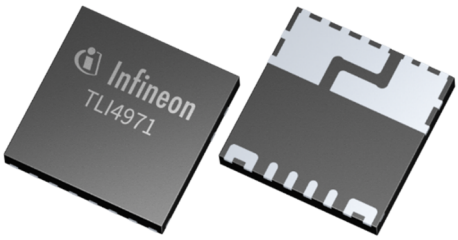
Current Sensor TLI4971

Programming Guide and User Manual



Infineon Coreless Current Sensor for high voltage industry applications

About this document

- This document describes how to program the TLI4971 with the Infineon proprietary one wire interface (SICI) to set different gain levels, over current thresholds, operating modes and further features described in the data sheet.
- Besides the timing of the serial inspection interface, the command structure and all possible commands for write read and EEPROM access are described in this document.
- A detailed description of the user changeable EEPROM bits are part of this application note.
- The document includes a programming example for changing the measurement range to ±120A full scale range by changing the parameter via the interface.
- Besides the document also describes application circuits for three phase systems as they are typically used in inverter and motor control applications.
- In order to allow in circuit programming of the sensor in an application the document gives a recommendation how to protect a micro controller against the required programming voltage of 20.6V.
- In addition, there is also a description of the different operating modes and the OCD functionality.
- Since the TLI4971 has also implemented an internal diagnostic mode this application note also describes how to trigger the diagnosis mode and how to interpret the output pattern.

Scope and purpose

TLI4971 Coreless Current Sensor Feature set, EEPROM and interface description.

Intended audience

- Users who use the high variety of the TLI471 current sensor by programming the functionality like full scale or over current detection, operating modes etc. to their need.
- Current Sensor Module Developers.

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1 Application and Programming circuit

The sensor supports a variety of output modes as well as measurement ranges. Also the threshold and blanking time of the over current channels can be programmed. Therefore, the device has implemented a serial interface to set the EEPROM content of each sensor separately. This chapter describes the hardware implementation to program the device. Further, it shows the recommended circuit for a three-phase GPD application.

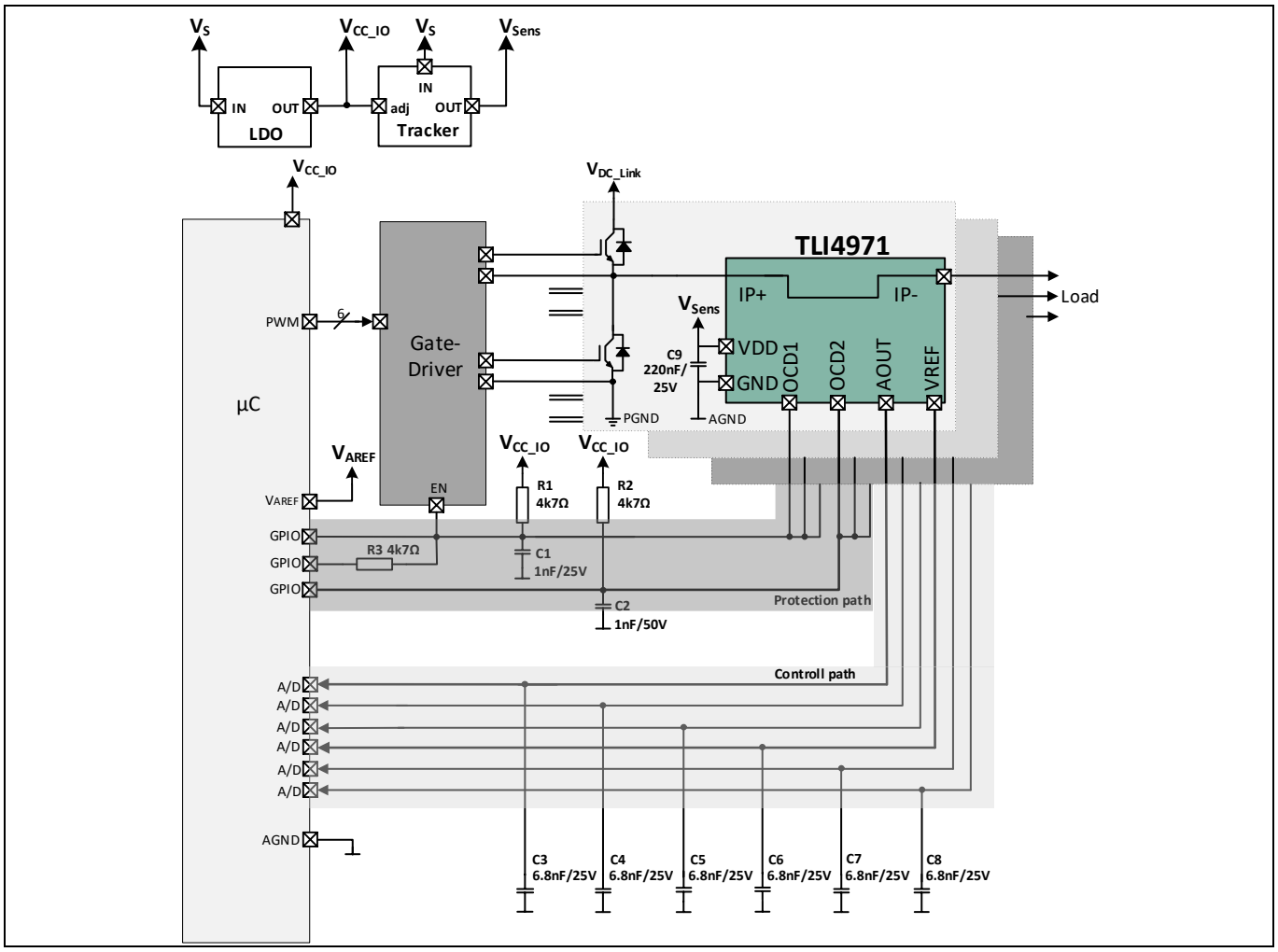

Figure 1 TLI4971 3-phase GPD application circuit for semi and or fully- differential mode

Figure 1 shows the recommended circuit for a three-phase GPD application. As shown in the figure, the sensor provides a control as well as a protection interface. The protection functionality is covered by two open drain outputs (OCD1 and OCD2) to indicate an overload and to protect the system in case of an over current event. In case of an over load the OCDs will indicate an over current event in less than 1µs. The OCD1 output is typically connected to the enable input of the HV gate-driver to de-activate the IGBT in case of an over current event. The second open drain output OCD2 is connected to an interrupt input of the microcontroller. The threshold of the OCD2 is typically set below the threshold of the OCD1 to enable a pre-warning in case of an over load event. For controlling purpose, the AUOT and VREF are connected with the analog to digital converter of a microcontroller or FPGA.

In-circuit programming of the sensor device can be done with an external programmer. It is also possible to access the EEPROM without an external programmer by using the GPIO pin of the controller or FPGA used in the current sensing application to establish a communication with the sensor.

1.1 Circuit / Precondition

- Each device can be set separately via the SICI-one wire interface.
- In order to communicate with the sensor via the SICI one wire interface the AOUT lines of each sensor has to be connected with a microcontroller or FPGA. Figure 3 shows a simple drawing how to connect the relevant pins to enable an in-circuit communication between the sensors and a microcontroller.
- In order to use an external programmer, a programing connector has to be linked with each A_{OUT} pin to establish a communication to the sensors.
- As a first step of the programming procedure, the parameter has to be downloaded into the volatile memory area of the sensor via the SICI interface.
- As a second step of the programming procedure, the parameter needs to get stored into the non volatile memory (EEPROM) by sending the programming command via the AOUT pin and applying the programming voltage of 20.65V on OCD2 pin.
- Therefore, the OCD2 needs also to be connected to the programming connector in order to apply the programming voltage to the device.
- In order to enter the interface the controller needs to enable a power down of the sensor. Therefore, also the sensor supply needs to be controlled by the programmer.

1.2 In-circuit programming with external Programmer

This chapter shows the hardware implementation for a programming connector to be used with an external programmer in order to program the sensors.

To enter the sensor's interface a control of the sensor supply is necessary to enable a controlled power down of the sensor. Therefore, the sensor supply must be accessible by an external controller. Beside the OCD2 and the AOUT pin must be connected to an external programmer.

The sensor's non-volatile memory (EEPROM) can be accessed with a bidirectional one-wire interface. Therefore, the sensor features a digital interface via the AOUT pin. In order to program the EEPROM the AOUT pin is used as programming pin to apply the particular programming sequence. After sending the programming sequence, an assertion of the programming voltage is required. The 20.5V – 21V programming voltage needs to be applied on the OCD2 pin. It is not possible to reprogramming the sensor without sending the according programming sequence via the AOUT pin before. Therefore, the OCD2 can be tied together because each sensor will receive their individual data set via the separated AOUT pin connection. The programming voltage can then be applied to all sensors in parallel considering the max current consumption. Find a detailed programming example in the chapter 4.2.

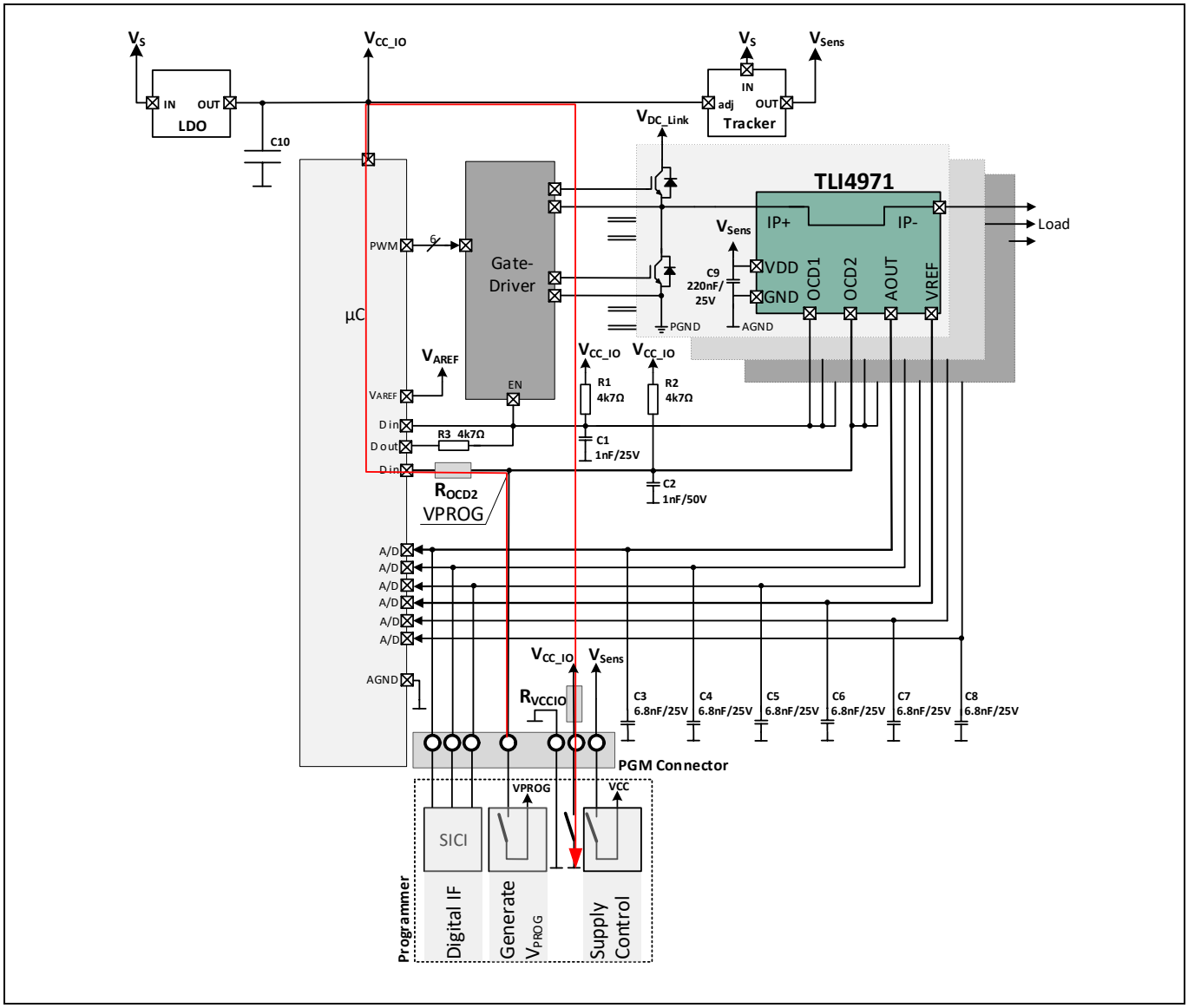

Figure 2 External Programmer connected to GPD application circuit (TLI4971 in-circuit-programming)

Figure 2 shows the recommended circuit for a three-phase GPD application with the required add-on circuit to enable in-circuit programming.

- A programming connector needs to be linked to each AOUT pin of the sensor to access the digital interface.
- In addition, also the OCD2 pin needs to be linked to the connector to apply the programming voltage.
- The senor supply also needs to be connected to the programmer in order to allow a controlled power down of the sensor.
- The serial resistors R_{OCD2} and R_{VCCIO} are recommended to avoid a current feedback into the supply and to avoid possible high floating of the µC supply.

Figure 2 shows the overall programming circuit including the µC supply, the tracker and the programmer. The high voltage assertion during programming may cause a current feedback into the supply rail of e.g. the µC. This can happen when the µC does not pull-down the pin or a needle prober would keep the line to 3.3V or the rail current consumption is lower than the current via the series resistor R_{OCD2}. If this can happen, a protection-circuit is required. Figure 2 shows the recommended series resistors to avoid a feedback current into the supply.

- Therefore, the resistors R_{OCD2} and R_{VCCIO} have to be determined as described in following formula.
- $\frac{V_{CCIO}}{R_{VCCIO}} > \frac{V_{PROG}-V_{CCIO}}{R_{OCD2}}$ | $R_{OCD2} = 10\text{k}\Omega$ $R_{\text{VCCIO}} = 330\Omega$
- Alternatively, the OCD2 channel can be connected with a pull down resistor to GND while applying the programming voltage on the OCD2 pin as shown in Figure 4.

1.3 In-circuit programming w/o external Programmer

This chapter describes the hardware implementation allowing in-circuit programming of the device without an external controller.

As mentioned before the device features a digital interface to access the sensor's memory, which can be accessed via the AOUT pin. To enter the interface the senor supply needs to be controlled to enable a power-down respectively power on of the device. To store the data into the non-volatile memory of sensor a programming voltage has to be applied (20.5 – 21V) on the OCD2 pin. Therefore, the following has to be considered:

- Connect the AOUT pin of each device with a GPIO port.
- For a proper communication between the sensor and the controller, the GPIO pin shall support open drain as well as push pull functionality. (The GPIO port mode has to be changed several times during a communication.)
- While sending data to the sensor the GPIO pin shall be set into push-pull mode. While reading data from the sensor the GPIO pin shall behave in open drain mode.
- To program the content of the register into the non-volatile memory (EEPROM) a programming voltage of 20.5V – 21V has to be applied on the OCD2 pin.
- The microcontroller shall control the programming voltage.
- The high voltage assertion of the programming voltage might cause a current feedback into the supply rail of e.g. the µC. If this can happen, protect the µC against possible high floating voltage by connecting the OCD2 pin to GND. Figure 3 shows an optional BRT to connect the OCD2 to GND while applying the programming voltage to the device preventing the µC supply to float high.
- The microcontroller shall control the sensor supply in order to meet the correct timing to enter the interface. A controlled power-down respectively power-on of the sensor's supply is required to enter the interface. A suggested circuit can be seen in Figure 3.

A detailed programming example is described in the chapter 4.2.

