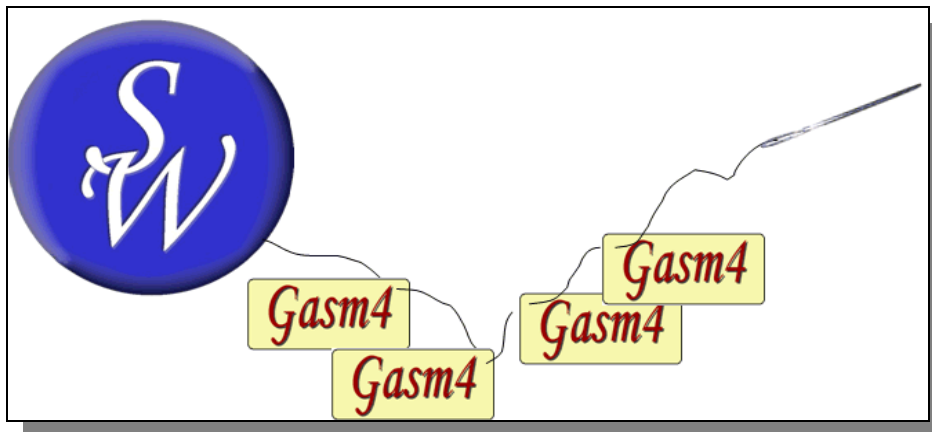




# Gas Sensor Modules for the *SensorWire* Measurement System, compliant with the Standard IEEE1451.4



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In collaboration with JLM Innovation



# Modules for SensorWire: GASM4

Modules for SensorWire: GASM4.....	2
1. The SensorWire measurement system.....	2
2. Gas Sensor Modules: GASM4-r3 .....	3
2.1. Conditioning of the Sensor resistance .....	5
2.2. Conditioning of the Sensor Heater.....	6
2.3. The choice of embedding the AD.....	7
2.4. Several configuration in one module.....	8
2.5. Sensor Connectors .....	8
3. Transducer Electronic Data Sheet – TEDS.4.....	10
3.1. Basic TEDS for GASM4.r3 .....	10
3.2. Templates for GASM4.r3 .....	12
3.3. User Data for GASM4.r3.....	12
4. Software for module configuration .....	12
5. Guidance to module configuration. ....	14
Appendix A: Overview on IEEE1451 and IEEE1451.4 .....	22
6. Overview of the Standard IEEE 1451 [1] .....	22
7. The IEEE 1451.4 .....	23
7.1. Mixed-Mode Interface .....	24
7.2. Dot 4 TEDS .....	25
Appendix B: The 1-Wire bus.....	29
8. Basic Overview .....	29
9. 1-Wire Master .....	29
10. 1-Wire Slaves .....	30
11. 1-Wire Communication Protocol.....	31
12. 1-Wire Software.....	32
References .....	33

## 1. The SensorWire measurement system

*SensorWire* is a measurement system for gas sensors based on a control unit that can be either a microcontroller or a personal computer (PC) or laptop. *SensorWire* is a modular system offering plug&play and self-configuration capabilities, and communicates with up to tents modules through a USB/1-Wire interface, by using only 2 wires (data + supply and ground).

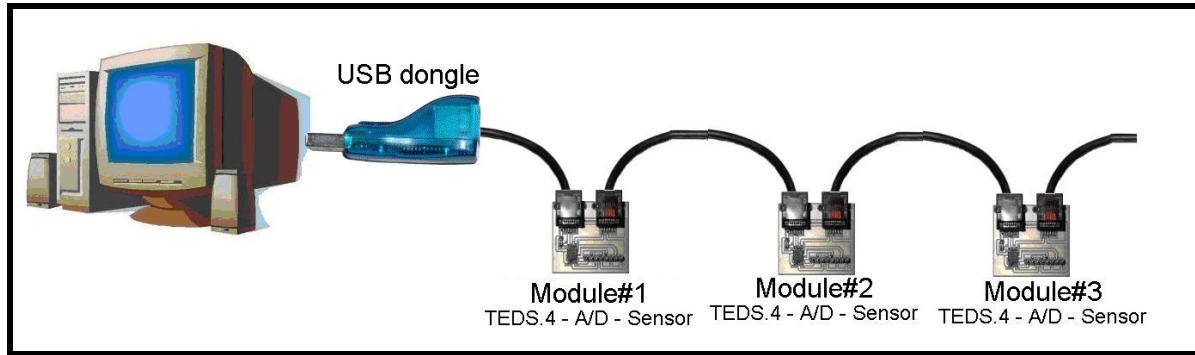


Figure 1: Block diagram of the system

The interface may be the DS9490R by Dallas or the interface provided by JLM Innovation.

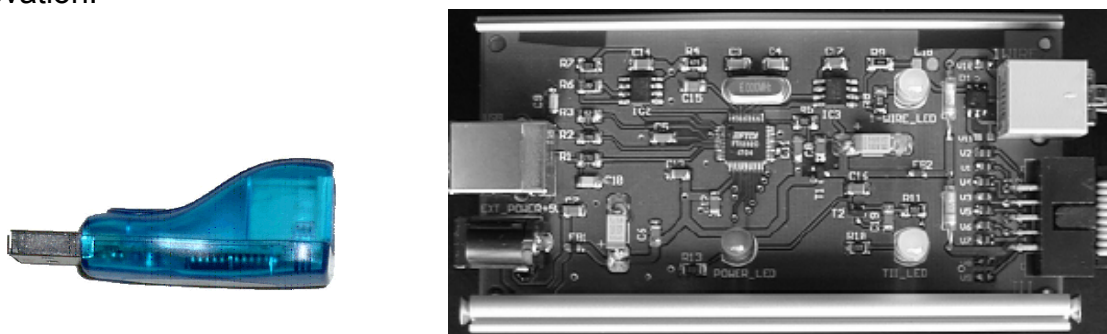


Figure 2: Pictures of the DS9490R USB/1-Wire Interface (left) and the USB TII and SensorWire Interface (right).

The interface also provides 5V supply (~150mA). External power supply is necessary if more current is required (e.g. when metal oxide sensors – MOX - are connected) and when more than 3.5V supply is necessary for the heater supply. In the latter case the power supply has to be 9-12V.

Each module embeds the hardware to provide plug&play capabilities for resistive (metal oxide and polymeric) gas sensors to connect and communicate with the control unit. The modules embed an EEPROM containing the Transducer Electronic Data Sheet (TEDS), compliant with the Standard IEEE1451.4, for both a resistive sensor and the sensor heater. In fact, the module provides the conditioning electronics for a sensor heater as well. Moreover, the modules embed an analog-to-digital converter for sending data through 1-Wire® bus.

## 2. Gas Sensor Modules: GASM4-r3

The modules composing the SensorWire system are called **GASM4**: GAs Sensors Modules compliant with IEEE1451.4.

The implementation described in this document is the third version designed for usage with **resistive** (polymeric, metal oxide) gas sensors and provides also MOX heater supply and heater temperature reading: **GASM4-r3**.

The modules GASM4-r3 have designed to allow easily creating and configuring new generation of olfactory electronic systems with **plug-and-play** capabilities.

The pictures below shows the block diagram of the module where the various sub-parts are indicated.

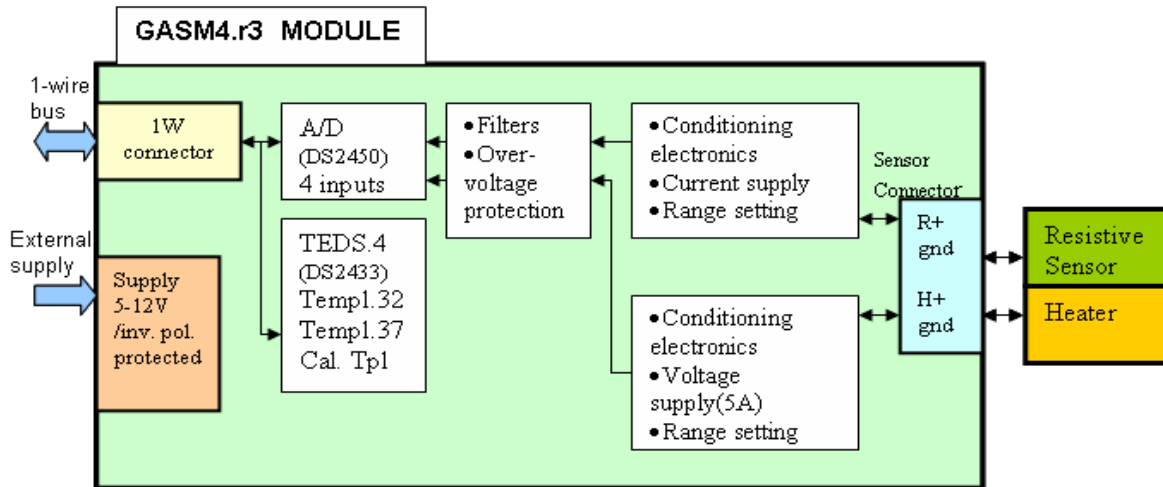


Figure 3: Block diagram of the module

The requirements at the base of the project are:

- Compliance with standard IEEE1451.4
- Easy to connect to the measuring system
- Easy to configure
- Easy to use
- Versatile for usage with various type of gas sensors
- Low-cost
- Good performances

The module requires a single supply (5 or 9-12V depending on the configuration) that can be external or provided by the interface. A diode on the supply prevent of damages due of polarity error.

Each module embeds (see figures 3, 4, 5):

- EEPROM 1-wire memory (DS2433, 4kbits) containing the TEDS.4
- 1-Wire A/D converter DS2450 with four inputs (Zener diodes on the A/D inputs prevents from extra-voltage).
- Conditioning electronic for resistive gas sensors, compliant with standard IEEE1451.4 Class 2, Template 32 for generic resistive sensors (the voltage output is sent to A/D input #D – see details afterwards)
- Conditioning electronics for MOX heater supply: 0-3 A (the voltage output is sent to A/D input #C – see details afterwards)
- Filters for signal noise removing.
- Two connectors are provided for connection to 1-wire bus, in order to facilitate multidrop connection.
- One power connector that allows screwing several wires in order to easily transport supply to other modules.
- Several connectors are available for external sensor connection or direct plugging on the board for test. Pins placement is suitable for TGS, FIS, AppliedSensor and other sensors. The module allows using gas sensor with shared pin (gnd) for heater and sensor resistor (e.g. FIS).

