Melexis

INSPIRED ENGINEERING

24 May 2023

Revision 1.9

Current Sensors Programming and Calibration

Melexis
INSPIRED ENGINEERING

Calibration Overview

	No calibration/ Blind Calibration	Frontend (sensor-level) Calibration			Backend (MCU-level) Calibration
		PTC mode	MUST mode	VREF mode	
Hardware	None/PTC04+DB	PTC-04, sensor-specific DB			MCU
Accuracy	≈5%	0.5% (91218/19) / 0.1% (Others)			ADC resolution
Pros	▪ plug & play ▪ factory TC calibration	▪ accurate analog output ▪ only 3 wires	▪ accurate analog output ▪ VDD=5V or 3.3V		▪ no specific HW ▪ factory TC calibration
Cons	▪ magnetic design ▪ low absolute accuracy	▪ VDD increases to 8V ▪ change from factory calib	▪ 4/5 wires ▪ change from factory calib	▪ 4 wires ▪ Change from factory calib	▪ magnetic design should match sensor sensitivity
Sensors	ALL	ALL	91208/09 91216/17 91218 3.3V 91219 SOIC8 3.3V	91218 91219 SOIC8	ALL

Blind Calibration (MLX91208/09/16/17)

Melexis
INSPIRED ENGINEERING

Concept

The sensitivity of each Sensor is individually factory calibrated, using 2 EEPROM parameters RG and FG (Rough Gain, Fine Gain), to reach the target sensitivity, as defined in the datasheet.

Blind calibration consists in recalibrating the sensitivity of the part without performing measurements.

- The operation is accomplished by reading and manually change the RG and FG values stored in the in the EEPROM.
- These 2 parameters, codes the amplification chain that amplify the signal from the hall plates.
- Modifying RG, FG allows to change the output sensitivity of a sensor.

Typical gains and sensitivities

- RG controls a **non-linear** amplification block
- FG controls a **linear attenuation** block going from 0.5 to 1

- Since all sensors are intrinsically different, the RG and FG values needed to reach the target sensitivity are different from one sensor to the other It's possible to relate RG/FG combination to typical sensitivities:

RG [LSB]	FG [LSB]	Sensitivity [mV/mT]			
		91209	91208CAV	91208CAH	91208CAL
1	0	7	11	18	29
1	1023	14	22	35	59
3	0	17.5	28	44	73
3	1023	35	55	88	147
5	0	40.5	63	101	169
5	1023	81	127	203	338
7	0	95	150	240	400
7	1023	190	300	480	800

RG Code [LSB]	Gain Factor
0	2
1	3.6
2	6.25
3	9
4	12.4
5	20.7
6	30
7	49

Table 1: Gain Factor VS RG Code

(non linear amplifier)

FG Code [LSB]	Gain Factor
0	0.5
512	0.75
1023	1

Table 2: Gain Factor VS FG Code

(linear attenuator)

Melexis INSPIRED ENGINEERING

Blind calibration flow: Example

Recalibrate MLX 91208CAH from S= 100 [mV/mT] to 120 [mV/mT] needs to (i.e. 120% of the actual sensitivity)

1. Extraction of RG, FG values from the EEPROM
   - Results for this specific sensor: RG=3, FG=768
   - The actual amplification gain is:
   - $G = G_{rg} * G_{fg} = 9 * \left(0.5 + \frac{1-0.5}{1023-0} * (768-0)\right) = 7.88$

2. RG/FG have to be redefined to get a gain of G = 120%*7.88 = 9.46
   - We choose:
   - RG = 4 → $G_{rg} = 12.4$
   - $G_{fg} = \frac{G}{G_{rg}} = \frac{9.46}{12.4} = 0.763$ → $FG = \frac{0.763-0.5}{0.5} * 1023 = 538$
   - RG = 4, FG = 538

RG Code [LSB]	Gain Factor
0	2
1	3.6
2	6.25
3	9
4	12.4
5	20.7
6	30
7	49

Table 1: Gain Factor VS RG Code (non linear amplifier)

FG Code [LSB]	Gain Factor
0	0.5
512	0.75
1023	1

Table 2: Gain Factor VS FG Code (linear attenuator)

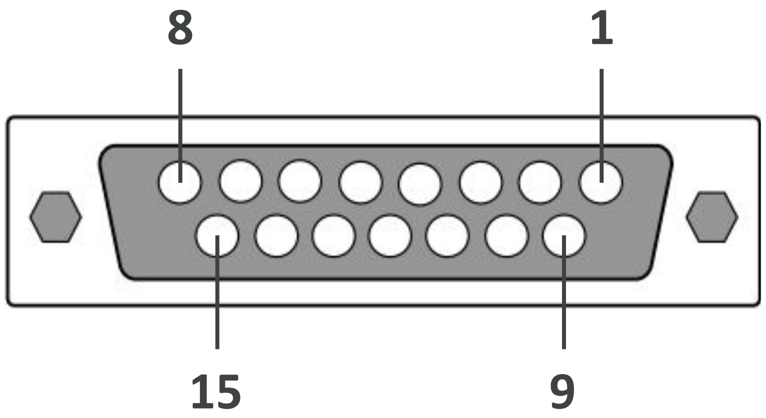
Front-end (sensor level) Calibration

Melexis
INSPIRED ENGINEERING

Hardware Structure

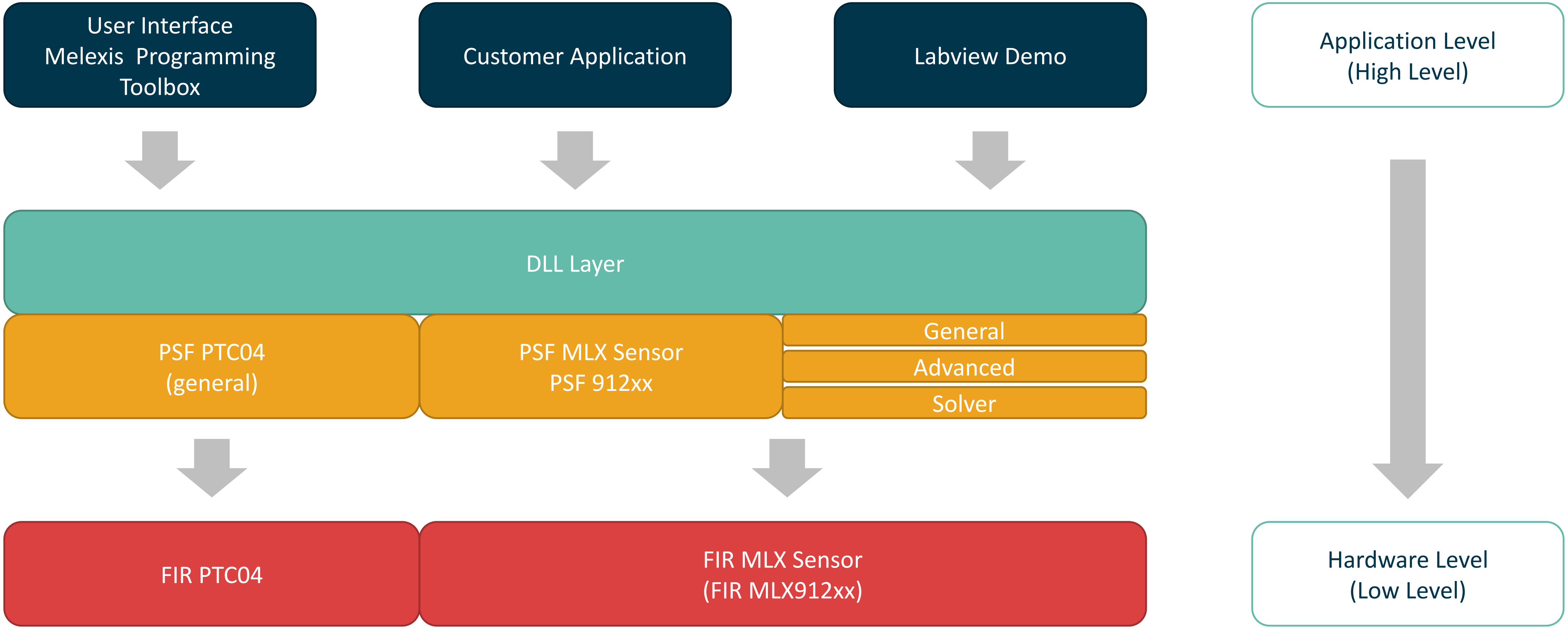
- Melexis PTC04: *Universal Programmer for Melexis sensors calibration*
- Sensor-specific Daughter-Board (DB): *Interface between PTC04 and application connector*

Daughter Board	Compatible Current Sensors
PTC04-DB-HALL05	MLX91208/09 MLX91216/17 MLX91218/19



Daughterboard Connector Pinout

Software structure



Setup

PC

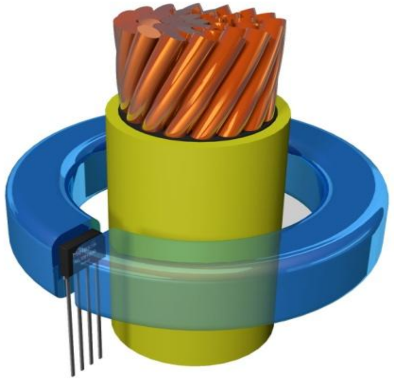
USB/RS232

PTC04 + DB*

PTC/MUST mode**

3/4/5-wire

Sensor



SW implemented in:

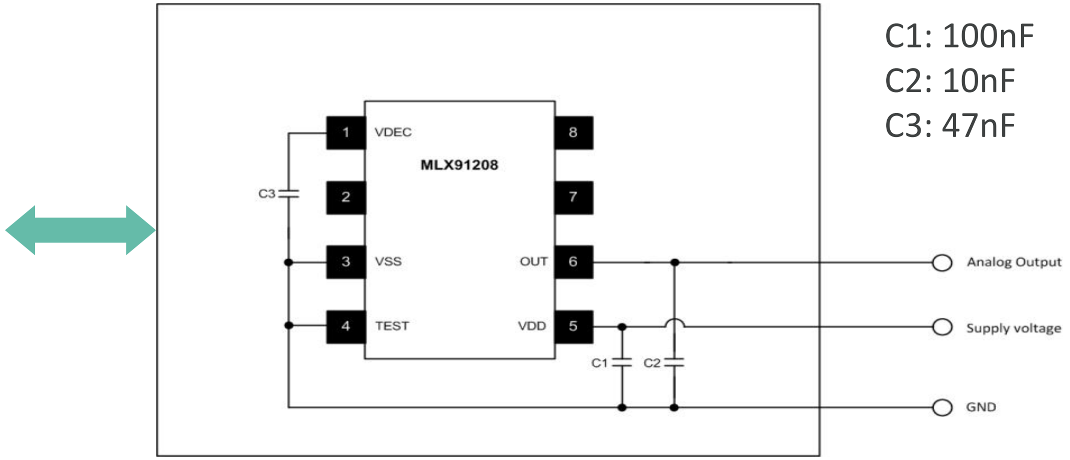
- Labview, Python
- C++, VB
- etc..

*DB = Daughter Board

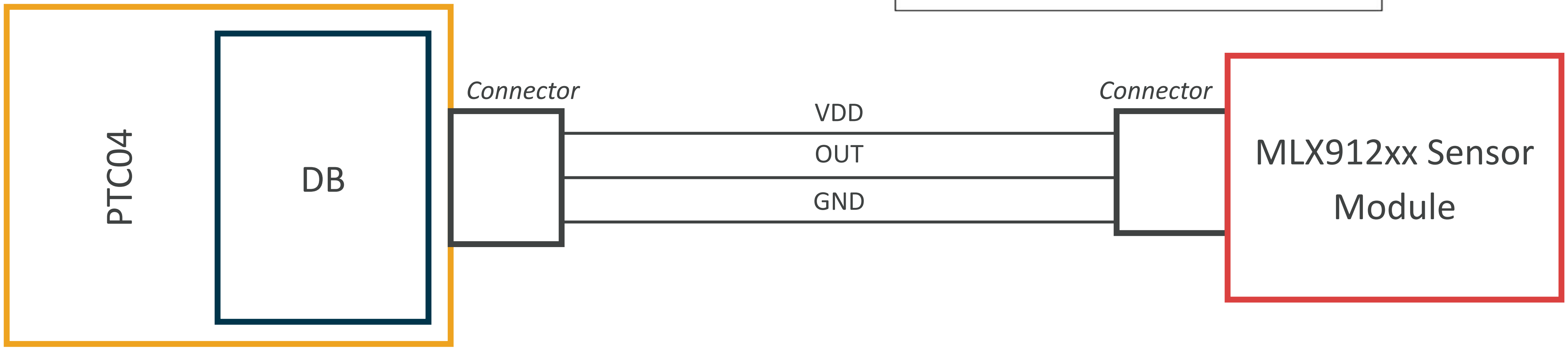
**Protocol to be selected in PSF/UI settings

PTC Communication Mode (3-wire)

- **Available on all current sensor family**
- Supply during communication:
  - VDD = 8 [V]
- Communication :
  - Bi-directional on OUT line



C1: 100nF
C2: 10nF
C3: 47nF

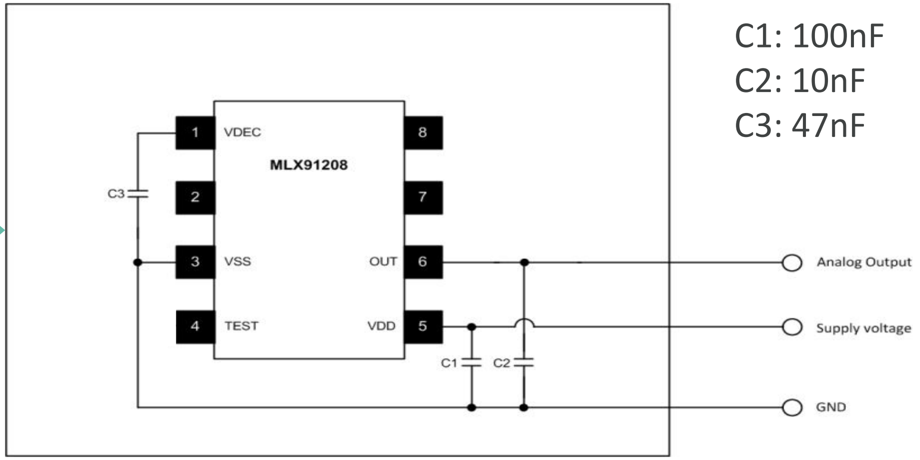


All unused pins (e.g.: TEST/MUST pin) can be connected to GND for better noise and EMC/ESD performance
GND connection of unused pins avoids coupling with the supply and ground loops

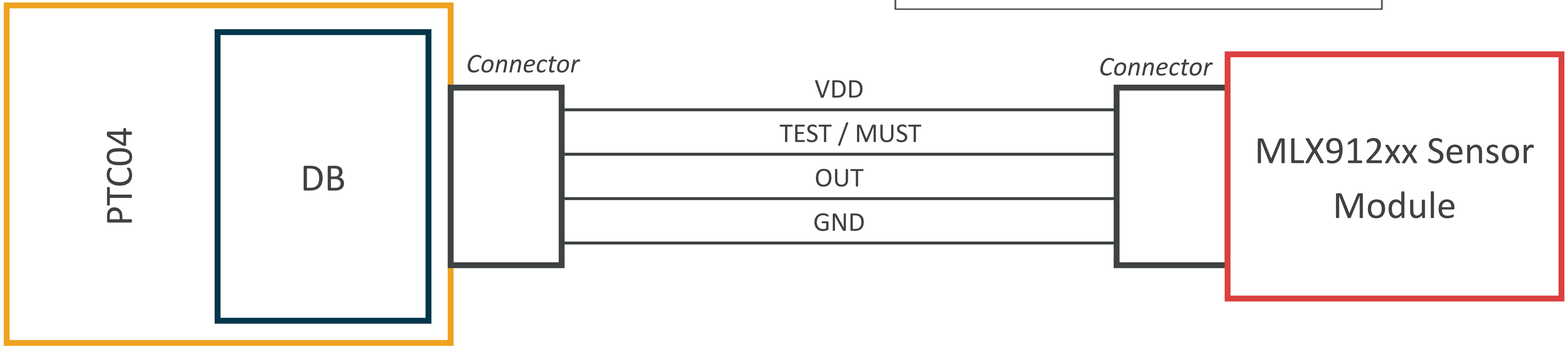
Melexis
INSPIRED ENGINEERING

MUST Communication Mode (4-wire)

- **Available for MLX91208/09/16/17 only**
- Supply during communication:
  - VDD = 5 [V]
- PTC-04 to sensor communication: on TEST / MUST line
- Sensors to PTC-04 communication: on OUT line



C1: 100nF
C2: 10nF
C3: 47nF



All unused pins (e.g.: TEST/MUST pin) can be connected to GND for better noise and EMC/ESD performance
GND connection of unused pins avoids coupling with the supply and ground loops

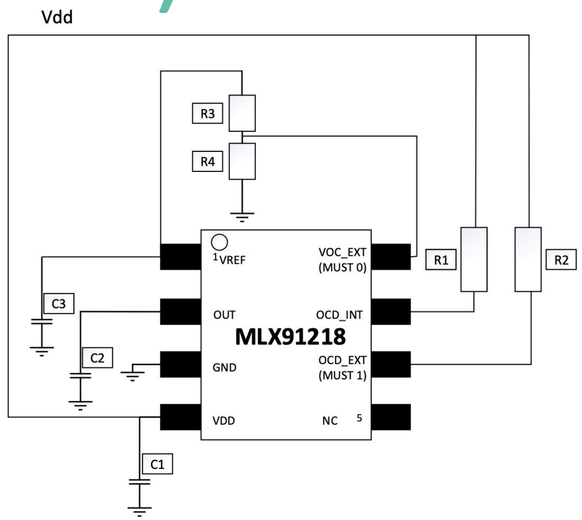
MUST Communication Mode (4-wire)