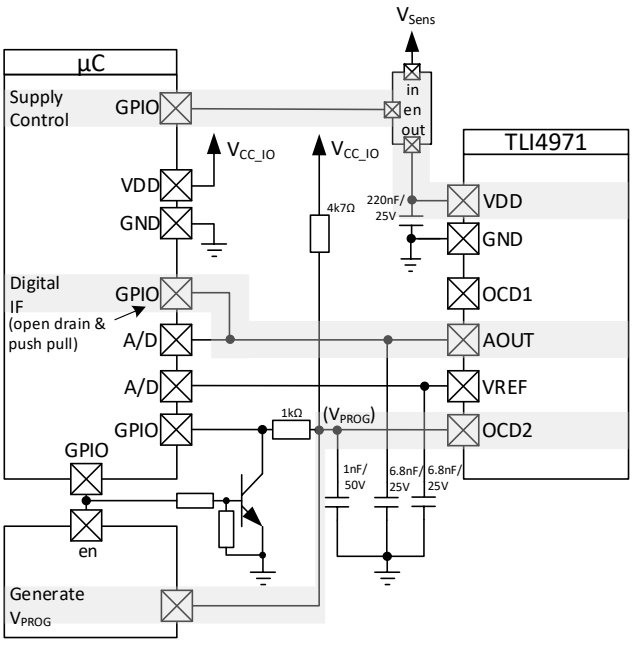

Figure 3 TLI4971 In-circuit programming without external programmer

2 Serial Inspection and Configuration Interface (SICI)

The sensor features a digital interface (SICI) to access the internal EEPROM. Connect the AOUT pin to a GPIO port in order to establish a communication between the sensor and the controller. The SICI interface is a 16bit bidirectional one wire interface. The protocol specification and command structure is described in this chapter.

2.1 Hardware Implementation

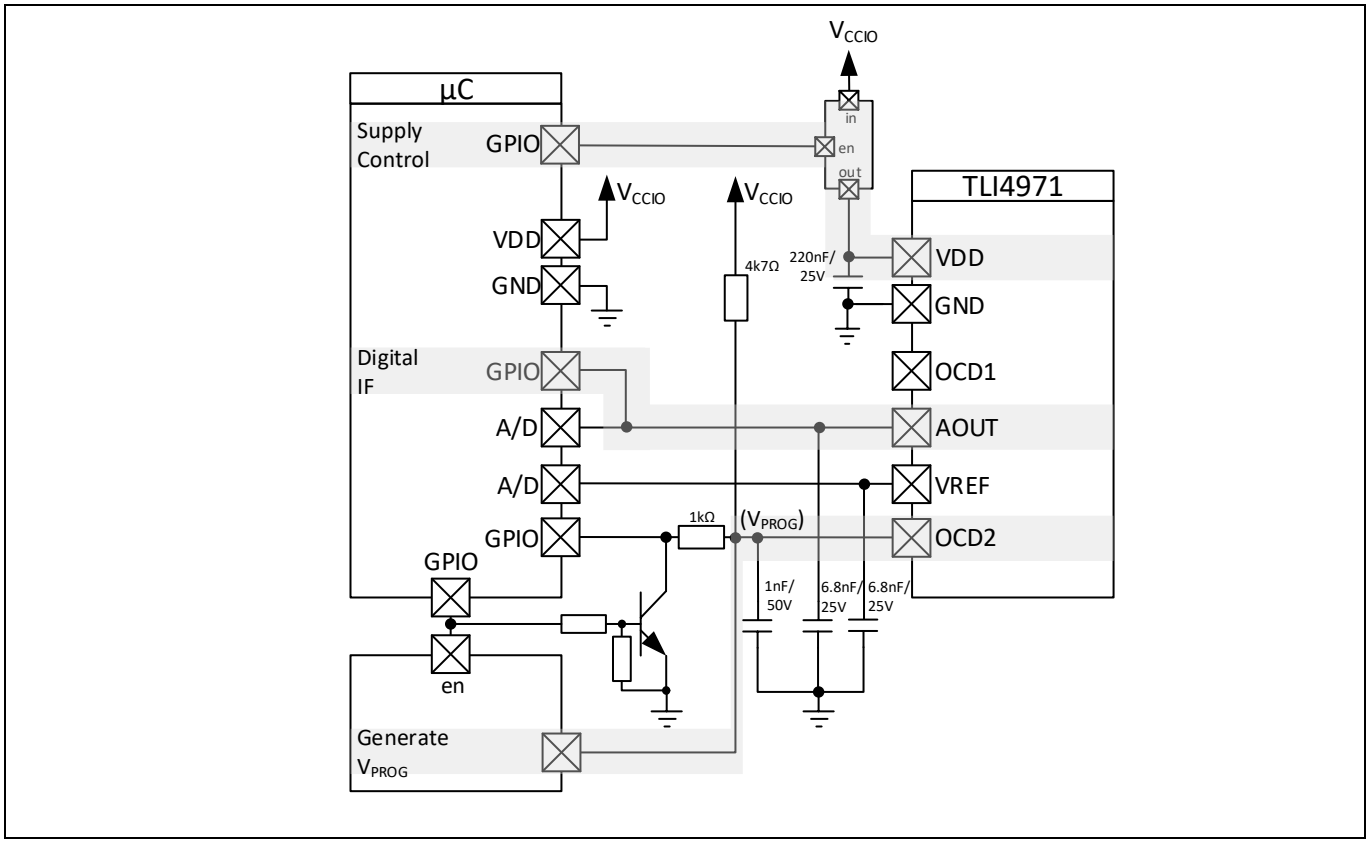

Figure 4 SICI application circuit

- Figure 4 shows the application circuit to communicate with the TLI4971 current sensor.
- In order to change the EEPROM values the sensor features a digital interface, which can be accessed by a microcontroller via the AOUT pin. Therefore, the microcontroller needs to drive the AOUT pin to GND to modulate the pin according to the SICI protocol description.
- For communication, it is necessary that the AOUT have to be connected to a GPIO port of a microcontroller.
- To activate the interface the AOUT has to be forced to GND after the sensor startup.
- Therefore, the external controller shall control the sensor supply to meet the correct timing and to allow a successful interface activation.
- The communication is based on transmitting a bit stream to the sensor driven by an external controller. For this interface, the AOUT pin is used as an I/O pin to read from the device and to write the EPPROM of the device by forcing the pin with a defined timing.
- The interface timing specification is shown in Table 1 and described in Figure 6 and Figure 7.

2.2 Entering Communication Mode

After or while suppling the sensor, the A_{OUT} pin has to be forced to GND to enter the interface mode of the device. Figure 5 shows the “interface enable time” t_{IFen} which is the valid time window to enable the SICI interface. Therefore, it is important to control also the device supply to meet the correct timing after supplying the sensor. The output buffer of the sensor keeps the AOUT pin to VDD (open drain with internal pull up) within the first 400µs after supplying the device. The A_{OUT} pin has to be driven by an external controller to GND for t_{low} time in between the defined time window t_{IFen}. This low state has only to be present once after start up to allow the device to receive the 16 bit enter interface command. The activation will also work if the A_{OUT} stays at ground from the beginning onwards. There is no need to set the A_{OUT} to V_{DD} before forcing it to GND. Figure 5 shows the modulation of the AOUT pin while enabling the interface after supplying the sensor.

While sending the enter-interface-command, the device answers to each sent bit with logic “0” as shown in Figure 5.

After a correct enter-interface-command has been sent out, the AOUT pin will remain at V_{Sens} (open drain).

If the interface activation is unsuccessful then the A_{OUT} pin will reflect the quiescent voltage.

To enable the access to the sensor memory the internal intelligent state machine (ISM) needs to be disabled with a dedicated command like described in chapter 0.

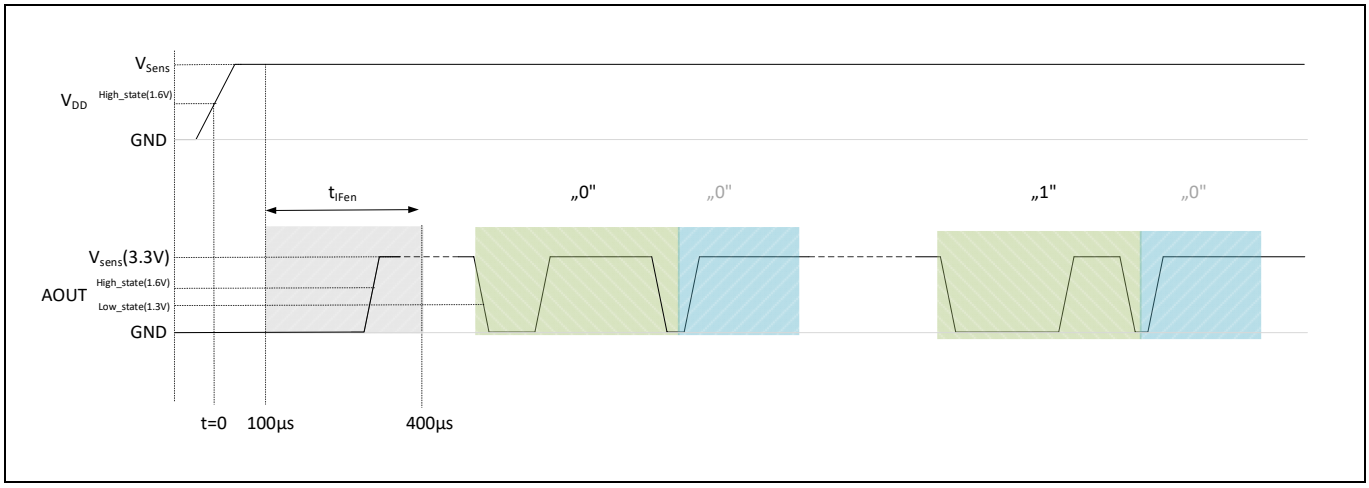

Figure 5 Enabling SICI interface after device start up

2.3 Communication timing

This describes the timing of the AOUT pin to ensure a correct communication between the sensor and a microcontroller. To set the A_{OUT} to low state, force the A_{OUT} to GND from an external micro controller or FPGA.

- By default, the device drives the AOUT to high state except during response time depending on the sent data (open drain).
- The GPIO for the AOUT pin to set the A_{OUT} to high state, the external controller must support tri state.
- Force the A_{OUT} to GND within the first 400µs after power on to activate the interface.
- After releasing the A_{OUT} back to V_{Sens}, send the 16-bit enter-interface-command with LSB first from controller. Figure 5 shows the LSB and MSB of the enter-interface-command.
- In the Figure 5, the green highlighted squares indicate the received bit while the blue highlighted squares indicate the bits sent by the sensor.

2.3.1 Single low/high PWM transmission

For a single low/high PWM transmission, the duty cycle shall be at least 30/70 or 70/30.
– Logic “0” is sent as a short low and long high PWM pulse
– Logic “1” is sent as a long low and short high PWM pulse

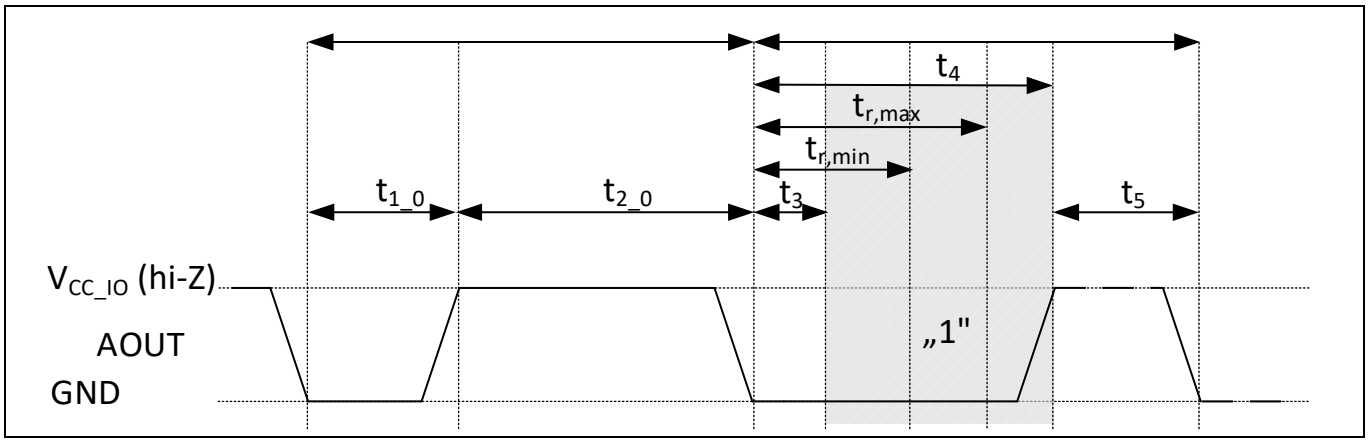

Figure 6 SICI duty cycle; sending logic '0' to the device; receiving logic '1' from the device

- The initial pulse length t_1 & t_2 in Figure 6 and Figure 7 determines the write sequence. The read-out time t_4 is marked with a grey square shown in Figure 6 and Figure 7
- Table 1 describes the interface timing. An example of a 1-bit transmission sending a logic ’0’ to the device by receiving a logic ’1’ can be seen in Figure 6.
- Figure 7 shows an example of a 1-bit transmission sending logic “1” to the device by receiving logic “0”.
- When sending a logic “0” to the device the low time t_1 has to be shorter than the high time t_2.
- The timing of the read sequence t_4 is depending on the low time t_1 and high time t_2 as described in Table 1.
- Perform a read access at half of the t_4 time window. Figure 6 shows the voltage level of the AOUT pin while sending a logic “1” bit. Figure 7 shows the voltage level of the AOUT while sending a logic “0”.
- The grey squares in Figure 6 and Figure 7 mark the time window when reading shall be performed by a microcontroller or FPGA. During the reading time, the master shall not drive the AOUT pin.

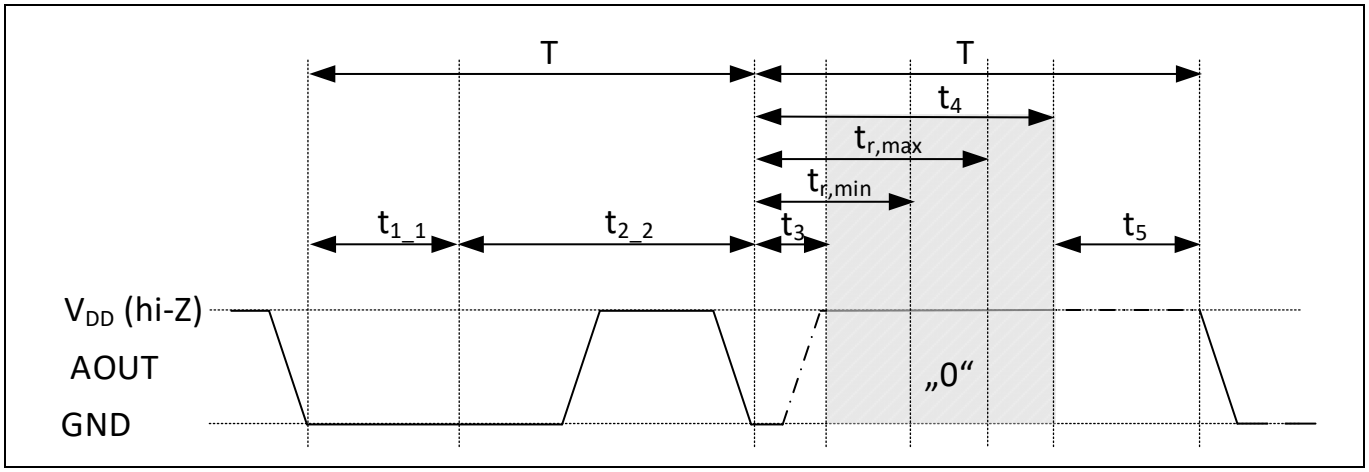

Figure 7 SICI duty cycle; sending logic '1' to the device; receiving logic '0' from the device

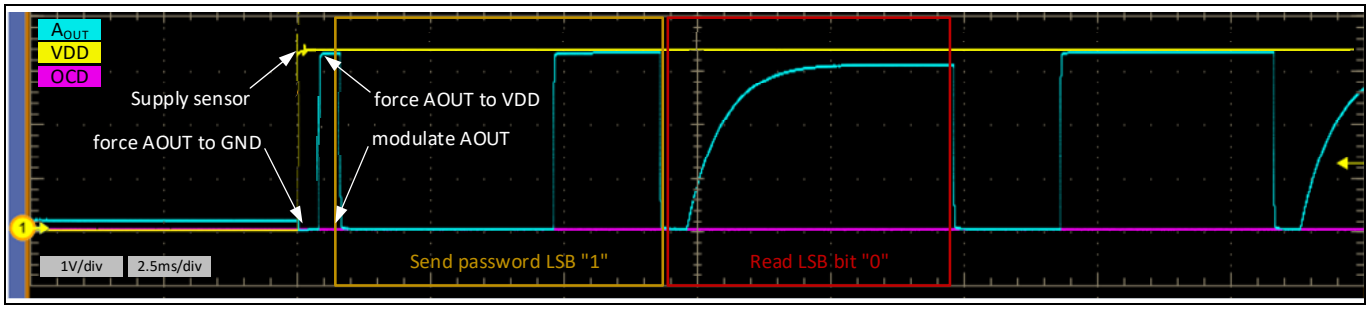

Figure 8 SICI enter interface sequence

Figure 8 describes the interface activation by modulating the AOUT after startup. The modulation of the first two password bits can be seen in the oscilloscope picture.