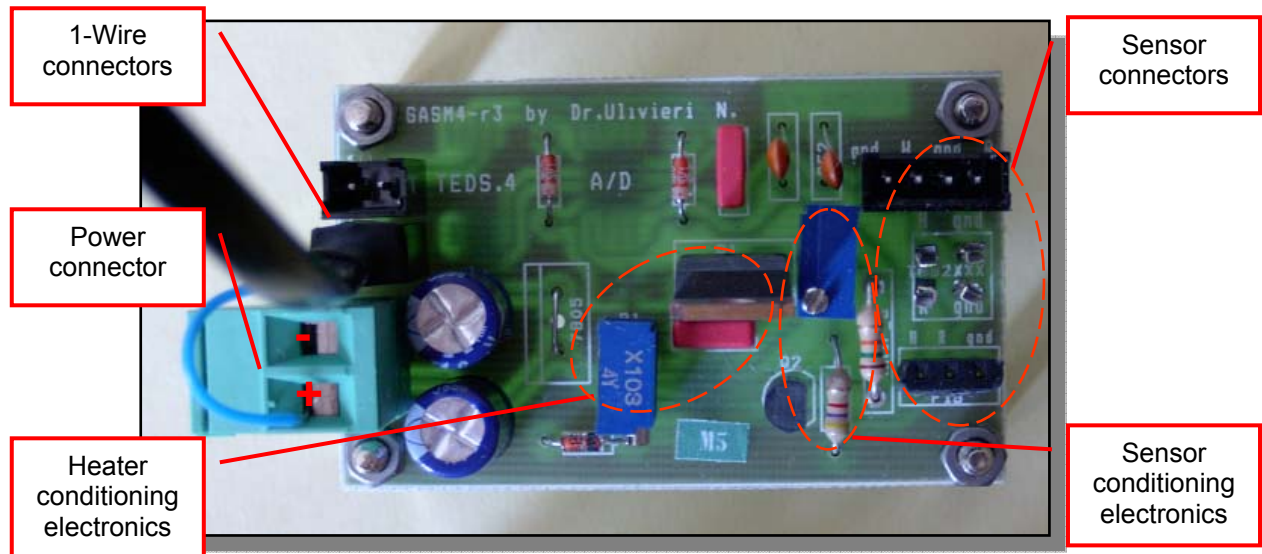


Figure 4: Picture of the module topside

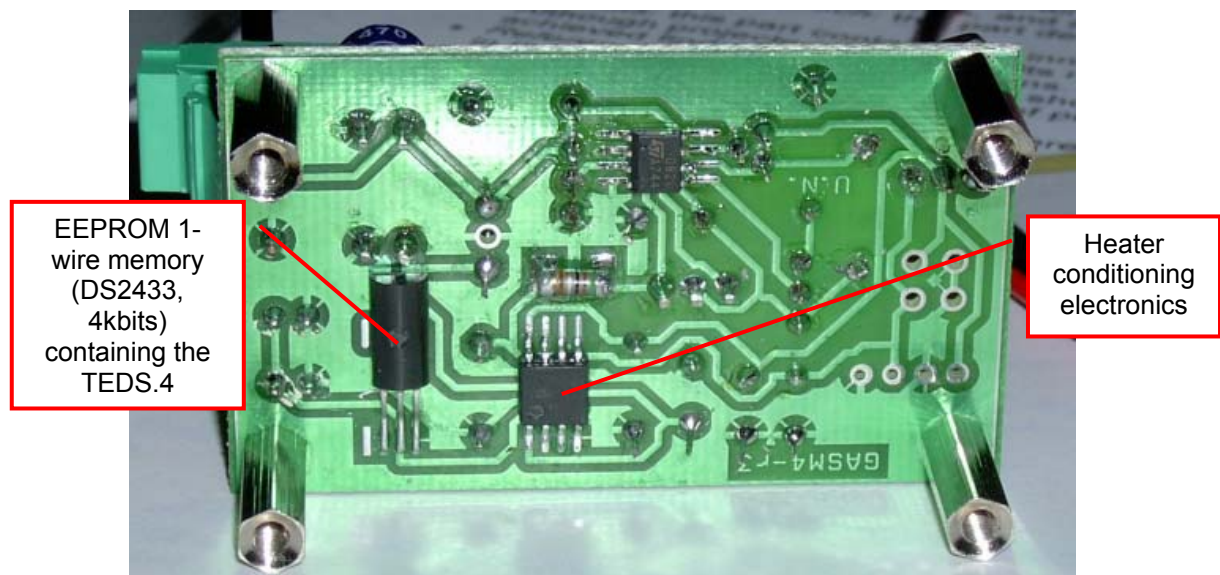


Figure 5: Picture of the module bottom side

Below some details on the module sub-parts are reported.

### 2.1. *Conditioning of the Sensor resistance*

The board provides suitable electronics for compliance with Template 32 (Output resistance sensor) of Standard IEEE1451.4. The standard requires a constant current generator supplying the sensor. The voltage across the sensor is read and converted by the embedded A/D. In case the user wants to use a different A/D, it is possible to read the voltage across the sensor that is available at the pin 'R' of the sensor connectors. The Template 32 allows the SensorWire or another IEEE1451.4

compliant system to automatically convert the voltage value read by the A/D into the sensor resistance:  $R_s = \frac{V(AD)}{I_{nom}}$

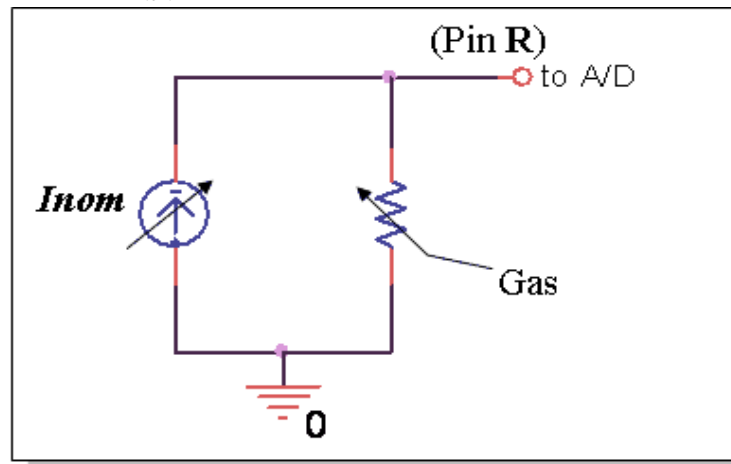


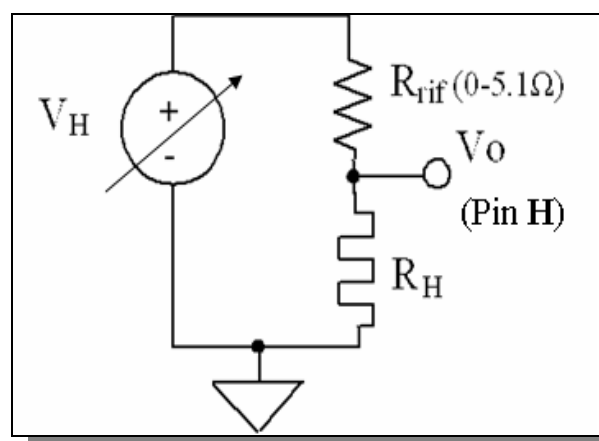
Figure 6: Simplified scheme of the sensor resistance conditioning electronics

It is possible to trim the current supply to the desired value by means of the trimmer  $R2$  and a reference resistance  $Rref\_s$  in order to suit the module to various sensor baseline resistance values. See the section “Guidance to module configuration” for instruction on current setting. Once the supply current is regulated, the TEDS.4 must be updated with the new value.

## 2.2. Conditioning of the Sensor Heater

A voltage generator, able to provide up to 3A, is used to supply the sensor heater. This generator can be trimmed by means of the trimmer  $R1$  in order to adapt to various heater requirements. See the section “Guidance to module configuration” for instruction on voltage setting. The heater consumption must be taken into account to know if the interface will be able to provide enough current (~150mA); in the other case, an external supply will be necessary. The module GASM4-r3 supplied with 5V may provide up to 3.5V to the heater. If a higher heater supply value is required (e.g. 5V for Figaro sensors), the module must be supplied with 9 to 12V.

The heater is inserted in a voltage divider configuration where a reference resistance, with low thermal dependence, is used. In this way the heater can be used contemporarily as actuator and sensor.



**Figure 7: Simplified scheme of the heater conditioning electronics**

The voltage across the heater is read and converted by the A/D on the module that communicates the value to the SensorWire. Alternatively, it can be read by others A/D by taking the analog output at the pin 'H' of the sensor connectors. The voltage read can be converted into the temperature value by knowing the voltage supply and the coefficients of the heater that relate the heater resistance to the heater temperature:  $R_H = R_0 \cdot (1 + A \cdot T + B \cdot T^2)$ . This is achieved by writing the coefficients  $R_0$ ,  $A$  and  $B$  into Template 37 and the heater supply voltage  $V_H$  into Template 32 (see chapter "Guidance to module configuration"). The operations that the measurement system automatically does are:

$$R_H = \frac{V_o \cdot R_{rif}}{V_H - V_o}$$
$$T = \frac{-A + \sqrt{A^2 - 4B \left(1 - \frac{R_H}{R_0}\right)}}{2B}$$

NOTE: The hardware configuration for the heater supply of the GASM4-r3 modules (voltage divider with 5.1Ohm reference resistance) is different from the one required by the Template 37 for RTD (constant current supply) since it is known that, with a voltage supply, we reduce the dependence on the ambient temperature [6]. See below the chapter on the TEDS for details on the coefficients stored into the templates.

### 2.3. The choice of embedding the AD

The module GASM4-r3 are compliant with the Standard IEEE1451.4 with class 2 interface concerning the block relative to the analog signal conditioning of the sensor response and the presence of a TEDS.4 stored in a Dallas DS2433 EEPROM (see Appendix "Overview on IEEE1451 and IEEE1451.4"). The heater conditioning block is chosen in order to reduce the ambient temperature variation and the heater information is stored in templates inside the TEDS.4. The analog output signals (sensor voltage, heater voltage) are available through the connectors pins  $R$  and  $H$ .

In order to obtain full Plug and Play capabilities of the *SensorWire* system and to simplify module connection and self configuration, an analog-to-digital converter (A/D) with four analog inputs with 1-Wire bus interface (DS2450 [5]), was embedded within the module. The unique identification number (URN, see chapter on the 1-Wire bus) of the A/D allows to automatically identify it to the SensorWire system (see chapter on TEDS.4).

Moreover, an A/D on-board connected to the 1-Wire bus highly simplify module connection in a multidrop configuration by using only 2 wires.

