FES SENSOR TECHNOLOGY GMBH

H2-CNI I2C-I FWB-A

H2-CNI I2C-I FWB-B

www.fes-sensor.com

Full Digital High-precision Hydrogen Sensor

1. FEATURES

- Detection of hydrogen levels up to 12 vol-% with 100 ppm resolution in air
- Industrial temperature range from -40 °C to +85 °C
- Ultralow thermal drift
- 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 %
- Linear output
- No cross-sensitivity against hydrocarbons such as methane and ethane
- Full Wheatstone bridge (FWB) configuration, including a digital rheostat with a nonvolatile memory for offset adjustment
- Available as advanced version FWB-A and basic version FWB-B with adjustable precision voltage source for bridge excitation (FWB-A only), programmable gain amplification (PGA), 16-bit ΔΣ analog-to-digital converter, on-board digital temperature sensor, and a 1K EEPROM, all of them with I2C®bus connectivity

2. APPLICATION

- Hydrogen warning systems in a wide temperature range
- Hydrogen measuring instrumentation

3. DESCRIPTION

H2-CNI I2C-I FWB is a calorimetric hydrogen sensor with a catalytically highly active and siloxane-resistant sensor element and is based on a non-isothermal calorimetric operation principle. It is fully digital with digital conversion of the sensor signal and it contains a digital temperature sensor and an EEPROM for an advanced control of sensor characteristics in a wide temperature range of -40 to +85°C. As a result of high-precision adjustment, the thermal drift of the zero-signal is very small.

4. SIMPLIFIED SCHEMATIC

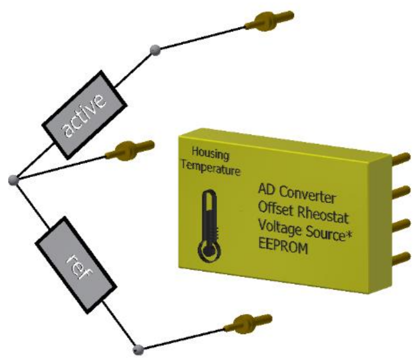

TABLE OF CONTENTS

5. REVISION HISTORY

Date	Rev.	
Jan 15, 2024	1.0	Initial Version

6. PIN CONFIGURATION AND FUNCTION

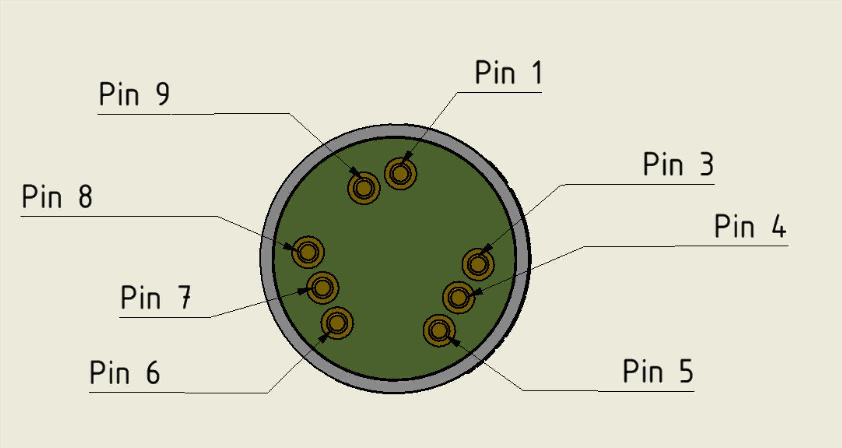

Figure 1: Bottom view of sensor

Table 1

PIN NO.	SIGNAL NAME	DESCRIPTION
1	INN	Midpoint of the 2nd branch of the Wheastone bridge
3	SCL	SCL line of I2C bus
4	VBRIDGE	Bridge excitation voltage connected to 1st junction of the active sensing element, can be connected to VPOW if a single supply voltage is used (FWB-B only). Otherwise, a positive voltage with respect to AGND must be applied. Leave unconnected for FWB-A sensors.
5	INP	Junction between active sensor element and reference element
6	IN-CURR	1st junction of reference element, must be connected to AGND
7	AGND	I2C ground
8	SDA	SDA line of I^2C bus
9	VPOW	Supply voltage of internal electronics.

7. SPECIFICATIONS

7.1. ABSOLUTE MAXIMUM RATINGS

Values are given for an ambient temperature of $T_{ambient}$ = 20 °C.

Table 2

Supply voltage VPOW	+9 V (H2-CNI I2C-I FWB-A) +12 V (H2-CNI I2C-I FWB-B)
Bridge excitation voltage VBRIDGE at pin 4 (from which a minimum current of 80mA can be drawn)	+7 to + 8.5 V
Storage temperature	-40°C to 135 °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 is fabricated using a high-precision adjustment of the thermal coupling of its sensor elements and must not subjected to severe shocks which might result from suddenly applied forces or abrupt changes in motion. They may cause permanent damage to the device.

7.4. RECOMMENDED OPERATING CONDITIONS

Values are given for an ambient temperature of $T_{ambient}$ = 20 °C (unless otherwise noted).

Table 3

	MIN	NOM	MAX	UNIT
FWB-B: Supply voltage at pin 9 if **not** connected to pin 4 for dual-supply-voltage operation	+5.5	+9	+15	V
FWB-B: Supply voltage at pin 9 if connected to pin 4 for single-supply-voltage operation)	+7	+8	+9	V
FWB-A: Supply voltage at pin 9	+9		+12	V
FWB-B: Bridge excitation voltage at pin 4	+7	+8	+9	V
FWB-A: Bridge excitation voltage at pin 4	Leave unconnected or use for measuring of the internally generated bridge excitation voltage			

7.5. MECHANICAL

Table 4	
Housing material	Stainless steel (1.4404; SUS316L)
Potting	Polyurethane
Weight	15 g
Diameter	20.0 mm
Height (housing)	16.6 mm
Height (overall)	20.0 mm
Pins	Gold over nickel
Pin diameter	1.0 mm
Pin length	4.7 mm

7.6. ELECTRICAL

Table 5		
	Ambient temperature	*Supply Current@ 8V*
Supply current	-40 °C	44 mA
	-20 °C	44 mA
	0 °C	44 mA
	20 °C	43 mA
	40 °C	41 mA
	60 °C	40 mA
	80°C	37 mA

7.7. ENVIRONMENTAL

Table 6	
Ambient temperature range during operation	-40 to +85 °C
Operation humidity	0 to 100 % r.h.