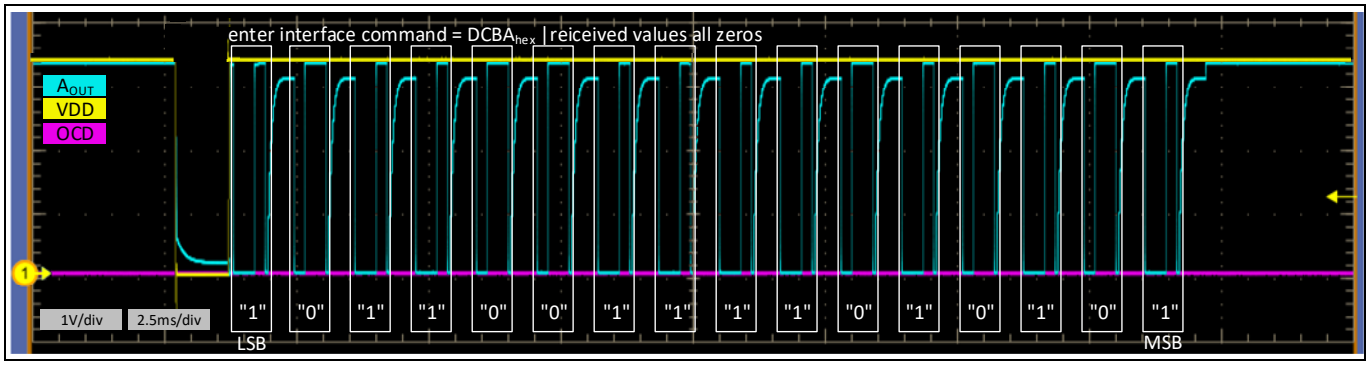

Figure 9 SICI enter interface command

- Figure 9 shows the oscilloscope picture of the enter interface command to activate the sensor interface after performing the startup sequence.
- The oscilloscope pattern shows the PWM-modulation of each sent bit followed by the answer bit.
- After sending the enter interface command the next falling edge of the AOUT will start the subsequent 16bit commands.
- After sending a 16bit command, the A_{OUT} is still driven high by the device.
- To perform a high state the AOUT shall be set to tri state. Especially during the response phase, the A_{OUT} shall be set to tri state because the sensor needs to drive the A_{OUT}.

Table 1 shows the defined timing for the SICI interface. There is no timing restriction between two commands.

2.4 Interface Timing Definition

Table 1 describes the SICI interface timing.

Table 1 Interface timing

Parameter	Symbol	Min.	Typ.	Max.	Unit	Notes
Interface enable time	t_{IFen}	100	150	400	µs	Drive AOUT to GND
Period time of 1 bit	T	40	t_1+t_2	7500	µs	One communication frame consist of 16 x 2 bits (16bits write / 16bits read)
Low time sending 0	t_{1_0}	28	33	38	% of T	Drive A_{OUT} to GND
Low time sending 1	t_{1_1}	62	67	72	% of T	The device drives A_{OUT} to V_{DD} by default.
High time sending 0	t_{2_0}		$T-t_{1\_0}$		µs	Drive A_{OUT} to GND
High time sending 1	t_{2_1}		$T-t_{1\_0}$		µs	The device drives A_{OUT} to V_{DD} by default.
Low time before read	t_3	10	-	30	% of t_4	Drive A_{OUT} to GND $t_4 = 2 * ABS(t_{1\_x} - t_{2\_x})$ t_3 can be set as applicable. Increase of t_3 will reduce sensor response time t_4. Therefore t_r has to be set accordingly
Reading time	t_r	50	-	80	% of t_4	The device drives A_{OUT} to V_{DD} by default. Set the external controller in tri state.
Response time	t_4	2 abs(t_{1_x}-t_{2_x})	-	-	µs	t_3 can be set as applicable. Increase of t_3 will reduce the response time t_4.
Time between 2 bits	t_5	1	$T-t_4$	5400	µs	
Max high time	t_{high}	1	-	5400	µs	Only valid for a single bit high time. There is no restriction in timing between two commands
Min low time	t_{low}	1	-	5400	µs	

- There is no timing restriction between two commands as long as the AOUT pin is not driven to GND.
- The typical threshold level to detect a logic “0” during a high to low transition is 1.3V.
- The typical threshold level to detect a logic “1” during a low to high transition is 1.6V.

Interfaces enable time
The interface enable time t_{IFen} defines the time window to force the A_{OUT} pin to GND after start up to enable the interface communication via SICI.

Period time of 1 bit
The period time defines the time to transmit 1 bit between the device and a micro controller. One communication frame consists of 16 write and 16 read bits.

Low time sending 0
The t_{1_0} defines the first low time of a bit. The low time has to be shorter than the next high time to send a logic 0 bit to the device. Every bit has to start with a low time.

Low time sending 1
The t_{1_1} defines the first low time of a bit. The low time has to be longer than the next high time to send a logic 1 bit to the device. Every bit has to start with a low time.

High time sending 0
The t_{2_0} defines the first high time after the low time of a single bit. In order to send a logic 0 to the device the high time has to be longer than the previous low time.

High time sending 1
The t_{2_1} defines the first high time after the low time of a single bit. In order to send a logic 1 to the device the high time has to be shorter than the previous low time.

Low time before read
The A_{OUT} pin has to be forced to GND after the first high time of a transmitted bit to initiate the reading sequence. This low time is described by t_3.

Response time
During this time, the A_{OUT} pin is driven from the device. Therefore, the A_{OUT} pin shall not be driven by the master. The device drives the A_{OUT} either to GND or V_{DD} as described in Figure 6 and Figure 7. The A_{OUT} pin level shall be read by the master in the defined time window to receive the answer. The data from the device shall be read between 50% and 80% of the response time (t_r).

Time between two bits
The maximum high time between two bits is limited by the maximum allowed high time. By exceeding the maximum high time, the interface is deactivated and can only be entered after restarting the device.

Max high time
If A_{OUT} stays at V_{DD} longer than the defined max high time t_{high}, the SICI communication is closed and the sensor starts working in the defined operating mode. To start a new communication the sensor shall be powered off and on again.

Min low time
If A_{OUT} stays at GND longer than the defined max low time t_{low} the SICI communication is closed and the sensor starts working in the defined operating mode. To start a new communication the sensor shall be powered off and on again.

2.5 Definition of Voltage Levels

The SICI interface voltage levels and the voltage level to program the EEPROM are specified in Table 2.

Table 2 SICI High and low level definition

Parameter	Symbol	Min.	Typ.	Max.	Unit	comment
Voltage level for SICI – High	V_{SICI_High}	1.6	3.3	3.5	V	high state (transition from low to high)
Voltage level for SICI – Low	V_{SICI_Low}	1.3	0	3.5	V	low state (transition from high to low)
EEPROM programming Voltage	V_{PROG}	20.5	20.6	20.7	V	
OCD2 current consumption	I_{OCD2}	-	6	10	mA	Current consumption during applying the programming voltage on OCD2.

3 Interface description

3.1 Command Structure

A typical SICI communication consists in multiple input commands sent to the device via AOUT voltage modulation, to which the sensor responds modulating the AOUT pin voltage between GND and VDD.

An input command is composed of 16 bits LSB first. One bit consists of a transmission sequence initiated by the master and a receiving sequence driven by the device. The reply data stream sent by the device starts with the LSB.

A typical communication consists of a command including the access information and address sent by the master to the device. The device replies with the data, which has been addressed by the former received command.

The upper nibble of the command include the access information. The MSB has to be set to '1' to perform a write command. To send a read command the MSB has to be set to '0'. Depending on the two LSB of the upper 4 bits, the sent data will be set in the addressed register.

Table 4 describes the usage of the access bit.

Table 3 describes the command structure. Depending on the access bit, the device interprets the received data as either a write or a read command.

Table 3 SICI Command structure

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	LSB
w/r	0	Ac1	Ac0	Ad7	Ad6	Ad5	Ad4	Ad3	Ad2	Ad1	Ad0	0	0	0	0

Table 4Access bit description

w/r	Ac1	Ac0	description
1	0	X	Set ones and zeros like the sent 16 bit data word
1	1	0	Set only the sent zeros. The ones will not be set
1	1	1	Set only the sent ones. The zeros will not be set

3.2 Interface Commands

Table 5 Available Commands

Command name	address$_{hex}$	command$_{hex}$	description
Enter Interface command	---	ABCD$_{hex}$	Activate communication as described in chapter Entering Communication Mode
Power down ISM	25$_{hex}$	8000$_{hex}$	reserve if-access to the EEPROM data bus to avoid that ISM is blocking the data bus
Disable failure indication	02$_{hex}$	0000$_{hex}$	Prevent unintended activation of the OCD2 output
Write command	40$_{hex}$ to 42$_{hex}$	8400$_{hex}$	Initialize Write command to address 40$_{hex}$
Send values		XYXY	send data XYXY to previous addressed line where XYXY stand for 16bit data placeholder
Read command	40$_{hex}$ to 51$_{hex}$	0400$_{hex}$	Initialize read command at address 40$_{hex}$
Read command	41$_{hex}$	0410$_{hex}$	Initialize read command at address 41$_{hex}$ read data from previous address 40$_{hex}$
Read command	51$_{hex}$	0510$_{hex}$	Initialize read command at address 51$_{hex}$ read data from previous address
NOP		FFFF$_{hex}$	No operation command, to read former addressed values.
EEPROM set all zeros	3E$_{hex}$	0248$_{hex}$	Set all EEPROM bit to zero
EEPROM set all ones	3E$_{hex}$	024B$_{hex}$	Set all EEPROM bit to one
EEPROM refresh	3E$_{hex}$	024C$_{hex}$	Refresh the all EEPROM lines
EEPROM program zeros	3E$_{hex}$	024E$_{hex}$	Program all set zeros into EEPROM
EEPROM program ones	3E$_{hex}$	024F$_{hex}$	Program all set ones into EEPROM

3.3 Read Command

There is always a delay of one command between the request command and the addressed data. When a new read command is sent to the sensor, the device replies with the data requested with the former command. Therefore, two commands have to be sent to read one address. A read sequence consists of the read command with the requested address followed by a second command to receive the previous addressed data. The second command can either be a read or write command to address the next line. The NOP command terminates a read sequence without initializing a new read or write sequence. Every command replies with the previous addressed data except the enter interface command. While sending the enter interface command the device replies with all zeros.

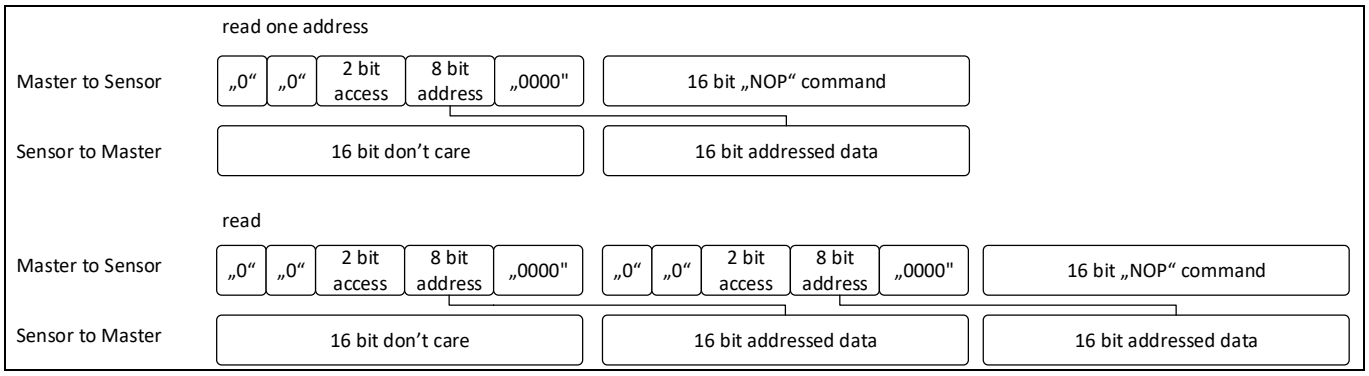

Figure 10 SICI read sequence

3.4 Write Command

To perform a write command in order to change register values in the device the MSB of the command has to be set to one as described in Table 4. After each write command, the device is expecting further 16 bit of data. To perform an EEPROM command send a write sequence to the device. A write sequence consists of two 16 bits data sets. Before sending the 16 bits command data, send the write command with the according address and access information to the device.

Table 5 describes the EEPROM commands, which have to be send to their corresponding addresses.

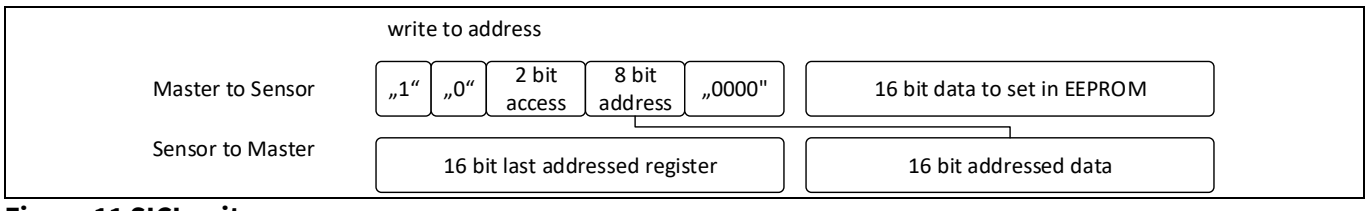

Figure 11 SICI write sequence

3.5 Write and programming sequence

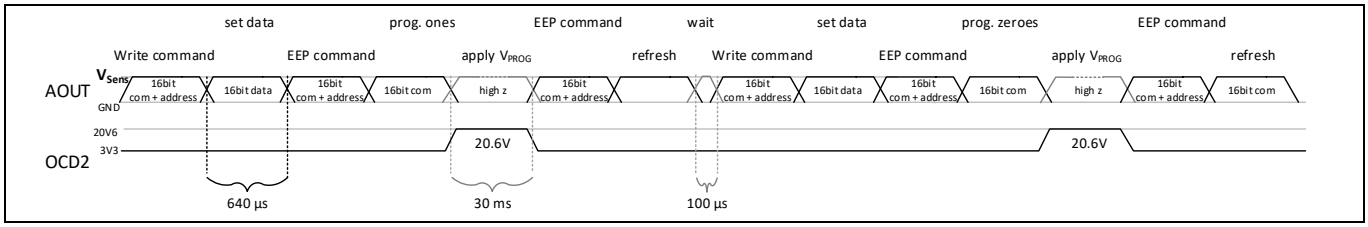

Figure 12 Programming Seequence

Figure 12 shows the command sequence for a write command and describes the sequence to program the EEPROM.

- A command always consists of a 16bit command which also includes the address followed by 16bit data
- After writing the values into the EEPROM, the programming voltage has to by applied for 30ms to program the values.
- After programming, a refresh command shall be performed as shown in Figure 12.

3.5.1 Temporary register

- For test purpose, it is possible to change the sensor settings in the temporary registers. This allows testing all user access able settings without applying the programming voltage to the sensor.
- It is not possible to store the content of the temporary registers in to the EEPROM.
- It is not recommended to write into the temporary register to change sensor settings to be used in normal operating mode.
- The addresses for the temporary registers are different from the EEPROM addresses. Table 1 shows the correlating address for the temporary and EEPROM registers.
- In order to get access to the register send 0x8000 to address 25_{hex}.
- To temporary disable the CRC-check, set the register 1_{hex} to 0x0000.
- Set the register 25_{hex} to 0x1000 to leave the interface mode and to change into normal operating mode.
- After the sensor remains in operating mode until the next power down.
- The sensor uses the content of the temporary registers instead of the correlating EEPROM values until the next power down.