The A/D range can be set to 5.12V or 2.56V and its resolution ( $\Delta V = 5.12V/2^{16} = 78\mu V$  or  $\Delta V = 2.56V/2^{16} = 39\mu V$ ) is sufficient for the most of application ( $\Delta R = \Delta V / I_{nom}$ ; e.g.  $39\mu V/100\mu A = 0.39\Omega$ ).

Concerning the four analog inputs (channels A to D) of the DS2450, channel D is used to acquire the sensor voltage output and channel C for the heater voltage output, when present.



Another advantage of the choice of the 1-Wire bus for signal reading is the possibility to use other 1-Wire devices such as the thermometers DS18S20, by using the same two wires already present.

#### 2.4. *Several configuration in one module*

The modules GASM4-r3 are designed to offer the possibility to manage polymeric or MOX sensors. It is possible to supply the modules with 5V or 9-12V by using or shortcutting the voltage regulator 7805. It is also possible to avoid the usage of the embedded A/D in order to employ the module as IEEE1451.4 compliant transducer with a different acquisition board (e.g. DAQ board of National Instruments or others) According to the particular configuration chosen we may define the different variants:

**GASM4-r3a:** Module for MOX - powered with 9-12V

[Heater coefficients are known and its temperature is measured - TEDS is configured with Templates 32, 37 and 30 (heater supply  $V_{nom}$  is written in template 30. Reference resistor is known 5.1ohm)]

**GASM4-r3b:** Module for MOX - powered with 9-12V

[Heater coefficients are unknown and its voltage is monitored - TEDS is configured with Templates 32 and 30 (heater supply  $V_{nom}$  is applied to heater without reference resistor and it is written in the template 30)]

**GASM4-r3c:** Module for Polymer - powered with 9-12V

[TEDS is configured with Template 32]

**GASM4-r3d:** Module for MOX/Polymer to use with DAQ board (e.g. Nat. Instruments DAQ)- no A/D on board - powered with 9-12V

[TEDS is configured with templates 32, 37 and 30 as r3a (An external heater supply can be inserted in the place of the trimmer for temperature control, Reference resistance is known 5.1ohm)]

**GASM4-r3e:** Module low-power for Polymer - powered with 5V

[TEDS is configured with template 32]

**GASM4-r3f:** Module low-power for MOX - powered with 5V

[TEDS is configured with templates 32, 37 and 30 as r3a]

#### 2.5. *Sensor Connectors*

Several sensor connectors allow plugging several types of sensors. The following pictures show how to plug some commonly used gas sensors:

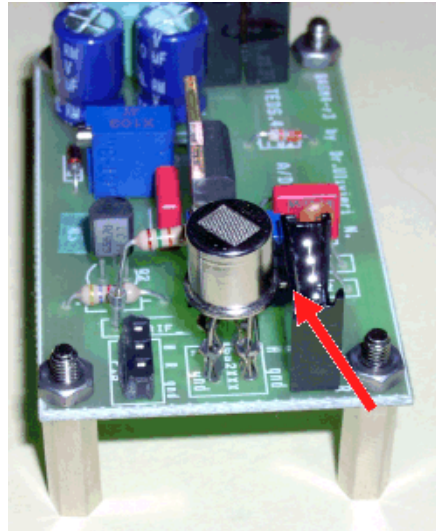


Figure 8: correct placement for TGS 2xxx series gas sensors.



Figure 9: correct placement for FIS gas sensors.



Figure 10: correct placement for AppliedSensor

gas sensors.

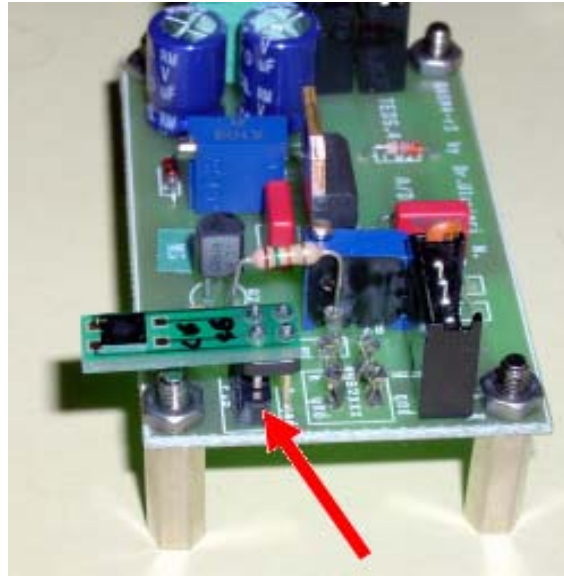


Figure 11: correct placement for polymeric gas sensors from SRL (Warwick University).

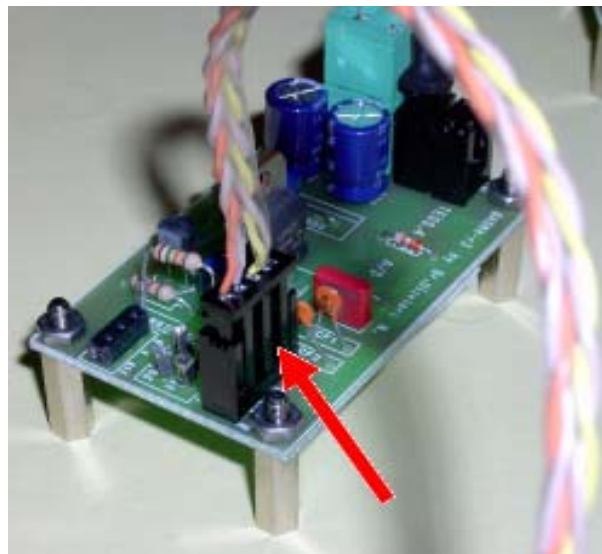


Figure 12: external gas sensors can be plugged to the connector for measurements.

### 3. *Transducer Electronic Data Sheet – TEDS.4*

The TEDS.4 (see Appendix on Standard IEEE1451.4) for the modules described in the present document is composed by a Basic TEDS, one or more Templates, as indicated before, an optional Calibration Template and a User Data section. Hereafter the details of each part.

#### 3.1. *Basic TEDS for GASM4-r3*

The basic TEDS defined by IEEE1451.4 is composed by 64 bits.



- **Manufacturer ID (14bits)**

For GASM4.r3 module we use the Manufacturer ID: **77**, that is not assigned to other company, so far.

Here are the bits to store in the TEDS (LSB-MSB): **01111111111111**

- **Model Number (15 bits)**

For GASM4.r3 module we use Model Number **3**, since it is the third model.

Bits to store in the TEDS (LSB-MSB): **100000000000000**

- **Version Letter (5 bits)**

Version Letter is used to indicate the type of gas sensor. As suggested in [1], we use letters that indicates the type of gas sensor according to the following table:

<b>Version Letter</b>	<b>Gas sensor type</b>
<i>M</i>	<i>Metal Oxide</i>
<i>Q</i>	<i>Quartz Crystal Microbalance</i>
<i>S</i>	<i>Surface Acoustic Wave</i>
<i>B</i>	<i>Biosensor</i>
<i>P</i>	<i>Polymer</i>
<i>F</i>	<i>MOSFET</i>
<i>H</i>	<i>Heater</i>
...	...

For the module GASM4-r3, letters **M** or **P** are used. This is an important field that is used by the SensorWire system to know if a heater is present in the sensor.

Bits to store in the TEDS (LSB-MSB) **M: 10110**

**P: 00001**

- **Version Number (6 bits)**

Version Number may be used to indicate the Active Material of the gas sensor. As suggested in [1], we use values that indicate the type of material. With this approach, we are limited to 64 materials for each type of sensor. It is not a vast choice but it allows saving bits. Anyway, different solution can be used like, for instance, write the information in the User Data.

<b>Version Letter</b>	<b>M</b>	<b>P</b>	<b>H</b>	...
<b>Version Number</b>	<b>Active Material</b>	<b>Active Material</b>	<b>Active Material</b>	<b>Active Material</b>
<i>0</i>	<i>No description</i>	<i>No description</i>	<i>No description</i>	<i>No description</i>
<i>1</i>	<i>Tin oxide</i>	<i>Conductive polymer (generic)</i>	<i>Platinum</i>	...
<i>2</i>	<i>Tin oxide, doped with Platinum</i>	<i>Carbon black</i>	<i>Ruthenium Oxide</i>	
<i>3</i>	<i>Tin oxide, doped with Gold</i>	...	...	
<i>4</i>	<i>Indium Oxide</i>			
<i>5</i>	<i>Zinc Oxide</i>			
<i>6</i>	<i>Tungsten Trioxide</i>			
...	...			



Bits to store in the TEDS (LSB-MSB), if we don't know the material: **000000**

- **Serial Number (24 bits)**

Enumeration of the GASM4-r3 produced.

Bits to store in the TEDS; for the first module produced(LSB-MSB):  
**100000000000000000000000**

### 3.2. Templates for GASM4-r3

Templates 32, 37 and 30 are used in the same TEDS.4 to store information on the sensor and the sensor heater, when present.

The **Template 32** for resistive sensor is used for the polymeric or MOX sensor description.

The most important part of this template is the field “excitation current, nominal” that it is used to evaluate the sensor resistance:

$$R_s = \frac{V(AD)}{I_{nom}}$$

Where V(AD) is the voltage acquired by the DS2450, and  $I_{nom}$  (see Fig. 6) is the nominal excitation current read from the Template.

The **Templates 30** and **37** are used for the heater description, when it present, i.e. when MOX sensor is used. For polymeric sensor, those Templates are not written in the TEDS.4.

Template 30 is used to store the voltage supplied to voltage divider where the heater is placed (see *Conditioning of the Sensor Heater*)

Template 37 is used to store the coefficients relating the heater temperature to the heater resistance ( $R_0$ ,  $A$ ,  $B$ ).

Concerning the sensor location in the array, there is the field “Measurement location” already provided at the end of each Template.

### 3.3. User Data for GASM4.r3

Plug and Play capabilities are obtained by the SensorWire system by storing in the User Data of the TEDS.4 the ID of the Dallas A/D converter embedded with the gas sensor. In this way it is possible to automatically know which is the A/D associated to a certain sensor. Actually, only the serial-number of 48 bits is written, since the first 8 bits of the URN is the device family and the last byte is the CRC.

If the GASM4-r3 is used to send analog signal to a different A/D (GASM4-r3d), an initial configuration must be done manually as in the case of National Instruments DAQ board where Measurement & Automation Explorer [4] is used for this purpose [6].

## 4. Software for module configuration

The TEDS.4 for the modules GASM4-r3 may be easily created by the software (see figure below) developed for the 4<sup>th</sup> NOSE II School in Analipsi, Greece, by JLM Innovation and Dr. Nicola Ulivieri. The picture below shows the front panel of the virtual instrument, developed within the LabVIEW environment, that allows to create and save the TEDS.4 for the modules GASM4-r3 in a file.