7.8. SENSOR PARAMETERS

Table 7	
Digital output	I^2C bus
Response time	≈ 1 s
Cross sensitivity for humidity	negligible

7.9. SENSOR CROSS SENSITIVITIES

Table 8

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

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 $\geq$4 vol-%, appropriate flows of pure oxygen replace synthetic air flows to achieve 21 vol-% oxygen in the test gas. For figures 3 and 4, pure hydrogen is used instead of 5 vol-% H_2 in nitrogen. Ambient temperatures are adjusted in a cooled or heated test chamber at which the sensor is assembled.

8.1. INITIAL WARM-UP

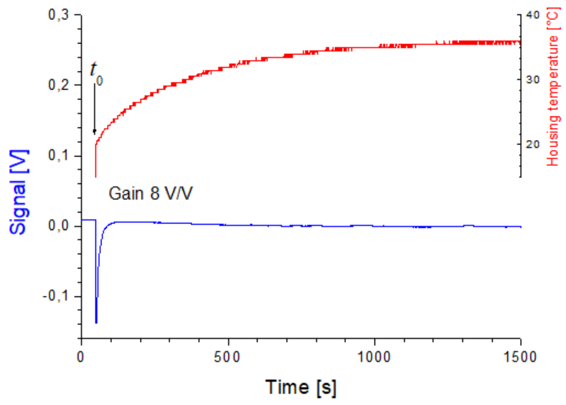

Figure 2. Typical signal characteristics of the sensor (blue curve) after powering-up at t_0. The sensor is operational shortly after switching on and the signal approaches the zero level after full thermal equilibration. The red curves shows the housing temperature, as determined with the internal temperature sensor.

8.2. CALIBRATION CURVE

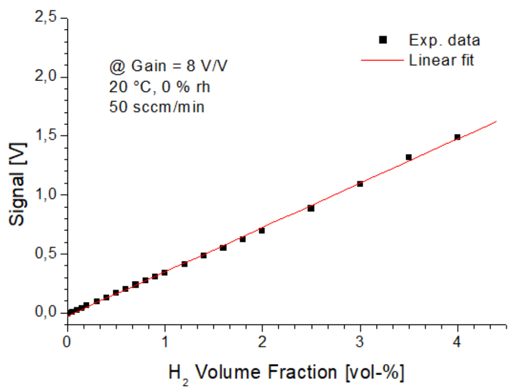

Figure 3. Typical values of the signal (at a gain of 8 V/V) as a function of hydrogen volume fraction in air (LEL regime) and a bridge excitation voltage of 8.0 V. Conditions: 20 °C ambient temperature, dry air, 50 sccm/min volume flow.

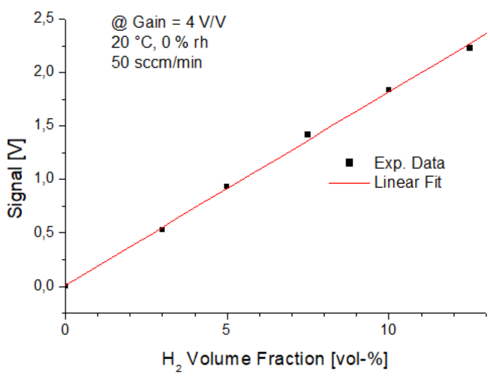

Figure 4. Typical values of the signal (at a gain of 4 V/V) as a function of hydrogen volume fraction in air (over-LEL regime) and a bridge excitation voltage of 8.0 V. Conditions: 20 °C ambient temperature, dry air, 50 sccm/min volume flow.

8.3. LOW DETECTION LIMIT AND RESOLUTION

The sensor can detect hydrogen volume fractions down to 100 ppm and its resolution is better than 100 ppm. See the corresponding chapter in Specification Sheet H2-CNI I2C-E-ULTD Rev. 1.0.

8.4. TEMPERATURE-DEPENDENCE

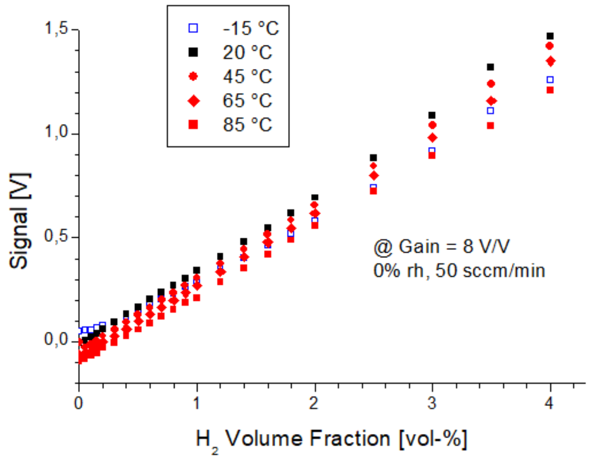

Figure 5. Temperature dependence of the signal from -15 °C to 85 °C. Conditions: dry air, 50 sccm/min volume flow.

8.5. EFFECT OF RELATIVE HUMIDITY ON THE BASE LINE

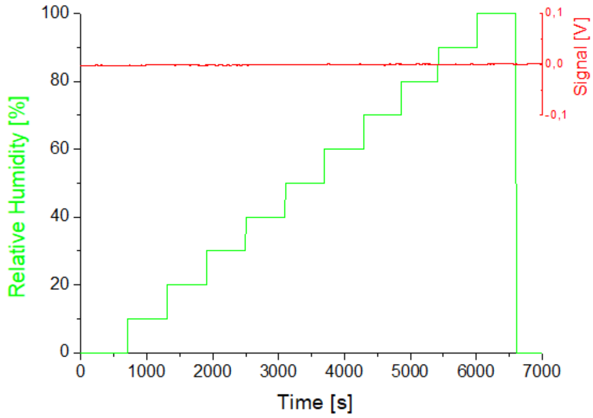

Figure 6. Sensor signal (gain 8 V/V) as a function of time at different levels of relative humidity from dry air to 100 % at 20 °C (8 V bridge excitation voltage, total flow = 50 sscm/min).

