 0x06 keep basic information about the sensor, including a CRC value calculated from the entries and stored in 0x04. This information must not be altered.

Table 10. Contents of the EEPROM

Word address	Data byte	Remarks
0x00	Device code	Data must not be changed
0x01	Serial number (upper byte)	
0x02	Serial number (middle byte)	
0x03	Serial number (lower byte)	
0x04	CRC value	
0x05	Fabrication date/month	See (a)
0x06	Fabrication month/year	
0x07...0x02F	Fabrication-related data	Encrypted data. Not intended for users
0x30	Excitation	Default settings for evaluation kit PGA-ADC 3.4
0x31	Gain preamplifier	
0x32	Gain	
0x33	Offset A (upper byte)	
0x34	Offset A (lower byte)	
0x35	Offset B U(upper byte)	
0x36	Offset B (lower byte)	
0x37…0x4D	Control data for other evaluation kits not useful for H2-CNI 0-10V-I sensors	Encrypted data. Not intended for users
0x4E…0x52	Resistances and thermal coefficients of sensor and reference elements	Encrypted data. Not intended for users
0x53…0x6E		Encrypted data. Not intended for users
0x6F		Not used
0x70	Calibration offset (upper byte)	See equation (b) for decoding
0x71	Calibration offset (lower byte)	
0x72	Calibration gain (upper byte)	See equation (c) for decoding
0x73	Calibration gain (lower byte)	
0x74…0x7F		Not used

Read operations allow the master to access any memory location. Sequential reads are also possible. Any read operation is initiated by the bust master with the Start signal (S), followed by the address AD = 1010000, and the R/$\overline{W}$ bit, which is a logic low. The EEPROM will acknowledge (ACK) this byte during the ninth clock pulse. The next byte transmitted by the master is the word address and will be written into the address pointer of the EEPROM. After receiving another acknowledge signal from the EEPROM the master must transmit a Start signal (repeated Start, Sr), followed by the address AD= 1010000 and the R/$\overline{W}$ bit set to one. The EEPROM issues an acknowledge and the eight-bit data word.

For a single read operation, the master does not acknowledge the transfer but generates a Stop signal (P) which terminates the read operation.

S	AD,0	ACK	Word Address (n)	ACK	Sr	AD,1	ACK	Data word n	P

The sequential read of data bytes are initiated in the same way but the master transmits an acknowledge after the first data word is send by the EEPROM. This directs the EEPROM to transmit the next sequentially addressed data byte.

S	AD,0	ACK	Word Address (n)	ACK	Sr	AD,1	ACK

Data word n	ACK	Data word n+1	ACK	Data word n+2	…	Data word n+X	P

Use the following decoding procedure to get the required information from the word addresses:

a) Fabrication time from data bytes in 0x05 and 0x06

Data byte in 0x06								Data byte in 0x05							
MSB							LSB	MSB							LSB
+ 2000 = Fabrication year							Fabrication month				Fabrication date				

b) Calibration offset from data bytes in 0x70 and 0x71

Data byte in 0x70								Data byte in 0x71							
MSB							LSB	MSB							LSB
MSB															LSB
16 bit word															

$$Offset = -0.15\text{ V} + \frac{\text{16 bit word}}{65535} \times 0.30\text{ V}$$

c) Calibration slope from data bytes in 0x72 and 0x73

Data byte in 0x72								Data byte in 0x73							
MSB							LSB	MSB							LSB
MSB															LSB
16 bit word															

$$Slope = \frac{16\ \text{bit word}}{1{,}000{,}000}\ \text{V/vol-\% } H_2$$

To write a single byte into a memory location, the master issues a Start signal, followed by the, address code AD=1010000, and the R/$\overline{W}$ bit, which is a logic low. The device will acknowledge this byte during the ninth clock pulse. The next byte transmitted by the master is the word address and will be written into the address pointer of the EEPROM. After receiving another acknowledge bit from the EEPROM the master device will transmit the data bye to be written into the addressed memory location. The EEPROM acknowledges again and the master generates a Stop condition. This initiates the internal write cycle, and during this time the EEPROM will not generate acknowledge signals.

S	AD,0	ACK	Word Address (n)	ACK	Data word n	ACK	P

Write operations should be limited to the free memory locations 0x75…0x7F or if the calibration offset and slope must be adapted to sensing conditions different from those used during the initial calibration of the sensor.

10.2. OFFSET ADJUSTMENT

The H2-CNI 0-10V-I sensors contain a digital-analog converter with 12-bit output voltage resolution, operated in a “window” configuration, to enable a precise balancing of the Wheatstone bridge.

The adjustment is initiated by the following write operation to the digital-analog converter with the Start signal, followed by the address AD=1100000 and the R/$\overline{W}$ bit, which is a logic low. The DAC acknowledges and the master sends an instruction byte 01110000 (to update the volatile register) or 01010000 (to update the volatile and nonvolatile register). After receiving the next acknowledge condition the master transmits two data bytes. After the next ACK the master terminates the write operation with the Stop signal.

S	AD,0	ACK	Instruction byte	ACK	Data byte 1	ACK	Data byte 2	ACK	P

The data bytes adjust the 12-bit long output voltage of the DAC, coupled to the Wheatstone bridge through the resistor R_5 (see figure 17).

Data byte 1	Data byte 2
D11 D10 D09 D08 D07 D06 D05 D04	D03 D02 D01 D00 X X X X
	X = Don´t care

To save the offset adjustment permanently the output voltage must be written to nonvolatile memory of the DAC. This is done by using 01010000 as instruction byte, preceding the data bytes 1 and 2.