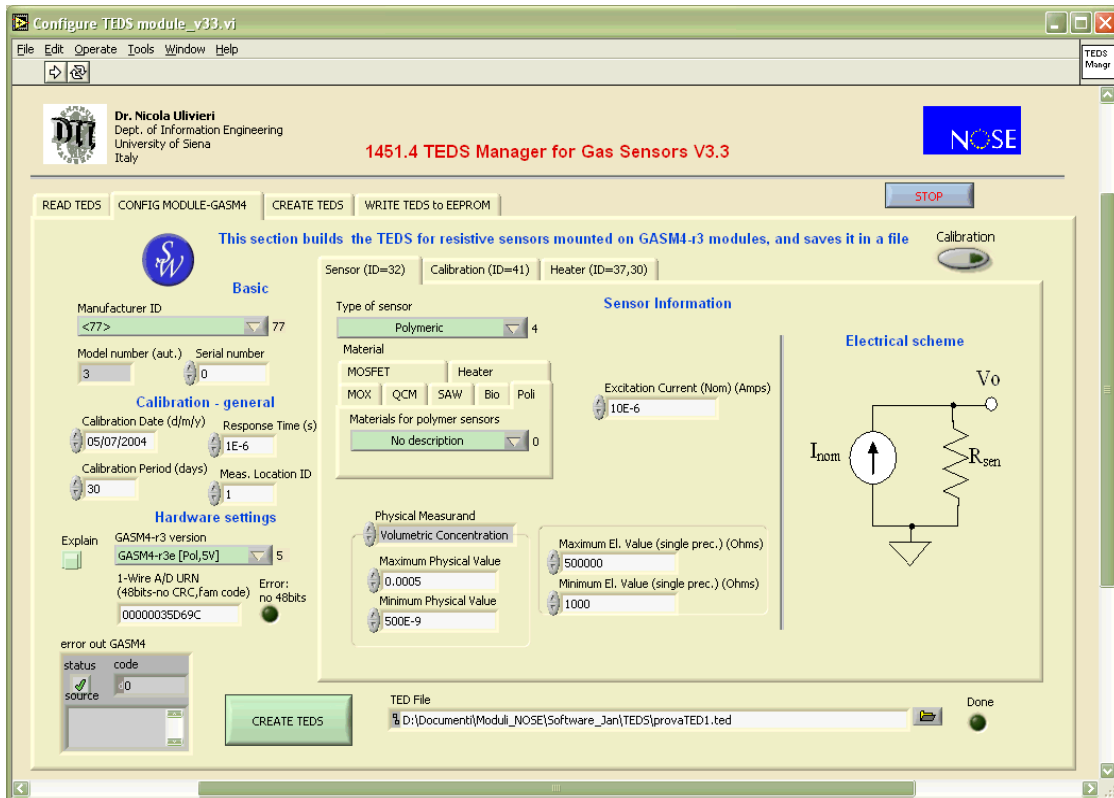


Figure 13: front panel of the virtual instrument that allows to create TEDS.4 for GASM4-r3

The *TEDSWriter*, by JLM Innovation (Fig.14), allows to store the TEDS.4 to the EEPROM embedded with the module GASM4-r3 and permits automatically adding the A/D 48bits serial number in the User Data.

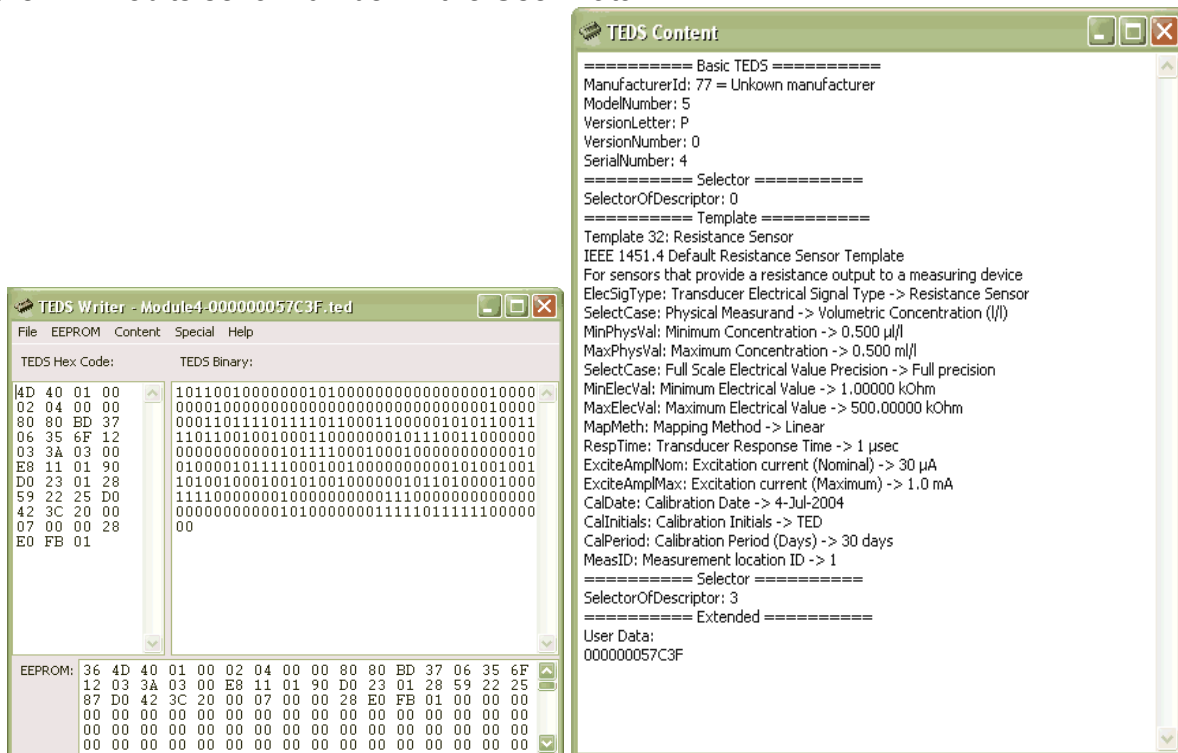


Figure 14: TEDS Writer windows

Multisens, by JLM Innovation, manages the SensorWire system.

## 5. Guidance to module configuration.

Configuration and functionality of the module are explained in form of exercises.

### Exercise 1 – Power consumption

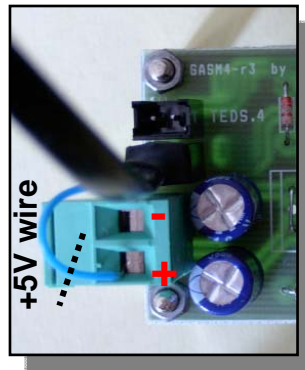
Evaluate the power consumption of a GASM4 module when no sensor is connected.

#### Solution

Don't connect the +5V wire from SensorWire interface to the module.

Use the multimeter configured as ammeter.

Connect the ammeter between the +5V wire from SensorWire and the +pin of the supply connector and measure the current.



Suppose you read 13.43 mA. Since the power supply is 5V the power consumption is:

$$W = V \cdot I = 5 \text{ V} \cdot 13.43 \text{ mA} = 67.15 \text{ mW}$$

### Exercise 2 – Configure GASM4 for polymeric sensor

Configure a GASM4-r3 to measure a given polymeric sensor.

Remind that on a GASM4-r3:

- the value of the current generator is given by the voltage across the reference resistor  $R_r$  divided per the  $R_r$  value;
- the voltage across the reference resistor  $R_r$  is advised to be set around 0.5V for the modules supplied with 5V and up to 1V if the supply voltage is 9-12V;
- the embedded analog to digital converter (A/D) can be set to a range of 5.12V or 2.56 V. When the supply voltage is 5 V use range=2.56 V to increase measurement resolution and because it is not possible to exploit all the 5V range.



Verify that the module provides the programmed current.

### Solution

1) Use the multimeter to measure the sensor baseline resistance with a reference gas (laboratory air).

Suppose your reading is:

$$R_s = 6.62 \text{ k}\Omega$$

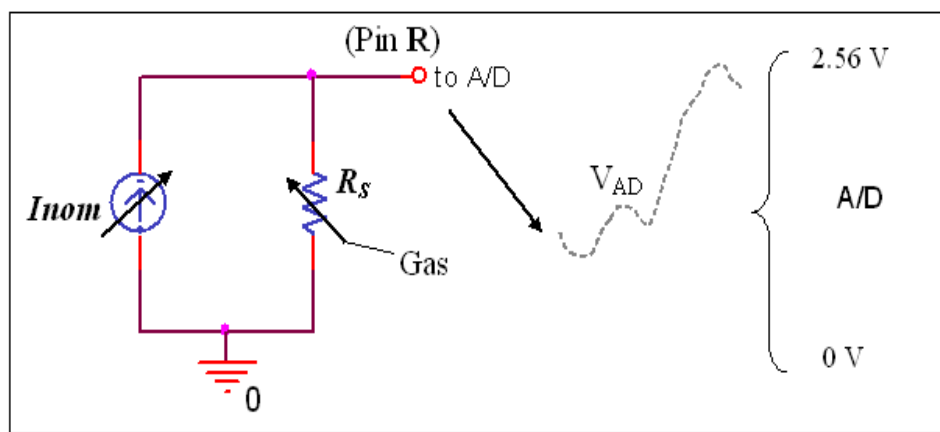
You know that the sensor resistance will increase in presence of a target gas.

Suppose you know that the maximum increasing would be 5% of the baseline value so:

$$R_{s\_max} = R_s \cdot 1.05 = 6.62 \text{ k}\Omega \cdot 1.05 = 6951 \text{ }\Omega$$

In this case we may consider  $R_{s\_max} = 7 \text{ k}\Omega$  or higher to prevent from expected drift.

2) Now you can evaluate the current  $I_{nom}$  that the module should supply to the sensor:



$$V_{AD\_Range} = I_{nom} \cdot R_{s\_max} \rightarrow$$

$$I_{nom} = V_{AD\_Range} / R_{s\_max} = 2.56 \text{ V} / 7 \text{ k}\Omega \approx 370 \text{ }\mu\text{A}$$

3) Since the voltage across the reference resistor  $V_r$  will be set to 0.5 V and  $I_{nom}$  is now chosen, you can evaluate the value for the reference resistance  $R_r$ :

$$I_{nom} = V_r \cdot R_r \rightarrow$$



$$R_r = V_r / I_{nom} = 0.5 \text{ V} / 370 \mu\text{A} = 1367 \Omega$$

Take a resistor with the closer value, e.g.  $R_r = 1500 \Omega$ .

