Application Note

SL900A

External Sensor Interface

Content Guide

1 General Description

This document describes the external sensor interface (SFE – sensor front end) of the SL900A smart label device. For a complete description of the SL900A device, please refer to the datasheet.

The SFE pins are:

- EXT1: External sensor 1 connection used for:
  - Linear-resistive sensors
  - DC voltage source (sensors with external analog processing)
  - Capacitive and resistive sensors with AC driving

- EXT2: External sensor 2 connection used for:
  - Linear-conductive sensors
  - Reverse-polarized diode type sensors
  - Sensors that form a DC voltage source with serial resistance
  - Sensors that form a DC current source to VSS

- EXC: Supply voltage for the external sensors or AC signal source for external sensors that do not allow a DC voltage.

- VREF: Reference voltage pin used for capacitive and resistive sensors with AC excitation.

The SL900A has 2 inputs for analogue external sensors. The following type of sensors can be used:

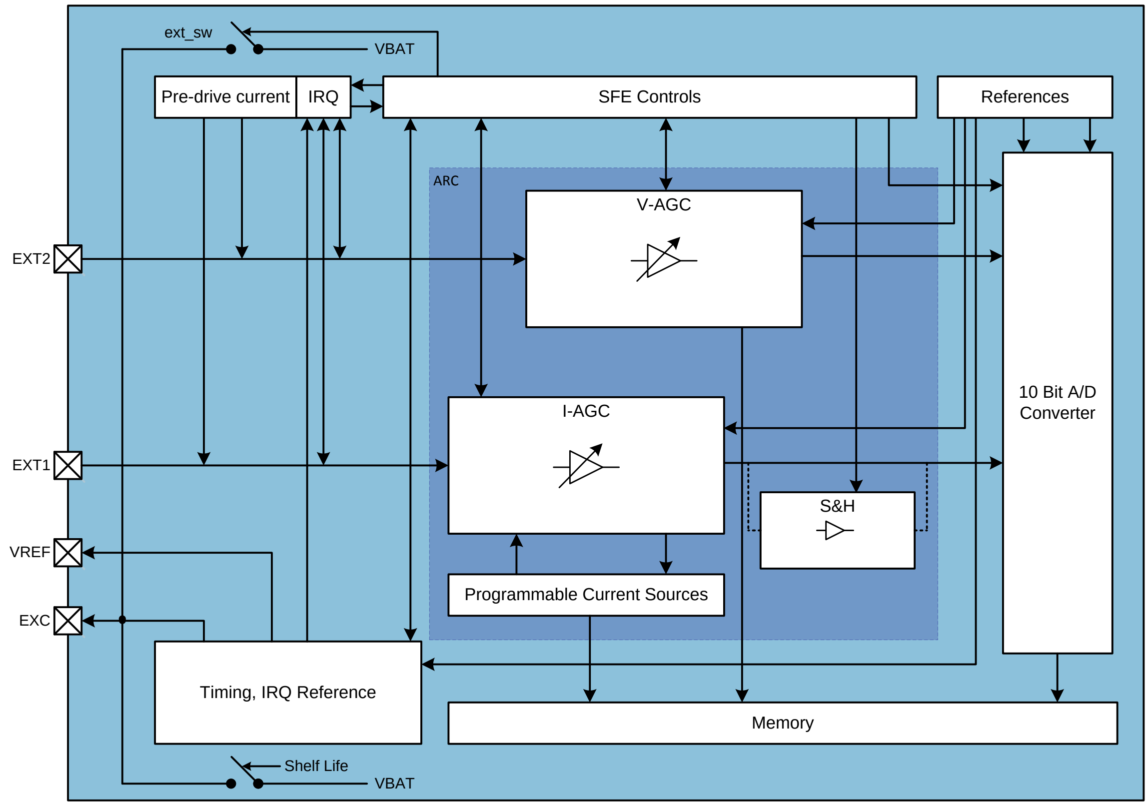
Figure 1: Example External Sensor Types

Sensor Type	Manufacturer	Model	Comment
Resistive Bridge	X	X	Any resistive sensor (pressure, humidity, temperature...)
Capacitive - no DC (AC excitation)	E+E Elektronik	HC105, HC109, P14thermo	Humidity
Resistive - no DC (AC excitation)	GE Sensing, Ghitron Technology	EMD4000,HCZ-D5	
Resistive – linear conductance	FlexiForce	A201	Pressure
Resistive – linear resistance	X	X	
Photodiode, opto-sensors	Hamamatsu	S10170	Light, Color
Voltage source	X	X	
Current source	X	X	