8.6. EFFECT OF RELATIVE HUMIDITY ON THE SIGNAL

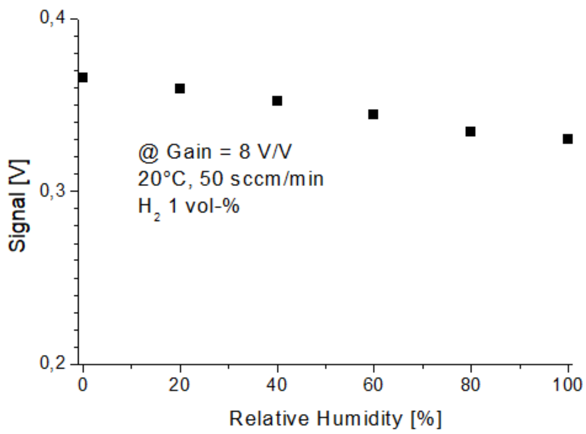

Figure 7. Sensor signal (gain 8 V/V) at 1 vol-% H_2 in air of varying relative humidity at 20 °C (8 V bridge excitation voltage, total flow = 50 sscm/min).

8.7. EFFECT OF FLOW RATES

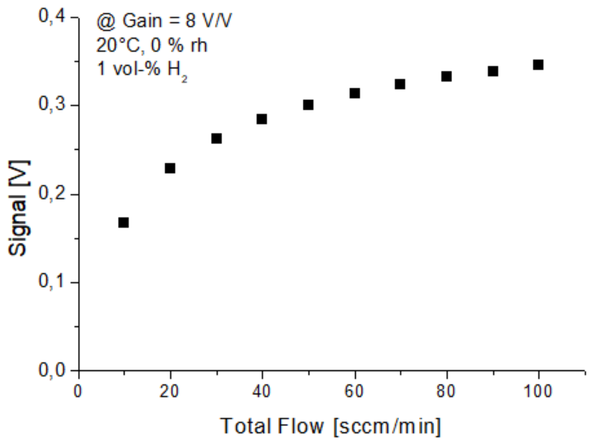

Figure 8. Sensor signal (gain 8 V/V) as a function of at low values of the total flow for 2 vol-% H2 in dry air at 20 °C (8 V bridge excitation voltage).

8.8. RESPONSE AND DECAY TIMES

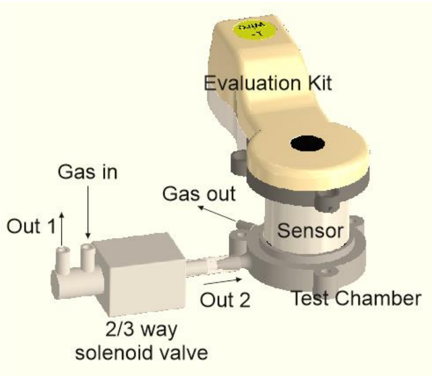

Figure 9. Special setup to determine the response and decay time of the sensor. A flow of 1 vol-% H_2 in air with 100 sccm/min flows into the system at the "Gas in" port. The flow can be switched electrically between Out 1 and Out 2. The voltage, applied to the valve, and the sensor signal are recorded. At zero valve voltage, the gas flows to a small test chamber and the sensor.

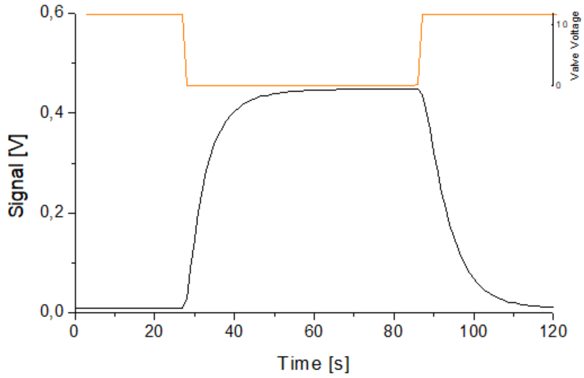

Figure 10. Sensor signal (black, gain 8 V/V) and valve voltage (orange) as a function of time after applying 1 vol-% H_2 in dry air at 20 °C (8 V bridge excitation voltage). The time delay is approx. 1 s. The sensor signal reaches a steady-state signal with a t_{90} response time of 10 s. After re-directing 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.

8.9. EFFECT OF THERMAL SURROUNDING

As with all devices based on calorimetric concepts, the hydrogen sensor H2-CNI I2C-I FWB is sensitive against changes of its thermal surrounding. This gives rise to noticeable variations of the base line of such devices. H2-CNI I2C-I FWB has precisely adjusted sensor and reference elements that operate at virtually identical temperatures when the sensor is powered up. Consequently, the signal, which is the balance voltage of the full Wheatstone bridge (see chapter 9), alters only little with the bridge excitation voltage. 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 in the mV range under good conditions. Consider a vertical upside or upside-down direction of the sensor if possible.

9. THEORY OF OPERATION

The hydrogen sensor H2-CNI I2C-I FWB comprises two temperature-sensitive transducers that form one branch of a Wheatstone bridge configuration (Figure 11). The second branch of the Wheatstone bridge is made up by resistors and a digital rheostate for offset adjustment. One transducer (the so-called active sensor element R_{active}) is covered with an advanced highly stable catalytic layer that promotes the hydrogen-to-water oxidation while the second transducer forms the inactive element R_{ref} and is used as a reference. Its purpose is to compensate variations of the out-of-balance voltage with changing ambient temperature which is accomplished to a large extent.

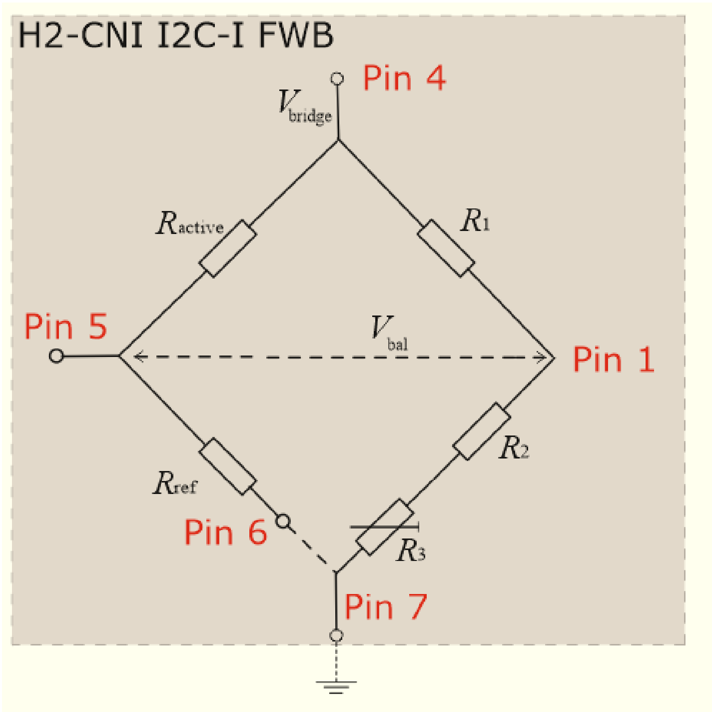

Figure 11. Wheatstone bridge configuration with H2-CNI I2C-I FWB (schematic). The dotted line between pin 6 and pin 7 represents an external low-impedance connection.