In this case (when the sensor resistance raises in presence of gases) it is better to use a resistor with higher value in order to obtain a lower current. This allows to work a bit far from the maximum voltage chosen = 2.56V. If the sensor voltage exceed this value there will be an error in the A/D reading, but no problem occurs to the circuit. Another way to adjust the current, avoiding to change the  $R_r$ , is to use the trimmer to change the voltage across the reference resistor. Don't exceed 0.7V with 5V supply for proper module working.

4) Now you have to put your hands on the GASM4-r3.

Place the reference resistor on the module.

Set the voltage across  $R_r$  around 0.5 V by means of the trimmer next to the resistor.

5) Measure the current inserting the ammeter between a pin  $R$  and  $gnd$ .

Don't be scared if the value you read is not exactly the one you programmed (e.g.  $300 \mu\text{A}$ ) since (1) you have used an available resistor, (2) its nominal value instead of the real one and, moreover, (3) there is a little current in the circuit that "flows away" from the one you program (base current of the transistor).

Write down the current reading for the TEDS module programming.

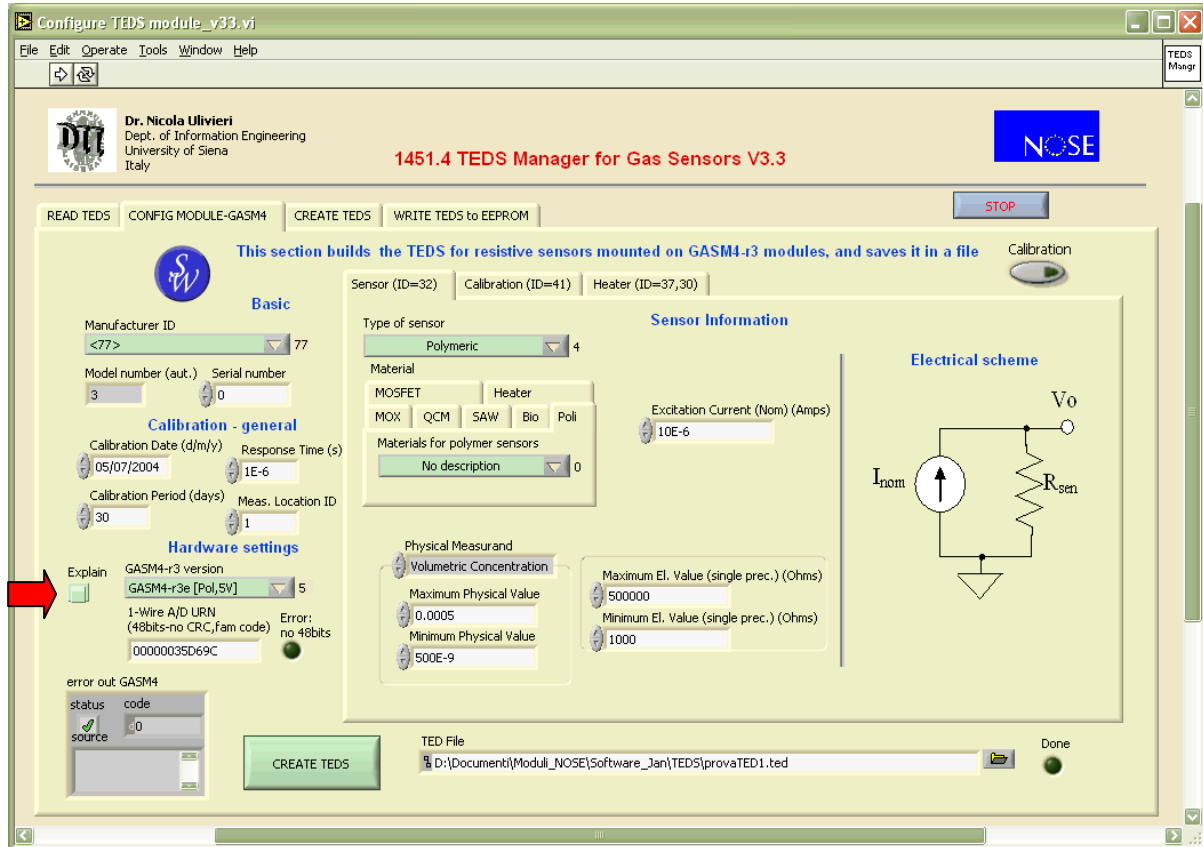
### **Exercise 3 – Create a TEDS.4 for a polymeric sensor and try SensorWire**

Create a TEDS.4 for a GASM4-r3 with a polymeric sensor. Use data of exercise 2. Perform measurements with the given sensor. Measure the power consumption.

#### **Solution**

1) Read the URN of the A/D of your module by using the software provided. Discard the first and the last byte (family and CRC); keep the device unique number (6bytes, 48 bits).

2) Run the *ConfigGASM4* virtual instrument.



Select the correct version of GASM4-r3.

Press button *Explain* to read the various versions implemented: version **e** is for polymeric sensors when the voltage supply is 5V.

Write the URN without CRC and family code of the A/D embedded in your module. Write the current value provided by your module (measured in the previous exercise) in the *Excitation Current (nom)*.

Select type of sensor: polymeric.

Don't care about other fields, for now.

Select a file with extension .ted to create your virtual TEDS file.

Press the button CREATE TEDS

3) Read the TEDS you have created to check if there are any errors.

Then store the TEDS on the GASM4-r3 with the given software.

4) plug the sensor on the board and measure the current required by the module.

Suppose you read  $I_{supply} = 14.05 \text{ mA}$ . Since the power supply is 5V the power consumption is:

$$W = V \cdot I = 5 \text{ V} \cdot 14.05 \text{ mA} = 70.25 \text{ mW}$$

In this case only few *mW* more than the module alone.

5) Run Multisens.

Start a measurement and observe the sensor resistance.

## Exercise 4 – Configure GASM4 for MOX sensor

Configure a GASM4-r3 to measure a given metal oxide sensor.  
Measure the power consumption with the MOX inserted.

### Solution

1) If you don't know the sensor baseline you may use the GASM4 to measure it. For this purpose it is necessary to supply the sensor heater to bring the sensor to the operating conditions.

First of all select the correct heater voltage! You may use 2.1 V. Use the trimmer on the centre of the module and measure the voltage on one of the *H* pins. Use one of the gnd connection as reference.



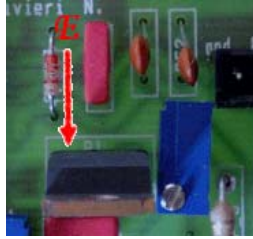
**IMPORTANT:** when you supply GASM4 with 9-12 V particular care must be taken when setting the heater voltage since values higher than 5V may damage not only the sensor but also a protection diode and, if it occurs, the A/D. Anyway values up to 7 V are not critical for short time. No problems occur when the supply is 5 V.

2) plug the sensor on the board after checking its correct position.



**NOTE:** The voltage we have set at this step is measured without heater and it will be the value applied to a series *reference resistor-heater*. Hence the actual heater voltage will be less.

Measure again the heater voltage that should be lower than the one set before and, if necessary, adjust it again to the desired value. In this case measure also the voltage at the Darlington Emitter (voltage applied to the resistors series) and write down this value to use it afterwards to fill the TEDS.4.



3) Remove the reference resistance RRIF! then measure the sensor baseline with the multimeter,

Suppose your reading is:

$$R_s = 27.2 \text{ k}\Omega$$

You know that the sensor resistance will decrease in presence of a target gas.

So you may use this value as the maximum. To be safe use a higher value, let's say:

$$R_{s\_max} = 30 \text{ k}\Omega$$

4) Now you can evaluate the current  $I_{nom}$  that the module should supply to the sensor:

$$I_{nom} = V_{AD\_Range} / R_{s\_max} = 2.56 \text{ V} / 30 \text{ k}\Omega \approx 85.3 \mu\text{A}$$

5) Since the voltage across the reference resistor  $V_r$  will be set to 0.5 V and  $I_{nom}$  is now chosen, you can evaluate the value for the reference resistance  $R_r$ :

$$R_r = V_r / I_{nom} = 0.5 \text{ V} / 85.3 \mu\text{A} = 5861\Omega$$

Take a resistor with the closer value. Suppose you have available only  $R_r = 5600 \Omega$ .

It would be better a higher value in order to obtain a lower current and not to risk to exceed the maximum voltage as it was previously explained. In any case no damage will occur and you may change the resistance afterwards.

6) Place the reference resistor on the module.

Set the voltage across  $R_r$  around 0.5 V by means of the trimmer next to the resistor.

7) REMOVE THE SENSOR! Verify the current supplied by the module inserting the ammeter between the pins **R** and **GND**.

Suppose the reading is  $I_{nom} = 80 \mu\text{A}$

8) Insert again the MOX on the module and measure the current required by the GASM4 by inserting the ammeter between the +5V supply wire and the + supply connector.

Suppose the reading is  $I_{supply} = 29.8 \text{ mA}$

Since the power supply is 5V the power consumption is:

$$W = V \cdot I = 5 \text{ V} \cdot 29.8 \text{ mA} = 150 \text{ mW}$$

### Exercise 5 – Create a TEDS.4 for a MOX sensor

Create a TEDS.4 for a GASM4-r3 with a metal oxide sensor. Use data of exercise 4. Write the EEPROM and test the module

## Solution

1) Read the URN of the A/D of your module by using the software provided. Discard the first and the last byte (family and CRC); keep the device unique number (6bytes, 48 bits).

2) Run the *ConfigGASM4* virtual instrument.

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University of Siena  
Italy

1451.4 TEDS Manager for Gas Sensors V3.3

NOSE

READ TEDS CONFIG MODULE-GASM4 CREATE TEDS WRITE TEDS to EEPROM STOP

This section builds the TEDS for resistive sensors mounted on GASM4-r3 modules, and saves it in a file Calibration

Sensor (ID=32) Calibration (ID=41) Heater (ID=37,30)

**Basic**

Manufacturer ID: <77> 77  
Model number (aut.): 6 Serial number: 0

**Calibration - general**

Calibration Date (d/m/y): 05/07/2004 Response Time (s): 1E-6  
Calibration Period (days): 30 Meas. Location ID: 1

**Hardware settings**

GASM4-r3 version: GASM4-r3f [MOX,5V] 6  
1-Wire A/D URN (48bits-no CRC, Fam code): 00000035D69C Error: no 48bits

error out GASM4 status code: 0 source

**Heater Information**

Maximum Electrical Value (Ohms): 400  
Minimum Electrical Value (Ohms): 10  
Vh Excitation Level (Nom) (Volts): 2.1

**RTD Curve (CVD Coefficients)**

R0 Resistance (Ohms): 95  
RTD Coef\_A (single prec.): 3.908E-3  
RTD Coef\_B (single prec.): -580.2E-9  
Maximum Physical Value (deg C): 500  
Minimum Physical Value (deg C): 0

**Electrical scheme**

value: R<sub>ref</sub> (5.1 Ω)  
V<sub>H</sub> V<sub>O</sub>

$$T = \frac{-A + \sqrt{A^2 - 4B \left(1 - \frac{R_H}{R_B}\right)}}{2B}$$

TED File: C:\Documents and Settings\Nicola\Desktop\prova.ted Done

Select the correct version of GASM4-r3.