The SFE interface is optimized for low-power operation. The external sensor excitation or supply will only be active for the duration of sampling and AD conversion. All other time the SFE is in stand-by mode and consumes only the leakage current. It is also optimized for minimum count of external components, so in most cases only the sensor itself is needed. Some types of sensors (with AC excitation or resistive bridge) require an external reference component (resistor or capacitor).

2 Detailed Description

Figure 2: SFE Block Diagram



The SFE interface can be used in manual gain selection mode or in automatic gain selection mode (auto-range). The SFE interface can be configured by using the cool-Log™ command "Set SFE Parameters", or with the SPI interface by writing the appropriate data to the EEPROM physical address 0x017 and 0x018 followed by an SPI - Start Log (0xC5) and an SPI - Stop Log command (0xC6). The last two commands will load the EEPROM data into the registers. After every power up this sequence is required.

Figure 3: SFE Parameters

SFE Parameters	FUNCTION	DESCRIPTION	
rang[4:0]	External sensor 2 range	Resistor feedback ladder	
seti[4:0]	External sensor 1 range	Current source value	
EXT1[1:0]	external sensor 1 type	00	Linear resistive sensor
		01	High impedance input (voltage follower), bridge
		10	RFU
		11	Capacitive or resistive sensor without DC AC signal on EXC pin)
EXT2	external sensor 2 type	0	Linear conductive sensor
		1	High impedance input (voltage follower), bridge
Range preset	Use preset range	Autorange function is turned off	
Verify sensor ID[1:0]	Sensor used in limit check (sensor enable bits in log mode group)	00	first selected sensor
		01	second selected sensor
		10	third selected sensor
		11	fourth selected sensor

The rang[4:0] and seti[4:0] bits are used only if the Autorange function is turned off (Range Preset). The rang[4:0] value is coded is one-hot and selects the feedback resistor value for the EXT2 input in linear conductance mode (EXT2=0). The seti[4:0] value is binary coded and selects the current source value for the EXT1 input in linear resistance and capacitance mode (EXT1=00 or 10) Otherwise those values are ignored. The values are defined as:

Figure 4: Resistor Feedback Ladder for external sensor 2 input

rang[4:0]	Feedback Resistor Value R_f [kΩ] (EXT2)
00000	Not allowed
00001	3875
00010	1875
00100	875
01000	400
10000	185
All other values	RFU

Figure 5: Current source values for external sensor 1 input

seti[4:0]	Current Source Value I_{STEP} [µA] (EXT1)
00000	0
00001	0.25
00010	0.5
00011	0.75
…	
11110	7.5
11111	7.75

The external sensor type is selected with the EXT1[1:0] and EXT2 bits. The 'Verify Sensor ID[1:0]' value is used for the sensor selection in limits mode. By default the integrated temperature sensor is selected.

The hierarchy of the sensors for SL900A is:

1. Ext1
2. Ext2
3. Internal Temperature Sensor
4. Battery Level

In case limits are used with any of the external sensors, the auto-ranging has to be disabled and manual gain selection has to be used. The limits are used only on the 10-bit AD converter value and not on range bits, so in case that auto-ranging would be enabled, the limit comparison would not be reliable.

The AD converter can be started with the cool-Log™ RFID command GET SENSOR VALUE or with the SPI[1] commands:

- 0xC1 (Get Temperature)
- 0xC2 (Get Battery Level)
- 0xC3 (Get External Sensor 1)
- 0xC4 (Get External Sensor 2)

The reply in both cases is 16 bits long (with RFID also CRC is attached), where the MSB is the Error bit, next 5 bits are the Range (set[4:0] or rang[4:0]) and the lower 10 bits are the AD converter output code:

[1] For detailed description on the SPI command, please refer to the document "AN1 – SL900A – SPI Interface".