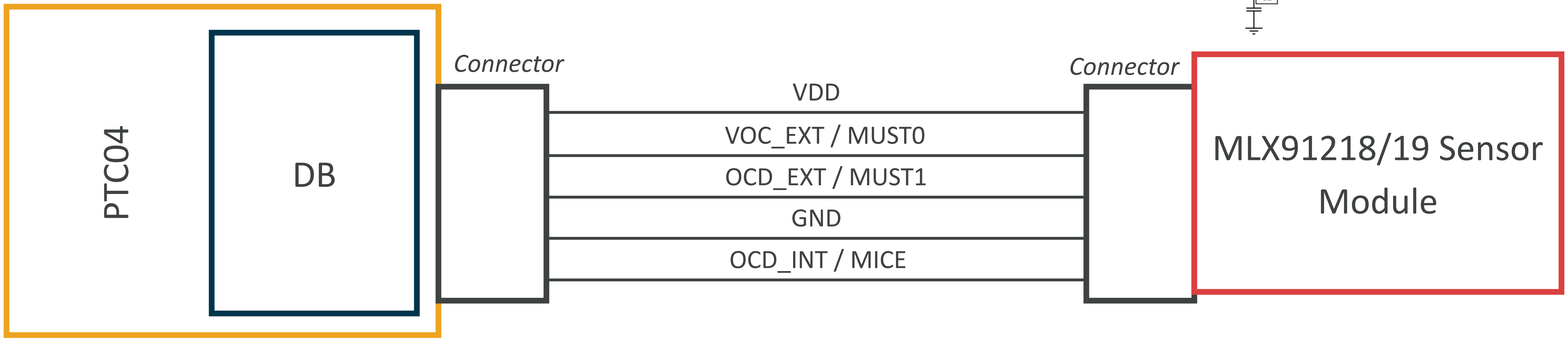
DBHALL05 Pins	Names	Description	MLX91208/16 pins	MLX91209/17 pins
1	VDD_DIE	Device Supply both dies	VDD / 5	VDD / 1
2	OUT_DIE1	Device Output Die 1	OUT / 6	OUT / 2
3	OUT_DIE2	Device Output Die 2	-	-
4	GND_DIE	Analogue Ground both dies	GND / 3	GND / 4
5	TEST_MUST_DIE1	Digital test pin _ MUST	TEST / 4	TEST / 3
6	NC	Not Conncted	-	-
7	NC	Not Connected	-	-
8	S2M	Master-Slave approach	-	-
9	VDD_SENS_DIE	Sensing Device Supply	VDD / 5	VDD / 1
10	OUT_SENS_DIE1	Sensing Device Output Die 1	OUT / 6	OUT / 2
11	OUT_SENS_DIE2	Sensing Device Output Die 2	-	-
12	GND_SENS_DIE	Sensing Analogue Ground Device	GND / 3	GND / 4
13	TEST_MUST_DIE2	Digital test pin - MUST	-	-
14	DB_TEST	Not Connected NC	-	-
15	M2S	Master-Slave approach	-	-

MUST Communication Mode (5-wire)

- **Available for MLX91218/19 SOIC8 only**
- Supply during communication:
  - VDD = 3.3 [V] **(5[V] not supported)**
- PTC-04 to sensor communication: on MUST0 and MUST1 lines
- Sensors to PTC-04 communication: on MICE line

C1: 47nF
C2: 4.7nF
C3: 47nF
R1: 10 kOhms
R2 : 10 kOhms
R3/R4 : OCD ratio





All unused pins can be connected to GND for better noise and EMC/ESD performance
GND connection of unused pins avoids coupling with the supply and ground loops

MUST Communication Mode (5-wire)

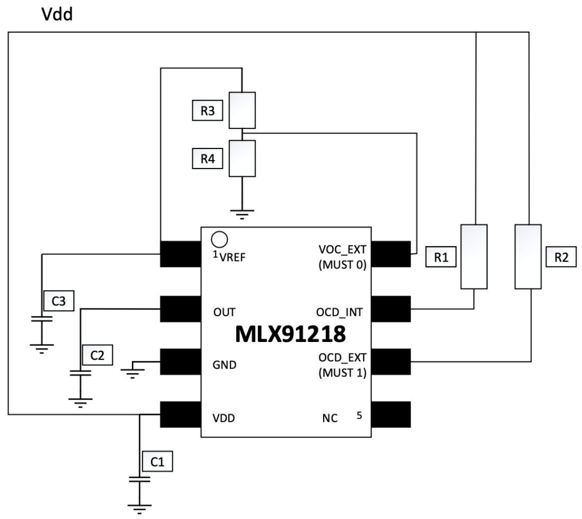
DBHALL05 Pins	Names	Description	MLX91218/19 SOIC8 pins
1	VDD_DIE	Device Supply both dies	VDD / 4
2	OUT_DIE1	Device Output Die 1	OUT / 2
3	OUT_DIE2	Device Output Die 2	OCD_INT/ 7
4	GND_DIE	Analogue Ground both dies	GND / 3
5	TEST_MUST_DIE1	Digital test pin _ MUST	-
6	NC	Not Conncted	-
7	NC	Not Connected	-
8	S2M	Master-Slave approach	VOC_EXT / 8
9	VDD_SENS_DIE	Sensing Device Supply	VDD / 4
10	OUT_SENS_DIE1	Sensing Device Output Die 1	OUT / 2
11	OUT_SENS_DIE2	Sensing Device Output Die 2	OCD_INT/ 7
12	GND_SENS_DIE	Sensing Analogue Ground Device	GND / 3
13	TEST_MUST_DIE2	Digital test pin - MUST	-
14	DB_TEST	Not Connected NC	-
15	M2S	Master-Slave approach	OCD_EXT / 6

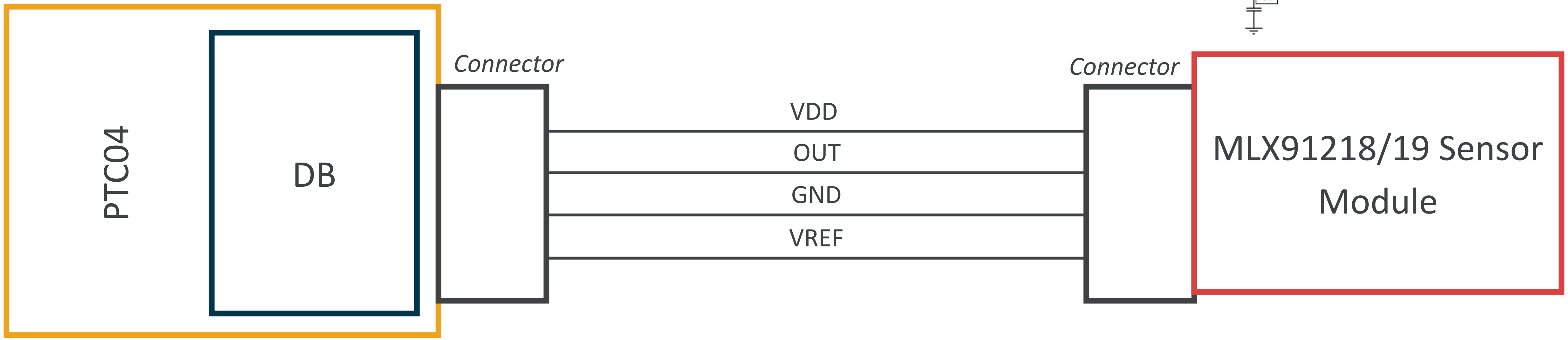
Melexis
INSPIRED ENGINEERING

VREF Communication Mode (4-wire)

- **Available for MLX91218/19 SOIC8 only**
- **Hardware patch needed (cf next slide)**
- Supply during communication:
  - VDD = 5 [V] or 3.3 [V]
- VREF raised to VDD
- Sensors to PTC-04 communication: on OUT line

C1: 47nF
C2: 4.7nF
C3: 47nF
R1: 10 kOhms
R2 : 10 kOhms
R3/R4 : OCD ratio



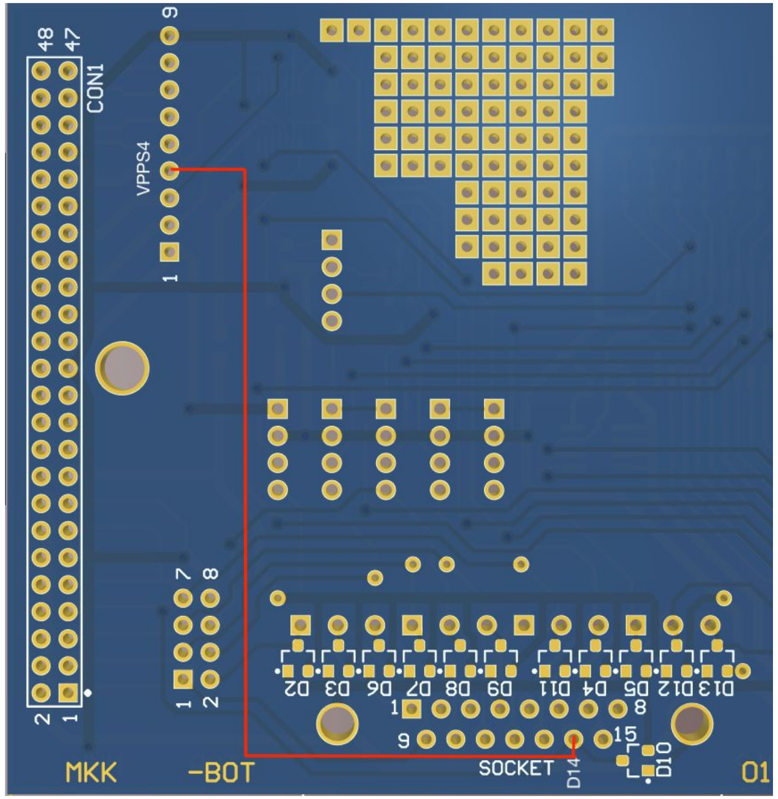


All unused pins can be connected to GND for better noise and EMC/ESD performance
GND connection of unused pins avoids coupling with the supply and ground loops

