



# SFS01 EvaKit

## Thermal mass flow sensor

### Optimal for demonstration and evaluation of the SFS01 (Silicon Flow Sensor)

#### Benefits & Characteristics

##### Characteristics

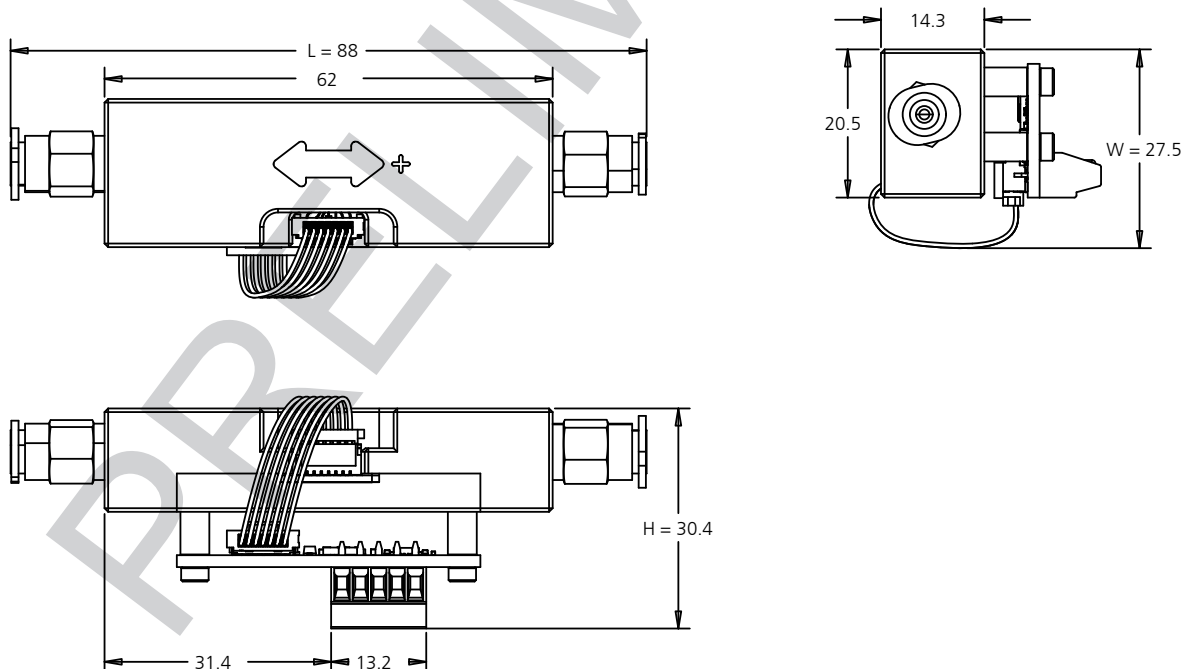
- Measurement from 0 to 200 sccm
- Detection of flow direction
- Analog and digital (I<sup>2</sup>C) connection
- Pneumatic connections for gas

##### Applications

- Automation technology
- Process and regulation technology
- Medicinal and biological technology
- Air conditioning
- Battery-operated applications in portable devices

#### Illustration

Illustration and dimensions (in mm) of the SFS chip



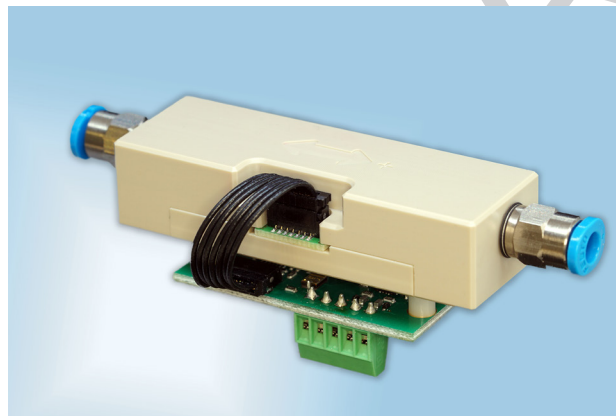
1) For exact size see measurements



## Technical Data

Integrated sensor:	SFS01
Dimensions (L x W x H):	88.0 (±0.5) x 27.5 (±1.0) x 30.4 (±0.5)
Channel dimensions (L x W x H):	35.0 (±0.15) x 1.0 (±0.05) x 1.0 (±0.05)
Pneumatic connections:	QSM M5-4
Temperature range:	0 °C to +80 °C
Storage temperature:	-20 °C to +80 °C
Pressure load:	Up to 1 bar (one-sided on membrane over 10 years)

## Product Photo



## Electrical Data

Supply voltage:	5 ± 5% V
Power:	Typ 30 mW
Output voltage:	0 to 5 V, ca. 2.5 ±0.2 V at 0 sccm
Digital connection:	3.3 V I <sup>2</sup> C (pull up resistors on board)
Digital signal:	Calibrated signal (up to ±200 sccm) Raw signal (digits)
Analog output load:	< 1 mA

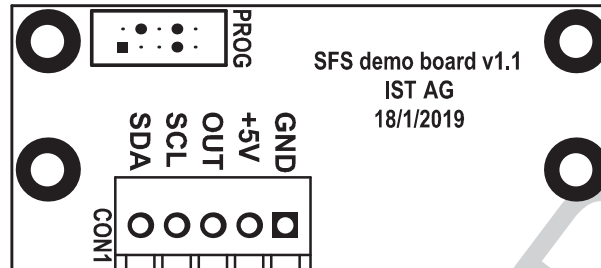
## Flow Performance

The following values are viewed as typical and achieved in laboratory conditions. The gas used was nitrogen.