Both transducers are directly heated by passing a current from the voltage source V_{bridge}, applied to pin 4 with respect to pin 6. Pin 6 must be connected to Pin 7 externally simply by a wire or by an ampmeter if an additional measurement of the current is intended. Because the second branch of the bridge consists of high-ohmic resistors, the current through the bridge equals approximately $I = V_{bridge}/(R_{ref} + R_{active})$.

The out-of-balance voltage V_{bal}, measured between pin 5 and the midpoint of the second branch of the bridge at pin 1, can be set to zero by means of the internal digital rheostat R_3. An additional resistor R_2 in series to the digital rheostat allows a well-resolved zero-setting with the 256-step rheostat. Note that V_{bal} depends linearly on V_{bridge} due to Kirchhoff´s rules applied to a Wheatstone bridge configuration.

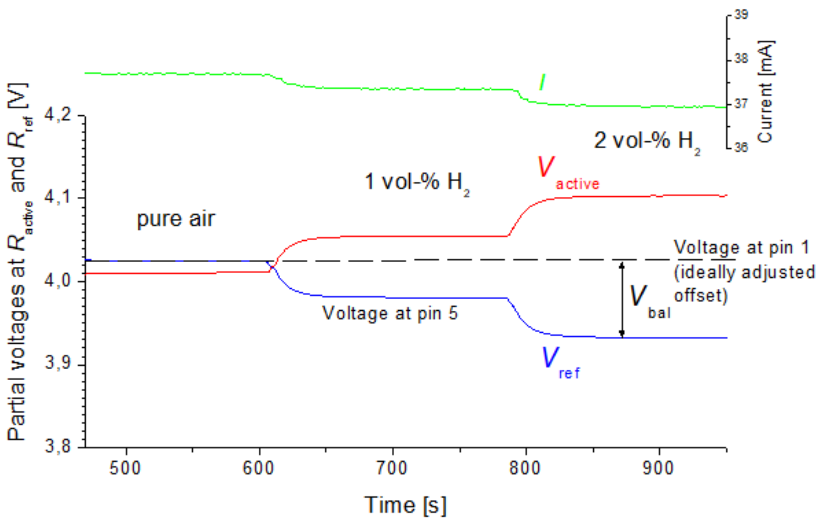

Figure 11. Partial voltages over the active sensing element R_{active} (red curve, measured between pins 4 and 5) and the reference element R_{ref} (blue curve, measured between pins 5 and 6) measured as a function of time in pure air, at 1 and 2 vol-% H_2. The upper diagram shows the current I through R_{active} and R_{ref} (green curve) as determined between pins 6 and 7. The sum of both partial voltages equals the constant bridge voltage V_{bridge} = 8.07 V. Note the current drop due to the increase of the resistance of the active sensor element (and hence the overall resistance R_{active} + R_{ref}) upon hydrogen exposure. Simultaneously, the reference element´s temperature decreases with respect to the pure-air situation because less electrical power V_{ref} •I dissipates under this condition. The signal of the sensor is the balance voltage V_{bal} of V_{ref} with respect to the voltage at pin 1.

Exposure of the sensor to hydrogen and oxygen-containing atmospheres (e.g. air) results in the generation of a chemical reaction heat that causes a temperature increase and hence a resistance increase of the active sensor element R_{active}. This effect can be detected by measuring the partial voltages over R_{active} and R_{ref} (figure 15) as well as the change of the current through both elements. The variation of the out-of-balance voltage V_{bal} is the result. This voltage is measured and digitalized with the internal 16-bit $\Delta\Sigma$ analog-to-digital converter that also contains a programmable gain amplifier (PGA) with gains from 1 to 256 in 8 steps (figure 12).

Typical gains of the amplification of V_{bal} should be in the range of 4 to 64, depending on the desired hydrogen sensitivity and detection range. The basic version of the sensor H2 CNI-I FWB-B requires a constant bridge excitation voltage V_{bridge} provided at pin 4. The advanced version H2 CNI-I FWB-A has a precison voltage source on-board which generates V_{bridge} from the applied supply voltage VPOW at pin 9. Typical values are in the range of +7 to +8.5 V and are chosen as a function of the ambient temperature. Unlike the H2-CNI I2C-E ULTD sensors, the active sensor element is connected to pin 4 for both FWB-A and B versions to ensure that the absolute voltage applied to the positive input of the analog-to-digital converter never exceeds the converter´s supply voltage of +5 V. The negative input of the converter is connected to the midpoint of the second branch of the Wheatstone bridge which lies approximately at $V_{bridge}/2$.

