
PRODUCT SPECIFICATIONS SGX – TRDU5

Battery Thermal Runaway Detection Unit for Automotive Application

This document describes the main characteristics and functions of TRDU5 module for Automotive Application. The information in this document is proprietary, and cannot be disclosed to a third party without prior written approval of SGX Sensortech.

TRDU5 is a Battery Thermal Runaway Detection Unit that combines several sensors in a single LIN2.1 communication module.

It has been designed to monitor various measurement technologies used to detect changes in gas concentrations, pressure and temperature occurring during battery venting.

The module has to be placed in the enclosure with permeable opening allowing to sense the venting gas mixture generated by battery during failing mode.

TRDU5 and derived solutions allow Battery Management System (BMS) to monitor the safe operation of the battery and to signal thermal runaway warning to allow time for safe egress of the vehicle.

Features :

- Fast response time (< 5 seconds)
- Thermal conductivity gas sensor inside
- Metal oxide gas sensor inside
- Absolute pressure sensor inside
- High sensitivities to gases H₂, CO, CH₄ and Hydrocarbons
- Measurement redundancy (gases, pressure, temperature)
- LIN 2.1 output
- Thermal Runaway Trigger Signal and self diagnostic (IN DEVELOPMENT)
- Standard 3 pin connector
- Watertight housing



1 Functional specifications

1.1 Principle

Li ion batteries are rapidly becoming a means of providing the energy storage for both stationary and mobile applications with an ever growing share of the market in xEV's.

Due to the prominence and increasing frequency of xEV battery fires as the fleet size increases, as well as the challenges of first and second responders to safely dissipate the battery pack energy, regulations across the globe are emerging.

Those regulations will likely require the detection of battery thermal runaway and provide the occupants warning to allow time for safe egress of the vehicle.

Different inputs are available for the BMC (voltage, temperature) but it is supposed that this is not enough to ensure fast and reliable detection of battery thermal runaway.

A "Thermal Runaway" (TR) is a term used when a battery cell suffers short circuit from either external damage by either excessive heat beyond 70 deg C or mechanical impact and can also suffer from internal short circuit through dendritic growth or damage to the proton exchange membrane.

Battery cells are designed to allow irreversible venting of internal pressure to mitigate the above conditions to reduce the risk of combustion that could lead to cascade failure beyond a single cell.

The combustible gases concentrations released during TR show generally several gases above the Lower Explosive Limit (LEL) (4% for H₂, 4.4% for CH₄, 12.5% for CO, 2.7% for Ethylene (C₂H₄), 3% for Ethane (C₂H₆...).

Real test session with monitored automotive battery packs TR have demonstrated the interest of having gas venting detection through usage of gas and pressure sensors for early TR warning.

The TRDU5 module includes a microcontroller that can interpret signal provided by multiple sensors and generates a trigger alarm output that is representative of the presence of a TR of the battery pack. As a basic version raw values from sensors are monitored through LIN2.1 communication. TR trigger signal and trigger strategy being developed and refined according to multi sensor data analysis. Those strategies being different according to the battery pack type and sensor installation.

1.2 Sensor technologies

In TRDU5 several sensing technologies are present in order to detect gas venting. Two SGX gas sensor technologies combined to an absolute pressure sensor and a temperature & relative humidity are used to detect released gases in a redundant manner.

- Thermal conductivity gas sensor: detection of hydrogen and other combustible gases
- Chemoresistive metal oxide (MOX) gas sensor: detection of reducing gases and oxidizing gases
- Pressure sensor: detection of absolute pressure changes
- Temperature and humidity sensor (T&RH): used to perform gas sensor compensation

SGX gas sensors are manufactured on silicon wafers. A thin membrane is etched on the silicon chips. This provides very low thermal mass to the heating structure, and therefore very low sensor power consumption.

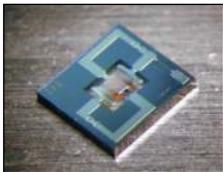
The same MEMS technology is used for both type of SGX gas sensors.

SGX TC-1326 Thermal Conductivity (TC) sensor has two fully independent sensor chips, packaged in two SMD cases. One sealed in air is used as reference and the second one in contact with the air to be monitored and used as detector.