Medium:	non-aggressive gases (5-95 % rel. humidity, non-condensing)
Measurement range:	0 to ±200 sccm
Sensitivity:	0.1 sccm
Response time $t_{63}$ :	10 ms
Accuracy:	3.0 % F.S.
Temperature sensitivity:	< 0.25 %/K F.S.



## Pin Assignment



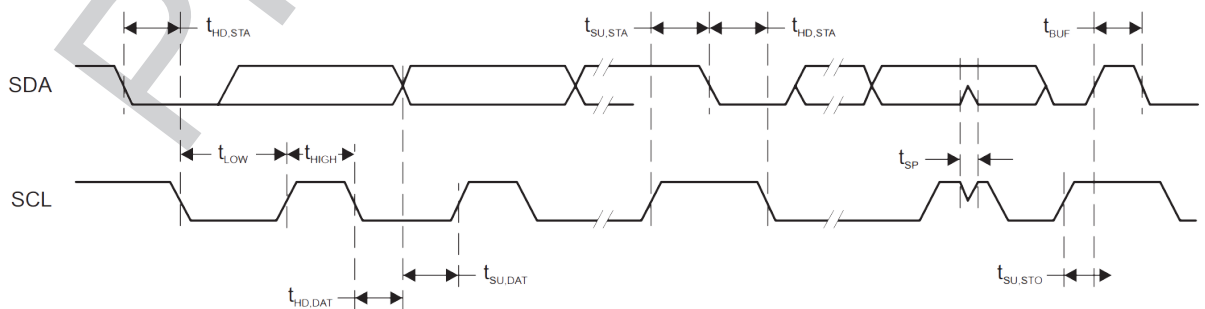
1	2	3	4	5
SDA Serial Data	SCL Serial Clock	OUT Output	+5V Supply voltage	GND Ground

## I<sup>2</sup>C Protocol

### I<sup>2</sup>C Protocol Description

For integration with a micro-controller, the SFS Demo Board has an I<sup>2</sup>C-compatible interface which supports both 100 kHz and 400 kHz bit rates. The default I<sup>2</sup>C slave address is programmed on 0x28 and can be adjusted in the entire 7-bit address range (0x00 to 0x7F).

Parameter	min	max	unit
$f_{SCL}$ SCL clock frequency	100	400	kHz
$t_{HD,STA}$ Hold time (repeated) START	0.6		$\mu$ s
$t_{SU,STA}$ Setup time for a repeated START	0.6		$\mu$ s
$t_{HD,DAT}$ Data hold time	0		$\mu$ s
$t_{SU,DAT}$ Data setup time	250		$\mu$ s
$t_{SU,STO}$ Setup time for STOP	0.6		$\mu$ s
$t_{SP}$ Pulse duration of spikes suppressed by input filter	50	600	ns





### Reading the data form SFS Demo Board

During normal operation the SFS Demo Board is ready to transmit current calibrated and raw flow's value. The typical transmission is:

Start	Address	R	ACK	Data[0]	ACK	Data[1]	ACK	Data[2]	ACK	Data[3]	ACK	Stop
-------	---------	---	-----	---------	-----	---------	-----	---------	-----	---------	-----	------

Start	Address	R	ACK	Data[0]	ACK	Data[1]	ACK	Stop
-------	---------	---	-----	---------	-----	---------	-----	------

Data	Parameter	Unit	
Data [0]	higher bite	Calibrated flow	sccm
Data [1]	lower bite		
Data [2]	higher bite	Raw flow value	
Data [3]	lower bite		

The calibrated flow read from the module is in signed fixed-point integer Q6 format. To convert it to decimal format, the read value has to be divided by  $2^6 = 64$ . The minimum value is -512, the maximum value is 511.98438. The resolution of each value is  $1/2^6 = 0.015625$ . The raw value read from the module is in unsigned integer format.

MSB															LSB
Integer bits										Fractional bits					

### Entering the Command Mode

To read, write parameters or remote-reboot, the SFS Demo Board must be set to command mode by writing 0xA0.

Start	Address	W	ACK	Data = 0xA0	ACK	STOP
-------	---------	---	-----	-------------	-----	------

In the command mode the SFS Demo Board switches off flow's measurement and waits for further communication. The module will reboot automatically after 0.5 second of idle or unsuccessful transmission. The module requires up to 1 ms for entering the command mode (counted from stop bit).

### Entering the Command

In the command mode the user can transmit a 1-byte instruction to the module. The module requires up to 1 ms to process the instruction.