Table 6 Temporary register description

Temporary register address	EEPROM register address	Note
25_{hex}	-	Write 0x1000 to this address to get access to the register (otherwise the registers gets occupied / overwritten by the sensor)
01_{hex}	-	Write 0x0000 to temporary disables failure indications like CRC check.
17_{hex} [1)]	40_{hex}	Bit description and bit position same for both addresses
18_{hex} [1)]	41_{hex}	Bit description and bit position same for both addresses
19_{hex} [1)]	42_{hex}	Bit description and bit position same for both addresses

1) Change values in temporary registers for test purpose only. Please refer to bit description of corresponding EEPROM address.

3.6 Read Example (temperature register read out)

The accurate and linear temperature value can be read out via the SICI interface. The following example describes the required command sequence to enter the interface and to read out the 16 bit temperature value. In the following table the commands with the correct timing order and the required minimum time for each command respectively sequence are listed. The temperature sensitivity is set to a sensitivity of 16LSB16/°C. The ADC value for 25°C corresponds to .1408LSB16. The following formula describes how to calculate the temperature dependent on the 16bit value.

$$Temperature = \frac{ADC_{value} - 2048}{16} + 65$$

Table 7 Command sequence example to read out the internal 16 bit temperature value

Command / sequence	minimum frame time	Description
$ABCD_{hex}$	0.64ms	Enter interface command (sending 16bit reading 16bit)
Write command to address 25_{hex}	0.64ms	Power down ISM (write to address 25_{hex})
8000_{hex}	0.64ms	Power down ISM (write data)
Read command at address 18_{hex}	0.64ms	Sending the address to read the temperature value
$FFFF_{hex}$	0.64ms	Reading the data by sending the next command or sending the NOP command. In case of sequential read out the data can be received every 1.28 ms.
Power on and off the device to activate normal operating mode. (1.5ms typical after power on) Alternatively set the device in normal operating mode by sending the following commands:		
Write command to address 25_{hex}	0.64ms	Power on ISM (write command to address)
1000_{hex}	0.64ms	Power on ISM (send data)
Wait until the A_{OUT} settles back into calibrated mode. In calibrated mode, the A_{OUT} reflects the voltage level of the V_{REF} pin. Assumed no current flows through the primary current rail of the device.		

4 EEPROM

The sensor's non volatile memory (EEPROM) is organized in 16-bit (word) registers which can be addressed individually. The storage space is separated into two areas, a user area with allows read/write access and a reserved area with read access only.

When content in the user area is reprogrammed, a CRC check register has to be updated. Since the EEPROM CRC is calculated covering the entire EEPROM storage space, the user is required to readout the entire EEPROM content, calculate the new CRC values and store it into the respective registers. An incorrect CRC value will be detected by the sensor and cause a transition to its safe state. In case of a CRC error the OCD open drain output will be set to GND.

This chapter gives an overview of the programmable content of the current sensor. Figure 13 shows the structure of the EEPROM. The addresses indicated in green are accessible for the user and can be set to according to individual application requirements. All 17 lines of the EEPROM are readable because the CRC calculation has to be done with the complete data content of the EEPROM. The device is doing a cyclic redundancy check (CRC) of the EEPROM content while accessing the EEPROM and indicates an error on the OCD pin in case of a wrong programmed CRC. Therefore, program the CRC according to the EEPROM content. This safety feature protects the sensor to load EEPROM values which are has been programmed unintended. A detailed description of the user accessible content is described in this chapter. The CRC calculation procedure explained in detail at the end of this chapter.

A programming example shows how to use the EEPROM commands to program the sensor to the user needs.

Address	15	14	13	12	11	10	09	08	07	06	05	04	03	02	01	00
40_{hex}	Customer accessible settings								Customer accessible settings							
41_{hex}	Customer accessible settings								Customer accessible settings							
42_{hex}	Customer accessible settings								Customer accessible CRC							
43_{hex}	read only								read only							
...	read only								read only							
51_{hex}	read only								read only							

Figure 13 EEPROM overview

- The EEPROM consist of 18 lines. Each line consists of 16 bit.
- The lower 8 bits of address 42_{hex} are used for the CRC value to protect the EEPROM with a cyclic redundancy check.

4.1 EEPROM Content

Table 8 EEPROM (address 40_{hex} – 42_{hex})

address	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
40_{hex}	$OCD2_{en}$	$OCD1_{en}$	$OCD2_{deglitch}$				$OCD1_{deglitch}$			OP_{mode}		$MEAS_{rng}$				
41_{hex}	$OCD2_{thrsh}$						$OCD1_{thrsh}$					OCD_{comp_hyst}				
42_{hex}	$RATIO_{Off}$	$RATIO_{Gain}$	$OCD2f_{only}$	$QV1V5_{sd}$	Empty	$VREF_{ext}$				CRC						

Table 9 EEPROM Address 40_{hex}

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
$OCD2_{en}$	$OCD1_{en}$	OCD2deglitch				OCD1deglitch			OPmode		MEASrng				

Table 10 Functional description Address 40_{hex}

Bit field name	Bit	Type	Bit field description	Default value
$MEAS_{rng}$	4:0	rw	The measurement range bits define the sensitivity in mV/A according to Table 4 described in the data sheet The standard setting is S1 as described in the data sheet. Further information are listed in Table 15	00101
OP_{mode}	6:5	rw	The operating mode can be set according to Table 15 The device standard setting is the semi-differential mode	00
$OCD1_{deglitch}$	9:7	rw	The deglitching time of the over-current channel 1 can be set according to Table 15. The device standard setting is 0 (no additional delay)	000
$OCD2_{deglitch}$	13:10	rw	The deglitching time of the over-current channel 2 can be set according to Table 15. The device standard setting is 0 (no additional delay)	0000
$OCD1_{en}$	14	rw	The over-current detection enable bit 1 activates the over-current functionality of channel 1. If this bit set to zero the OCD pin 1 will not indicate an internal failure or an over-current event. The standard setting is 1 = enabled	1
$OCD2_{en}$	15	rw	The over-current detection enable bit 2 activates the over-current functionality of channel 2. If this bit set to zero the OCD pin 2 will not indicate an internal failure or an over-current event. The standard setting is 1 = enabled	1

Table 11 EEPROM Address 41_{hex}

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
$OCD2_{thrsh}$						$OCD1_{thrsh}$						OCD_{comp_hyst}			

Table 12 Functional description Address 41_{hex}

Bit field name	Bit	Type	Bit field description	Default value
OCD_{comp_hyst}	3:0	rw	Over-current detection hysteresis setting. Settings are listed in Table 16	0111
$OCD1_{thrsh}$	9:4	rw	The threshold level of the over-current detection channel 1 shall be set according to the set Full Scale (FS) in Table 15. The OCD settings are described in Table 16	100101
$OCD2_{thrsh}$	15:10	rw	The threshold level of the over-current detection channel 2 shall be set according to the set Full Scale (FS) in Table 15. The OCD settings are described in Table 16	100011

Table 13 EEPROM Address 42_{hex}

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
$RATIO_{Off}$	$RATIO_{Gain}$	$OCD2f_{only}$	$QV1V5_{sd}$	$VREF_{lp}$	$VREF_{ext}$			CRC							

Table 14 Functional description Address 42_{hex}

Bit field name	Bit	Type	Bit field description	Default value
CRC	7:0	rw	The calculation of the EEPROM is performed byte by byte, starting from address 42_{hex}. After reaching the end of the EEPROM (address 51_{hex}), the address 40_{hex} to 41_{hex} are appended. The CRC calculation is based on the polynomial $x^8+x^4+x^3+x^2+1$	--------
$VREF_{ext}$	10:8	rw	The external VREF bits have to be set according to Table 17 depending on the external applied reference voltage on the VREF pin. Standard is set to 1.65V	000
Empty	11	rw	Empty bit field	0
$QV1V5_{sd}$	12	rw	The bit enables the quiescent voltage to 1.5V in semi-differential. Default is 0 (=disabled)	0
$OCD2f_{only}$	13	rw	If the bit is set to one only failure indication is activated at the OCD2 channel. Over current detection is not activated if the bit is set to one. Default is 0 (= fault signal on both OCDs)	0
$RATIO_{Gain}$	14	rw	If the bit is set, the sensitivity is ratio metric to VDD respective to VREF in single-ended mode. Default is 0 (=disabled)	0
$RATIO_{Off}$	15	rw	The ratio-metric offset behavior of the quiescent voltage is activated if the bit is set to one. Default is 0 (=disabled)	0

Table 15 EEPROM bit field description address 40_{hex}

Bit field name	Description		
$MEAS_{rng}$	Symbol	Setting	Description / Full Scale setting
	S1	05_{hex}	±120A Full Scale (FS) / 10mV/A standard setting
	S2	06_{hex}	±100A / 12 mV/A
	S3	08_{hex}	±75A / 16 mV/A
	S4	$0C_{hex}$	±50A /24 mV/A
	S5	10_{hex}	±37.5A / 32 mV/A
	S6	18_{hex}	±25A / 48 mV/A
OP_{mode}	Symbol	Setting	Description
	SD bid	0_{hex}	Semi-differential bidirectional V_{OQbid_1} : $V_{REF} = V_{DD} / 2$ standard setting V_{OQbid_2} : V_{REF} = 1.5 (QV1V5 = 1)
	FD	1_{hex}	Fully-differential ($V_{OQ} = V_{DD}/2$) (doubled sensitivity)
	SD uni	2_{hex}	Semi-differential unidirectional V_{OQuni} : $V_{REF} = V_{DD}/5.5$
	SE	3_{hex}	Single-ended $V_{OQ} = V_{REF} = V_{REF\_ext}$
$OCD1_{deglitch}$	Symbol	Setting	Deglitch time in ns
	d0	0_{hex}	0 / standard setting
	d1	1_{hex}	500
	d2	2_{hex}	1000
	d3	3_{hex}	1500
	d4	4_{hex}	2000
	d5	5_{hex}	2500
	d6	6_{hex}	3000
	d7	7	3500
$OCD2_{deglitch}$	Symbol	Setting	Deglitch time in ns
	d0	0	0 / standard setting
	d1	1	500
	d2	2	1000
	d3	3	1500
	d4	4	2000
	d5	5	2500
	d6	6	3000
	d7	7	3500
	d8	8	4000
	d9	9	4500
	d10	10	5000
	d11	11	5500
	d12	12	6000
	d13	13	6500
	d14	14	7000
	d15	15	7500

Table 16 EEPROM bit field description address 41hex

<table>
<tr><th>Bit field name</th><th>Description</th></tr>
<tr><td>OCD_{comp_hyst}</td><td>OCD_{comp_hyst} [dec] = round (hex2dec ($OCDx_{thrsh}$)*(X %)).

$OCDx_{thrsh}$ = $OCD1_{thrsh}$ or $OCD2_{thrsh}$ level
X% = percentage of the threshold level

e.g. $I_{THR1.1}$ = (1.25 x FS) in S1 = 26_{dec}
$OCD_{comp\_hyst(20\%)} = 26_{dec}$ * 20 % = 5

See further calculation example described in chapter Over Current detection (OCD).

Standard setting = 7_{hex}</td></tr>
<tr><td>$OCD1_{thrsh}$</td><td>
<table>
<tr><td>Symbol</td><td colspan="7">Setting</td></tr>
<tr><td>level</td><td>x FS</td><td>S1</td><td>S2</td><td>S3</td><td>S4</td><td>S5</td><td>S6</td></tr>
<tr><td>$I_{THR1.1}$</td><td>1.25</td><td>$1A_{hex}$</td><td>15_{hex}</td><td>$0E_{hex}$</td><td>$1B_{hex}$</td><td>13_{hex}</td><td>$0A_{hex}$</td></tr>
<tr><td>$I_{THR1.2}$</td><td>1.39</td><td>$1E_{hex}$</td><td>18_{hex}</td><td>10_{hex}</td><td>$1F_{hex}$</td><td>15_{hex}</td><td>$0C_{hex}$</td></tr>
<tr><td>$I_{THR1.3}$</td><td>1.54</td><td>21_{hex}</td><td>$1B_{hex}$</td><td>13_{hex}</td><td>22_{hex}</td><td>18_{hex}</td><td>$0E_{hex}$</td></tr>
<tr><td>$I_{THR1.4}$</td><td>1.68</td><td>25_{hex}</td><td>$1E_{hex}$</td><td>15_{hex}</td><td>26_{hex}</td><td>$1B_{hex}$</td><td>10_{hex}</td></tr>
<tr><td>$I_{THR1.5}$</td><td>1.82</td><td>28_{hex}</td><td>21_{hex}</td><td>17_{hex}</td><td>$2A_{hex}$</td><td>$1E_{hex}$</td><td>12_{hex}</td></tr>
<tr><td>$I_{THR1.6}$</td><td>1.96</td><td>$2C_{hex}$</td><td>24_{hex}</td><td>19_{hex}</td><td>$2E_{hex}$</td><td>21_{hex}</td><td>14_{hex}</td></tr>
<tr><td>$I_{THR1.7}$</td><td>2.11</td><td>30_{hex}</td><td>27_{hex}</td><td>$1C_{hex}$</td><td>31_{hex}</td><td>24_{hex}</td><td>16_{hex}</td></tr>
<tr><td>$I_{THR1.8}$</td><td>2.25</td><td>33_{hex}</td><td>$2A_{hex}$</td><td>$1E_{hex}$</td><td>35_{hex}</td><td>26_{hex}</td><td>18_{hex}</td></tr>
<tr><td colspan="8">Standard setting = 25_{hex}</td></tr>
</table>
</td></tr>
<tr><td>$OCD2_{thrsh}$</td><td>
<table>
<tr><td>Symbol</td><td colspan="7">Setting</td></tr>
<tr><td>level</td><td>x FS</td><td>S1</td><td>S2</td><td>S3</td><td>S4</td><td>S5</td><td>S6</td></tr>
<tr><td>$I_{THR2.1}$</td><td>0.50</td><td>13_{hex}</td><td>$0F_{hex}$</td><td>$0A_{hex}$</td><td>15_{hex}</td><td>$0E_{hex}$</td><td>08_{hex}</td></tr>
<tr><td>$I_{THR2.2}$</td><td>0.61</td><td>18_{hex}</td><td>13_{hex}</td><td>$0D_{hex}$</td><td>$1A_{hex}$</td><td>12_{hex}</td><td>$0B_{hex}$</td></tr>
<tr><td>$I_{THR2.3}$</td><td>0.71</td><td>$1E_{hex}$</td><td>18_{hex}</td><td>11_{hex}</td><td>20_{hex}</td><td>16_{hex}</td><td>$0D_{hex}$</td></tr>
<tr><td>$I_{THR2.4}$</td><td>0.82</td><td>23_{hex}</td><td>$1C_{hex}$</td><td>14_{hex}</td><td>25_{hex}</td><td>$1B_{hex}$</td><td>10_{hex}</td></tr>
<tr><td>$I_{THR2.5}$</td><td>0.93</td><td>28_{hex}</td><td>21_{hex}</td><td>17_{hex}</td><td>$2A_{hex}$</td><td>$1F_{hex}$</td><td>13_{hex}</td></tr>
<tr><td>$I_{THR2.6}$</td><td>1.04</td><td>$2E_{hex}$</td><td>25_{hex}</td><td>$1A_{hex}$</td><td>30_{hex}</td><td>23_{hex}</td><td>15_{hex}</td></tr>
<tr><td>$I_{THR2.7}$</td><td>1.14</td><td>33_{hex}</td><td>29_{hex}</td><td>$1E_{hex}$</td><td>35_{hex}</td><td>27_{hex}</td><td>18_{hex}</td></tr>
<tr><td>$I_{THR2.8}$</td><td>1.25</td><td>38_{hex}</td><td>$2E_{hex}$</td><td>21_{hex}</td><td>$3B_{hex}$</td><td>$2B_{hex}$</td><td>$1B_{hex}$</td></tr>
<tr><td colspan="8">Standard setting = 23_{hex}</td></tr>
</table>
</td></tr>
</table>

Table 17 EEPROM bit field description address 42hex

Bit field name	Description		
$Vref_{ext}$	Symbol	Setting	Description
	1V65	0_{hex}	V_{REF_nom} = 1.65 V (±10% if ratiometricity is enabled) standard setting
	1V2	1_{hex}	V_{REF_nom} = 1.2 V (±10% if ratiometricity is enabled)
	1V5	2_{hex}	V_{REF_nom} = 1.5 V (±10% if ratiometricity is enabled)
	1V8	3_{hex}	V_{REF_nom} = 1.8 V (±10% if ratiometricity is enabled)

4.2 Programming Example

This chapter gives an example how to change the EPPROM content in order to change the sensitivity range of the device. Therefore, the interface to allow the communication between a microcontroller and the sensor has to be activated as described in the chapter Serial Inspection and Configuration Interface (SICI).