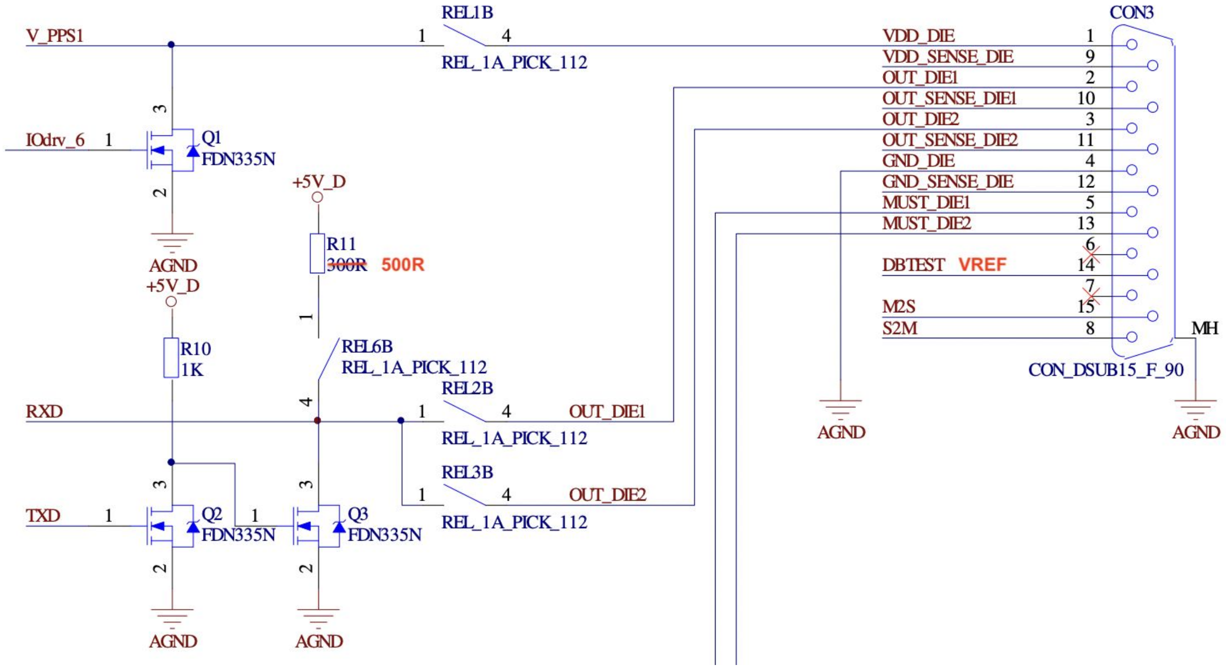
VREF Communication Mode (4-wire)

DBHALL05 Hardware patch (for DBHALL05 v1.1 and prior)

1. Route VPPS4 to pin14 of the DB15 connector



2. Change R11 from 300Ohms to 500Ohms



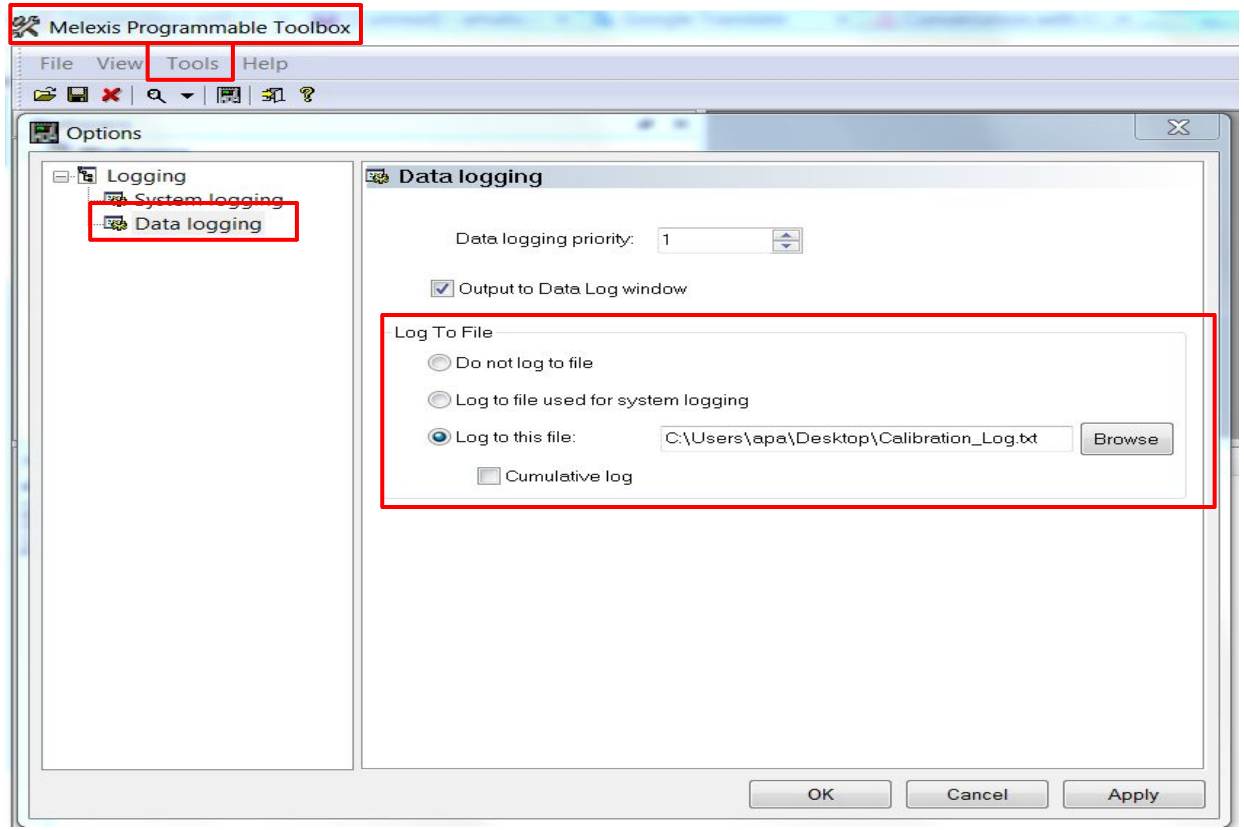
VREF Communication Mode (4-wire)

DBHALL05 Pins	Names	Description	MLX91218/19 SOIC8 pins
1	VDD_DIE	Device Supply both dies	VDD / 4
2	OUT_DIE1	Device Output Die 1	OUT / 2
3	OUT_DIE2	Device Output Die 2	-
4	GND_DIE	Analogue Ground both dies	GND / 3
5	TEST_MUST_DIE1	Digital test pin _ MUST	-
6	NC	Not Conncted	-
7	NC	Not Connected	-
8	S2M	Master-Slave approach	-
9	VDD_SENS_DIE	Sensing Device Supply	VDD / 4
10	OUT_SENS_DIE1	Sensing Device Output Die 1	OUT / 2
11	OUT_SENS_DIE2	Sensing Device Output Die 2	-
12	GND_SENS_DIE	Sensing Analogue Ground Device	GND / 3
13	TEST_MUST_DIE2	Digital test pin - MUST	
14	DB_TEST	Not Connected NC	VREF / 1
15	M2S	Master-Slave approach	-