Start	Address	W	ACK	Data = Instruction's code	ACK	STOP
-------	---------	---	-----	---------------------------	-----	------

- 0x00: read Flow A calibration's parameter (do not change!)
- 0x01: read Flow B calibration's parameter (do not change!)
- 0x02: read Flow C calibration's parameter (do not change!)
- 0x03: read Flow D calibration's parameter (do not change!)
- 0x04: read Flow's Range
- 0x05: read I<sup>2</sup>C\_address – own address on I<sup>2</sup>C bus
- 0x06: read Serial Number
- 0x07: read Firmware Revision
- 0x20: write Flow A calibration's parameter (do not change!)
- 0x21: write Flow B calibration's parameter (do not change!)
- 0x22: write Flow C calibration's parameter (do not change!)
- 0x23: write Flow D calibration's parameter (do not change!)
- 0x24: write Flow's Range
- 0x25: write I<sup>2</sup>C\_address – own address on I<sup>2</sup>C bus
- 0xa1: exit command mode (without reset)
- 0xa2: reboot



### Reading parameters from the module

After successful read instruction the module fills the I<sup>2</sup>C buffer with the selected parameter. All parameters read from the module, except I<sup>2</sup>C\_address, Serial Number and Firmware Revision, are in signed fixed-point long IQ22 format (4 bytes). To convert them to decimal format the read value has to be divided by  $2^{22} = 4\,194\,304$ . The minimum value is -512, the maximum value is 511.999 999 762. The resolution of each parameter is  $1/2^{22} = 0.000\,000\,238$ . I<sup>2</sup>C\_address, Serial Number and Firmware Revision parameters are read in unsigned long format. Additionally, I<sup>2</sup>C\_address is internally masked with 0x3ff.

Start	Address	R	ACK	Data[3]	ACK	Data[2]	ACK	...	Data[0]	ACK	Stop
-------	---------	---	-----	---------	-----	---------	-----	-----	---------	-----	------

Data		Parameter
Data [3]	1 <sup>st</sup> byte (highest)	Parameter
Data [2]	2 <sup>nd</sup> byte	
Data [1]	3 <sup>rd</sup> byte	
Data [0]	4 <sup>th</sup> byte (lowest)	

After transmitting 4 bytes, the module resets the internal timer and waits in command mode for the next command. The module will reboot automatically after 0.5 second of idle or unsuccessful transmission.

### Writing parameters to the module

After successful write instruction the module waits for 4 bytes with the new parameter. All parameters except I<sup>2</sup>C\_address, Serial Number and Firmware Revision written to the module are in signed fixed-point long IQ22 format (4 bytes). In order to convert decimal format to IQ22, the decimal value has to be multiplied by  $2^{22} = 4\,194\,304$ . To reduce the error, this calculation should be done as double precision floating point number. The minimum value is -512, the maximum value is 511.999 999 762. The resolution of each parameter is  $1/2^{22} = 0.000\,000\,238$ . I<sup>2</sup>C\_address, Serial Number and Firm-ware Revision parameters are written in unsigned long format. Additionally, I<sup>2</sup>C\_address is internally masked with 0x3ff. Please mind that the new I<sup>2</sup>C address applies after reboot. The module requires up to 1 ms after stop bit to flash the internal memory with the new parameter.

Start	Address	W	ACK	Data[3]	ACK	Data[2]	ACK	...	Data[0]	ACK	Stop
-------	---------	---	-----	---------	-----	---------	-----	-----	---------	-----	------

Data		Parameter
Data [3]	1 <sup>st</sup> byte (highest)	Parameter
Data [2]	2 <sup>nd</sup> byte	
Data [1]	3 <sup>rd</sup> byte	
Data [0]	4 <sup>th</sup> byte (lowest)	

After receiving 4 bytes, the module resets the internal timer and waits in command mode for the next command. The module will reboot automatically after 0.5 second of idle or unsuccessful transmission.

### Exit command code

After receiving this command, the module returns to normal operation, taking the new parameters' values except the I<sup>2</sup>C address.

Start	Address	W	ACK	Data = 0xA1	ACK	STOP
-------	---------	---	-----	-------------	-----	------



### Reboot

After receiving this command, the module reboots.

Start	Address	W	ACK	Data = 0xA2	ACK	STOP
-------	---------	---	-----	-------------	-----	------

### Typical parameter's read sequence

To read parameter(s) from the flash memory please follow steps:

1. Write 0xA0 to the module – start the command mode
2. Wait 1 ms
3. Write 0x00...0x07 to the module – an address of the parameter
4. Wait 1 ms
5. Read 4 bytes from the module
6. If needed repeat steps 3-5 for another parameter
7. Write 0xA1 to the module – exit command mode

### Typical parameter's write sequence

To write parameter(s) to the flash memory please follow steps:

1. Write 0xA0 to the module – start the command mode
2. Wait 1 ms
3. Write 0x20...0x25 to the module – an address of the parameter
4. Wait 1 ms
5. Write 4 bytes to the module
6. Wait 1 ms
7. If needed repeat steps 3-6 for another parameter
8. Write 0xA1 to the module – exit command mode or 0xA2 – reboot the module

### Parameter's description

Parameters: Flow A, Flow B, Flow C, Flow D are used to calculate flow from heater's power, and fluids temperature using equation:

$$flow = A + B \frac{RAW}{2^{10}} + C \left( \frac{RAW}{2^{10}} \right)^2 + D \left( \frac{RAW}{2^{10}} \right)^3$$

Where:

A: flow A, B: flow B, C: flow C, D: flow D

RAW: Raw flow value

Parameter Flow's Range limits the maximum and minimum calibrated flow's readout from the module. It should be written as the last calibration point (or slightly higher). It prohibits the user to measure the flow outside the calibration's range.