Table 18 will guide the user through a complete programming sequence by just following the listed commands line by line. Figure 12 shows an exemplary sequence to program the EEPROM.

- The first command sequence which has to be sent after power up is the enter interface command. Therefore, the power supply of the sensor has to be controlled by the microcontroller to ensure the correct modulation sequence within the defined start up window of the AOUT pin. A detailed description on how to enter the interface is described in the chapter Entering communication mode.
- After activating the interface the sensors integrated intelligent state machine (ISM) has to be powered down by sending the “power down ISM” command.
- To avoid unintended high current consumption during applying the programming voltage at the OCD2 pin, the error indication has to be disabled by writing the disable failure indication command to the device.
- Since the device is doing a cyclic redundancy check the EEPROM content should be read before the values gets modified. Once the values are modified, the CRC has to be calculated. EEPROM Content
- Table 8 gives an overview of the EEPROM content and the composition of the different parameters.
- Programming requires two single commands followed by the programming pulse that has to be applied on the OCD2 pin. One sequence is required to program the ones and one sequence to program the zeros into the EEPROM. After this, all digital values are stored in the EEPROM. Figure 12 gives an exemplary description of the programming sequence. Figure 12 also shows the timing when and how long the programming voltage of 20.6V has to be applied on OCD2.
- After sending the values to the EEPROM, the program one command has to be sent.
- After sending the programming command, the programming voltage shall be applied for $t_{EEPVPROG}$ as seen in Figure 14 and Figure 12.
- After $t_{EEPWAIT}$ the refresh command has to be executed.
- Then the “program – zero” command shall be sent followed by the programming pulse.
- The programming voltage shall be applied again for $t_{EEPVPROG}$.
- After refresh command shall be executed or the device shall be powered off and on. Table 18 describes an exemplary programming sequence.

Table 18 EEPROM programming example

Command name	address$_{hex}$	command$_{hex}$	description
Enter Interface	---	ABCD$_{hex}$	Enter interface as described in chapter Entering Communication Mode
Power down ISM	25$_{hex}$	8250$_{hex}$	Write command get access to the register by the interface
		8000$_{hex}$	Set data
Disable failure indication	01$_{hex}$	8010$_{hex}$	Write command
		0000$_{hex}$	Set data
Read all register			Read data before modifying values to CRC calculation
Read command	40$_{hex}$	0400$_{hex}$	Read command at EEPROM line 0
Read command	n	00n0	Read command for address “n” Receive previous addressed data
Read command	51$_{hex}$	0510$_{hex}$	Address last line in EEPROM Receive previous addressed data
NOP	---	FFFF$_{hex}$	Read values from previous address without initializing a new command. The data can also be read with the next write command instead of using the NOP command
Write command	40$_{hex}$	A400$_{hex}$	Write command to EEPROM line 0 Access: only set sent zeros
Write data		FFF0$_{hex}$	Write meas$_{rng}$ to all zero
EEPROM program zeros	3E$_{hex}$	83E0$_{hex}$	Write to EEPROM command line
		024**E**$_{hex}$	Set EEPROM command program zeros
			Applying the programming voltage at ocd2 pin for $t_{EEPvprog}$
EEPROM refresh	3E$_{hex}$	83E0$_{hex}$	Write to EEPROM command line
		024**C**$_{hex}$	Set EEPROM command refresh

Table 18 cont.…

Command name	address$_{hex}$	command$_{hex}$	description
			Wait for 100 µs
Write command	40$_{hex}$	B400$_{hex}$	Write command to EEPROM line 0 only set sent ones
Write data		0005$_{hex}$	Write meas$_{rng}$ to 5 (FS = 120A)
EEPROM program ones	3E$_{hex}$	83E0$_{hex}$	Write to EEPROM command line
		024**F**$_{hex}$	Set EEPROM command program ones
			Applying the programming voltage V_{PROG} at OCD2 pin
EEPROM refresh	3E$_{hex}$	83E0$_{hex}$	Write to EEPROM command line
		024C$_{hex}$	Set EEPROM command refresh
			Wait for 100 µs

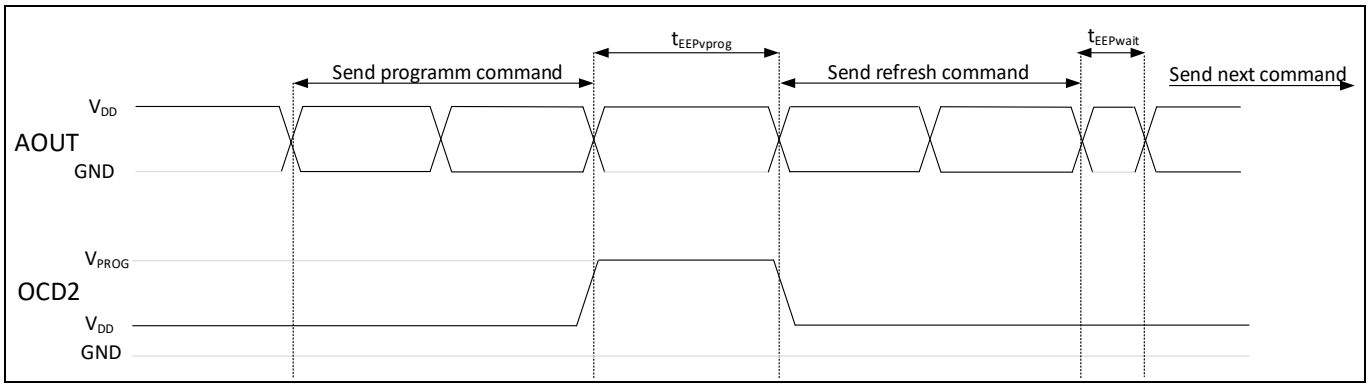

Figure 14 Programming sequence

Table 19 EEPROM voltage and timing parameter

Parameter	Symbol	Min	Typ	Max	Unit	note
Programming Voltage	V_{PROG}	20.5	20.6	20.7	V	
EEPROM Programming time	$t_{EEPvprog}$		30		ms	Time to apply programming voltage V_{PROG} on OCD2 pin
EEPROM wait time	$t_{EEPwait}$		100		µs	Wait time after EEPROM refresh command
Programming Current consumption	I_{PROG}		6	10	mA	Current consumption of OCD2 while applying the programming voltage

4.3 Cyclic Redundancy Check

To detect accidental changes of the EEPROM content the data in the EEPROM are protected with a cyclic redundancy check (CRC). The CRC calculation is based on the polynomial x8+x4+x3+x2+1. Table 20 describes the CRC calculation. The seed word is defined as 0xAAhex. The CRC calculation of the EEPROM is performed byte by byte, starting from the EEPROM line three (address 43_{hex}). After reaching the end of the EEPROM the line 0 (address 40_{hex}) to line 2 are appended. The CRC byte is not used for the calculation. The end word is defined as 0xFFhex.

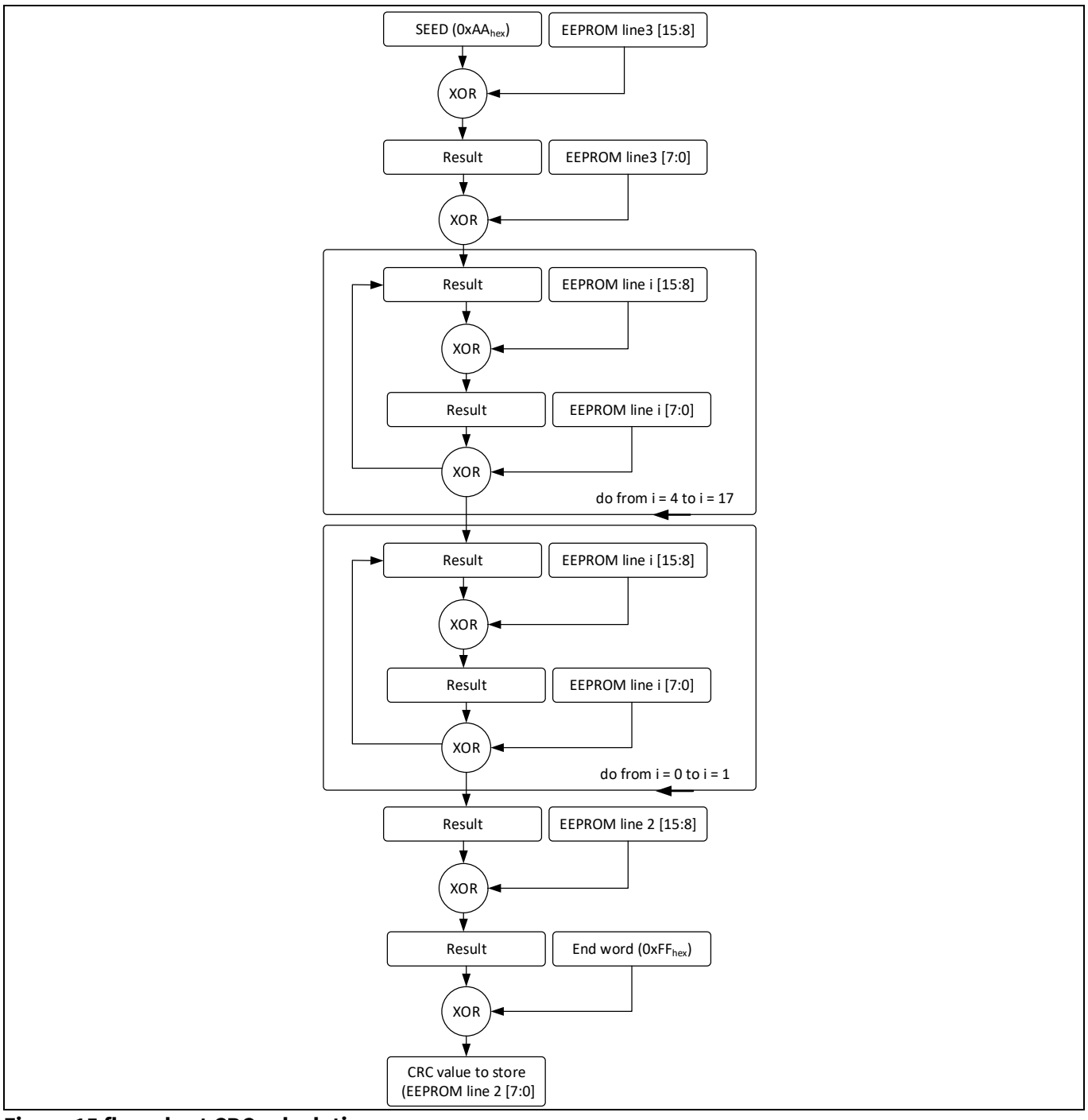

Figure 15 flow chart CRC calculation

Table 20 CRC calculation specification

CRC value	operation	comment
CRC_3_1	[$0xAA_{hex}$] XOR [EEPROM_line_03_bit15_downto_bit8]	The CRC calculation starts with the content of the upper 8 bits in the EEPROM line 3
CRC_3_2	CRC_3_1 XOR [EEPROM_line_03_bit07_downto_bit0]	Continue calculating the CRC with the lower 8 bits stored in the EEPROM line 3
CRC_4_1	CRC_3_2 XOR [EEPROM_line_04_bit15_downto_bit8]	
CRC_4_2	CRC_4_1 XOR [EEPROM_line_04_bit07_downto_bit0]	
. . .	. . .	Proceed calculation until EEPROM line 17
CRC_n_2	CRC_n_1 XOR [EEPROM_line_17_bit07_downto_bit0]	CRC_n stands for CRC_17 to represent the CRC calculation with the content of the last line (17) of the EEPROM
CRC_0_1	CRC_n_2 XOR [EEPROM_line_00_bit15_downto_bit8]	Continue calculating the CRC with the content of EEPROM line 0
. . .	. . .	Proceed calculation until EEPROM line 2
CRC_k_1	CRC_k-1_2 XOR [EEPROM_line_02_bit15_downto_bit8]	CRC_k represents the CRC value calculated with the EEPROM content of the third EEPROM line (line 2).
CRC	CRC_k XOR [$0xFF_{hex}$]	The CRC has to be stored into the lower 8 bits of the EEPROM line 2.

4.4 Code example CRC calculation

```
//CRC calculation example for Infineon TLI4971 current sensor
//CRC 8 (SAE - J1850) CRC polynomial: x^8 + x^4 + x^3 + x^2 + 1
// len = 18 (EEPROM line 0-17)
#define CRC_POLYNOMIAL 0x1D
#define CRC_SEED 0xAA

//check CRC
bool checkCRC (uint16_t* data, int len) {
 uint8_t checkSum = data[2]&0xFF;//CRC lower byte in EEPROM line2
 return checkSum == crcCalc(data, len);
}

//read data beginning in EEPROM line 3 to line 17, append line 0 to line 2
uint8_t crcCalc(uint16_t* data, int len) {
 uint8_t crcData8[len*2];
 for(int i = 0; i < len; i++) {
  crcData8[i*2] =     ( data[(i+3)%18] >>8 ) & 0xFF;//read upper 8 bit
  crcData8[i*2+1] = ( data[(i+3)%18]       ) & 0xFF;//read lower 8 bit
 }
return crc8(crcData8, len*2-1); //do not include last byte (line 2 lower byte)
}

// CRC calculation
uint8_t crc8(uint8_t *data, uint8_t length) {
 uint32_t crc;
 int16_t i, bit;
 crc = CRC_SEED;
  for (i = 0; i < length; i++) {
   crc ^= data[i];
   for (bit = 0; bit < 8; bit++) {
    if ((crc & 0x80) != 0) {
    crc <<= 1;
    crc ^= CRC_POLYNOMIAL;
    } else {
    crc <<= 1;
  }
  }
 }
 return ~crc;  // ~crc = crc^0xFF;
}
```

5 Operation Mode

The TLI491 supports multiple output modes, which are programmable in the EEPROM. The default output mode is pre-configured by IFX (semi-differential mode V_{OQ} = V_{OQbid1}), a non-default output mode can be selected by reprogramming the respective bits in the EEPROM. Table 21 gives an overview of the different operation modes. The application circuits for the different operation modes are described in this chapter. The electric parameter to be used in the application circuit are listed in Table 22. Furthermore schematic explanations of the output signal waveform depending on an AC input current signal and the set output mode is explained.

Table 21 Operation Mode Overview

Operation Mode	Output Voltage V_{AOUT} , V_{REF}	Quiescent Voltage V_{OQ}	Sensitivity S
Semi-Differential SD	$V_{AOUT} = V_{OQ} + S * I_{PN}$ $V_{REF} = V_{OQ}$	$V_{OQbid1} = 1.65V$ 1)2) $V_{OQbid2} = 1.5V$ 2)	$S = S_{NOM} * \frac{V_{DD}}{3.3V}$ 2)3) $S = S_{NOM}$ 1)2)4)
Fully-Differential FD	$V_{AOUT} = V_{OQ} + S * I_{PN}$ $V_{REF} = V_{OQ} - S * I_{PN}$	$V_{OQ} = \frac{V_{DD}}{2}$	$S = S_{NOM} * \frac{V_{DD}}{3.3V}$ 2)3) $S = S_{NOM}$ 1)
Single-Ended SD	$V_{AOUT} = V_{OQ} + S * I_{PN}$ $V_{REF} = V_{OQ}$	$V_{OQ} = V_{REFext}$ 2)5)	$S = S_{NOM} * \left[\frac{V_{REF}}{V_{REF\_nom}}\right]$ 2)3)6) $S = S_{NOM}$ 1)2)4)

1) Standard setting.
2) Can be programmed by user.
3) If $RATIO_{GAin}$ is activated in EEPROM.
4) Nominal sensitivity according to EEPROM setting $Meas_{range}$.
5) External reference voltage provided at V_{REF} must correspond to the EEPROM setting for V_{REFExt}.
6) V_{REF_nom} corresponds to the set V_{REFext} value.