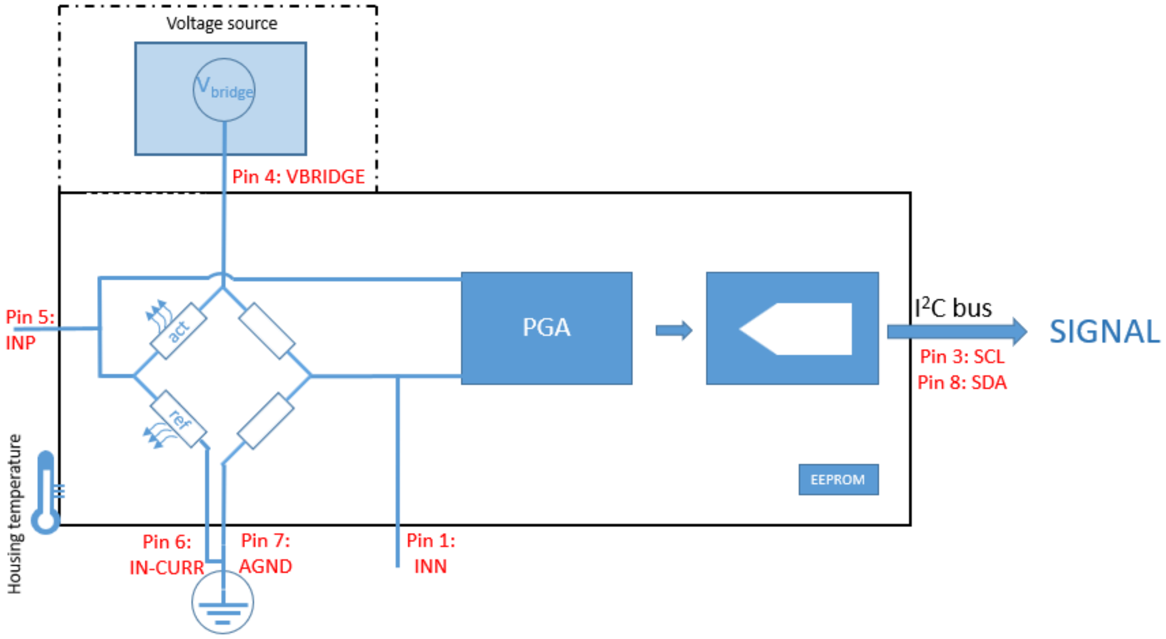

Figure 12. Components of the circuitry of H2-CNI I2C-I FWB hydrogen sensors. Note that pin 9 (not shown) must be connected to an external supply voltage. The SCL and SDA lines require external pull-up resistors (e.g. 4.7 kΩ).

10.APPLICATION AND IMPLEMENTATION

For most applications, H2-CNI I2C-I FWB can be operated with just a few external components. For H2-CNI I2C-I FWB-B a low-impedance voltage source that delivers sufficient power to heat up the active and reference elements is required at pin 4. For single-source operation with a 7 to 8.5 V, pin 9 can be connected to pin 4 and the +5V supply voltage of the EEPROM, digital temperature sensor, offset rheostat, PGA and ADC is generated with an internal linear voltage regulator. If pin 9 is not connected to pin 4, a second voltage source between 5.5 and 15 V is needed at pin 9 to drive the internal electronics.

For H2-CNI I2C-I FWB-A, only a single voltage supply in the range of 9 to 12 V must be wired to pin 9. In this case, pin 4 is not-connected to any supply voltage as the internal precision voltage source, controlled by the I^2C bus, excites the Wheastone bridge with the correct voltage. However, pin 4 can be used to monitor the bridge excitation voltage with a high-impedance voltmeter.

The pins 6 and 7 must be short-circuited. If the current through the sensing and reference elements is monitored, pins 6 and 7 can be connected with a low-ohmic resistor with a maximum value of 1 Ω. Such a value is in most cases adequate to generate a sufficient voltage drop that monitors the current through the sensing and reference elements, e.g. with differential or a single-ended AD converter. However, it should be noted that an additional resistor in series with the reference element affects the balance voltage of the Wheatstone bridge and hence zeroing of bridge with the offset rheostate might not be possible.

10.1. I^2C BUS

Two pull-up resistors are required to ensure that the SCL and SDA lines of the I^2C bus are at high potential.

The following 7bit addresses are used in the H2-CNI I2C-I FWB sensors:

Table 9: 7bit Addresses

Binary code	Hexadecimal code	IC
1001000	x48	9- to 12-bit selectable, ±1.0°C accurate digital temperature sensor
1010000	x50	1K bit serial electrically erasable PROM
0100110	x26	16-Bit ΔΣ ADC with Easy Drive® technology and on-chip programmable gain as analog-to-digital converter with PGA
1001110	x4E	Nonvolatile 256-position digital potentiometer used as rheostat for offset adjustment
0101100	x2C	Single-channel 256-position, digitally controlled variable resistor used for the programmable voltage source

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

10.2. 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>
<tr><td colspan="4">Table 10. Contents of the EEPROM</td></tr>
<tr><td>Word address</td><td>Data byte</td><td colspan="2">Remarks</td></tr>
<tr><td>0x00</td><td>Device code</td><td rowspan="5"></td><td rowspan="7">Data must not be changed</td></tr>
<tr><td>0x01</td><td>Serial number (upper byte)</td></tr>
<tr><td>0x02</td><td>Serial number (middle byte)</td></tr>
<tr><td>0x03</td><td>Serial number (lower byte)</td></tr>
<tr><td>0x04</td><td>CRC value</td></tr>
<tr><td>0x05</td><td>Fabrication date/month</td><td rowspan="2">See (a)</td></tr>
<tr><td>0x06</td><td>Fabrication month/year</td></tr>
<tr><td>0x07...0x02F</td><td>Fabrication-related data</td><td colspan="2">Encrypted data. Not intended for users</td></tr>
<tr><td>0x30</td><td>Excitation</td><td colspan="2" rowspan="7">Default settings for evaluation kit</td></tr>
<tr><td>0x31</td><td>Gain preamplifier</td></tr>
<tr><td>0x32</td><td>Gain</td></tr>
<tr><td>0x33</td><td>Offset A (upper byte)</td></tr>
<tr><td>0x34</td><td>Offset A (lower byte)</td></tr>
<tr><td>0x35</td><td>Offset B U(upper byte)</td></tr>
<tr><td>0x36</td><td>Offset B (lower byte)</td></tr>
<tr><td>0x37…0x4D</td><td>Control data for other evaluation kits not useful for H2-CNI I2C FWB sensors</td><td colspan="2">Encrypted data. Not intended for users</td></tr>
<tr><td>0x4E…0x52</td><td>Resistances and thermal coefficients of sensor and reference elements</td><td colspan="2">Encrypted data. Not intended for users</td></tr>
<tr><td>0x53…0x56</td><td></td><td colspan="2">Encrypted data. Not intended for users</td></tr>
<tr><td>0x57</td><td>Sign A</td><td colspan="2" rowspan="15">Polynomial, see equation f)</td></tr>
<tr><td>0x58</td><td>A upper byte</td></tr>
<tr><td>0x59</td><td>A lower byte</td></tr>
<tr><td>0x5A</td><td>Divider A</td></tr>
<tr><td>0x5B</td><td>Sign B</td></tr>
<tr><td>0x5C</td><td>B upper byte</td></tr>
<tr><td>0x5D</td><td>B lower byte</td></tr>
<tr><td>0x5E</td><td>Divider B</td></tr>
<tr><td>0x5F</td><td>Sign C</td></tr>
<tr><td>0x60</td><td>C upper byte</td></tr>
<tr><td>0x61</td><td>C lower byte</td></tr>
<tr><td>0x62</td><td>Divider C</td></tr>
<tr><td>0x63</td><td>Sign D</td></tr>
<tr><td>0x64</td><td>D upper byte</td></tr>
<tr><td>0x65</td><td>D lower byte</td></tr>
</table>