## Order Information

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Description:	Item number:	Former main reference:
SFS01 EvaKit	105059	350.0033

## Additional Products

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Description:	Item number:	Former main reference:
SFS01	105050	350.00312

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# Application Note

## Silicon Flow Sensor

### SFS01

#### 1. SFS01 - Classification in the Product Portfolio

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Innovative Sensor Technology IST AG develops thermal mass flow sensors and offers solutions for a wide range of flow applications. Complete modules with integrated flow channels and passive or active outputs are often offered on the market. These systems are suitable for many general applications, but they are usually not suitable for price-sensitive or space-limited applications. As a sensor element only, the flow sensors from IST AG form the basis for many customer-specific applications and enable application-specific and individually tailored integration.

The Silicon Flow Sensor (SFS) is IST AG's first flow sensor based on silicon technology. With the SFS01 flow can be determined not only quantitatively, but also qualitatively (flow direction). This is possible due to the calorimetric measuring principle with which the SFS is generally operated. The calorimetric measuring principle (see section 2.4 for details) is based on a heater and two nearby temperature sensors. The heater generates a heat cloud in the flow medium. The expansion and orientation of the thermal cloud are defined by the strength and direction of the flow and the composition of the gas. The orientation of the thermal cloud results in a temperature difference between the two temperature sensors. By measuring this temperature difference, the flow strength and flow direction are determined.

The symmetrical design of the SFS01 allows easy interpretation and evaluation of the measurement signal. The sensor can be used for different gases. Furthermore, the SFS is characterized by a large measuring range, high sensitivity and a very fast response time. A good design of the channel geometry allows the performance of the sensor to be optimally matched to the desired application. The SFS flow sensor is ideally suited for space-limited applications, but can also be easily upgraded to complete ready-to-use systems. IST AG offers a wide range of customer support services and cooperation, including system integration, pre-assembled, customer-specific partial solutions and complete solutions tailored to the customer's application.

#### 2. Applications & Structure

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##### 2.1 Characteristics

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- Measuring range up to 3.5 m/s (gases)
- Detection of flow direction
- Very fast response time <5 ms
- Very low energy consumption
- Simple system integration

##### 2.2 Application Areas

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- Automation technology
- Process and regulation technology
- Medicinal and biological technology
- Air conditioning
- Battery-operated applications in portable devices





## 2.3 Sensor Design

In the following, the different layers of the SFS flow sensor and their production are explained.

### Substrate

The substrate of the SFS sensor and thus also the raw material for its production is a silicon wafer. First an oxide layer and then a silicon nitride layer are applied to the silicon. The silicon nitride layer later forms the sensor membrane of the SFS.

The high thermal conductivity of the silicon favours a homogeneous temperature distribution on the substrate as well as a constant reference temperature. This in turn enables measurements of very small temperature differences.

### Sensitive Structure

The heater and the temperature sensors (thermopiles) are produced in a multi-stage lithographic process. First, silicon doped with phosphorus is applied. Out of this, the two heating elements and the first half of the thermopiles are structured by means of lithography. Aluminium is then applied, from which the second half of the thermopiles, the electrical conductors and the bond pads are structured.

### Passivation

To protect the active surface (heater and temperature sensor) from aggressive media, a stack of silicon oxide and silicon nitride layers is applied. This layer forms the passivation of the sensor, which contributes not only to the protection but also to the stabilization of the SFS.

### Etching of cavity

Etching creates a cavity in the silicon wafer below the active surface. The etching process stops at the silicon nitride layer so that it remains as a thin sensor membrane.

### Finishing

In the last step, the wafers are diced and the sensors are separated with a fully automatic dicing machine.