10.3. GAIN ADJUSTMENT

The H2-CNI 0-10V-I sensors contain a nonvolatile 256-position digital potentiometer to adjust the output signal. The potentiometer picks up a fraction of the balance voltage which is amplified by an instrumentation amplifier. The gain adjustment hence controls the slope of the linear calibration curve.

The adjustment is initiated by the following write operation to the digital potentiometer with the Start signal, followed by the address AD= 0101110 and the $R/\overline{W}$ bit, which is a logic low. The digital potentiometer acknowledges and the master sends an instruction byte 00010001 (to update the volatile register) or 00100001 (to update the volatile and nonvolatile register). After receiving the next acknowledge condition the master transmits one data byte. After the next ACK the master terminates the write operation with the Stop signal.

S	AD,0	ACK	Instruction byte	ACK	Data byte	ACK	P

The data byte sets the taper of the digital potentiometer. A value close to zero means a low gain while values close to 255 represent high gains.

10.4. BRIDGE VOLTAGE ADJUSTMENT

The H2-CNI 0-10V-I sensors contain a nonvolatile 256-position digital rheostat to set the excitation voltage of the Wheatstone bridge. This voltage can vary between 8.6 (taper position = 255) and 9 V (taper position = 0) at 20 °C.

The adjustment is initiated by the following write operation to the rheostat with the Start signal, followed by the address AD= 0101000 and the $R/\overline{W}$ bit, which is a logic low. The rheostat acknowledges and the master sends an instruction byte 00000000 (to update the volatile register) or 11000000 (to update the nonvolatile register). After receiving the next acknowledge condition the master transmits one data byte. After the next ACK the master terminates the write operation with the Stop signal.

The data byte sets the taper of the rheostat between 0 and 255.

11. FOOTPRINT AND RECOMMENDED PLUG-IN SOCKETS

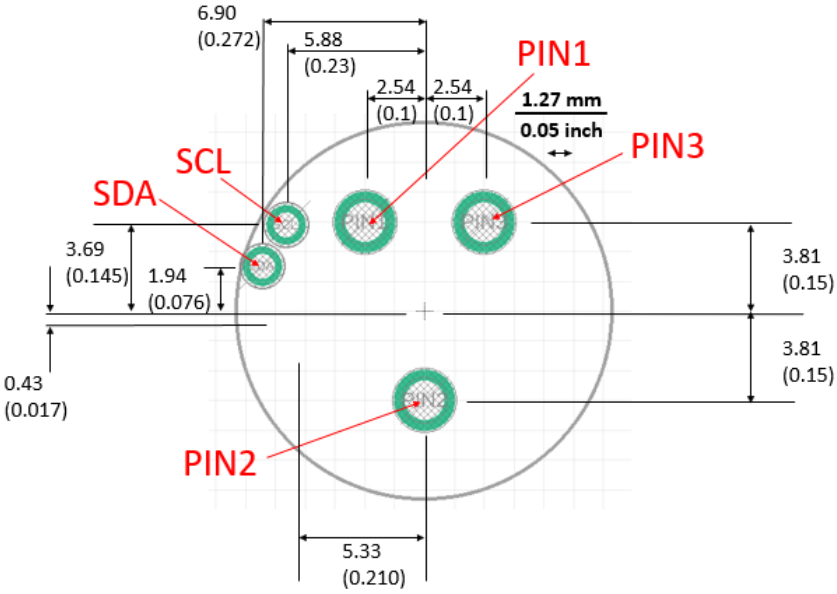


Figure 18: Footprint (dimensions shown in millimeter). The SCL and SDA sockets accepts pins of 0.38 to 0.5 mm diameter.

Table 9		
Recommended plug-in sockets/PCB pins	Drill hole	Pin dameter
450-3326-01-03-00 (Cambion Electronics LTD)	2.6 mm	
5928-0-00-15-00-00-03-0 (Mill-Max)	0.61 mm	0.5 mm

12. ORDERING INFORMATION

Hydrogen sensor H2- CNI 0-10V-I

13.PACKAGING/SHIPPING INFORMATION

This sensor is shipped individually in an ESD/EMI shielded and water vapor-proofed bag according to IPC/JDEC J-STAD-033.

14.ACCESSOIRES

The sensor requires only a +12V DC supply voltage and a 0…10 V display unit (such a digital multimeter) for operation. This sensor can also be operated with our display and data logger module “H2-Messmodul” that displays the hydrogen level. To allow the interaction with internal integrated circuits over the I2C bus, our kit “I2C-USB 1.1” can be intermediated between the sensor and the module or the +12V DC supply voltage. I2C-USB 1.1 can be linked with the USB port of a PC. The evaluation kit PGA-ADC is available to operate the sensor via a one-wire network and a PC. I2C-USB 1.1 and all versions of PGA-ADC run with our software “SensorControl”, distributed with the kits. Only the latest version PGA-ADC 3.4 features a pin connector for the I2C bus.

15. WARNINGS

Warnings: The sensor H2-CNI 0-10V-I is intended to be part of a customer safety system, enabling audible alarms, system shutdown, ventilation, or other measures to ensure safe handling and use of hydrogen gas. The sensor itself does not provide protection from hydrogen/air explosion. Make sure that your application meets applicable standards, and any other safety, security, or other requirements.

16.QUALITY CONTROL

Each sensor is tested before delivery. The test includes standard protocols and an exposure of the sensor to a hydrogen/air mixture with H_2 volume fractions above the low-explosion limit, performed at ambient temperature and pressure.

17.NOTES

18.WORLDWIDE SALES AND CUSTOMER SUPPORT

ALDERS electronic GmbH

Arnoldstraße 19 , 47906 Kempen (Germany)

sales@alders.de

+49 2152 8955-230