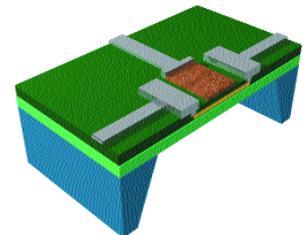
The two elements of this sensor are typically connected in a Wheatstone bridge circuit and operated at a constant voltage. When the heating structures are running in air, the heater resistors loose heat at a similar rate resulting in a set difference between the resistances providing a signal to the bridge, which can be zeroed within the bridge circuit.

When the sensor is exposed to the target gas, the atmosphere around the detecting element changes, resulting in a greater or lesser amount of heat being lost from the detector resistor, leading to a drop or increase in the resistor temperature and hence its resistance. The drop or increase is dependent on the target gases thermal conductivity being greater than or less than the thermal conductivity of the reference gas. The reference resistor being sealed does not show this effect. The drop or increase in the detecting resistor resistance is shown by a negative or positive output of the sensor circuit. Thermal conductivity sensor are able to cover 0 to 100% range of H₂. Resolution in TRDU5 is set at less than 0.2% H₂ allowing clear detection of hydrogen release during TR.

SGX-4524 chemoresistive MOX sensor



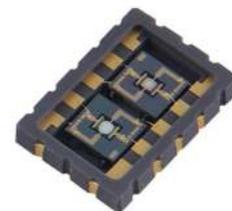
The sensitive layers are made of nanoparticles that provide a very large contact area with the gases to be detected and therefore very large sensitivities.



TRDU5 module includes a SGX-4524 sensor, which has two fully independent sensor chips, packaged in a SMD case.

One sensing chip detects reducing gas events, such as those caused by CO, H₂, while the other one detects oxidizing gas events.

The detection thresholds of the SGX-4524 are: approximately 1ppm for CO and approximately 10 ppb for NO₂. However, such small pollution steps might not trigger a TR alarm because the signal treatment algorithms are optimized for more significant gaseous events linked to battery gas venting.



Other types

Pressure and T&RH sensors are commercially available I2C calibrated devices providing absolute values of gas pressure, temperature and relative humidity.

An extra NTC device is also placed close to the TC sensor as a backup for temperature.

1.3 Theory of operation

Thermal conductivity

The most common theoretical explanation of heat conduction in gases is provided by the kinetic gas theory, which treats the collisions between the atoms or molecules as the prime mode of transfer of energy. Radiative heat transfer is neglected in this approach.

With regard to the temperature dependency of the thermal conductivity, it is noted that its value increases roughly in proportion with the absolute temperature, at least in the range of 'normal' pressures.

As pressure increases, so too does the thermal conductivity. At approximately 0.001 bar, the mean free path becomes of the same order as the walls confining the gas and the value increases linearly with pressure. Above 0.001 bar, the increase in thermal conductivity is of the order of magnitude of 1% per bar increase of pressure.

According to pressure measured in battery pack during trials (maximum absolute level reached approx. 1.6 bar), it can be concluded, that changes in thermal conductivity due to pressure increase and atmospheric variations can be neglected.

The thermal conductivity of a gas is relatively independent of pressure if the pressure is near 1 atm.

Temperature dependency can be compensated by the measure of ambient temperature through usage of a thermistor component placed on PCBA.

Humidity dependency is minor as water vapor has the same TC as air at the operating temperature of the sensor (400°C).

Since no catalytic processes are occurring, the sensor does not poison in atmospheres containing poisons such as organic silicones. However, some changes to the sensor response may be seen if decomposition of species onto the detecting resistor causes a change in the resistor operating resistance/temperature. This slow change can be compensated, if present, by internal firmware.

Chemoresistive metal oxide sensor

When the sensor is exposed to an atmosphere containing reducing gases, e.g., CO, the gas molecules adsorb on the surface and reacts with active oxygen species, e.g., O⁻, which liberates free electrons in the bulk. This lowers the potential barrier allowing electrons to flow more easily, thereby reducing the electrical resistance. With oxidizing gases such as NO₂ and ozone, the adsorption process increases instead the surface resistance.

MOX gas sensors are independent of pressure. The detection process is however dependent of oxygen presence and amount.