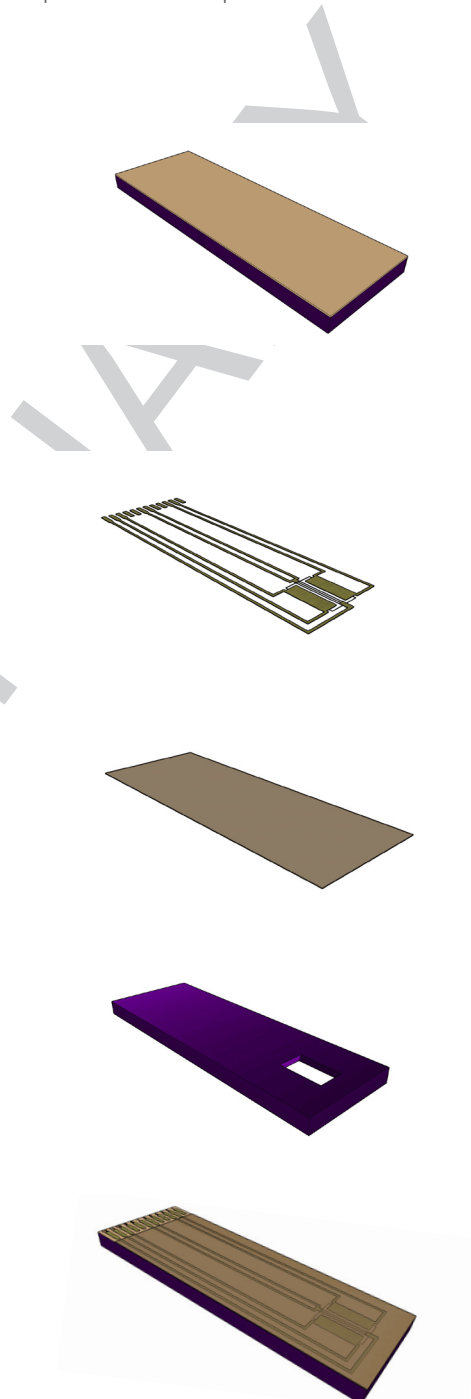


Fig. 1: Structure of the SFS01 sensor



## 2.4 Measuring Principle

IST AG offers thermal mass flow sensors using the calorimetric or anemometric measuring principle. The functionality of the SFS01 is based on the calorimetric measuring principle. The sensor element consists of a heater and two temperature sensors located next to the heater. The temperature difference between the two temperature sensors is flow-dependent and can therefore be used as a parameter for the flow.

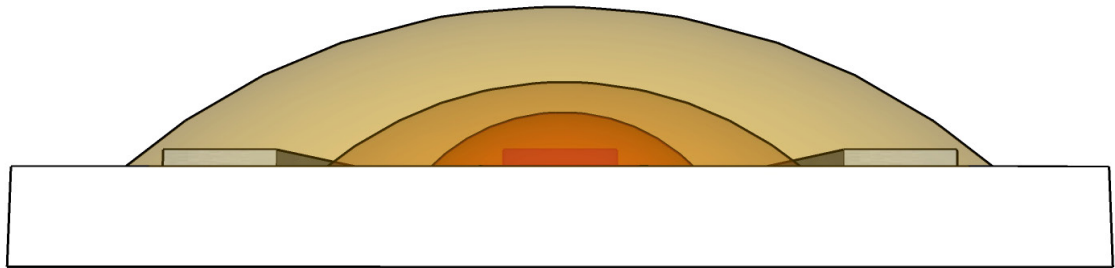


Fig. 2: Schematic representation of the thermal cloud in the calorimetric measuring principle, if no flow exists

If there is no flow, the thermal cloud is symmetrical (Fig. 2) around the heater, i.e. the temperature sensors have the same temperature. Thus the temperature difference is zero. The thermal cloud is generated by the heater with a defined thermal output (Joule Heating). The SFS is generally operated with a constant heat output, i.e. the output is a parameter.

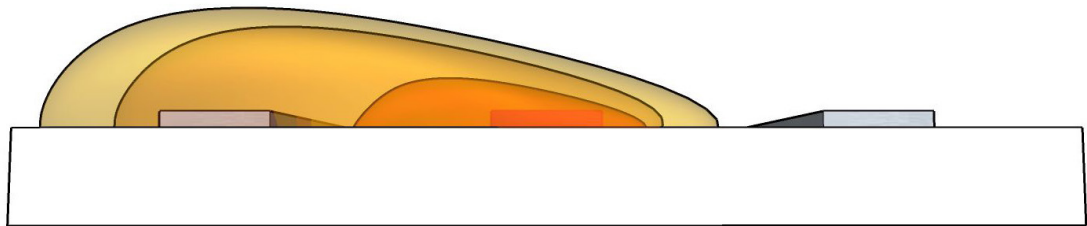


Fig. 3: Schematic representation of the thermal cloud in the calorimetric measuring principle with a finite flow

When a flow occurs, the thermal cloud shifts to one of the two temperature sensors according to the flow direction (Fig. 3), resulting in a temperature difference between the two sensors. Up to a certain point the temperature difference increases with increasing flow.

The temperature difference as a function of the flow strength is shown schematically in Fig. 4.

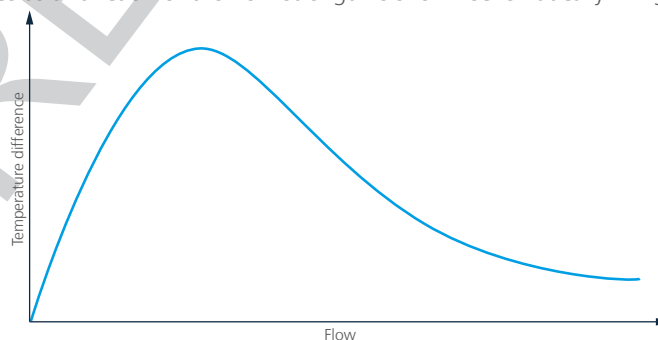


Fig. 4: Temperature difference as a function of flow

At a certain point or at a certain flow, as much heat is carried away by the flow as is generated by the heater and the temperature difference has reached its maximum. If the flow becomes even larger, the temperature difference decreases again. For a sensor operating on the calorimetric principle, the maximum flow range is defined by the maximum of the possible temperature difference, otherwise the uniqueness of the signal is lost.