0x66	Divider D	
0x67	Sign E	
0x68	E upper byte	
0x69	E lower byte	
0x6A	Divider E	
0x6B	Sign F	
0x6C	F upper byte	
0x6D	F lower byte	
0x6E	Divider F	
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	Bandgap reference × correction factor	Only for H2-CNI I2C-I FWB-A sensors, see equation (d)
0x75	Setting of the rheostat in the Wheatstone bridge for midpoint	
0x76…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													

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

d) Value of bandgap reference voltage from data byte in 0x74

Data byte in 0x74							
MSB							LSB
8 bit word							

$$\text{Bandgap reference voltage} = \text{8 bit word} \times 0.00025\text{ V} + 1.20\text{ V}$$

e) Offset rheostat´s setting for midpoint in 0x75 and 0x76

Data byte in 0x75							
MSB							LSB
8 bit word							

Offset = 8 bit word

f) Polynomial V_{bridge} as function of T_{ambient}

$$V_{\mathrm{bridge}} = A + BT_{\mathrm{ambient}} + CT_{\mathrm{ambient}}^2 + DT_{\mathrm{ambient}}^3 + ET_{\mathrm{ambient}}^4 + FT_{\mathrm{ambient}}^5$$

Parameters A, B, C, D, E, and F are stored according to the following scheme

- Sign of A: 0 means + and 1 means –
- Upper byte of A
- Lower byte of A
- Divider A

For example, A = +8.05 is converted into 805 $\times$ 10^{-2} and is stored as x00 in 0x56, x03 in 0x57, x25 in x58 (x0325 is the hexadecimal representation of the decimal number 805), x12 (1 for – and 2 for the exponent) in 0x59. The exponents are limited to -15 (or 1F) until +15 (or 0F)
-2,074E-10 would give x01, x1A, x08, x1D.

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/$\overline{\mathrm{W}}$ 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.

10.3. ADJUSTABLE PRECISON VOLTAGE SOURCE

The advanced version of the H2-CNI I2C-I FWB sensors contains an adjustable voltage source for bridge excitation which allows precise control of the voltage V_{bridge}. The source is driven by the supply voltage VPOW at pin 9 (see Table 3). After powering of the sensor, the initial voltage V_{bridge} is approximately 6.5 V only and must be set to an appropriate value.

The voltage source is initiated by the following write operation to the variable resistor, used in the rheostat operation mode, with the Start signal, followed by the address AD=0101100 and the R/$\overline{\mathrm{W}}$ bit, which is a logic low. The variable resistor acknowledges and the master sends an instruction byte 01000000. After receiving the next acknowledge condition the master transmits the 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 is calculated from

$$\text{Data byte} \approx \left[\left(\frac{91{,}000}{\frac{V_{\text{bridge}}}{\text{Bandgap reference voltage}}-1} - 10{,}000\right) - 60\right] \times \frac{256}{VR}$$

Values should be rounded appropriately. Note, that data bytes below 00110110 are not allowed to prevent the bridge voltage from exceeding its absolute maximum rating of 9 V (see figure 13).

After the initial write operation with the instruction byte 01000000, the following write operations are performed with an instruction byte 00000000 and a data byte for the chosen bridge excitation voltage as given by the formula.

The read mode is initiated by the master by sending the Start signal, followed by the address AD=0101100 and the R/$\overline{\text{W}}$ bit, which is a logic high. The data byte follows immediately after the acknowledgment. After receiving the 8 bits of the data byte, the master responses by leaving the SDA line high (no acknowledge bit, NACK) during the ninth SCL clock pulse and then terminates with a Stop signal.

S	AD,1	ACK	Data byte	NACK	P

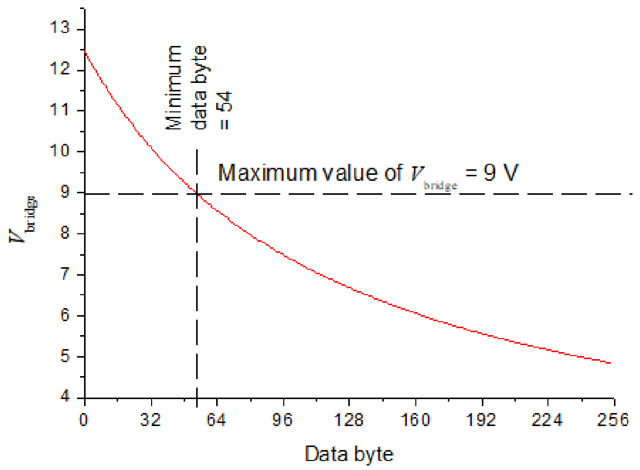

Figure 13. V_{bridge} as a function of decimal value of data byte.

10.4. ADJUSTING THE BALANCE VOLTAGE

The second branch of the Wheatstone bridge contains a nonvolatile 256-step variable resistor, used as rheostat, to allow precise zeroing of the balance voltage V_{bal}.

The corresponding wiper position is stored in the rheostat and automatically adjusted after powering-up. Due to the special configuration of the Wheatstone bridge, the change of the balance voltage depends nonlinearly on the rheostat wiper setting (see Figure 14). This allows the user to extend the AD converter input voltage beyond its usual limitation (0 to 2.5 V) into the negative voltage range (see Table 11 in Section 10.5). In this case the risk of overloading of the input of the AD converter at larger hydrogen volume fractions is reduced. On the other hand, precise zeroing of the Wheatstone bridge is also possible with rheostat settings at or in the vicinity of the ideal midpoint setting. The midpoint value is writing to 0x75 in the EEPROM of the sensor.

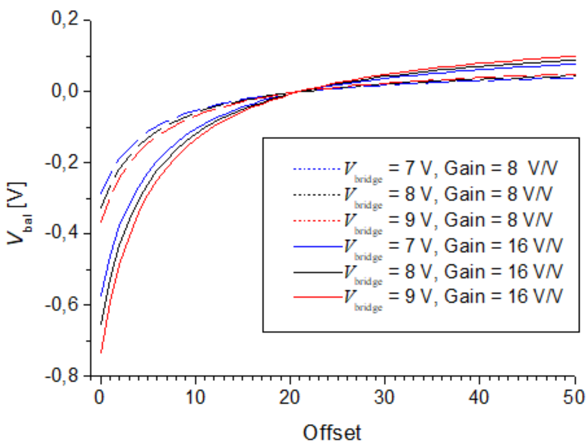

Figure 14. V_{bal} as a function of the rheostate offset setting for three different bridge excitation voltages.

Note that the balance voltage depends on the bridge excitation voltage linearly.