Temperature dependency can be compensated by the measure of ambient temperature through usage of a thermistor component placed on PCBA.

Humidity dependency is significant for such sensors as the water molecules are in competition with other species to be detected at sensing surface. Compensation can take place with usage of T&RH data.

This technology is more prone to contamination in atmospheres containing poisons such as organic silicones. Significant changes in sensitivity may be observed. It has been however observed that the detection of hydrogen is still possible with poisoned sensitive layers as H₂ molecules are small enough to pass through silicone layer deposited and to reach sensing grain boundaries.

1.4 Output signal

As starting point to define the criteria able to build a reliable thermal runaway detection and triggering a signal, the raw data from all sensors are available on LIN bus.

The data are available through two frames with data refreshed every 200 ms.
A Toggle clock allows to ensure that the module is not blocked in a loop.

TRDU1 FRAME1 Readings type: ADC values and Toggle clock (Watchdog)
frame 8 bytes

startbit	byte\bit	0	1	2	3	4	5	6	7
0	0	MOX_NOX_ADC							
8	1								
16	2	MOX_CO_ADC							
24	3								
32	4	TC_ADC							
40	5								
48	6	NTC_ADC							
56	7								

TRDU2 FRAME2 Readings type: I2C from various sensors (T&RH, Pressure)
frame 8 bytes

startbit	byte\bit	0	1	2	3	4	5	6	7
0	0	Pressure_absolute_pressure							
8	1								
16	2	Pressure_Temp							
24	3								
32	4	T&RH_Temp							
40	5								
48	6	T&RH_RH							
56	7								

The 4 ADC values contained in FRAME 1 contain the gas sensors data and NTC value.
The gas sensors data have to be compared to calibrated data available on request in order to quantify gas levels equivalence (H2, CO, ...).

Data from FRAME 2 are I2C digital readings.

- Pressure range of 260 to 1260 mBar, 16 bits with ± 0.2 mBar absolute accuracy and ± 0.1 mBar relative accuracy typical.
- Temperature from pressure sensor, 16 bits with $\pm 2^\circ\text{C}$ accuracy
- Temperature Sensor 16 bits with $\pm 0.4^\circ\text{C}$ (max)
- Relative Humidity Sensor 16 bits with $\pm 3\%$ RH (max)

Name	Description	ADC	Voltage readings [V]	Resistance [KOhms]	Comments
NOX_ADC	MOX NOX resistance value	171	0.5511	24.1	Part not calibrated (contact SGX for sensitivity data)
CO_ADC	MOX CO resistance value	427	1.3761	128.7	Part not calibrated (contact SGX for sensitivity data)
TC_ADC	Thermal conductivity output	278	0.8959		Part not calibrated (contact SGX for sensitivity data)

Name	Description	ADC_NTC	R_NTC [KOhms]	T [°C]	Comments
NTC_ADC	Temperature from NTC	323	4.61	46.87	

Name	Description	Readings	Measurement data	Unit	Comments
I2C_RH	Relative humidity	12618	18.07	%	
I2C_Temp	Temperature	35000	46.99	°C	
I2C_Pressure	Absolute pressure	45650	956.57	mBar	
I2C_Pressure_Temp	Temperature	45600	46.98	°C	

A binary Thermal Runaway trigger signal can be part of the LIN communication frame and its setting level can be defined in collaboration with battery manufacturers or OEMs during development.

1.5 Functional validation

As laboratory tests cannot be well correlated to battery vented gases tests data, due to the complex and variable chemical composition of battery vented gases, the more representative field test behavior is favored for functional validation purposes even though it is less repeatable than laboratory behavior with gas injections.

A functional validation is usually necessary with any new battery pack model equipped with the TRDU5.

Indeed, the software may need to be adapted to the specific battery type (NCM, LFP,...) used in the pack and to the configuration of the battery compartment. The operating mode (sensor duty cycle) may also play an important role in TR detection performance.

1.6 Recommendation for integration in the application

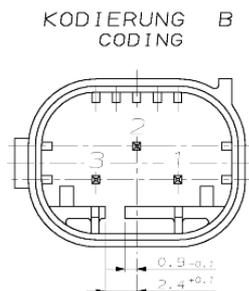
TRDU5 must be exposed to measured air at all times. The location must be chosen so as to maximize air exchange; dead spaces must be avoided.