Figure 6: Reply to the Get Sensor Value command

A/D error	Range	Sensor Value
1 bit - error [1]	5 bits	10 bits

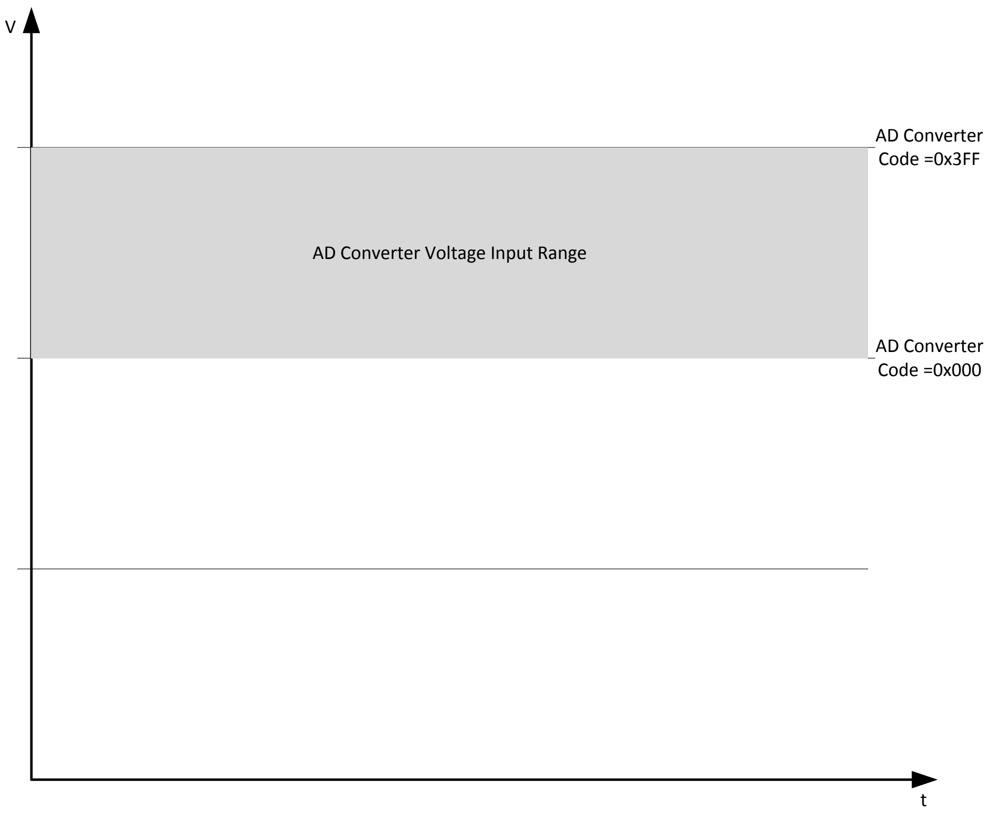
3 AD Converter Description

The SL900A device has an integrated 10-bit AD converter with selectable input voltage range. The voltage input range is selected with the 2 voltage references (Vo1 and VREF). The VREF voltage defines the lower voltage limit.

The upper voltage limit is defined by:

$$Upper\ Voltage\ Limit = 2 * VREF - Vo1$$

Figure 7: AD Converter Input Voltage Range



The reference voltages can be selected in steps of 50mV

Figure 8: Reference Voltage Levels

Calibration Code	Vo1	VREF (Vo2)
0b000	160mV	260mV
0b001	210mV	310mV
0b010	260mV	360mV
0b011	310mV	410mV
0b100	360mV	460mV
0b101	410mV	510mV
0b110	460mV	560mV
0b111	510mV	610mV

Factory defaults for the reference voltages are:

- Vo1 = 0V (VSS)
- VREF = 310mV

The input voltage V_{SENS} can be calculated from the following equation:

$$V_{SENS} = AD_{CODE} * \frac{V_{REF} - Vo1}{1024} + V_{REF}$$

while

$$\frac{V_{REF} - Vo1}{1024} = Resolution$$

and

$$V_{REF} = Offset$$

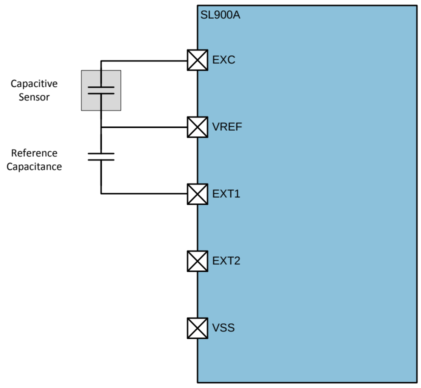
4 External Sensor Input 1 (EXT1)

The external sensor 1 interface (EXT1 pin) can be used for measurements with linear resistive sensors and capacitive sensors with AC excitation. It can also be used to measure 1 point of a resistive bridge (with the second point connected to the EXT2 pad).

4.1 Capacitive Sensor without DC

The processing of an external capacitive sensor without DC voltage is possible in case an external reference capacitor is used. The external sensor is excited with an AC signal from the EXC pin. The connection for this kind of sensors is shown in the figure below. There is no auto-ranging functionality in this mode available, so the reference capacitor needs to be selected according to the expected sensor capacitance.

Figure 9: Capacitive Sensor – No DC (EXT1[1:0] = 11)



The external capacitive sensor in the figure above is excited with a square wave signal around the reference voltage VREF (by default this is 310mV, but can be changed by the application). The amplitude of the AC signal is equal to the VREF voltage. The input AC amplitude is defined as:

$$V_{EXT1} = V_{REF} * \frac{C_{SENS}}{C_{REF} + C_{SENS}} + V_{REF}$$

The selection of the reference capacitor depends on the AD converter input voltage range and the expected capacitance range of the sensor. The maximum capacitance C_{SENS} should result to the maximum AD level (V_{EXT1}):

$$V_{EXT1\_max} = 2 * V_{REF} - Vo1$$

The minimum capacitance C_{SENS} should result to the minimum AD level (V_{EXT1}):

$$V_{EXT1\_min} = V_{REF}$$

The sensor capacitance value is calculated using the below relations:

$$C_{SENS} = C_{REF} * \frac{V_{EXT1} - V_{REF}}{2V_{REF} - V_{EXT1}} \rightarrow C_{SENS} = C_{REF} * \frac{AD_{CODE} * (V_{REF} - Vo1)}{1024 * V_{REF} - AD_{CODE}(V_{REF} - Vo1)}$$

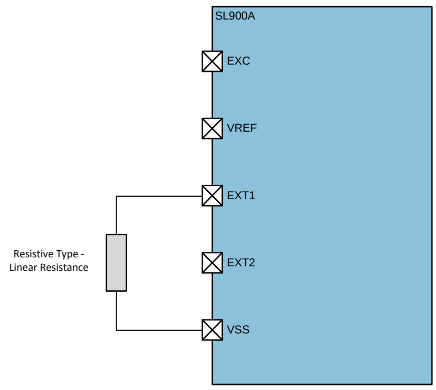
4.2 Resistive Sensor with linear resistance (EXT1 to VSS)

The minimum and maximum resistance values that can be measured on the EXT1 input are:

- R_{SENS_min} = 33.5kΩ
- R_{SENS_max} = 4.9MΩ

The connection diagrams are shown in the figure below.

Figure 10: Resistive Type - Linear Resistance (EXT1[1:0] = 00)



4.2.1 Auto-ranging

Voltage at a linear resistive sensor increases with increasing current to excite limit VREF:

$$I_{STEP} * R_{SENS} > V_{REF}$$

while I_{STEP} is shown in the table below:

Figure 11: Current source values for external sensor 1 input

seti[4:0]	Current Source Value I_{STEP} [µA] (EXT1)	Comment
00000	0	The absolute value of the current depends on integrated resistors value and can vary within process tolerances.
00001	0.25	
00010	0.5	
00011	0.75	
…		
11110	7.5	
11111	7.75	