10.5. READING THE BALANCE VOLTAGE

Both, the basic and advanced versions of the H2-CNI I2C-I FWB sensor contain a 16-bit plus sign no latency ΔΣ analog-to-digital converter which includes an on-chip programmable gain from 1 to 256 in 8 steps and reject line frequencies (50Hz, 60Hz or simultaneous 50Hz/60Hz). The converter powers up in a default mode with a gain of one, is automatically calibrated, and the digital filter simultaneously rejects 50Hz and 60Hz line frequency noise.

A gain of 4 V/V and 16 V/V is recommended for applications in a wide range of hydrogen volume fractions (0 to 15 vol-%) and for typical LEL values (0 to 4 vol%) in air. The gains are written by the following sequence, initiated by the Start signal (S) of the master and terminated by the Stop signal (P). The 7 bit address of the converter is AD = 0100110.

S	AD,0	ACK	Configuration byte	ACK	P

The following table configuration bytes are used to set the gain and consequently the input voltage span of the converter. These spans are resolved with a 16 bit resolution, and hence the smallest resolvable voltages increases with increasing gain. Since the balance voltage of the Wheatstone bridge decreases from zero to negative values in the presence of hydrogen, an appropriate gain should be set to prevent the converter from being overloaded.

Table 11. Gain, configuration byte, input voltage span, and resolvable voltages			
Gain	Configuration byte	Input voltage span	Resolvable voltages
1 (default)	00000110	±2.5 V	76 μV
4	00100110	±0.625 V	19 μV
8	01000110	±0.3125 V	4.77 μV
16	01100110	±0.156 V	2.38 μV
32	10000110	±78 mV	1.19 μV
64	10100110	±39 mV	0.596 μV
128	11000110	±19.5 mV	0.298 μV
256	11100110	±9.77 mV	0.149 μV

The balance voltage decreases by approximately 46 mV for 1 vol-% H2 and shows a linear dependence from the hydrogen volume fraction, so the above-given gains of 4 and 16 for wide-range and LEL applications are good starting values. Taking account of the various sources of noise, that may contribute to the signal, resolutions of better than 100 ppm H2 are achievable with gains of 4 and 16. For very stable ambient conditions, even higher gains might be used to reduce the low detection limit even further.

To initiate a conversion and to receive the balance voltage, the master must perform the following Read operation:

S	AD,1	ACK	Data byte 1	ACK	Data byte 2	ACK	Data byte 3	NACK	P

After the complete Read operation of 3 bytes, the output register of the converter is emptied, a new conversion is initiated, and a following Read request in the same input/output phase will be NACKed. The converter´s output data stream is 24 bits long:

Bit 23 SIG	Bit 22 MSB	Bit 21	Bit 20	…	Bit 6 LSB	Bit 5 PG2	Bit 4 PG1	Bit 3 PG0	Bit 2 x	Bit 1 IM	Bit 0 SPD

The first bit is the conversion result sign bit (SIG) and the second bit is the most significant bit. These two bits can be used to indicate over range conditions. If both bits are high, the differential input voltage is above + full-scale voltage and the following 16 bits are set to low to indicate an overrange condition. If both bits are low, the input voltage is below – full-scale voltage and the following 16 bits are set to high to indicate an underrange condition. The adjusted gain can be derived from the bits 5, 4, and 3 according to the following table.

Table 12. Gain of the converter from PG2, PG1 and PG0			
PG2	PG1	PG0	Gain
low	low	low	1
low	low	high	4
low	high	low	8
low	high	high	16
high	low	low	32
high	low	high	64
high	high	low	128
high	high	high	256

Bit 2 is reserved, bit 1 (IM) refers to the internal temperature sensor (not used here), and bit 0 (SPD) indicates the output rate (not used here).

The following table and the formulae in the flow diagram in figure 15 can be used to get the voltage from the converter´s output.

Table 13. Converter Output Format for SPD=0

V_{bal}	Bit 23 SGN	Bit 22 MSB	Bit 21	Bit 20	Bit 19	…	Bit 6
$V_{bal} \geq FS$	1	1	0	0	0		0
$V_{bal} = FS - 1LSB$	1	0	1	1	1		1
$V_{bal} = 0.5 \cdot FS$	1	0	1	0	0		0
$V_{bal} = 0.5 \cdot FS - 1LSB$	1	0	0	1	1		1
$V_{bal} = 0$	1	0	0	0	0		0
$V_{bal} = -1LSB$	0	1	1	1	1		1
$V_{bal} = -FS$	0	1	0	0	0		0
$V_{bal} < -FS$	0	0	1	1	1		1
Full-scale voltage $FS = 2.5 \frac{V}{Gain}$, LSB = least significant bit							

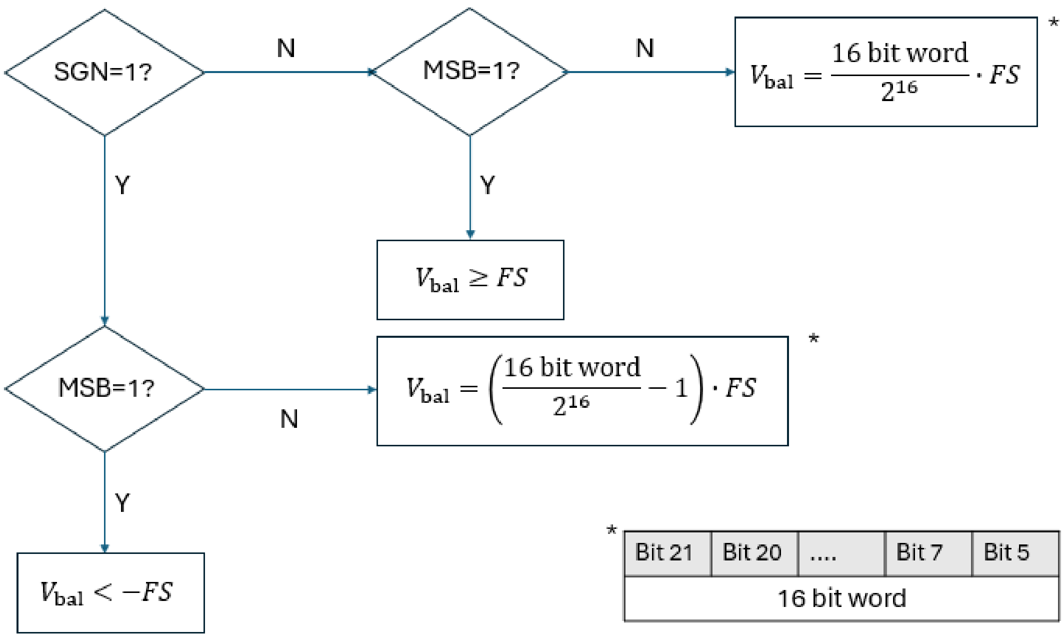

Figure 15. Flow diagram.