5.1 Single-Ended Mode

In Single-Ended Mode, the V_{REF} pin is used as an input pin to provide the analog reference voltage, V_{REF}. The voltage on A_{OUT}, V_{AOUT}, is proportional to the measured current I_{PN} at the current rail. Being S the sensitivity and V_{OQ} the quiescent voltage of the sensor, the output voltage can expressed as:

$$V_{O(IPN)} = V_{OQ} + S \cdot \mathrm{I_{PN}}$$

The quiescent voltage V_{OQ} is the value of V_{AOUT} when the primary current I_{PN}=0. V_{OQ} tracks the voltage on V_{REF}. The quiescent voltage V_{OQ} is ratio-metric with respect to the voltage applied on the V_{REF} pin.

$$V_{OQ}(VREF) = V_{REFext}$$

The output sensitivity is ratio-metric with respect to the reference voltage applied on the VREF pin if gain ratio-metric is enabled in the EEPROM ($GAIN_{ratio}$=1).

$$S(V_{REF}) = S(V_{REF\_nom}) \cdot \left[\frac{V_{REF}}{V_{REF\_nom}}\right]$$

Find the possible values of nominal V_{REF_nom} in Table 17.

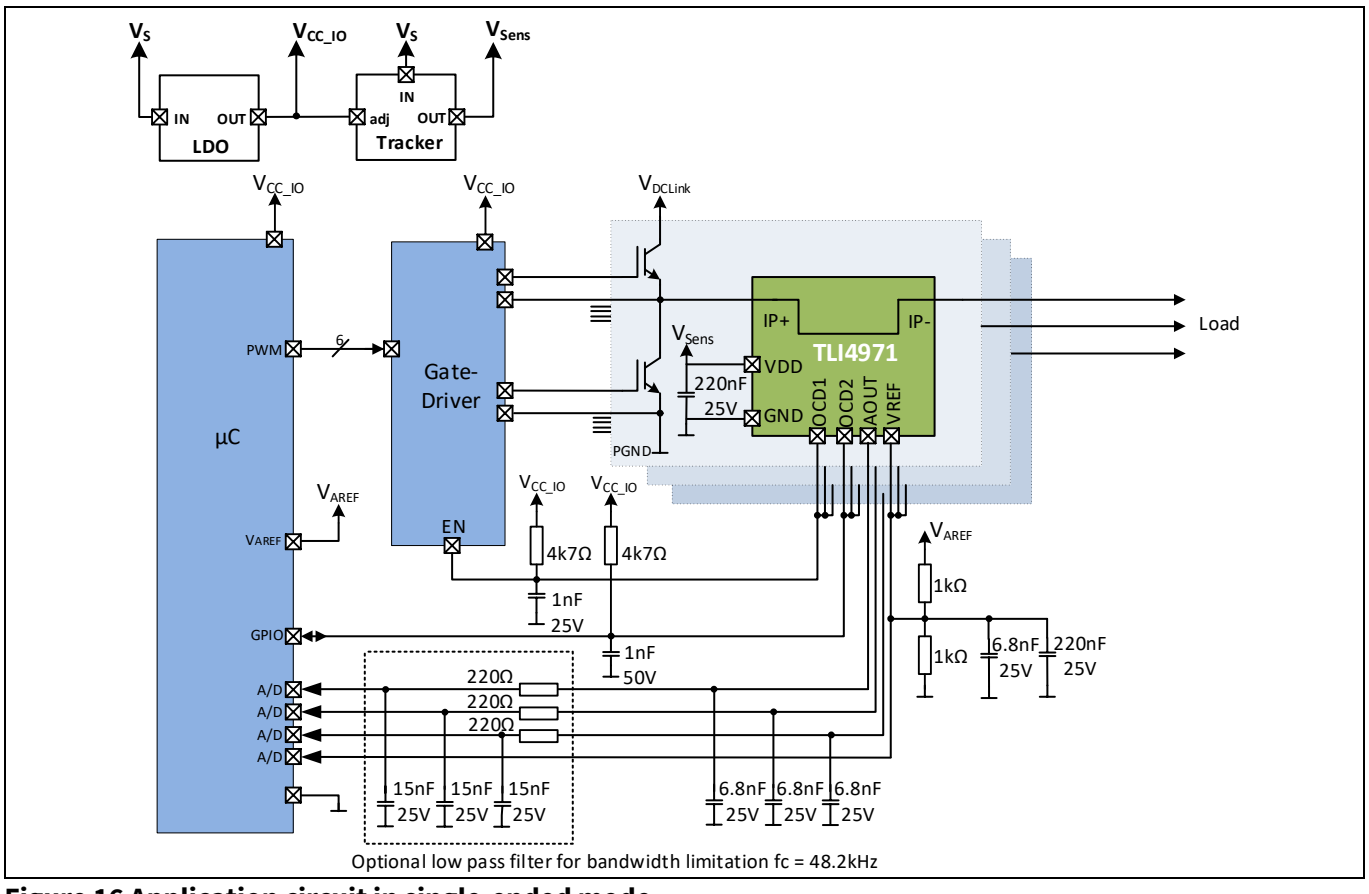

Figure 16 Application circuit in single-ended mode

Figure 16 shows a 3 phase application circuit in single-ended mode.

- The sensors reference voltage pin is set as input and supplied by an external reference voltage generation circuit (e.g. a voltage divider or voltage reference) as implied in Figure 16. Ideally, the V_{REF} is derived from the ADC reference voltage.
- The VREF input leakage current of up to 20µA has to be considered in the design of the reference voltage generation circuit.
- Therefore, it is recommended to use a controlled voltage source or a diode to guarantee a stable and precise voltage on the reference input.
- A low-ohmic voltage divider is also possible to provide the reference voltage as shown in Figure 16.
- Typically the reference voltage of the microcontroller which is measuring the sensor output is also used as reference as indicated in Figure 16.
- Figure 17 describes the output signal waveform dependent on an AC input current signal in single-ended mode.
- At A_{OUT} the voltage depending on the set sensitivity is proportional to the current in the primary conductor.
- There are four different external voltage levels defined which are allowed to apply on the V_{REF} pin. The EEPROM setting V_{refext} has to correspond to the applied voltage as described in Table 17.
- The ratiometricity works within an external voltage tolerance of ±10%.

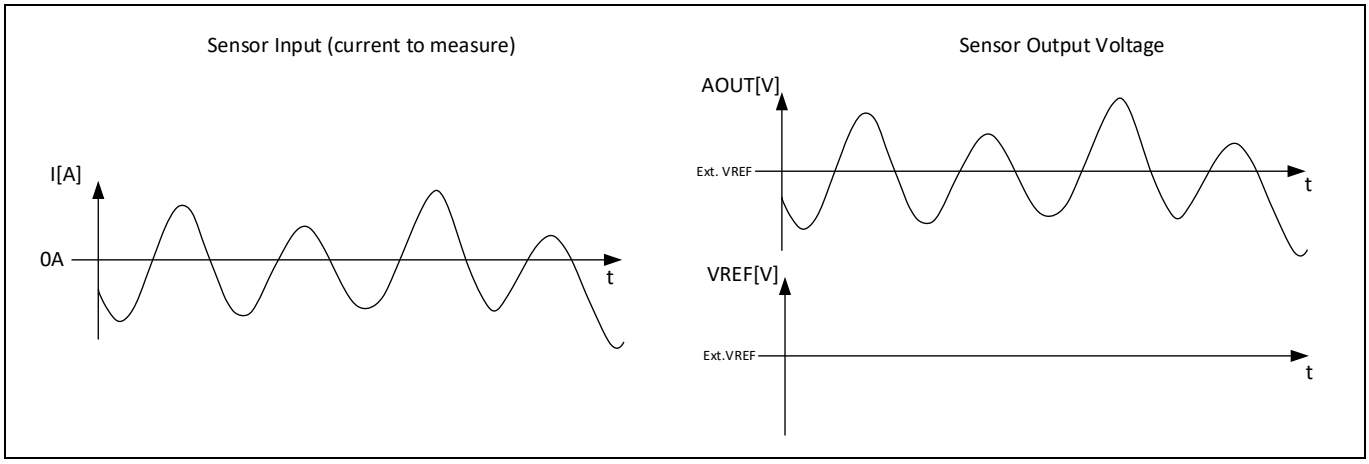

Figure 17 Sensor output signal dependent on input signal waveform in single-ended mode

- The block diagram shown in Figure 18 describes the connection of the sensor output to an ADC of a micro controller.
- In single-ended mode, the reference voltage of the microcontroller is used as input reference voltage at the current sensor.
- In this setup, the quiescent voltage at A_{OUT} has the same value as the reference voltage on V_{REF}.

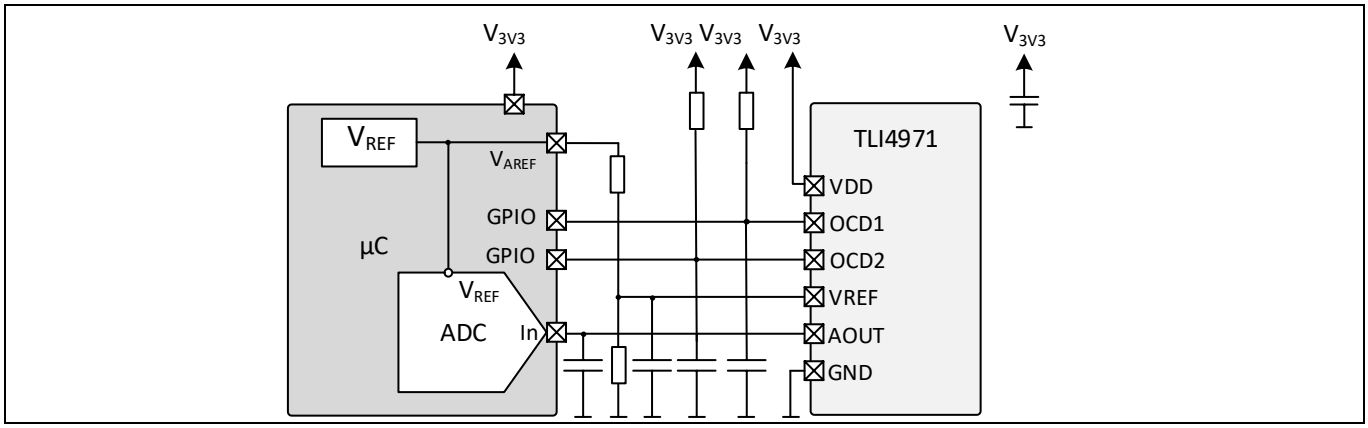

Figure 18 TLI4971 connected to µC in single-ended mode

5.2 Fully-differential Mode

In fully differential output mode, both V_{REF} and A_{OUT} are analog outputs to achieve double voltage swing. At zero input, both A_{OUT} and V_{REF} nominally provide a voltage level at $V_{DD}/2$. Compared to the single-ended mode, the available voltage swing at the output is doubled. Beside it gives the advantage of a better common mode noise rejection as well as better diagnostic considering that $V_{AOUT}+V_{VREF} = V_{DD}$. A_{OUT} is the non-inverting output, while V_{REF} is the inverting output.

$$V_{AOUT}(I_{PN}) = V_Q + S \cdot I_{PN}$$

$$V_{REF}(I_{PN}) = V_Q - S \cdot I_{PN}$$

If the nominal quiescent voltage is 1.65V and the offset ratiometricity is enabled, the quiescent voltage can be expressed as follows:

$$V_Q(V_{DD}) = \frac{V_{DD}}{2}$$

The sensitivity in the fully differential mode can be generally expressed as follows to show the dependency from the actual V_{DD} value:

$$S(V_{DD}) = S_{NOM} \cdot \frac{V_{DD}}{3.3V}$$

- Figure 24 shows the application circuit in fully differential mode where both analog output of the sensors are connected to the microcontroller input.
- Figure 18 describes the sensor output signal waveform dependent on an AC input signal. The figure shows the inverted signal on VREF and the directly proportional signal on A_{OUT}.
- The differential output signal gives the double output swing. The quiescent voltage is set to $V_{DD}/2$

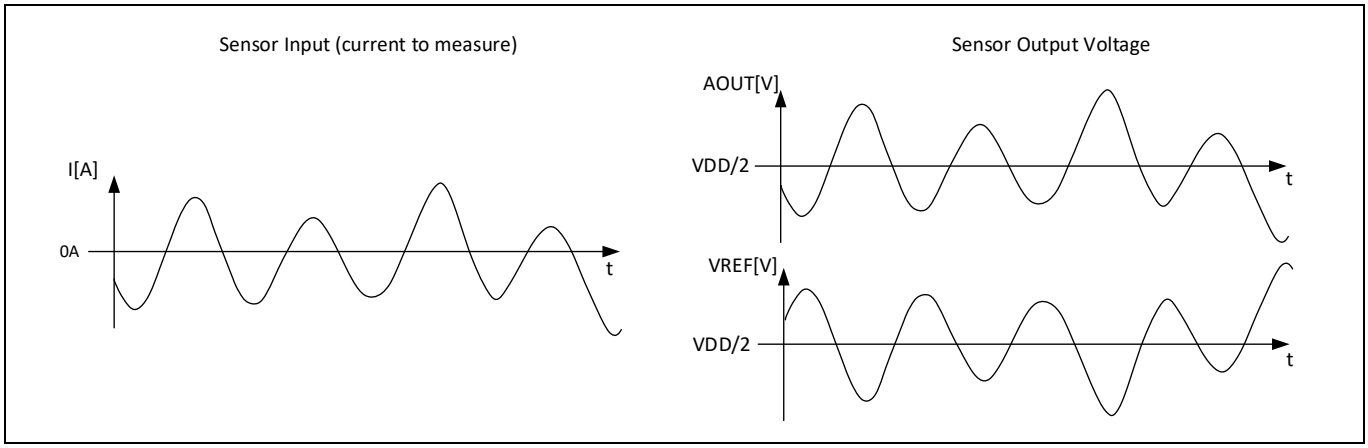

Figure 19 Sensor output signal dependent on input signal waveform in fully differential mode

- The block diagrams in Figure 20 and Figure 25 are describing how the sensor output can be connected to the microcontroller in fully differential mode.
- Furthermore it gives the advantage of a very high common mode noise rejection by measuring the signal differential.
- It is recommended to use a differential ADC as seen in Figure 20.
- A differential ADC gives the advantage that no further calculation of the differential signal has to be done.
- Alternatively, it is also possible to use one ADC for each channel where the differential signal is calculated after the analog to digital conversion in the microcontroller.

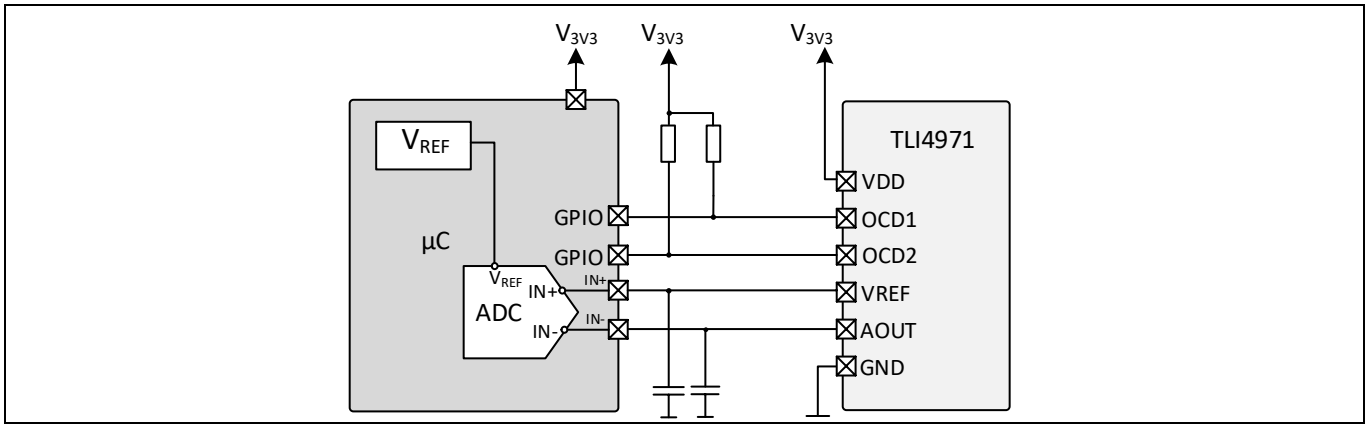

Figure 20 TLI4971 (fully-differential mode) connected to differential ADC

5.3 Semi-differential Mode

In Semi-Differential Output Mode, the sensor is using a chip-internal reference voltage. This reference voltage is then provided on the VREF. Therefore, the reference voltage can be monitored by the microcontroller and/or used for other devices as a reference voltage (cascade setup). The current-dependent output signal is provided as single-ended signal on AOUT.