Preferably, the filtering membrane included in the module should be facing downward. If this is not possible, it should be vertical, but should never be facing upward, to prevent accumulation of dirt, water.

If TRDU5 module is attached with a bayonet to the battery pack enclosure wall, the fixation should be sufficiently air tight so that no gas from the battery pack enclosure is released and that no external pollutants enter in the battery compartment.

2 Electrical specifications

Connector type	AMP 967642-1 Coding B
Pinout	Pin1: Vbat Pin2: Ground Pin3: LIN2.1 Signal
Operating voltage	9..16.5V
Nominal voltage	13.5V
LIN communication	19'200 Bds <u>Remark:</u> As data refresh is done every 200ms it is recommended to send LIN header at higher rate
Warm-up time	The module is directly operational at power – up (< 400 ms) The module self-heating period last several minutes to reach steady temperature, this is not affecting module detection capabilities
Current consumption	In rush current 2A/3 μ s Steady state current: 62 mA average in normal continuous operation mode Can be drastically reduced when operated with low duty cycle mode Only 100 ms of operation are necessary to perform gas measurement (Duty cycle mode operation version available on request)

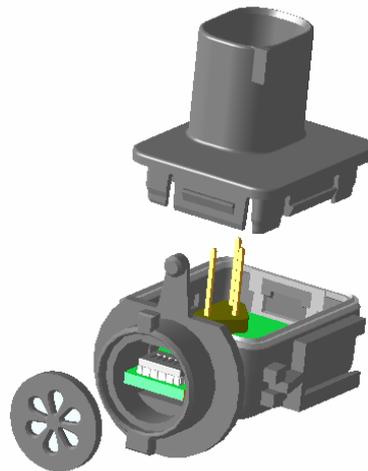


3 Environmental specifications

Operational temperature	-40°C to 85°C
Storage temperature	-40°C to 120°C
Humidity range	5% - 95% RH
Water tightness (with sealed connector)	IP6K7

4 Mechanical specifications

4.1 Assembly elements



The TRDU5 is composed of the following elements:

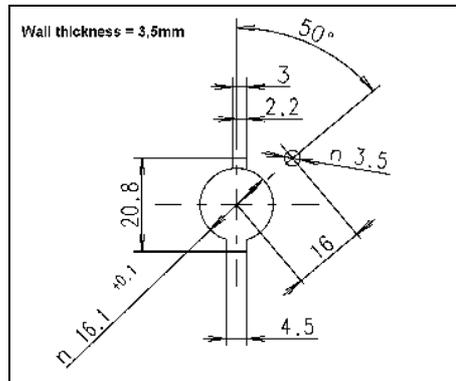
- PA66 plastic housing made of 3 parts:
 - The connector part,
 - and the bottom part with integrated seal
 - The protection ring carrying the Teflon membrane
- Teflon membrane glued on plastic ring for protection against dust and fluid projections.
- Board, including the following elements:
 - SGX-4524 metal oxide dual gas sensor (reducing + oxidizing sensing elements)
 - SGX TC-1326 thermal conductivity gas sensor (reference+detector)
 - Absolute pressure sensor, internally temperature compensated (I2C)
 - Temperature and humidity sensor (I2C)
 - Temperature sensor NTC
 - NXP microcontroller with embedded voltage regulator and LIN transceiver
 - Circuitry for sensor interfacing and readings
 - Three connector pins
 - ESD protection components

4.2 External dimensions, weight

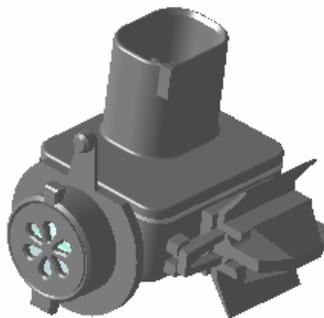
39mm x 35mm x 27 mm
Weight < 15 g

4.3 Connection interfaces

Bayonet fixing, mating with following interface:



Alternatively, the sensor can be mounted with a standard Delphi-clip.



Samples are provided with cable harness and banana plugs.

For samples availability check with your SGX Sensortech contact person.