Software for calibration MLX91208/09/16/17

Calibration Log

Before starting the Calibration Flow

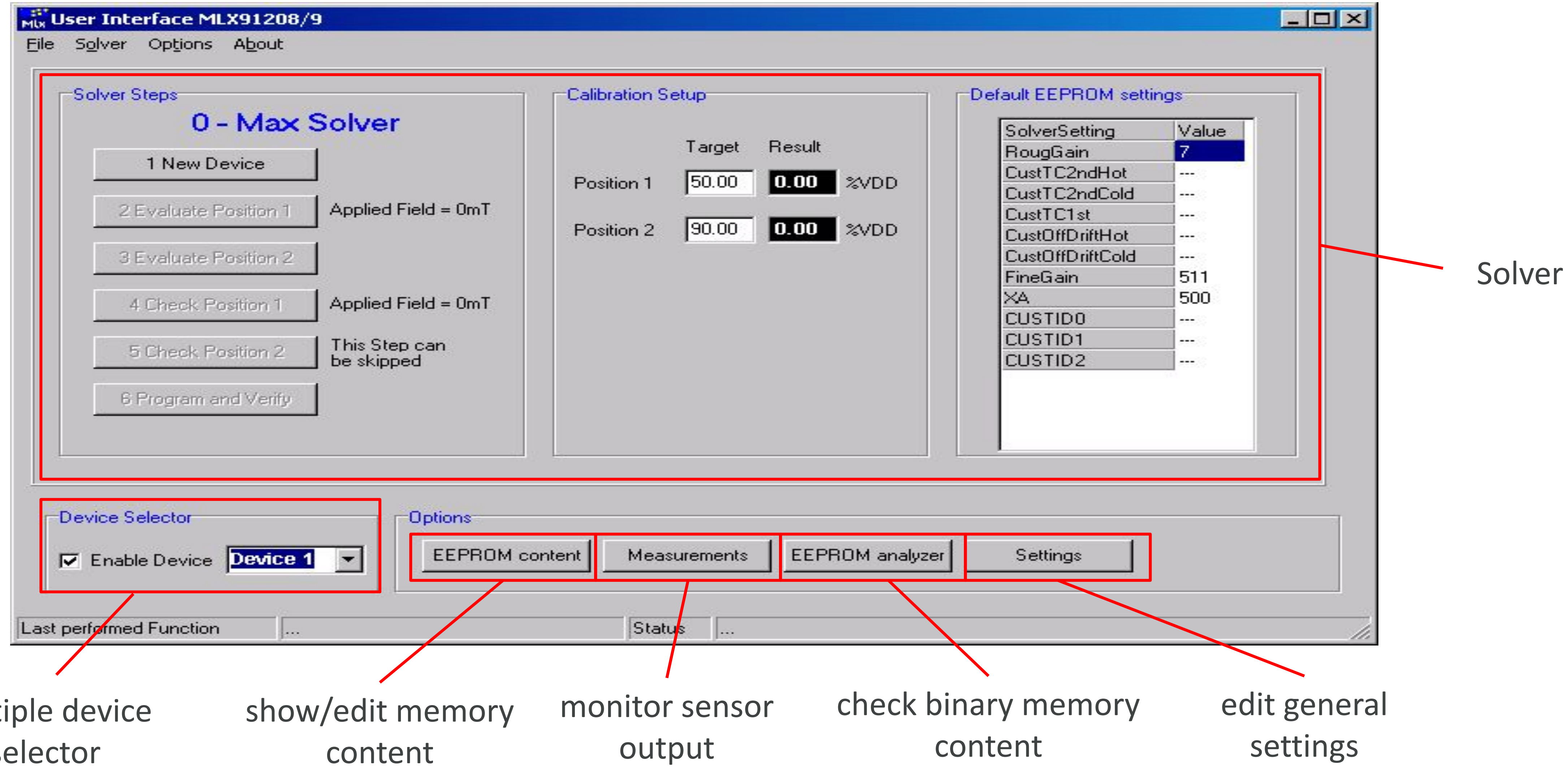


Optional:

Keep a copy of Calibration measures, steps, calculations

By default, the option“Do not log to file” is ticked

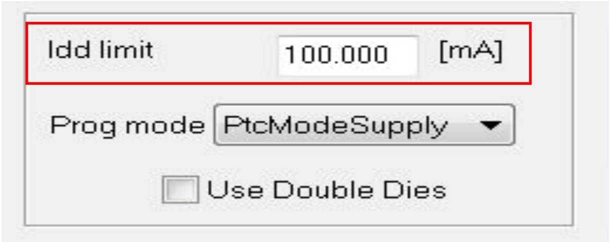
User interface



Melexis
INSPIRED ENGINEERING

Multiple Devices

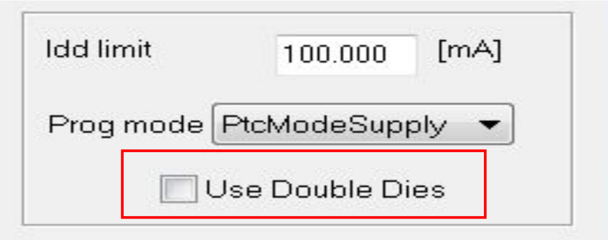
The software can store EEPROM information for up to 16 devices simultaneously. Each device can be selected/enabled with the device selector. However, only 1 device can be physically connected to the OUT1 line of the PTC04. An **external** hardware switch is required for this purpose. The solver will ask the user to switch between the devices at each step of the calibration process.



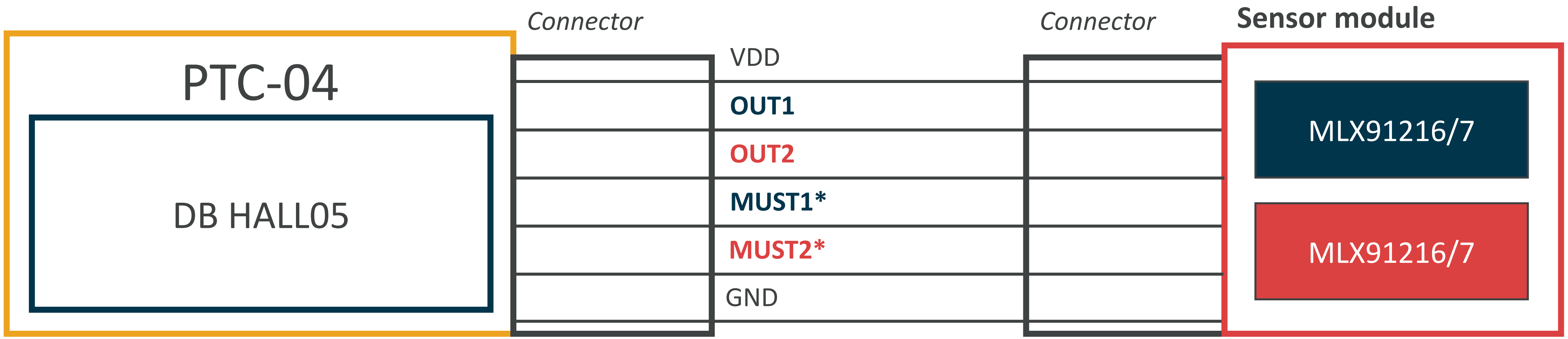
During communication, the current consumption increases significantly (short spikes/bursts). The default Idd limit of 100mA is sufficient for 2-3 devices only. For instance, a limit of 300mA is required for 8 devices (multi-socket).

Multiple Devices

Dual Die Configuration



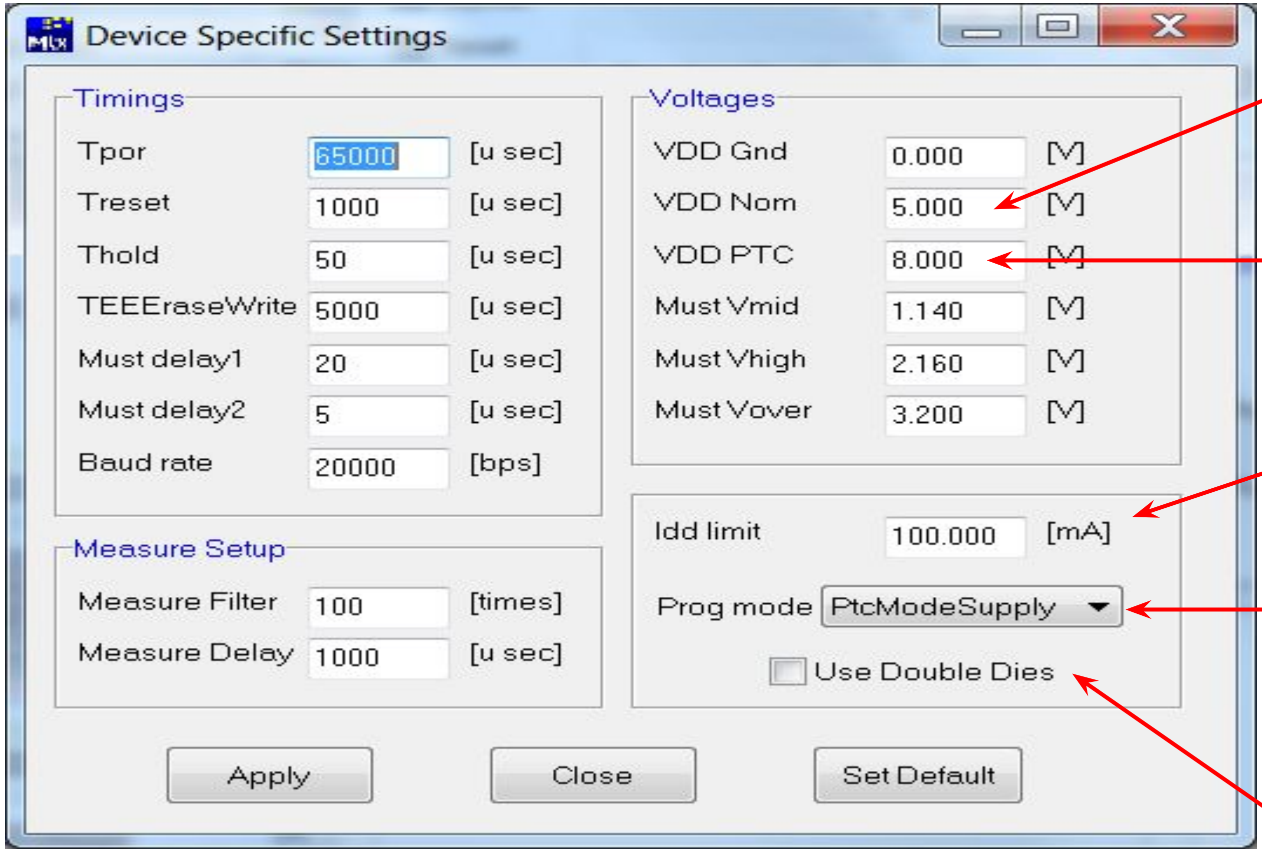
The “Use Double Dies” option in the “Settings” window allows to connect 2 devices to the PTC04 simultaneously. When this option is selected, “Device 1” is on OUT1 and “Device 2” is on OUT2.