The quiescent voltage is programmable at three different values,

- V_{OQbid_1} and V_{OQbid_2} for bidirectional current and
- V_{OQuni} for unidirectional current as shown in Table 15.

- The quiescent voltage on A_{OUT} is nominally equal to the internal reference voltage that is provided as an output on the V_{REF} pin.

- The Quiescent Voltage will be set to a value in the middle of the voltage range or at 1.5V (V_{OQbid}) to measure bidirectional current values, whereas when the direction of the current is already known by the application, the quiescent voltage can be set to a lower value (V_{OQuni}) in order to better exploit the full voltage range.
- Figure 19 shows the sensor output signal dependent on the AC input signal. The sensor mode has been set in to the bidirectional semi-differential mode. Therefore, the VREF voltage level shows $V_{DD}/2$ in the illustration.
- The output sensitivity is programmable to ratio-metric with respect to V_{DD}, according to the same formula specified for the fully differential mode, if semi-differential mode is selected and if the sensitivity ratio-metric is enabled in the EEPROM.
- Figure 24 shows a possible application circuit for a-3 phase implementation in semi-differential mode. Therefore the A_{OUT} and V_{REF} pins from the sensor are connected to the micro controller A/D input

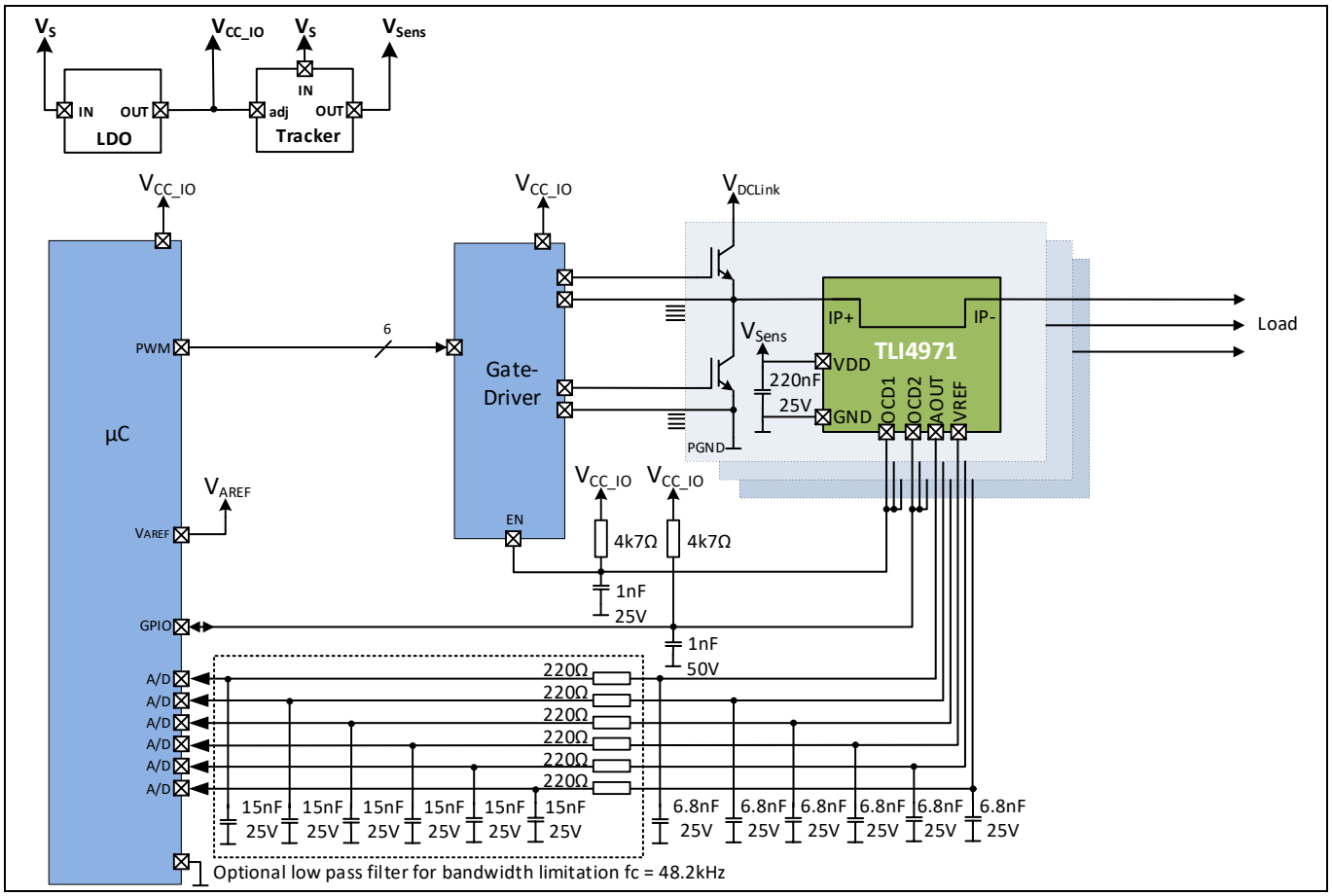

Figure 21 Three phase application circuit for semi-differential and fully differential mode

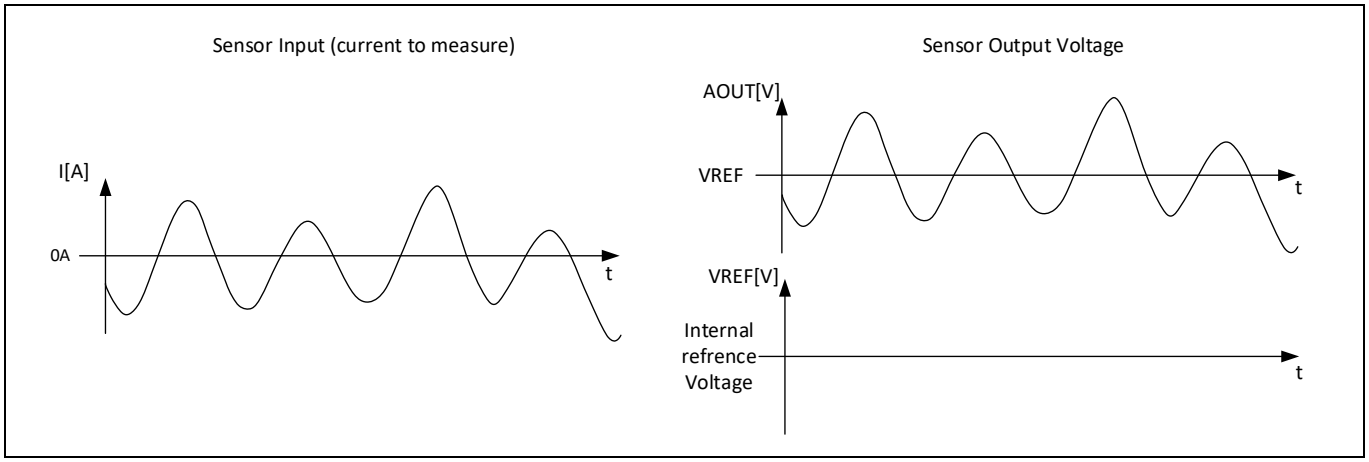

Figure 22 Sensor output signal dependent on input signal waveform in semi-differential mode

Figure 23 shows a recommendation how to connect the sensor with an ADC in semi-differential mode.

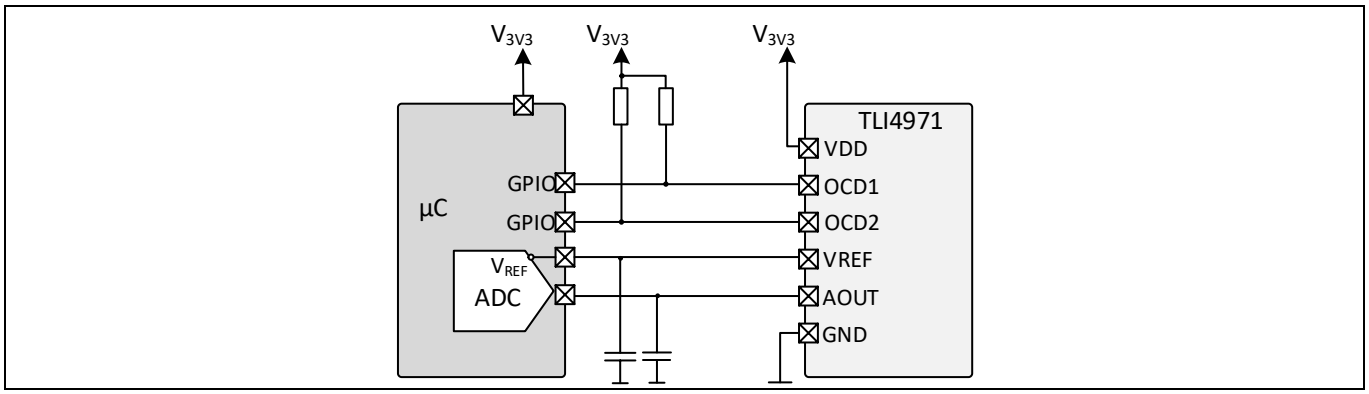

Figure 23 TLI4971 in semi-differential mode

6 How to connect the sensor in a 5V domain

This chapter gives a proposal how to connect the 3.3V sensor device with a 5V microcontroller. Values for the OCD pull up resistors and capacitors are the same as shown in the application drawing Figure 1. Find the recommended values in

Table 22 Electric parameter for application circuit

Name	Value	Unit
Capacitor on VDD	220	nF
Capacitor on analog outputs	4.6	nF
Pull up resistor on OCDs	4.7	kΩ

6.1 Single-Ended Mode

A proposal to use the 3.3V current sensor in a 5V environment can be seen in Figure 24.

- The 3.3V can be derived from the 5V domain by using a tracker like Infineon TLS115x.
- The open drain output of the OCD 2 can be connected via the pull up resistor to the 5V.
- The OCD1 has to be separated from the 5V with a level shifter since the maximum voltage is limited to 3.6V.
- To connect the analog output signals with the 5V microcontroller input an amplifier can be part of the signal conditioning circuit as shown in Figure 24.

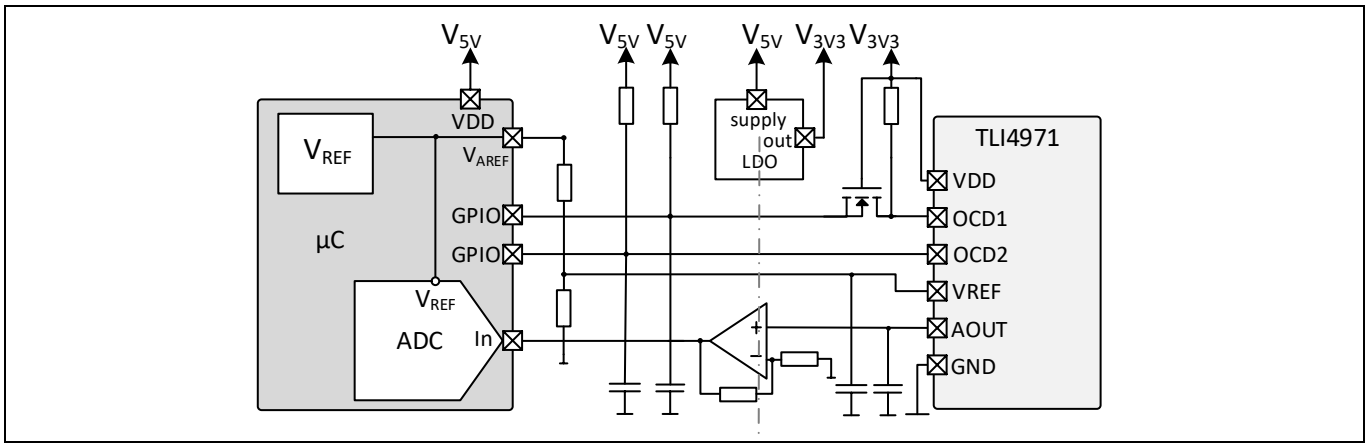

Figure 24 TLI4971 3.3 to 5V topology approach for single-ended mode

6.2 Semi and or Fully-differential Mode

In order to connect the sensor within a 5V environment an amplifier for each analog output can be part of the signal conditioning circuit as shown Figure 25.

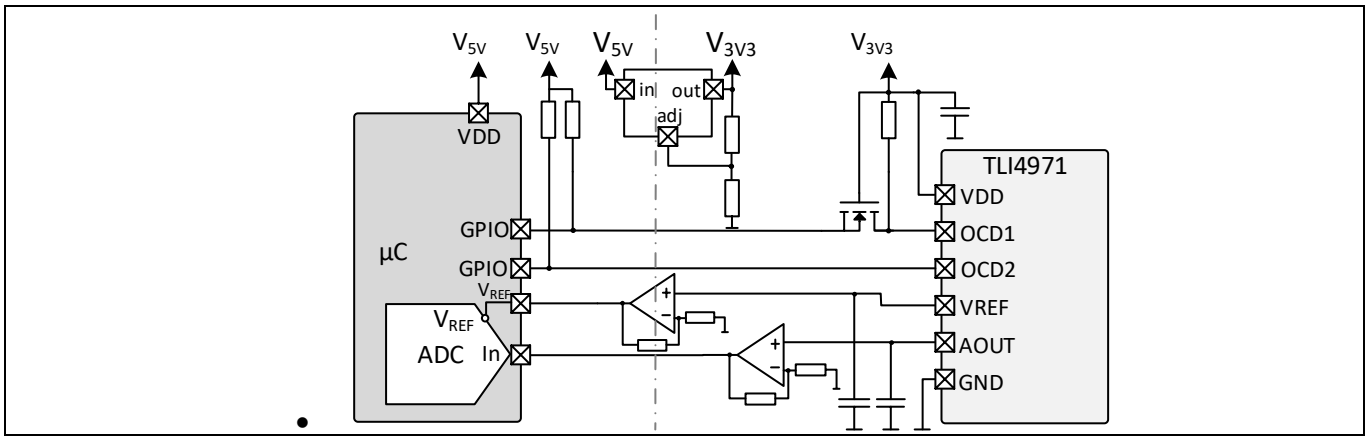

Figure 25 TLI4971 in fully differential mode (using two ADC input)

7 Diagnosis Mode

General Description

The TLI4971 current sensor is equipped with an internal self-diagnosis mode.

In order to verify the full functionality of the device signal path and the external signal conditioning circuit the diagnosis mode can be activated externally.

The diagnosis mode can be activated at any time after start up by forcing the OCD2 for at least 100µs to GND. The programmed threshold limits for the OCD channels are over written while the diagnosis test is activated.

It is recommended to run the diagnosis mode as an initial test after startup. If the test will run during normal operation, the current can be calculated based on the two other sensors during this time.

The sensor converts the magnetic flux density to output voltage, which is linearly proportional to the current through the sensor package.

In diagnosis mode, an additional known test voltage will be added to the current depending output voltage.

Figure 27 shows the block diagram of the TLI4971 where the diagnosis mode test voltage is injected at the front-end of the signal path.

The test voltage VTEST caused by the test signal is equivalent to a primary current of 40A.

The output voltage at AOUT is dependent on the internal set sensitivity ranges (S1, S2, S3, S4, S5, and S6).

The known test voltages VTEST+ and VTEST- are also applied at the input of the over current comparators. That is why the programmed threshold levels for over current detection is not valid while the diagnosis mode is running. Please consider that the over current detection is not working while the diagnosis mode is active.

The threshold voltage of the OCD comparators is set to fixed values (VTEST x 1.2, VTEST x 0.8) as seen in Figure 28 if the diagnosis mode is enabled. The OCD output pattern can be seen in Figure 28.

By measuring the output voltage and observing the OCD output switching during the diagnosis mode a high evidence of the sensor functionality can be reasoned.

How to Operate

- Ensure that the OCD2 are not tied together in a multiple sensor setup.
- Force OCD2 to GND for at least 100µs to activate the diagnosis mode.
- Observe the voltage on the AOUT and VREF pin according to the timing shown in Figure 28.
    - The additional output voltage caused by the test mode corresponds to an input current of about 40A.
    - The AOUT voltage will change accordingly to the set sensitivity range.
    - The coverage will be reduced for the sensitivity range S4 – S6 since the output will saturate with this sensitivity settings.
- If the Voltage level on AOUT meets the expected levels shown in Figure 28 the test is pass for the current sensing path.
- In parallel, also the OCD1 and OCD2 channel have to be monitored according to the timing shown in Figure 28.