The effective signal of the SFS is the two voltages of the thermopiles or the difference between the two voltages, which is proportional to the temperature difference between the two thermopiles.



## 2.5 Dimensions

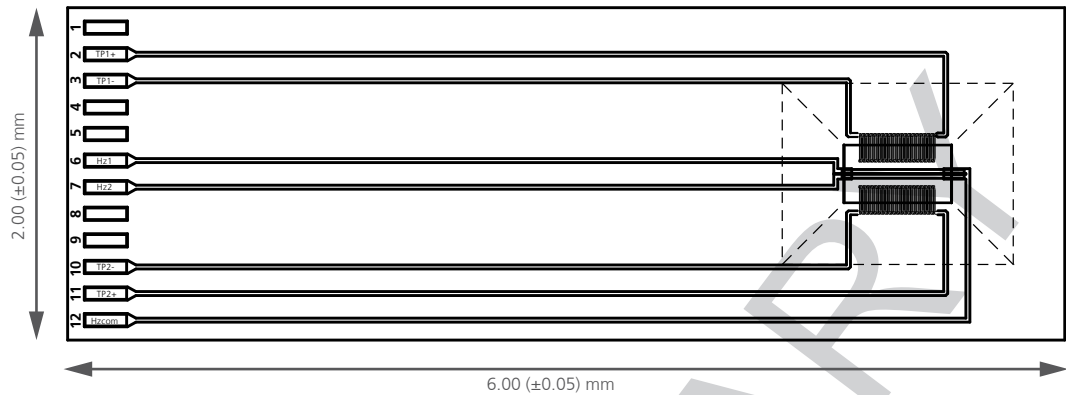


Fig. 5: Dimensions of the SFS sensor

The dimensions of the SFS01 sensor chip are  $6.00 \pm 0.05 \times 2.00 \pm 0.05 \times 0.525 \pm 0.1 \text{ mm}^3$  (L x W x H) (see fig. 5). The silicon nitride membrane (indicated by a dotted line) is approx.  $2 \mu\text{m}$  thick.

## 3. Assembly & Delivery

### 3.1 Assembly

The recommended bonding method for the SFS01 is Wedge-Wedge with aluminum wire.

The SFS01 can be mounted in a PCB cavity or directly in the flow channel. The connection between the sensor and the electronics is made using bond wires.

Customer-specific mounting of the SFS01 in an individual flow channel is also possible.

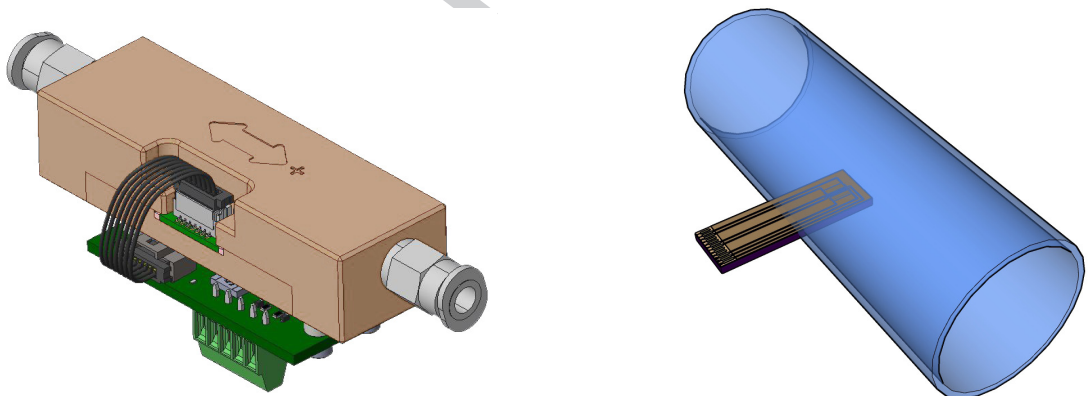


Fig. 6: Possible mountings: Bonded to a PCB and inserted into a flow channel according to customer specifications or bonded directly into a flow channel

### 3.2 Delivery & Contents

Small quantities can be delivered within one week, large quantities on request. The SFS01 is delivered without channel and electronics. A test module for the SFS01 can be purchased separately.



### 3.3 Handling

The sensors are sent in a chip tray. Fig. 7 shows how the sensors are placed in an open chip tray.



Fig. 7: SFS sensors in chip tray

The sensors may only be touched with plastic or vacuum tweezers. When removing the sensors from the chip tray, make sure that they are not touched in the area of the membrane. The membrane is very thin and can easily be damaged.

Fig. 8 shows in which areas the SFS01 chip may be touched with tweezers (green area) and which areas should not be touched (red areas).



Fig. 8: „Touch zone“ of the SFS01 (green) resp. „protective zones“ (red) which must not be touched



## 4. Performance & Linearization

### 4.1 Performance

The following graph (fig. 9) shows the typical characteristic curve of the SFS flow sensor under laboratory conditions (nitrogen, 25 °C, channel cross-section: 1 x 1 mm<sup>2</sup>). Application-dependent deviations are possible and must be verified in each case.