The sensor resistance can be calculated from:

$$R_{SENS} = \frac{V_{EXT1}}{I_{STEP}}$$

with

$$V_{EXT1} = AD_{CODE} * \frac{V_{REF} - Vo1}{1024} + V_{REF}$$

yields to:

$$R_{SENS} = \frac{AD_{CODE} * \frac{V_{REF} - Vo1}{1024} + V_{REF}}{I_{STEP}}$$

If default values for the AD reference voltages are used (VREF=310mV, Vo1=0V), then the equation above can be simplified to:

$$R_{SENS}[k\Omega] = \frac{AD_{CODE} * 302.7 * 10^{-3} + 310}{I_{STEP}}$$

4.3 Resistive Sensor with linear resistance (EXT1 to VREF)

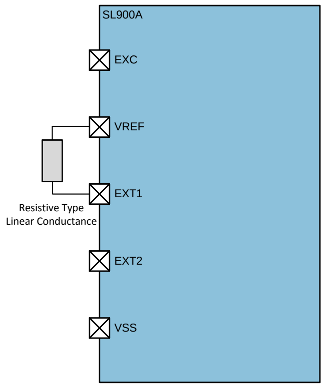
The minimum and maximum resistance values that can be measured in this configuration are:

- $R_{SENS\text{-}min}$ = 6.3Ω (maximal resolution)
- $R_{SENS\text{-}max}$ = 2.44MΩ

This connection type allows to measure lower resistances.

The internal ESD PAD resistance on VREF and EXT1 needs to be taken into account for low resistance measurements. The resistance value is 200Ω for VREF and EXT1. The pad resistance tolerance is ±37.5% with a temperature dependence of +0.18Ω/°C.

Figure 12: Linear Resistive Sensor (EXT1[1:0] = 00)



The resistive sensor is supplied with I_{STEP}. This current can be manually selected (see **Figure 11**), or can be automatically selected.

The sensor resistance can be calculated from:

$$R_{SENS} = \frac{V_{EXT1} - V_{REF}}{I_{STEP}}$$

with

$$V_{EXT1} = AD_{CODE} * \frac{V_{REF} - Vo1}{1024} + V_{REF}$$

yields to:

$$R_{SENS} = \frac{AD_{CODE} * (V_{REF} - Vo1)}{1024 * I_{STEP}}$$

If default values for the AD reference voltages are used (VREF = 310mV, Vo1 = 0V), then the equation above can be simplified to:

$$R_{SENS}[k\Omega] = \frac{AD_{CODE} * 0.31}{seti\langle 4:0\rangle * 0.256}$$

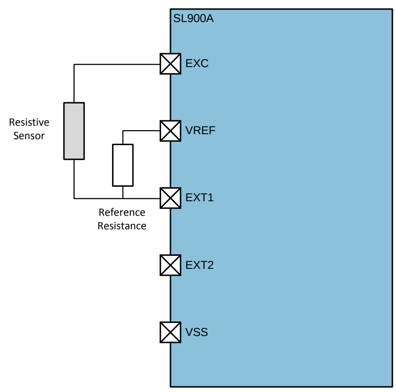
4.4 Resistive Sensor without DC

An additional external reference resistor has to be used for processing external resistive sensors with an AC excitation. Following relation is valid:

$$V_{REF} < V_{REF} + \frac{V_{REF}}{R_{SENS} + R_{REF}} * R_{REF} \leq 2 * V_{REF} - Vo1$$

The proper ratio between sensor and reference resistor should be chosen to comply with the upper relation and the resistance range of the sensor.

Figure 13: Resistive Sensor - No DC (EXT1[1:0] = 11)



The sensor resistance is calculated in the formula:

$$R_{SENS} = R_{REF} * \left(\frac{V_{REF}}{V_{EXT1} - V_{REF}} - 1\right)$$

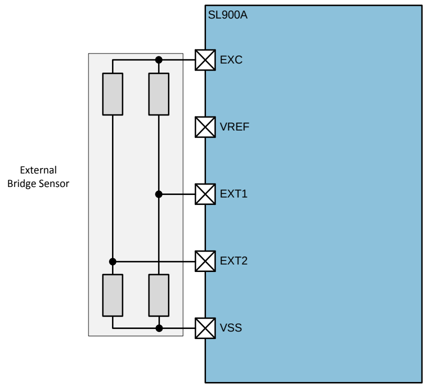
If default values for the AD reference voltages are used (VREF=310mV, Vo1=0V), then the equation can be simplified to:

$$R_{SENS}[k\Omega] = R_{REF} * \left(\frac{1024}{AD_{CODE}} - 1\right)$$

4.5 Resistive Bridge

A resistive bridge has to be connected to both sensor inputs (see figure below). The 2 input voltages are converted one after the other. In automatic logging both external sensors have to be enabled. If the resistor bridge is also used with the GET SENSOR VALUE cool-Log™ command, this command has to be sent twice – first for external sensor 1, second for external sensor 2. The resistive bridge can be supplied from the EXC pin. The battery voltage is internally switched to the EXC pin only for the duration of the measurement. At all other times the EXC pin is in tri-state and the bridge does not consume any current.

Figure 14: External Bridge Sensor (EXT1[1:0] = 01, EXT2 = 1)



The voltages on inputs EXT1 and EXT2 are calculated from:

$$V_{EXT1,EXT2} = AD_{CODE} * \frac{V_{REF} - Vo1}{1024} + V_{REF}$$

The overall minimum voltage that can be measured on the external sensor inputs EXT1 and EXT2 is 260mV.

The maximum voltage is 1.22V.

Those values depend on the selected VREF and Vo1 reference voltages.

5 External Sensor Input 2 (EXT2)

The external sensor 2 interface (EXT2 pin) can be used for measurements with linear conductive sensors, optical sensors (diode and to measure the second point of a resistive bridge (with the first point connected to the EXT1 pad).

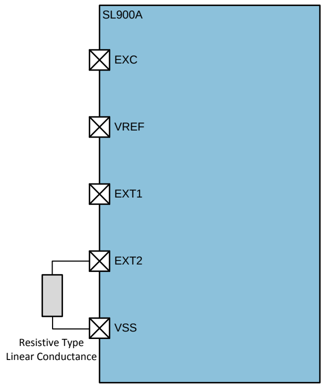
5.1 Resistive Sensor with linear conductance

The minimum and maximum resistance values that can be measured on the EXT2 input are:

- R_{SENS_min} = 20.5kΩ
- R_{SENS_max} = 2MΩ

The figure below shows the connection diagram for a resistive sensor with linear conductance (like a pressure sensor). In this mode, the sensor is supplied with a constant voltage of 135mV.

Figure 15: Resistive Sensor - Linear Conductance (EXT2 = 0)



The sensor resistance can be calculated as follows:

$$R_{SENS} = \frac{135mV}{I}$$

The operational amplifier (see **Figure 17**) balances the current I, so that the voltage on the 2 inputs is equal, so that R_{sens} sees 135mV.

The current I is defined by the V_{AD} voltage minus 135mV and the feedback resistor:

$$I = \frac{V_{AD} - 135mV}{R_f}$$

Therefore:

$$R_{SENS} = 135mV * \frac{R_f}{V_{AD} - 135mV}$$

135mv is the constant sensor supply voltage.

The code rang<4:0> is one hot coded and selects the feedback resistor value R_f of the input amplifier. Available values are shown in the figure below:

Figure 16: Resistor Feedback Ladder for external sensor 2 input

rang[4:0]	Feedback Resistor Value R_f [kΩ] (EXT2)	Comments
00000	Not allowed	Temperature coefficient of the gain depends only on temperature coefficient of the external sensor. The tolerance of the integrated resistors used in the feedback loop is ±17%
00001	3875	
00010	1875	
00100	875	
01000	400	
10000	185	
All other values	RFU	

Sensor resistance can be calculated as follows:

$$V_{AD} = AD_{CODE} * \frac{V_{REF} - Vo1}{1024} + V_{REF}$$

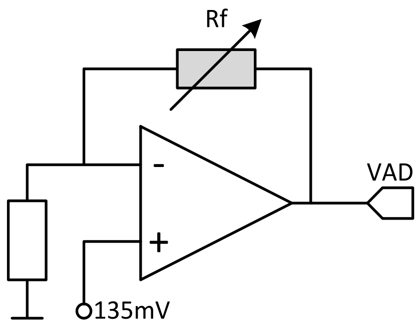
The sensor resistance can be calculated from:

$$R_{SENS} = 135mV * \frac{R_f}{AD_{CODE} * \frac{V_{REF} - Vo1}{1024} + V_{REF}}$$