*The MUST pins are only required for MUST mode communication.

Settings

Some of the most important settings are described here.



nominal chip supply (Vdd)

voltage level for «PtcMode» programming

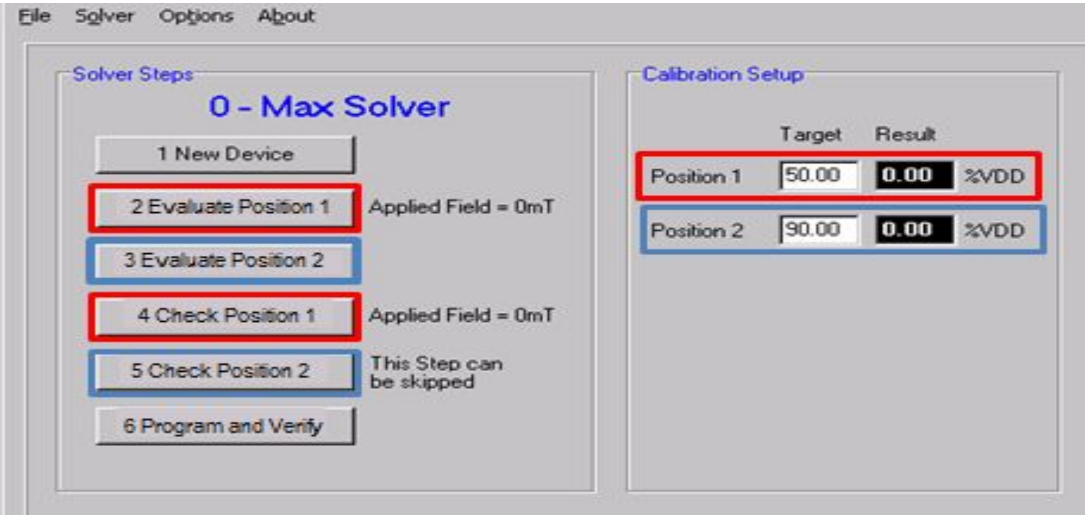
limit for PTC supply current (increase to supply several devices in parallel)

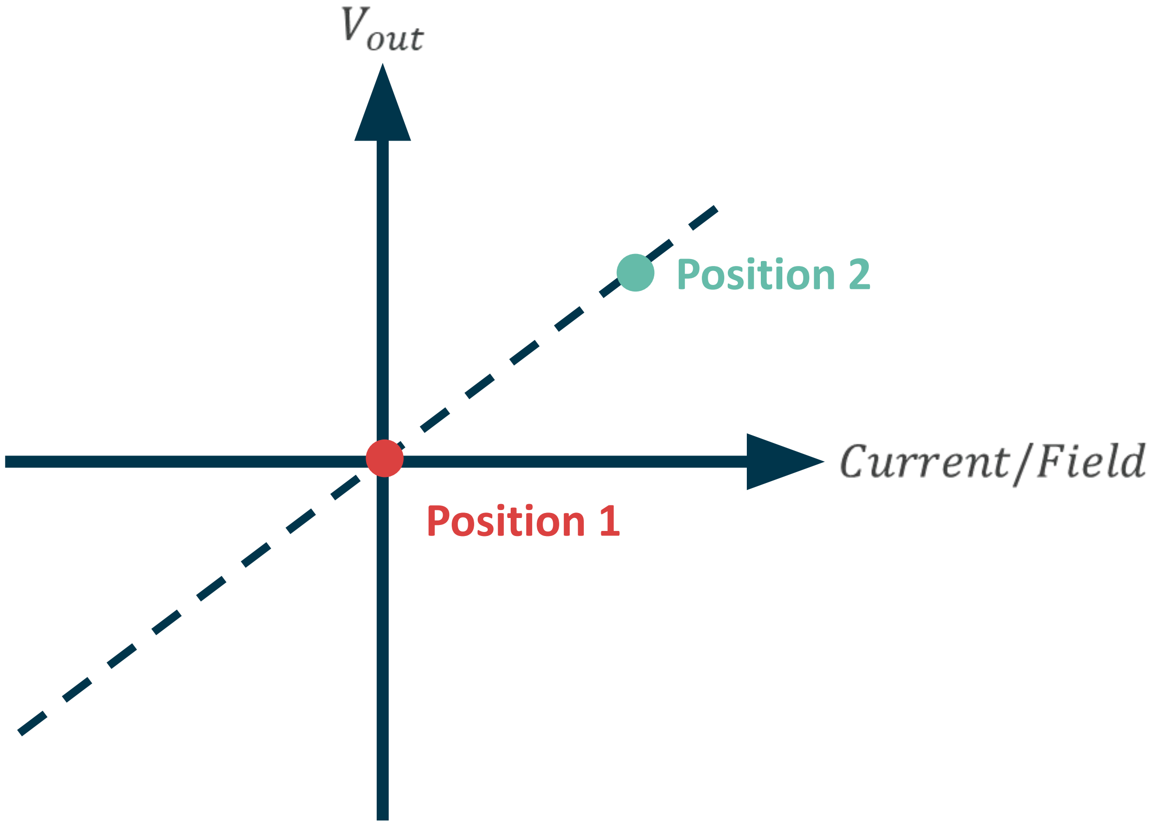
select **programming mode**:

- PtcModeSupply: use Vdd=8V to put chip in communication mode
- MUSTMode: use MUST/test pin to communicate (at nominal Vdd)

program two devices in parallel on OUT1 and OUT2

0-Max Solver





Concept: The solver starts from the preset gain and, if required, it sweeps through all allowed RG settings (max. +/-1 for 91206/07)