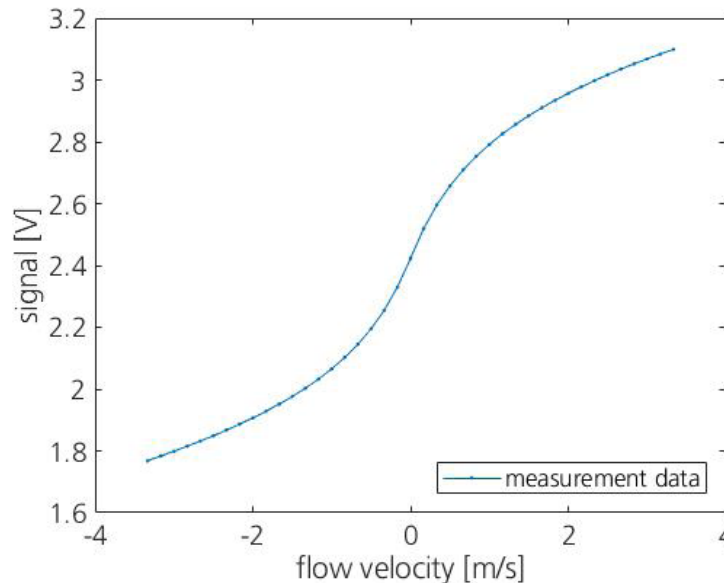


Fig. 9: Typical characteristic curve of the SFS flow sensor

This output signal was generated with an electronics that amplifies the difference of the thermopile voltage by a factor of 50. The flow medium was nitrogen. The heating power was adjusted in a way that the range of the output voltage covers the whole flow range. Here the output voltage without flow was 2.4 Volt. As a direct consequence of the symmetrical sensor construction, the signal is point symmetrical to this zero point.

### 4.2 Influences

The following points show examples of possible influences on the output signal. These influences are strongly dependent on the application. If you have any questions about a specific application and possible influences, please do not hesitate to contact us.

- Flow medium:** Due to the different specific thermal parameters (thermal conductivity, heat capacity, density, viscosity and others), the composition of the flow medium has an influence on the formation of the thermal cloud and thus the detection by the temperature sensors.
- Contamination:** Dust and impurities can influence the signal and in the worst case even damage the sensor.
- Implementation:** The determination of the flow over the complete flow profile must be carried out by extrapolation of the selectively recorded output signal of the SFS. Accordingly, the geometry of the channel and the associated flow profile are - indirectly - included in the calibration. The positioning of the sensor element relative to the flow profile also has an influence. The sensor element must be placed „sufficiently well“ in the flow channel so that the desired dynamic range is covered and the required measurement accuracy is achieved. The following factors can have an influence on the flow profile:
- channel diameter
  - inlet length
  - position of the sensor



Temperature: The output signal is temperature-dependent, as the thermal parameters of the medium are temperature-dependent, among other things.



We will be happy to support you in finding the best possible solution for your application.



### 4.3 Electrical circuit



Fig. 10 below shows a schematic and simplified circuit diagram in which the two heating resistors are connected in parallel. It is also possible to connect the two heating resistors ( $H_{z1}$ ,  $H_{z2}$ ) in series. Due to the thermo-electric effect, a voltage is generated at the two thermopiles ( $TP_1$ ,  $TP_2$ ), whereby the difference of the two thermopiles voltages is amplified and then measured.

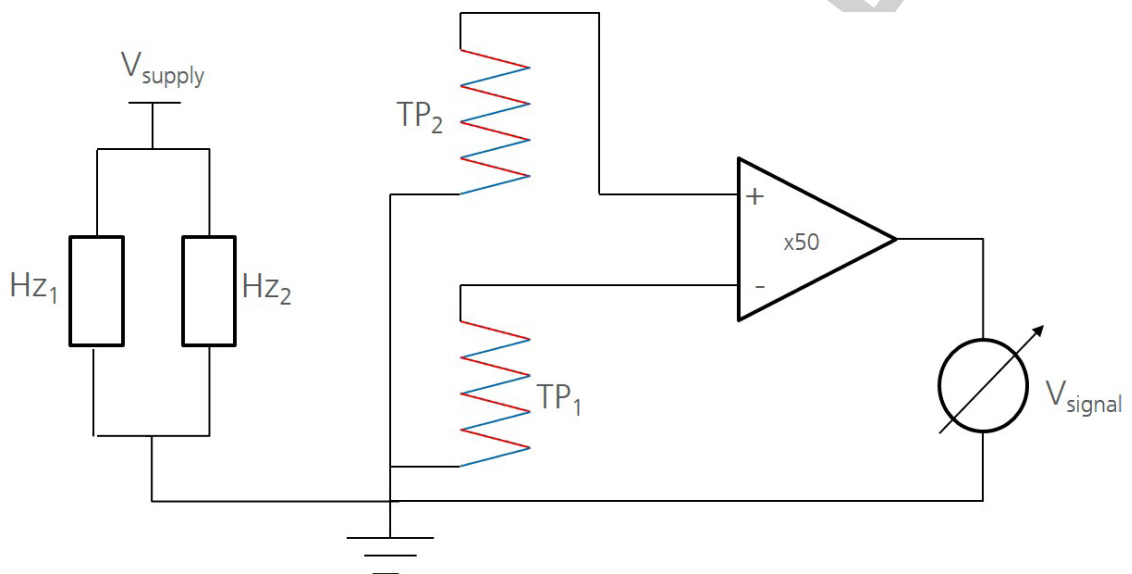


Fig. 10: Schematic and simplified circuit diagram of the SFS01

### 4.4 Calibration & Linearization

#### 4.4.1 Calibration

The following function was empirically determined for the SFS. It maps the output signal against the flow velocity and represents the basis of the calibration:

$$V_{signal}(v) = a + b \cdot \text{sgn}(v) e^{c|v|^d}$$

Where  $v$  is the signed flow velocity and  $V_{signal}(v)$  is the output signal. The function  $\text{sgn}()$  indicates the flow direction via the sign. The parameters  $a$  (offset),  $b$  (amplitude),  $c$  and  $d$  (damping factors) are the calibration parameters and must be determined for each application and geometry by a regression analysis. Depending on the application, the function can also be displayed in a different or simplified way.

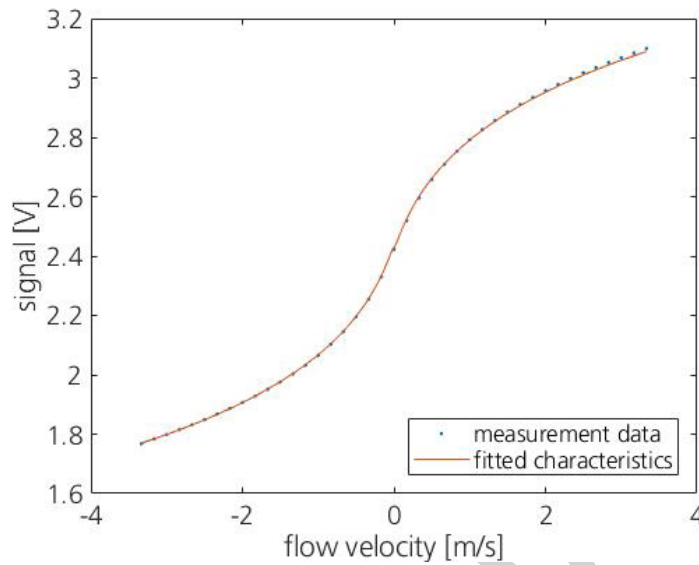


Fig. 11: Measured measuring points and fitted characteristic curve

To be able to calculate these four variables, at least four measurement points must be recorded. However, it is recommended to record significantly more measurement points. In addition, the measuring points should be selected in such a way that the entire dynamic range is covered in the later application. The best result can be achieved if the framework conditions during the calibration correspond to those of the end application. A check of the symmetry around the zero point ( $v=0$ ) allows conclusions to be drawn about possible optimization potential with regard to the positioning of the sensor element.

The calculated parameters for the measurement shown above (fig. 11) are:

- a = 2.43
- b = 3.36
- c = 2.23
- d = -0.26

In general, the calibration parameters of the SFS under laboratory conditions (nitrogen, +25 °C, channel cross-section: 1 x 1 mm<sup>2</sup>) are in the range of the exemplary values mentioned above. Depending on the application and sensor installation, however, these values differ.



#### 4.4.2 Linearization

Once the parameters a, b, c, d have been determined, the calibration is complete. The inverse function of  $V_{signal(v)}$  provides the signed flow velocity for a measured output signal.

$$v(V_{signal}) = \text{sgn}(V_{signal} - a) \left( \frac{-\log\left(\frac{|V_{signal}-a|}{b}\right)}{c} \right)^{1/d}$$

The linearized signal is shown in fig. 12.

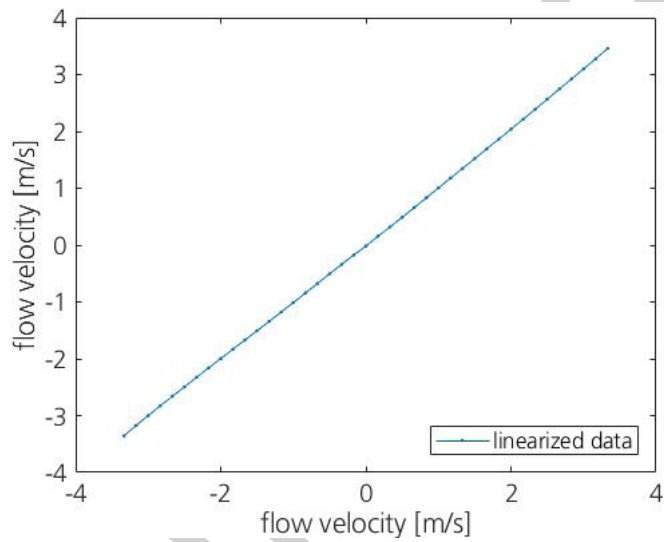


Fig. 12: Linearized signal of the SFS01

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Innovative Sensor Technology IST AG, Stegrütistrasse 14, 9642 Ebnat-Kappel, Switzerland  
Phone: +41 71 992 01 00 | Fax: +41 71 992 01 99 | Email: info@ist-ag.com | www.ist-ag.com