- If the switching behavior corresponds to the expected timing as shown in Figure 28 the over current signal path test is pass.
- If a current is flowing through the primary current rail the OCD pattern will be different as described in Figure 28. It has to be considered that the comparator level is set to VTEST x 1.2 and VTEST x 0.8 if the diagnosis mode is activated.
- After the sensor operates in normal sensing mode if the OCD2 pin is not forced to GND until the OCD2 will be forced to GND again.

Recommendation

- To avoid unintended activation, the minimum pulse width of the activation pulse applied at OCD2 has to meet the minimum timing constraint of 100µs.
- Since the OCD2 is kept to GND after startup by the sensor, the capacitance on the OCD2 pin shall be low to avoid unintended activation of the diagnosis mode because of a to slow release of the OCD2 level. This can happen if the threshold level for a logic “1” (1.6V) is not reached within 100µs.
- If all OCD2 are tied together the OCD2 fault indication might activate an unintended activation of the diagnosis mode by forcing the pin to ground due to an over current event. Therefore, the OCD2 outputs have to be traced separately as shown in Figure 26.
- Dependent on the set sensitivity range (S1, S2, S3, S4, S5, and S6) the voltage on the analog out will change proportional to the input current plus/minus the 40A test signal caused by the diagnosis mode test signal.
- Figure 28 describes the pin toggle timing after triggering the diagnosis mode from external. Furthermore, it shows the expected voltage level on the AOUT pin.
- The sensor changes back into normal operating mode after 750µs after the first falling edge of the OCD channels.

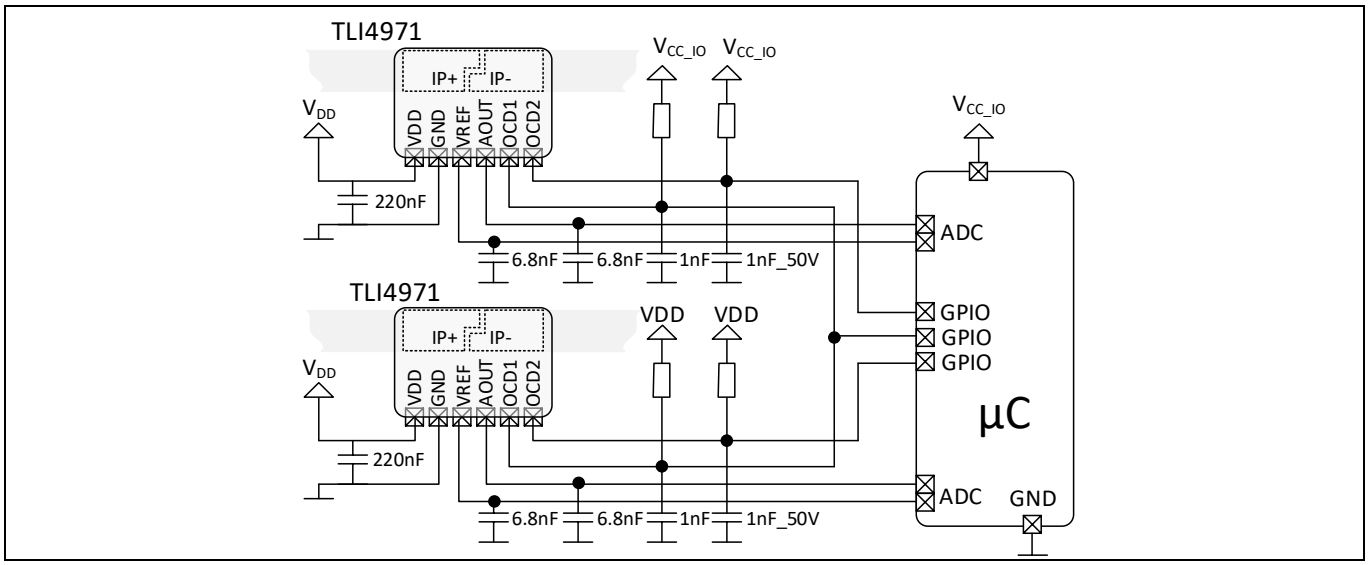

Figure 26 Application Circuit for diagnosis mode, OCD2 are wired separately

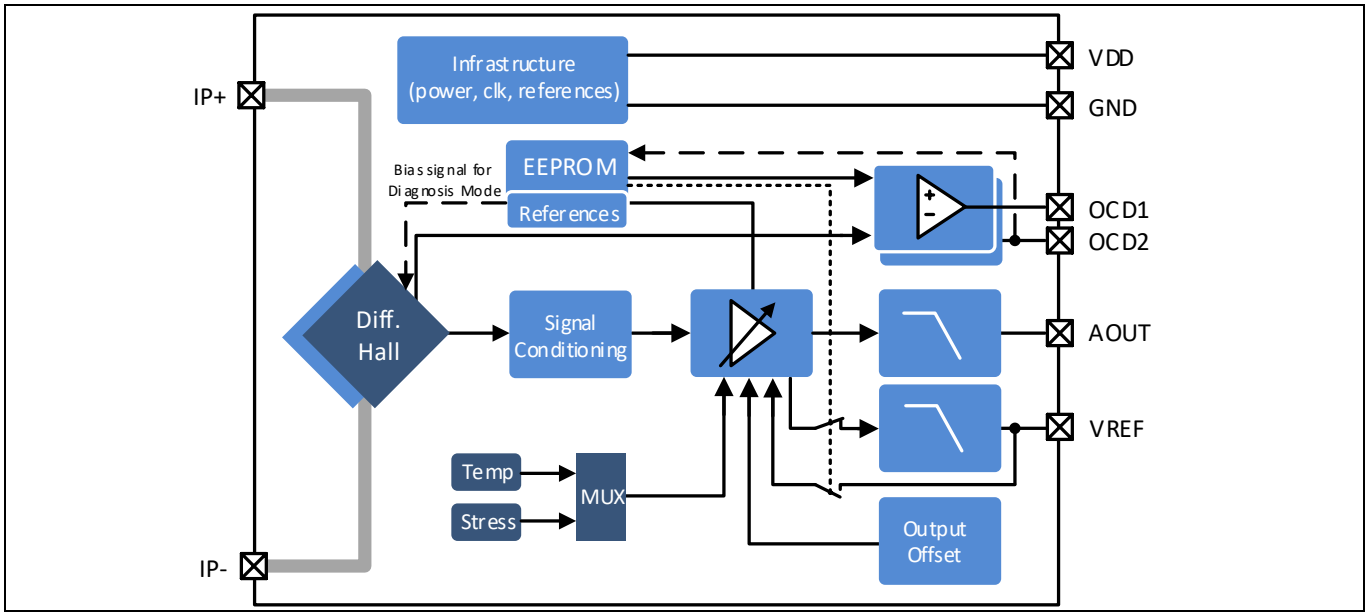

Figure 27 TLI4971 Block Diagram (force OCD2 to GND in order to start the diagnosis mode)

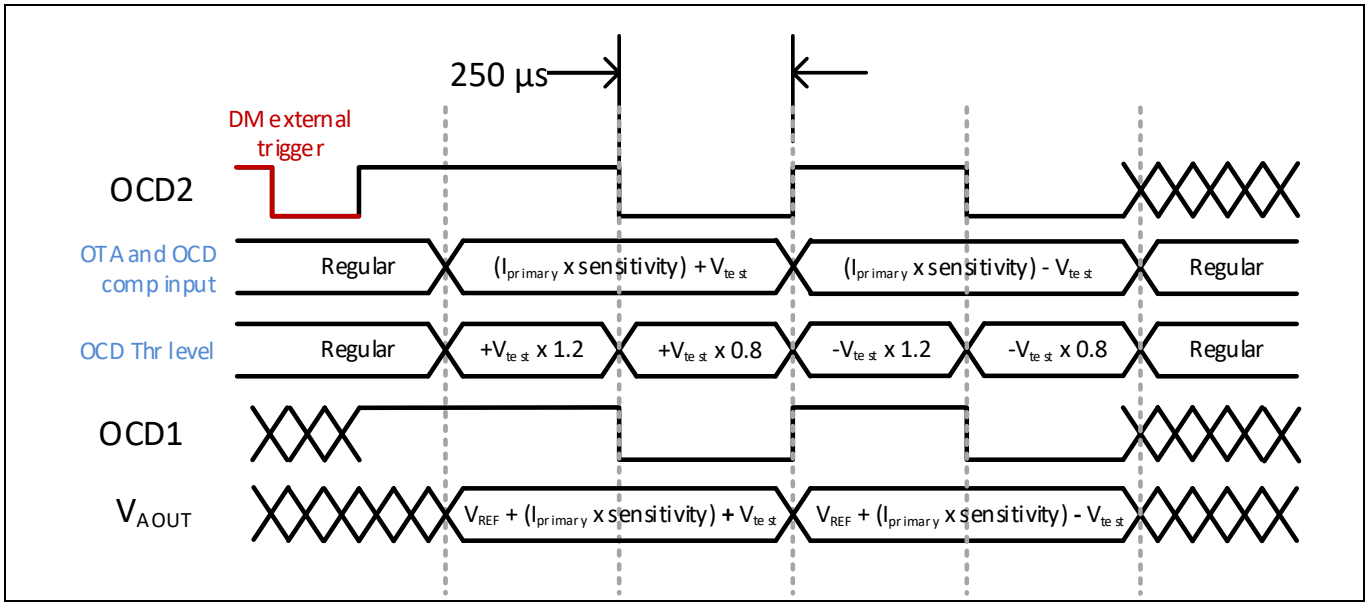

Figure 28 Diagnosis mode timing if 0A applied in the primary current path

8 Over Current detection (OCD)

The sensor provides two independent fast over current detection channels which can be programmed separately to an individual threshold and timing setting. In a typical inverter application the open drain outputs are used to allow the microcontroller or gate-driver stage acting very fast in terms of an over load in the system. In order to enable maximum design flexibility, both OCD provide different current thresholds and timing behaviors. A first output OCD1 can be connected with the gate-driver to disconnect the output stage in terms of an over current. The OCD2 open drain output is connected to the interrupt input of the microcontroller. Both channel are working independently of AOUT and VREF even if the thresholds are beyond the saturation levels of the AOUT or VREF.

Figure 29 gives an overview of the different threshold and timing settings, which can be programmed, for each channel. The green marked area represents the possible settings for the OCD1 channel where the threshold can be set in a range of 1 to 2.25 times the measurement range selected for AOUT and VREF, respectively.

- The de-glitch time of the OCD1 can be set from minimum 1µs up to 5µs in programmable steps of 500ns.
- The OCD2 threshold can be set to a value between 0.5 and 1.25 times the programmed full scale range as the orange area is indicating in Figure 29.
- The deglitch filter setting can be set from minimum 0µs up to 7.5µs in steps of 500ns.
- Table 15 and Table 16 is describing the corresponding EEPROM setting for the threshold levels as well as for the deglitch filter time settings.

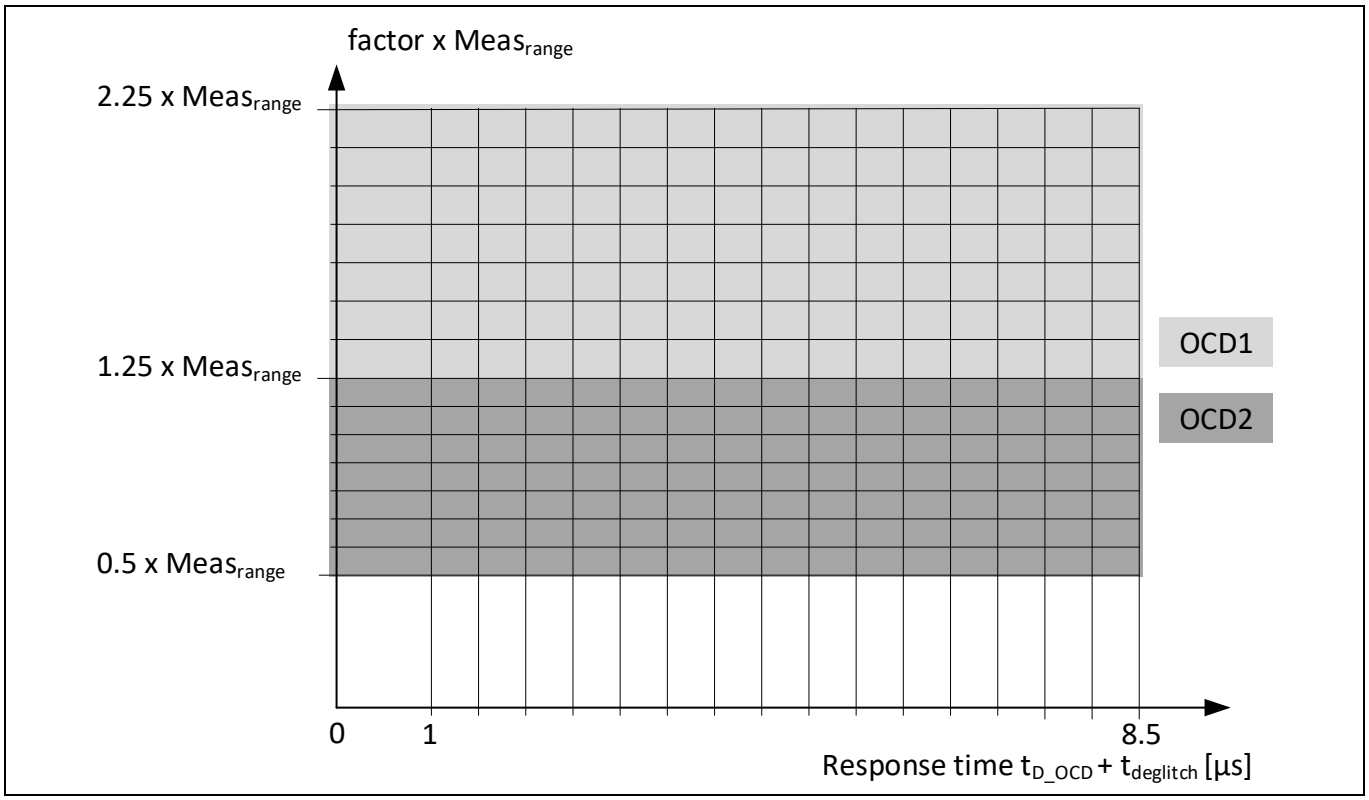

Figure 29 OCD threshold and deglitching illustration matrix

The following table shows an example of OCD1 threshold level settings and hysteresis settings in the EEPROM. Also, apply the same procedure for calculating OCD2 settings.

Table 23 OCD threshold hysteresis calculation example

Measurement range $MEAS_{rng}$ [dec]	Full Scale [A]	OCD threshold $OCD1_{thrsh}$ [dec]	OCD threshold $FS*I_{THR1.X}$ [1)] [A]	Hysteresis $OCD1_{thrsh}*(X\%)$ [2)] [dec]	Hysteresis level [A]
5	±120	26	150	6 at 25%	115
8	±75	30	168.75	6 at 20%	135

1) Possible settings for X are listed in and Table 16.
2) Set the number of required hysteresis (20% of threshold level is recommended)

9 Glossary

FS	Full Scale
SICI	Serial Inspection and Configuration Interface
EEPROM	Electrically Erasable Programmable Read-Only Memory
CRC	Cyclic Redundancy Check
VDD	Supply voltage
ISM	Intelligent State Machine
A/D	Analog Digital Converter Input
ADC	Analog to Digital Converter
FSR	Full Scale Range
CGS	Computer Gesteuerte Systeme GmbH……..
NI	National Instruments™
PC	Personal Computer
USB	Universal Serial Bus
OCD	Over Current Detection
VREF	Reference Voltage
AOUT	Analog Output
GND	Ground
GPIO	General Purpose Input Output
I/O	Input / Output
PWM	Pulse Width Modulation
NOP	No Operation
MSB	Most Significant Bit
LSB	Least Significant Bit
AC	Alternating Current
IGBT	Insulated Gate Bipolar Transistor
µC	Micro Controller
GPD	General Purpose Drive
IFX	Infineon

Revision history

Document version	Date of release	Description of changes
V1.0	20-12-2019	Initial version
V1.1	11-03-2020	Change OCD setting Table 16, Table 12
		Updated OCD example Table 23, updated Table 8 and Table 14
		Updated diagram Figure 16, Figure 21, Figure 26
		Editorial changes
		Changed to revision V 1.1

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