Press button *Explain* to read the various versions implemented: version *f* is for MOX sensors when the voltage supply is 5V.

Write the URN without CRC and family code of the A/D embedded in your module. Write the current value provided by your module (evaluated in the previous exercise) in the *Excitation Current (nom)*.

Select type of sensor: MOX.

Write the data of the heater: *Vh Excitation Level* and heater *CVD coefficients* used to evaluate its temperature.

CVD coefficients must be given by the producer or they are known for some materials e.g. Platinum.  $R_0$  may be evaluated by measuring the heater resistance with a (low-current) at a known ambient temperature:  $R_0 = R / (1 + \alpha \cdot T + \beta \cdot T^2)$ ;

Don't care about other fields, for now.

Select a file with extension .ted to create your virtual TEDS file.

Press the button CREATE TEDS



- 3) Read the TEDS you have created to check if there are any errors.  
Then store the TEDS on the GASM4-r3 with the software provided.
- 4) plug the sensor on the board and Run Multisens.  
Start a measurement and observe the sensor resistance.

# Appendix A: Overview on IEEE1451 and IEEE1451.4

## 6. Overview of the Standard IEEE 1451 [1]

The purpose of the IEEE 1451 Standards for Smart Transducer Interface for Sensors and Actuators, is to define a set of common interfaces for connecting transducers to microprocessor-based systems, instruments, and field networks in a network-independent fashion. The main goals of the standard are:

- Developing network-independent and vendor-independent transducer interfaces;
- Allowing transducers to be replaced and/or moved with minimum effort;
- Eliminating error prone, manual system configuration steps;
- Supporting a general transducer data, control, timing, configuration and calibration model;
- Developing Transducer Electronic Data Sheets (TEDS) that remain with the transducer during normal operation.

At present, the IEEE P1451 family standard is divided into seven parts named IEEE P1451.0, IEEE 1451.1, IEEE 1451.2, IEEE 1451.3, IEEE 1451.4, IEEE P1451.5 and IEEE P1451.6 where *P* stands for *Proposal* since some parts are not yet approved.

- The aim of *IEEE P1451.0* is to encourage compatibility across the IEEE1451 family. IEEE P1451.0 is a physical-layer independent NCAP-to-transducer module interface that includes the basic command set and communication protocol. It will also define a new version of TEDS that is common to the family members that deal with the physical layers.
- The *IEEE 1451.1* standard was published in 1999 and defines a Network Capable Application Processor (NCAP) to interface transducers to networks. This is done by means of a common control network information object model for smart sensors and actuators.
- The *IEEE 1451.2* standard was approved as a standard in September 1997 [14], and is currently under revision. IEEE 1451.2 defines the Transducer Electronic Data Sheet (*TEDS*) and a Transducer Independent Interface (*TII*). It does not specify signal conditioning, signal conversion, or how an application uses the TEDS data. The TEDS, stored in a non-volatile memory embedded with the transducer, contains the critical information needed by an instrument or measurement system to identify, characterize, interface, and properly use the transducer. The revised IEEE 1451.2 will include the addition of alternate physical layers, such as UART (Universal Asynchronous Receiver/Transmitter) interface, to utilize existing, widely available, low-cost data transfer methods in order to reduce cost and complexity.
- The recently approved standard *IEEE 1451.3* defines a digital interface for connecting multiple physically separated transducers. The standard is intended to allow synchronised reading of large sensor arrays on a parallel transducer bus using the multidrop connectivity by defining channel

identification protocols, hot-swap protocols, time synchronization protocols, and the read and write logic functions used to access the TEDS and transducer data.

- The *IEEE 1451.4* standard defines a mechanism for adding self-identification technology to traditional analog sensors and actuators and it is described in details in the next section.
- The *IEEE P1451.5* project will establish a standard for wireless communication methods and data format for transducers. It will adopt necessary wireless interfaces and protocols to facilitate the use of existing wireless technology solutions and it will define a TEDS based on the IEEE 1451 concept, and protocols to access TEDS and transducer data.
- Finally, the new project IEEE P1451.6 will establish a CANopen-based network for multi-channel transducer modules and will define a high-speed, CANopen-based Transducer Network Interface for Intrinsically Safe and Non-intrinsically Safe Applications.

## 7. The IEEE 1451.4

IEEE 1451.4 (dot 4 from now on) defines a mechanism for adding self-describing behaviour to traditional transducers with an analog signal interface. The dot 4 defines the concept of a transducer that supplies both analog and digital interface, namely, *mixed-mode interface* (Fig.x).

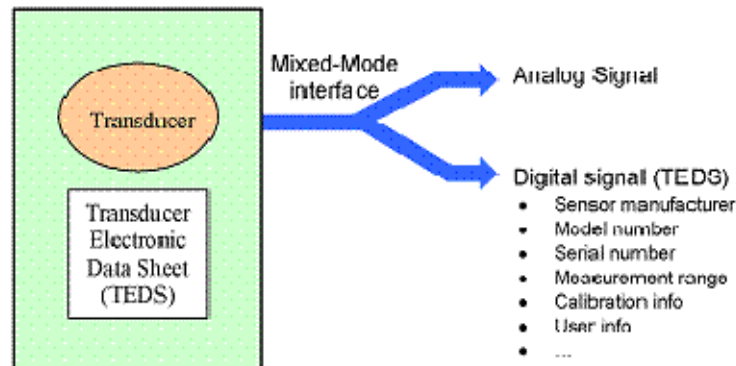


Figure 15: Smart Transducer Module with embedded TEDS.

The analog electrical interface provides a signal reflecting the physical phenomenon (such as temperature, pressure, and force) in the traditional manner. The digital interface allows communicating with an embedded memory device within the transducer in order to read/write the TEDS.

Figure 2 illustrates a typical configuration of a PC-based system implementing the dot 4 standard. The PC is provided with a data acquisition board (DAQ), to acquire/generate analog signals, and a TEDS interface, described later on.

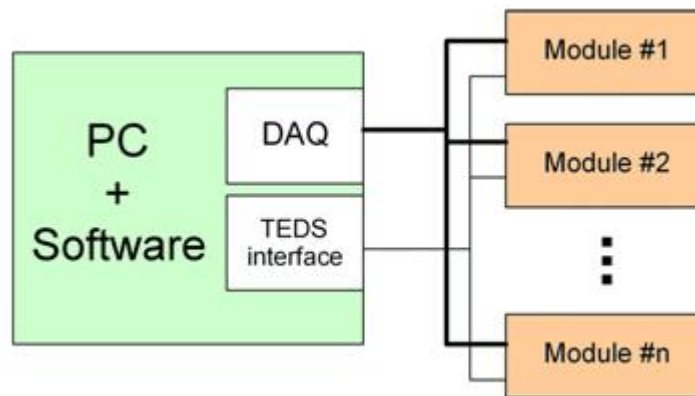


Figure 16: Set-up of a PC-based dot 4 system

### 7.1. Mixed-Mode Interface

IEEE 1451.4 defines two types of mixed-mode interfaces, namely, *Class 1* and *Class 2* interfaces. Class 1 interfaces have been defined for constant-current powered piezoelectric transducers (accelerometers, microphones, etc.) and define a scheme for sequentially switching between analog mode and digital TEDS mode on a single pair of transducer wires. Constant-current powered transducers, generally referred to as integrated electronics for piezoelectric (IEPE) transducers, incorporate internal signal conditioning powered by a constant current that is supplied by the measurement system on the signal wires. Class 1 transducers exploit this already existing analog standard by adding the TEDS with a switch that is controlled by the direction of the current source, as sketched in Figure 3. By reversing the direction of the current, the data acquisition system switches the sensor into digital TEDS mode.

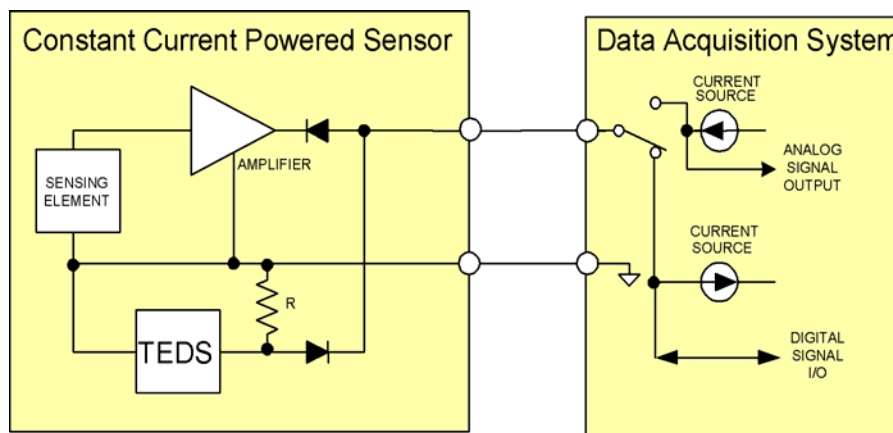
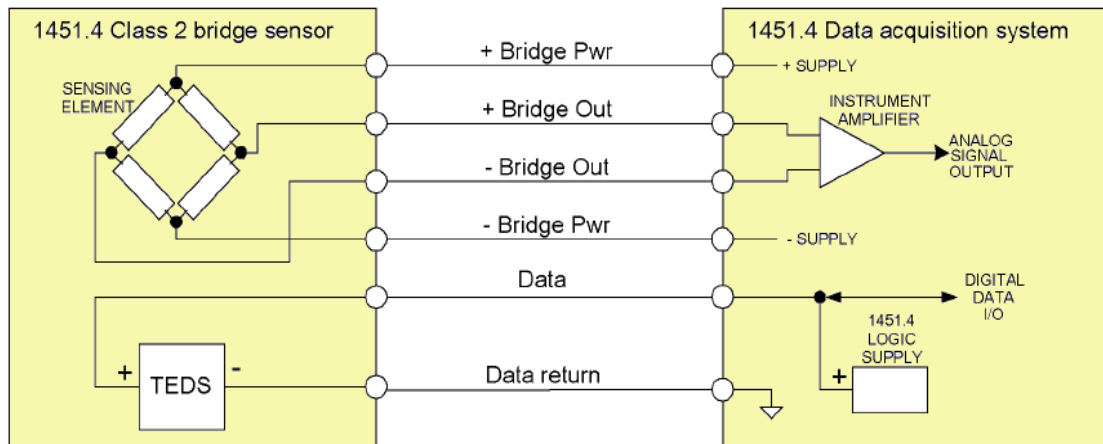


Figure 17: Example of IEEE 1451.4 Class 1, Two-wire Interface, with Constant-current Powered Sensor.