If default values for the AD reference voltages are used (VREF = 310mV, Vo1 = 0V), then the equation can be simplified to:

$$R_{SENS[\Omega]} = 0.135 * \frac{R_f}{AD_{CODE} * 302.7 * 10^{-6} + 0.31}$$

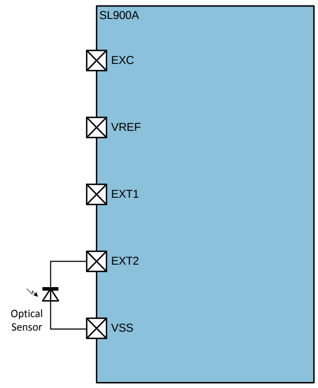
Figure 17: EXT2 Input for Conductance Sensor Measurement



5.2 Optical Sensor

The EXT2 pad can also be used for measurements with an optical sensor based on reverse biased diode current (see figure below):

Figure 18: Optical Sensor (Reverse Biased Diode) (EXT2 = 0)



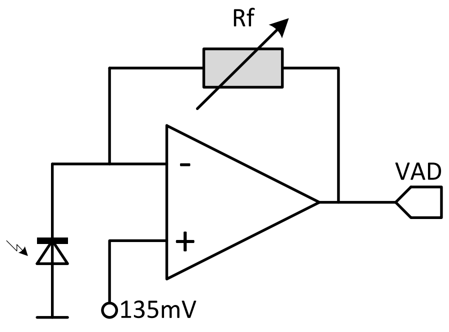
The current input range in this mode is defined as:

$$I_{min} = \frac{V_{REF} - 135mV}{R_{f\_max}}$$

$$I_{max} = \frac{(2 * V_{REF} - Vo1) - 135mV}{R_{f\_min}}$$

- Rf_min = 185 kΩ
- Rf_max = 3875 kΩ

Figure 19: EXT2 Input for Conductance Sensor Measurement



$$I_D = \frac{V_{AD} - 135mV}{R_f}$$

If V_{AD} is exchanged with the AD converter equation we get:

$$I_D = \frac{AD_{CODE} * \frac{V_{REF} - Vo1}{1024} + V_{REF} - 135mV}{R_f}$$

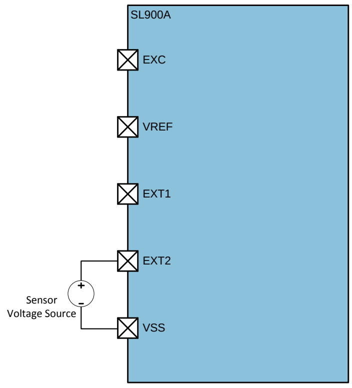
If default values for the AD reference voltages are used (VREF = 310mV, Vo1 = 0V), then the equation can be simplified to:

$$I_D = \frac{AD_{CODE} * 302.7 * 10^{-6} - 0.175}{R_f}$$

5.3 Voltage Output Sensor

A voltage source output sensor can be connected to the EXT2 pin. This can be used for integrated sensors with an analogue output signal.

Figure 20: DC Voltage Source with serial Resistance (EXT2 = 1)

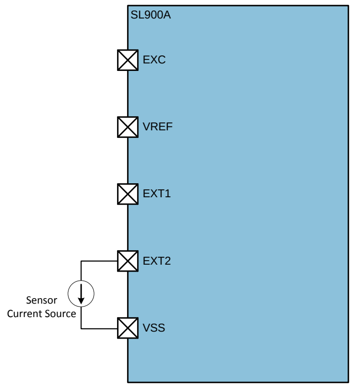


The voltage input range in this mode is the same as the AD converter voltage input range, as it is defined in section 3. The overall minimum voltage that can be measured on the external sensor inputs EXT1 and EXT2 is 260mV, the maximum is 1.22V. Those values depend on the selected VREF and Vo1 reference voltages.