Two reference positions are needed for offset and gain parameters calibration

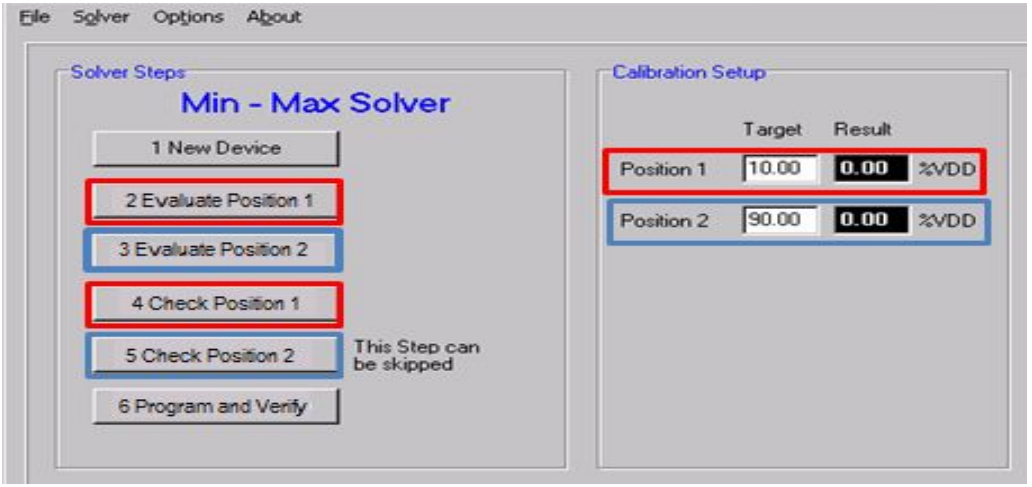
Position 1: Zero current/field

Position 2: Positive reference current/field

+ Low hysteresis, accurate fit

i Offset is adjusted by interpolation

Min-Max Solver

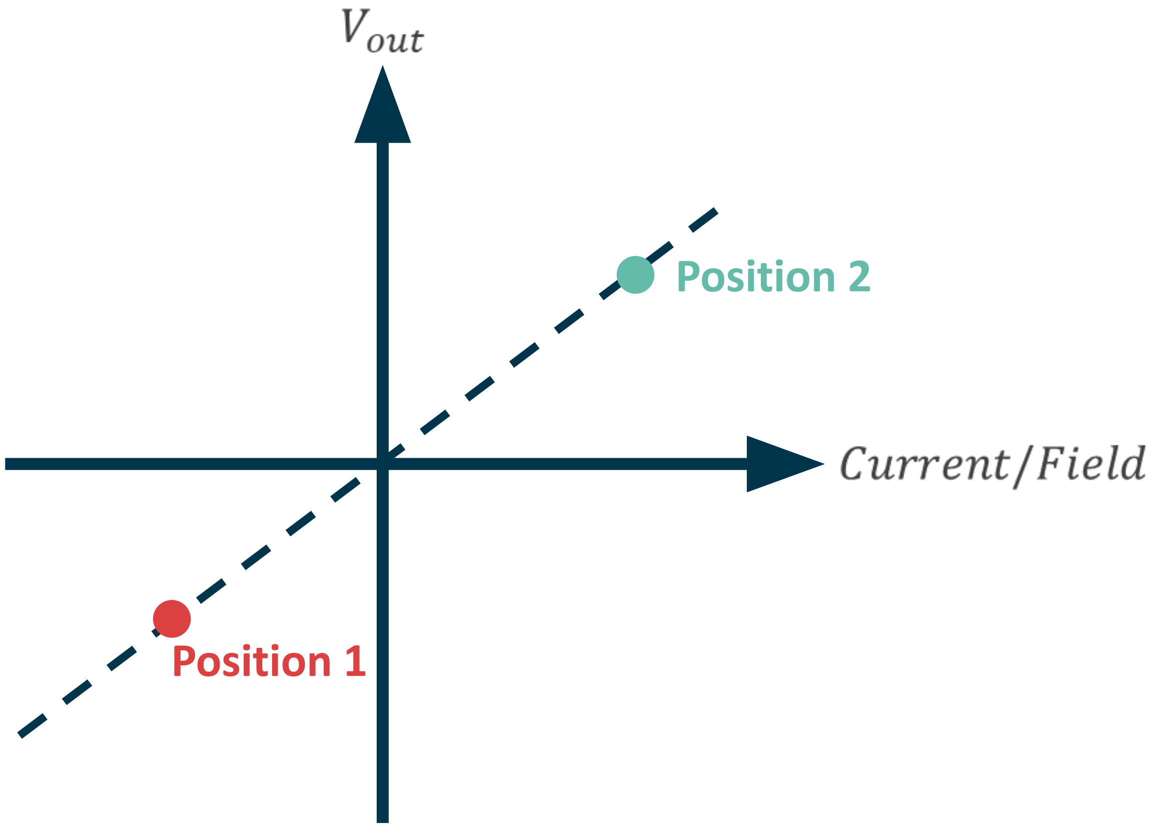


Concept: The solver starts from the preset gain and decreases RG only if the output is clamped at Position 1. No RG adjustment is possible at position 2.

Two reference positions are needed for offset and gain parameters calibration

Position 1: Negative reference current/field

Position 2: Positive reference current/field

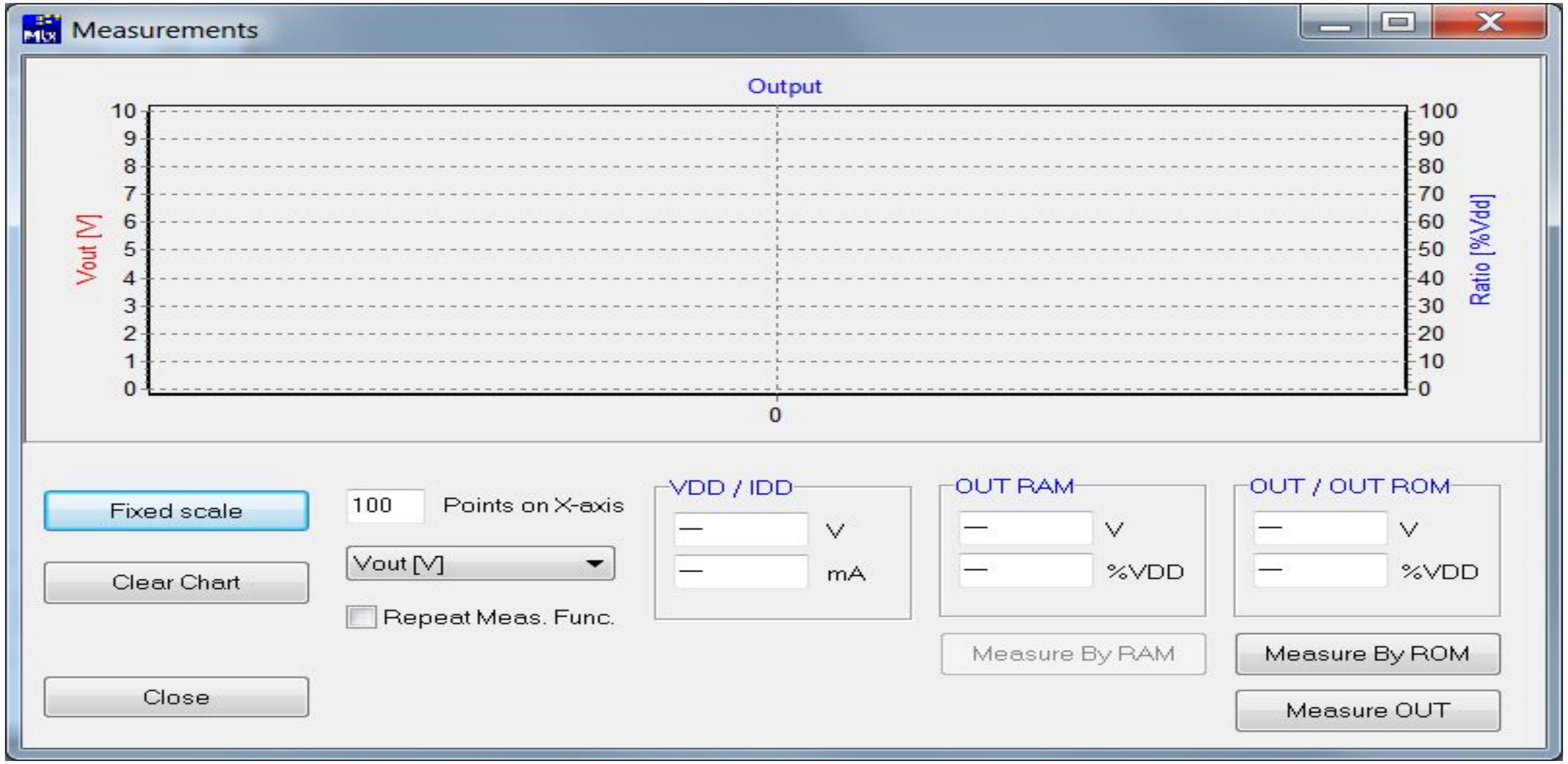


+ High accuracy for offset trimming

ℹ More sensitive to hysteresis and saturation

Measurements window

This window allows to monitor sensor supply and output. It is good practice to check that VDD and IDD are in the expected range before starting to program the sensor.

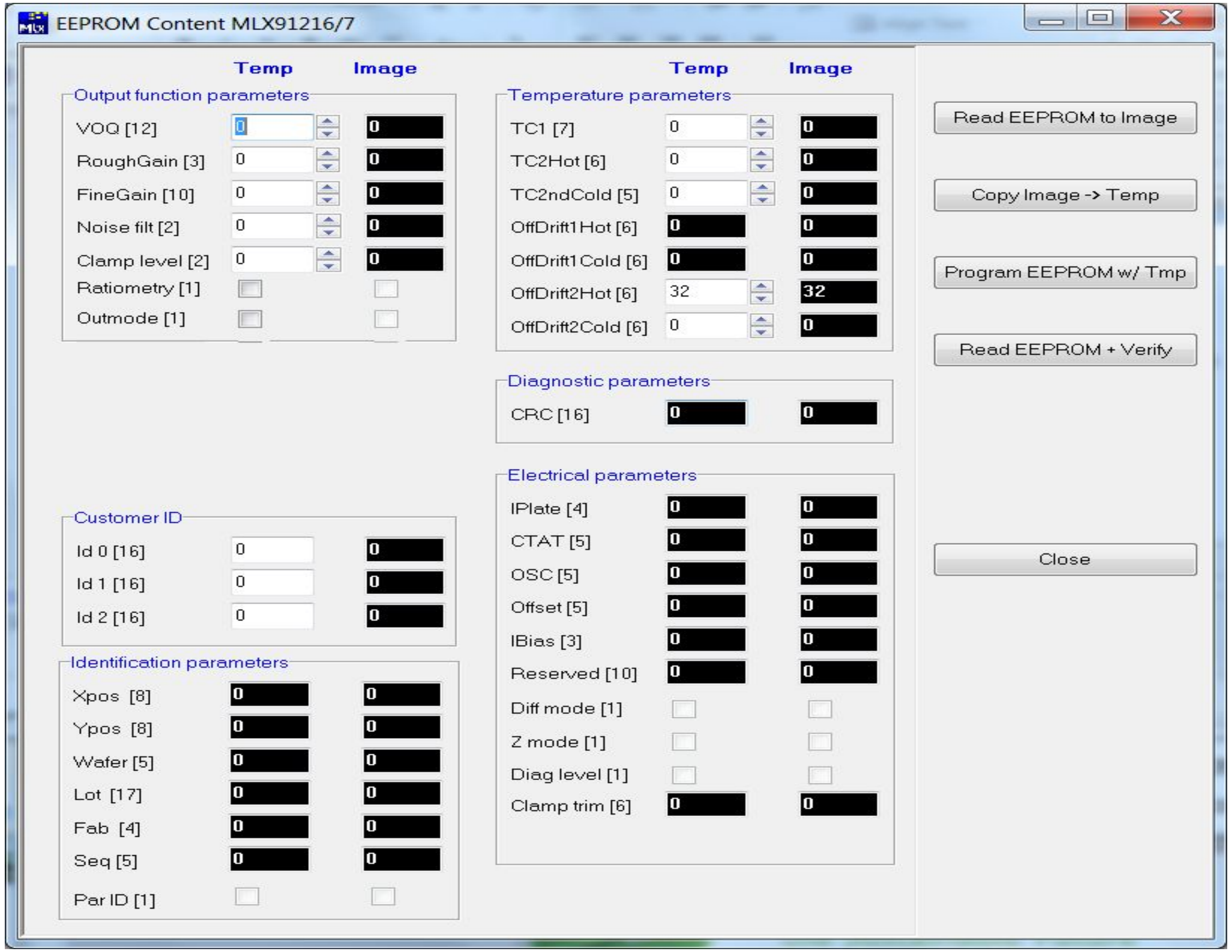


measure by RAM
program RAM with values from the TEMP register, then measure output

measure by ROM
reset device to program RAM with EEPROM values, then measure output

measure OUT
perform single measurement

EEPROM window



To change the value of one or several EEPROM parameter(s), always perform the following steps:

→ read EEPROM to Image
→ copy Image to Temp
→ edit the Temp value(s)
→ program EEPROM with Temp
→ read EEPROM and verify

The final verification step is required to readback the updated CRC code.