10.6. READING THE HOUSING TEMPERATURE

The temperature sensor is configured by the following write operation, initiated by the master with the Start signal, followed by the address AD=1001000 and the R/$\overline{W}$ bit, which is a logic low. The temperature sensor acknowledges and the master sends the data byte 00000001 to set the pointer to the configuration register of the sensor.

After receiving the next acknowledge condition the master terminates the write operation with the Stop signal.

In the next Write operation the master transmits the data byte 01100000 for selecting a 12 bit resolution of the temperature. The register of the temperature sensor must subsequently set back to the temperature register issuing a Write operation with the data byte 00000000.

S	AD,0	ACK	Data byte	ACK	P

The Read operation is initiated by the master by sending the address, followed by the R/$\overline{\text{W}}$ bit, which is a logic high. The temperature will send two data bytes according to the following sequence.

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

Bit 15 SIG	Bit 14 MSB	Bit 13	…	Bit 5	Bit 4 LSB	Bit 3 0	Bit 2 0	Bit 1 0	Bit 0 0

Table 14. Temperature Sensor Output Format

Temperature	Bit 15 SGN	Bit 14 MSB	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
+125 °C	0	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0
+100 °C	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
+75 °C	0	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0
+50.5 °C	0	0	1	1	0	0	1	0	1	0	0	0	0	0	0	0
+25.25 °C	0	0	0	1	1	0	0	1	0	1	0	0	0	0	0	0
+10.125 °C	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0
+0.0625 °C	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
0 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-0.0625 °C	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
-10.125 °C	1	1	1	1	0	1	0	1	1	1	1	0	0	0	0	0
-25.25 °C	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0
-50.5 °C	1	1	0	0	1	1	1	0	1	0	0	0	0	0	0	0
-55 °C	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0

The following block scheme reveals a LabVIEW® based solution to determine the temperature from data byte 1 and 2. The 'theoretical' resolution of the temperature sensor is 0.0625 °C within the maximum temperature regime between -55 °C and +125 °C. Note, that the hydrogen sensor only allows an industrial regime from -40 °C to +85 °C.

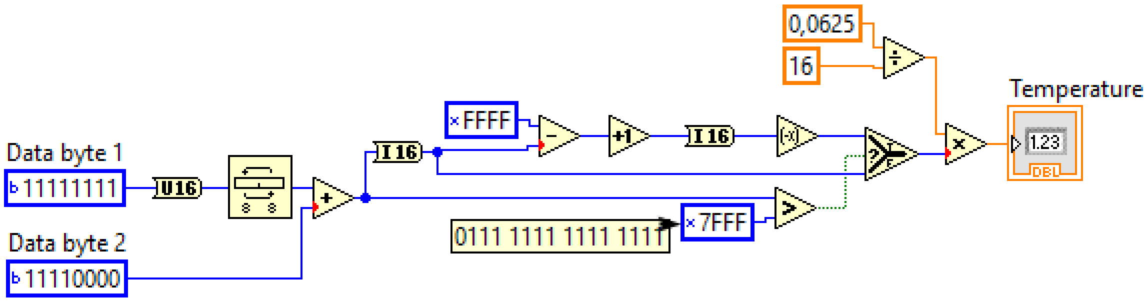

Figure 16. LabVIEW® code to get the temperature from the two data bytes.

10.7. CONTROL OF BRIDGE EXCITATION VOLTAGE BY TEMPERATURE

The bridge voltage V_{bridge} can be controlled by the ambient temperature to reduce the temperature-dependent hydrogen sensitivity, using the following 5th order polynomial

$$V_{\text{bridge}} = A + BT_{\text{ambient}} + CT_{\text{ambient}}^2 + DT_{\text{ambient}}^3 + ET_{\text{ambient}}^4 + FT_{\text{ambient}}^5$$

11. FOOTPRINT AND RECOMMENDED PLUG-IN SOCKETS

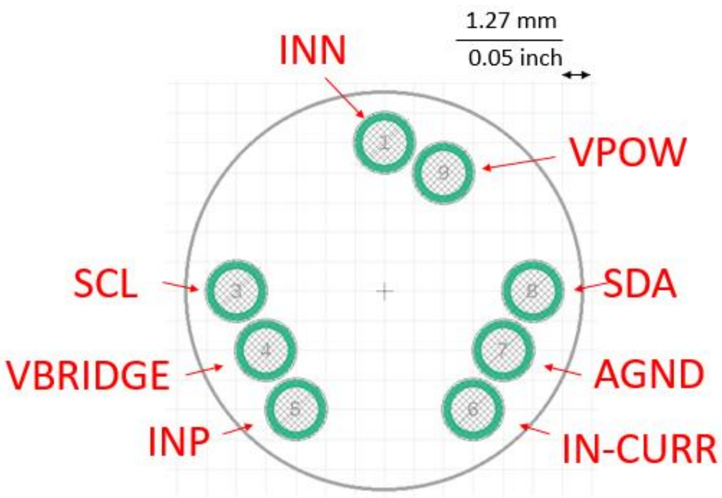

Figure 17. Footprint

Table 15	
Recommended plug-in sockets	450-3704-01-03-00 (Cambion)
Drill hole:	1.6 mm

12.ORDERING INFORMATION

Hydrogen sensor H2- CNI I2C-I FWB-A (advanced version)

Hydrogen sensor H2- CNI I2C-I FWB-B (basic version)

13. PACKAGING/SHIPPING INFORMATION

This sensor is shipped individually in an antistatic bag.

14. WARNINGS

Warnings: The sensor H2-CNI I2C-I FWB 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.

15.NOTES

16.DEVICE SUPPORT

An evaluation kit (PrecVS 3.1 with SBPS-eFuse-LDO 3.12 and additional accessories) is available to support customers in the performance evaluation of our H2-CNI I2C-I FWB-B sensors. The related user's manual can be requested at the website www.fes-sensor.com through the product folders. For our H2-CNI I2C-I FWB-A sensors we recommend the use of our evaluation kit I2C-USB 3.1 which can be connected directly to an USB port.

17.WORLDWIDE SALES AND CUSTOMER SUPPORT

ALDERS electronic GmbH

Arnoldstraße 19 , 47906 Kempen (Germany)

sales@alders.de

+49 2152 8955-230