In order to extend the dot 4 standard to every type of transducer, the IEEE1451.4 working group has introduced a more general class of interfaces: the Class 2. Class 2 interfaces require additional wires for digital TEDS communication. The analog input/output of the transducer is left unmodified, and the 2-wire TEDS interface is added in parallel to the analog interface. Using this approach, it is possible to implement TEDS on virtually any type of amplified or unamplified sensor or actuator (thermocouples, RTDs, thermistors, bridge sensors, electrolytic chemical cells, 4-20

mA current loop sensors, etc.). Figure x illustrates an example of IEEE 1451.4, Class 2, Multi-wire Interface, with bridge sensor. Other front-ends, such as a multi-wire interface with a 4-20mA sensor, are supported by the Class 2 interface as well.

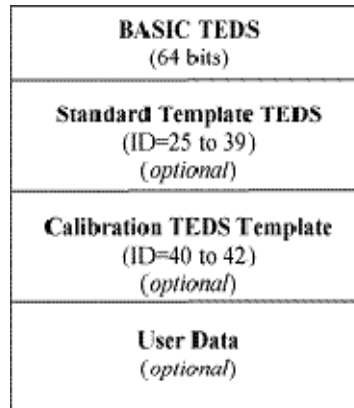


**Figure 18: Example of IEEE 1451.4 Class 2 MMI, resistive bridge sensor.**

The digital portion of the mixed-mode interface (Class 1 or Class 2) is based on the 1-Wire<sup>®</sup> protocol licensed by Maxim/Dallas Semiconductor [5]. This is a master-slave, multi-drop bus with serial communication protocol, requiring that a single master device (e.g. the data acquisition system) supplies power, and initiates each data transaction on a single wire with each node (EEPROM) according to a defined transaction timing sequence. Each node contains a unique address (64 bits serial number), identifiable by the master, allowing individual access. Maxim/Dallas Semiconductor manufactures two 1-Wire EEPROMs, the DS2430 (256 bits) and DS2433 (4 Kb) providing low-cost solutions for adding TEDS to sensors. The master also acts as interface between the EEPROMs and the PC through a RS232 interface (DS2480 ) or USB interface (DS2490).

## 7.2. Dot 4 TEDS

The description of the transducer data in the TEDS, defined by dot 4, is significantly changed from the version created by the IEEE1451.2 standard. In order to avoid misunderstanding, from now on we'll call them TEDS.4 and TEDS.2. The TEDS.4 structure is flexible and extensible to handle a wide range of sensor types and requirements and it is very compact allowing the saving of memory. In fact, while a TEDS.2 requires 1376 bits to describe one sensor (76 bytes for the Meta TEDS + 96 bytes for Channel TEDS ), a TEDS.4 requires only about 256 bits. The TEDS.4 is divided into four key sections: Basic TEDS, Template TEDS, Calibration TEDS and User Data (Fig. x).



**Figure 19: TEDS.4 general structure.**

The first section is obligatory and the last three ones are optional. The first 64 bits of the transducer TEDS forms the Basic TEDS that uniquely identifies the transducer by including Manufacturer ID (14 bits), model number (15 bits), version letter (5-bit character code), version number (6 bits), and serial number of the device (24 bits). This data is organized according to the format described in Table 1.

**Table1: Basic TEDS content.**

	<i>Bit Length</i>	<i>Allowable Range</i>
<b>Manufacturer ID</b>	14	17-16381
<b>Model Number</b>	15	0-32767
<b>Version Letter</b>	5	A-Z (data type Chr5)
<b>Version Number</b>	6	0-63
<b>Serial Number</b>	24	0-16777215

The Manufacturer ID is an enumeration of manufacturers. Some IDs are assigned to early adopters, and future assignments will be managed by IEEE. Software can use this ID to display the manufacturer names. Values 0-16 and 16382 and 16383 are reserved for special uses, such as user-defined template and node lists in a multi-node configuration, respectively. The application and assignment of the remained fields of the Basic TEDS are left to the discretion of the manufacturer.

The main innovation of the TEDS.4 is related to the definition of a collection of standard Templates that are specific for each class of transducers (Table 2).

The templates provide the means for the measurement system to convert the TEDS binary data stored on a EEPROM or on a file (in the second case the TEDS is called Virtual TEDS) into meaningful specifications for that sensor.

Each template has a specific ID. Templates 25 through 39 are transducer-type templates that contain properties that are needed for the specific types of transducers. Example of template fields are: “maximum electrical output”, “response time”, “excitation level”, “calibration date”, “measurement location”. Some fields are



read only, while others can be written by the user. Standard templates allow specifying both the *physical measurand* and *electrical value full scale precision* with respective standard units. In some cases, it is possible to indicate the coefficients' resolution in order to reduce the TEDS size.

**Table2: Standard Templates.**

Type	Template ID	Name of Template
Transducer type Templates	25	Accelerometers and Force
	26	Charge Amplifier (w/attached accelerometer)
	43	Charge Amplifier (w/attached force transducer)
	27	Microphone with built-in preamplifier
	28	Microphone preamplifier (w/attached microphone)
	29	Microphone (capacitive)
	30	High-Level Voltage Output Sensors
	31	Current Loop Output Sensors
	32	Resistance Sensors
	33	Bridge Sensors
	34	AC Linear/Rotary Variable Differential Transformer (LVDT/RVDT) Sensors
	35	Strain Gauge
	36	Thermocouple
	37	Resistance Temperature Detectors (RTDs)
	38	Thermistor
39	Potentiometric Voltage Divider	
Calibration Templates	40	Calibration Table
	41	Calibration Curve (Polynomial)
	42	Frequency Response Table

The collection of IEEE standard templates include IEPE (constant current powered) accelerometers and microphones, IEPE pressure sensors, Wheatstone bridge sensors, strain gauges, load and force transducers, thermocouples, RTDs, thermistors, LVDT/RVDT, resistive sensors, and amplified sensors (any type) with voltage or current outputs.

Templates 30, 31, and 32 are general purpose templates for voltage, current and resistive output sensors respectively. Templates 40, 41, and 42 are calibration templates and can be used with one of the transducer-type templates. The Calibration Table Template (ID = 40) allows the inclusion of multiple data pairs to specify the input-output function of the sensor. The Calibration Curve Template (ID =



41) allows the specification of the input-output function of the sensor as a multi-segment, multi-polynomial curve. Finally, the calibration templates 42 (Frequency Response Table Template) allows the specification of the frequency response function of a sensor as a set of amplitude-frequency data pairs.

Calibration templates 40 and 41 permit to apply data correction to physical measurand or to the electrical value. This allows the user to represent the acquired data with the correct units. For instance, by applying calibration to physical measure it could be possible to convert the measured voltage sensor output to gas concentration.

Another important difference between TEDS.4 and TEDS.2 is the enumeration of the units. The unit to be assigned to the physical measurand in templates 30, 31, 32, 33 and 39 can be selected among the 45 ones enumerated by the standard, by using only 6 bits. TEDS.2 is more general but it requires 10 bytes to describe a unit.

It is important to point out that the TEDS.4 describes only one transducer and not a transducer array. The array will be automatically configured by a NCAP after recognizing the various transducer modules.

Even though several types of sensors have been taken into account by the dot 4 working group, there are no specific templates related to gas sensors.

## Appendix B: The 1-Wire bus

### 8. Basic Overview

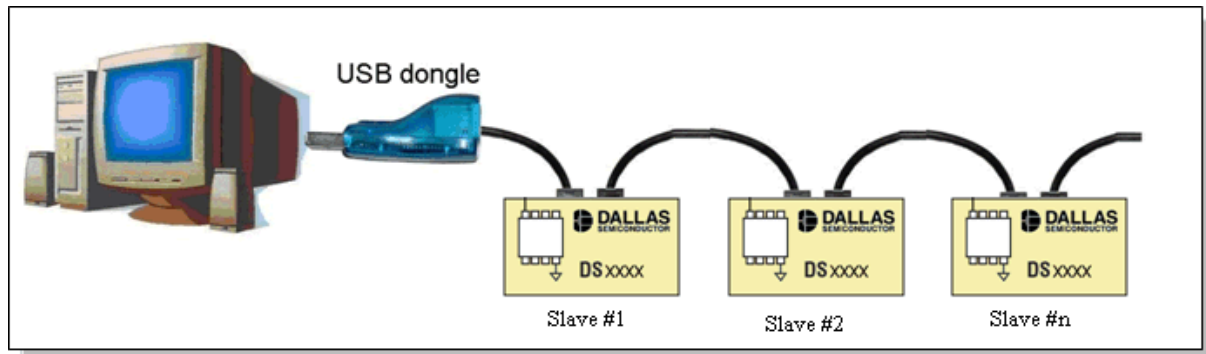


Figure 20: 1-Wire architecture.

- Only two wires (data+power and gnd)
- Master-slave network with a single master and up to 500 slaves
- Multi-drop architecture, serial communication protocol, half duplex.
- A single master device supplies power, and initiates each data transaction with each node on a single wire
- Slave devices powered by bus (parasite power).
- Transmission rate 16 kbps or 142 kbps in Overdrive Mode.
- No system Clock
- Bus length of up to 300 m.

### 9. 1-Wire Master

1-Wire protocol allows implementing measurement system based on PC or microcontroller.