5.4 Current Source Output Sensors

The EXT1 interface can also be used for external current source output sensors (figure below):

Figure 21: DC Current Source (EXT2 = 0)



For the sensor current calculation please refer to subsection **Error! Reference source not found.**

6 External Sensor Interface Settings

The external sensor interface is set up either with the SPI interface or with cool-Log™ RFID custom commands. The commands required for external sensor operation are:

- SET LOG MODE
- SET SFE PARAMETERS
- SET CALIBRATION DATA
- INITIALIZE

The SET LOG MODE command is used to setup various parameters required for the automatic logging process. If external sensors are used in the logging process, they have to be enabled with this command.

The SET SFE PARAMETERS command is used to set up the SFE functionality. The SFE can be used as an automatic range selection block, for sensors with a wide output range. It can also be used as a fixed gain preamplifier for sensors with a low output range. In this case the user application has to preset the range and enable the preset values. The preset range has to be selected in case the internal limits are used with an external sensor. The EXT1 interface gain is preset with the “seti [4:0]” field. The EXT2 gain is preset with the “rang [4:0]” field. The preset values are enabled with the “Autorange Preset” flag. The external sensor type “EXT1[1:0]” and “EXT2” can be set with the SET

SFE PARAMETERS command. This command is also used for selecting the sensor ("Verify Sensor ID") that will be used with the limits in out of limits logging mode.

The SET CALIBRATION DATA command is used to set up the supply switch for external sensors ("sw_ext_en") and to setup the interrupt voltage level for external sensors ("irlev[1:0]"). The external sensors can be supplied with the battery voltage from the EXC pin only during the conversion time. This will save power compared to a system where the sensor is supplied directly from the battery. This is especially useful for a resistive bridge sensor.

The INITIALIZE command is used to setup interrupt and timer logging modes in parallel ("IRQ + timer enable" flag). This special logging mode can be used for regular interval-based sensor sampling combined with the interrupt capability of the SFE.

7 External Sensor Interrupt

The external sensor interface can be used for sampling short events on the EXT1 and EXT2 pins. This can be used for shock sensors, acceleration sensors and other pulse response sensors. It is also useful for counting events on the external sensor pins. The sensors are pre-driven with a small current of 125nA and are constantly observed with a very low power comparator. The overall current consumption of the interrupt block is 0.5µA at room temperature. In case the sensor voltage exceeds the specified threshold ("irlev[1:0]"), the SFE will generate and IRQ request. This will wake up the whole system and the sensor data, together with the real time information, will be logged to the memory. The interrupt mode is selected with the SET LOG MODE command with the "Logging Mode[2:0]" field. The implemented IRQ modes are:

Figure 22: Interrupt Mode

Bit 2	Bit 1	Bit 0	Logging Form	Description
1	0	1	IRQ, EXT1	Interrupt triggered on the EXT1 external sensor input
1	1	0	IRQ, EXT2	Interrupt triggered on the EXT2 external sensor input
1	1	1	IRQ, EXT1, EXT2	Interrupt triggered on the EXT1and EXT2 external sensor input

Either of the 2 external sensor pads, or both of them, can be used for generating an interrupt. This function can also be used for button-triggered measurements, as the user selects which sensor will be logged during an interrupt event. The interrupt level can be selected by the application with the SET CALIBRATION DATA command ("irlev[1:0]"). The setting is valid for EXT1 and EXT2:

Figure 23: Interrupt Levels

Irlev [1:0] Bit 1	Irlev [1:0] Bit 0	EXT1 Capacitive – [pF]	EXT2 Resistive - [MΩ]	IRQ level - % of supply Bit voltage
0	0	> 500	< 3	< 25 %
0	1	> 160	< 1	< 8 %
1	0	> 115	< 4.2	< 35 %
1	1	> 290	< 5.2	< 43%

The IRQ threshold varies from chip to chip for a maximum of ±25% from its nominal specified value. The ratio between levels at different IRQ-level-CODE remains constant. The IRQ voltage levels are supply ratiometric.

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10 Revision Information

Changes from 1-03(2014-Sep-23) to 1-04 (2016-Mar-14)	Page
Corrected description of sensor connection type	11,13
Corrected formula in section 5.1	16

Note: Page numbers for the previous version may differ from page numbers in the current revision.
Correction of typographical errors is not explicitly mentioned.