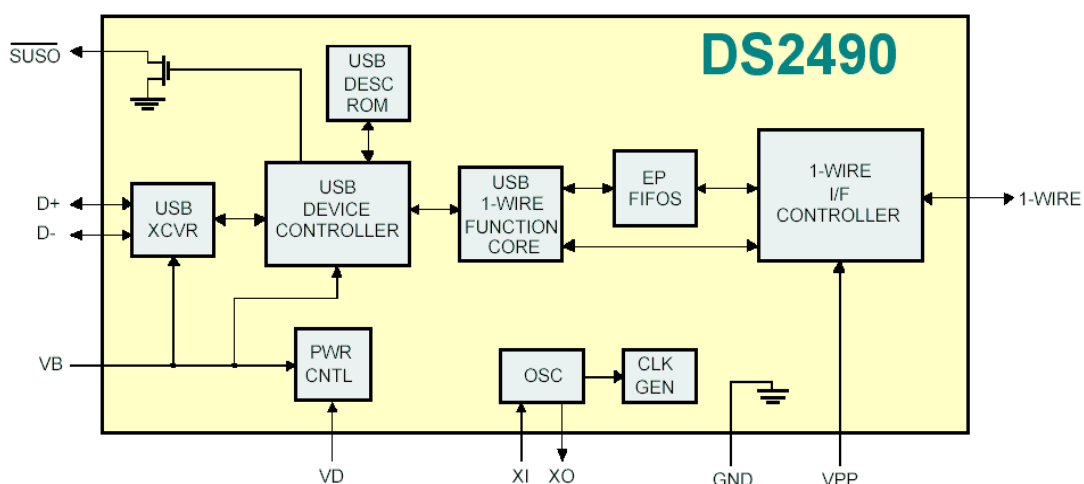


Figure 21: Block diagram of the USB/1-Wire interface.

- Several interface devices are provided by Dallas/Maxim to interface to the PC: *USB* (DS2490), *RS232* (DS2480) e *parallel* (DS1481).

- Also *VHDL and Verilog source code* are provided to embed a 1-Wire master in an ASIC (Application Specific Integrated Circuit).

## 10. 1-Wire Slaves

### • Type of devices

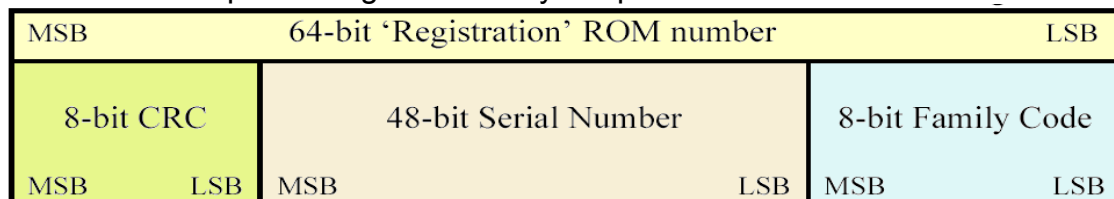
Several 1-Wire slaves are produced by Dallas/Maxim to provide all the “pieces” that one need to build a measurement system:

- *DS18S20*: Temperature sensor.
- *DS2438*: Contains 2 ADC and a temperature sensor.
- *DS2450*: Contains 4 programmable ADC from 1 to 16 bit with input range 2.56V or 5.12V. Analog input pins may be used as digital outputs if needed.
- *DS2760*: Temperature sensors that allows using some types of thermocouple.
- *DS2433*: EEPROM of 4kb
- *iButton*: EEPROM of 64kB with button shape utilized to store personal data such as fingerprints.
- ... and many other like *digital potentiometers, switches, clocks, counters* etc.

### • URN

Each 1-Wire device contains a unique address (Unique Registration Number, *URN*) of 64bits ( $2^{48}$  different codes for each family = over 280 thousand of billion!)

The absence of duplicate is guarantied by the producer.



The URN is divided into three sections:

- The first byte (start from LSB) contains the family code identifying the device type.
- Subsequent 6 bytes represents individual device address
- Last byte contains the CRC (Cyclic Redundancy Checksum) to allow the Master to recognize reading errors.

### • Parasite power

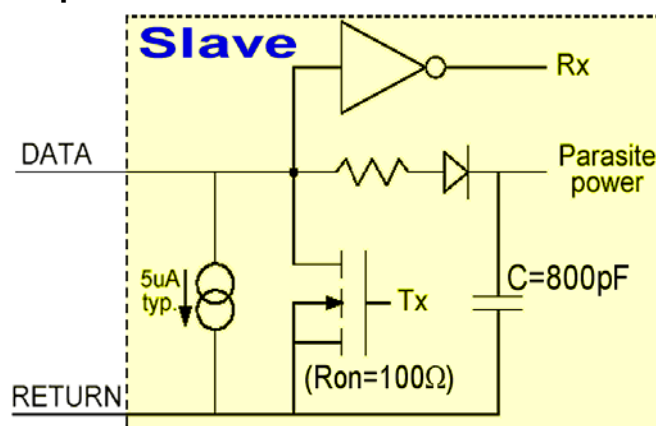
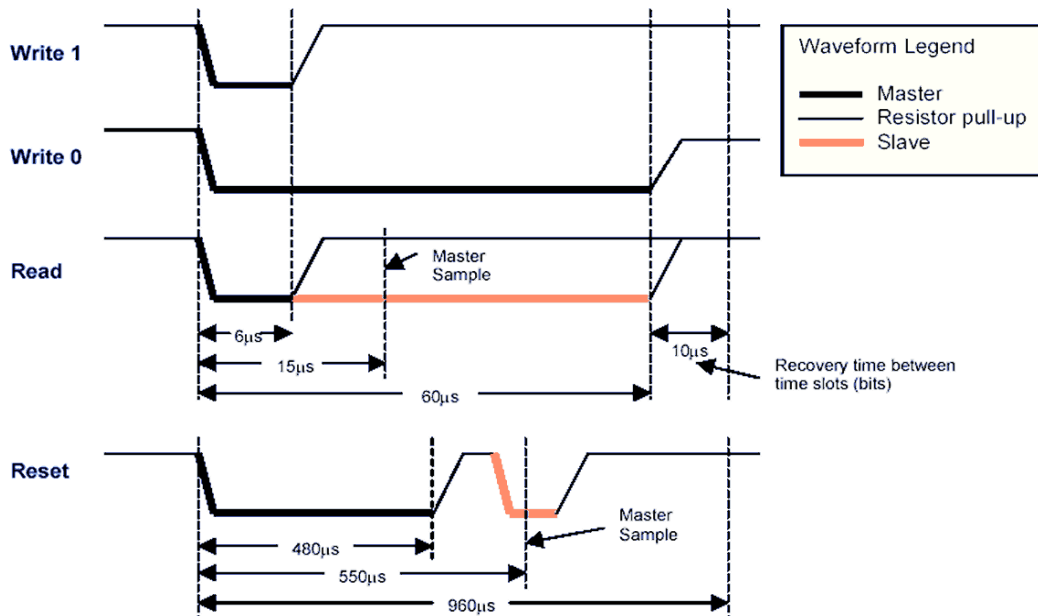


Figure 22: Block diagram of the power recovery section of 1-Wire slaves.

- Each slaves “steals” power from the bus when it is inactive (voltage = 5 V) by charging an internal capacitor (see figure).
- Each slave has an internal clock to synchronize with the Master
- Device resistance in ON state is  $R_{on}=100\ \Omega$ , value chosen to adapt to wire impedance (recommended cable: UTP (Unshielded Twisted Pair) Category 5 with characteristic impedance of  $R_c=100\ \Omega$  and capacitance  $C_c=50\text{pF/m}$ ).
- In OFF state  $R_{off}=1\ \text{M}\Omega$ , since  $5\ \mu\text{A}$  always flow on the device.

## 11. 1-Wire Communication Protocol

- 1-Wire makes use of conventional CMOS/TTL level: low level  $V\leq 0.8\text{V}$ , high level  $V\geq 2.2\text{V}$
- Note: Those are levels, not logical states!
- Typical bus power level is 5V, allowed range 2.8-6V



1-Wire communication protocol is based on 4 main operations:

**Write bit 1:** the Master pulls down the bus for up to  $15\ \mu\text{s}$  and then release it.

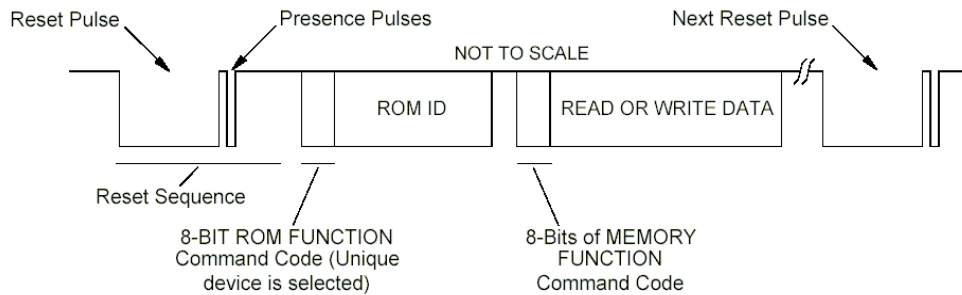
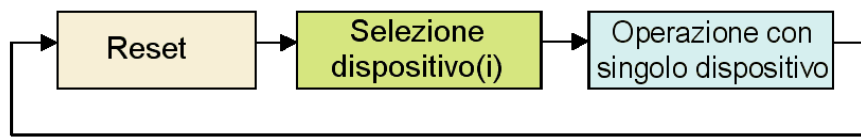
**Write bit 0:** the Master pulls down the bus for at least  $60\ \mu\text{s}$  and then release it.

**Read bit:** the Master pulls down the line for to  $15\ \mu\text{s}$ , then read the voltage level of the bus. If it is high the bit is 1 otherwise is 0.

**Reset:** the Master resets the bus every time it wants to send a new command by pulling down the line for  $\geq 480\ \mu\text{s}$ . After the Reset, each slave sends a presence pulse.

- 1-Wire data are based on **time-slot** that is defined as the time to send 1 bit
- The Byte trasmission occurs with 8 calls to the bit operation.
- Data are written and read from the less significant (LSB).
- The time to transmit a bit is  $70\ \mu\text{s}$  ot  $10\ \mu\text{s}$  in *Overdrive mode*

- **Commands**



- 1-Wire commands are known as *Network Commands* or *ROM Commands*.
- The first part of each communication starts with a Reset pulse from the Master that synchronizes the whole bus.
- The next operation is the selection of one slave by its URN. It is possible to select all the slave.
- If the URNs are not known (common case) it is possible to use the 'Search algorithm' to find them.
- When a slave is select, all the others ignore communication until the next Reset.

## 12. 1-Wire Software

Dallas/Maxim provides a choice of software to implement custom solutions:

- *OneWire Viewer* (Java) allows monitoring and test all 1-wire devices connected to the PC through an interface.
- C codes and .h libraries
- Source code for some microcontroller
- API for Windows
- VI to manage EEPROMs, but only through serial port.



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- [2] Kang Lee, IEEE 1451:a standard in support of smart transducer networking, in: IEEE Instrumentation and Measurement Technology Conference, Baltimore, MD, USA, May 1–4, 2000, pp. 525–528.
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- [4] [National Instruments Website](#)
- [5] [Dallas/Maxim Website](#)
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