Melexis
INSPIRED ENGINEERING

MLX91206 TC Particularity

- For MLX91206 only, the temperature compensation parameters TC1, TC2COLD, TC2HOT, OFFDRIFT COLD & HOT are re-trimmed when the gain (RG, FG) is changed in the application.

1) During Final Test

- Find optimal TC parameters for RG nominal, RG+1 and RG-1
- Store optimal TC parameters for nominal RG in EEPROM
- Store “delta TC” parameters for RG+1 and RG-1 in unused EEPROM bits

2) During EOL Front-End Calibration

- Find optimal gain settings based on applied field/current
- If RG and/or FG has changed: correct TC parameters for new gain settings based on “delta TC” parameters and look-up tables built based on the Final Test results

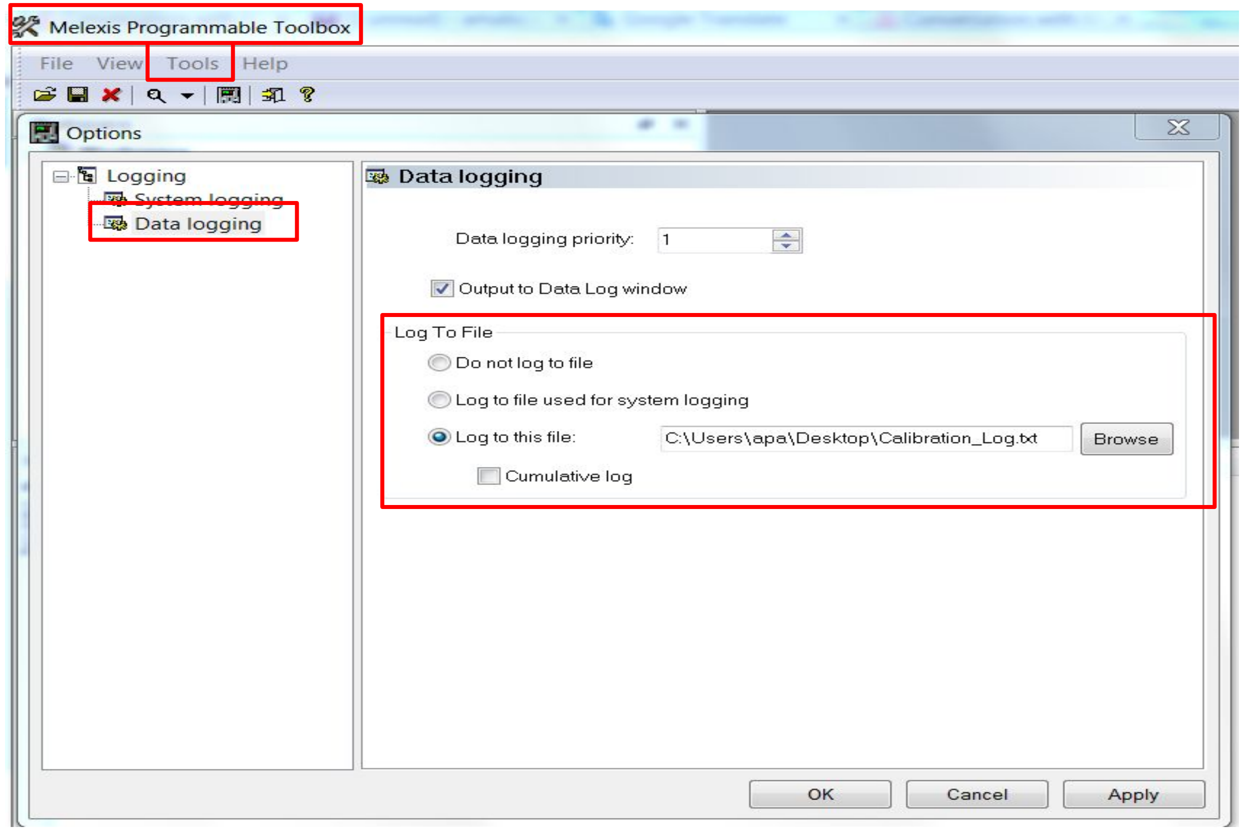
Note: the algorithm is based on relative gain/TC changes, therefore it will not work correctly if someone manually changes gain or TC between steps 1 and 2. If a setting is manually changed at any stage, the complete calibration is lost.

Software for calibration MLX91218/19

Melexis
INSPIRED ENGINEERING

Calibration Log

Before starting the Calibration Flow



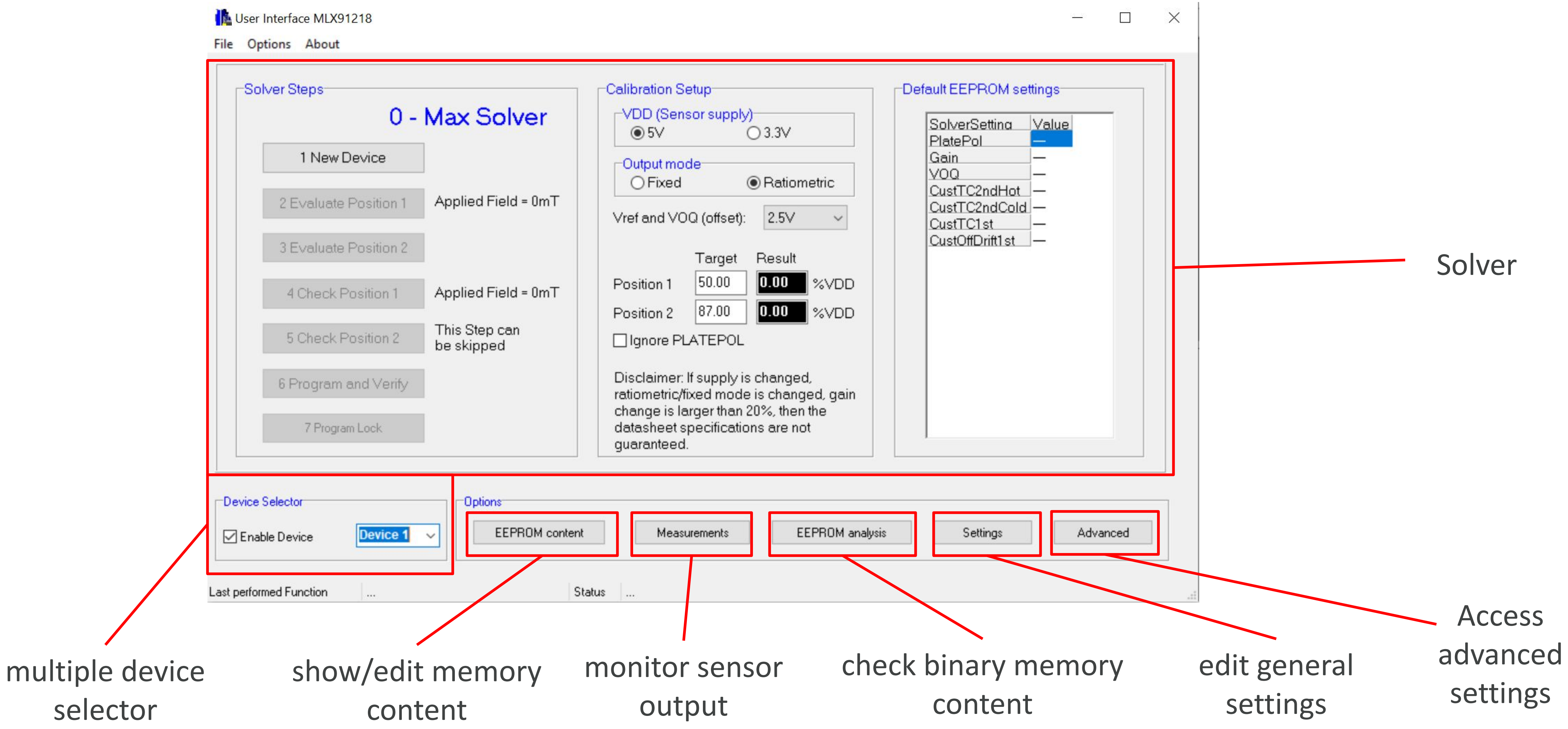
Optional:

Keep a copy of Calibration measures, steps, calculations

By default, the option“Do not log to file” is ticked

Melexis INSPIRED ENGINEERING

User interface



Disclaimer: gain range, supply and reference settings

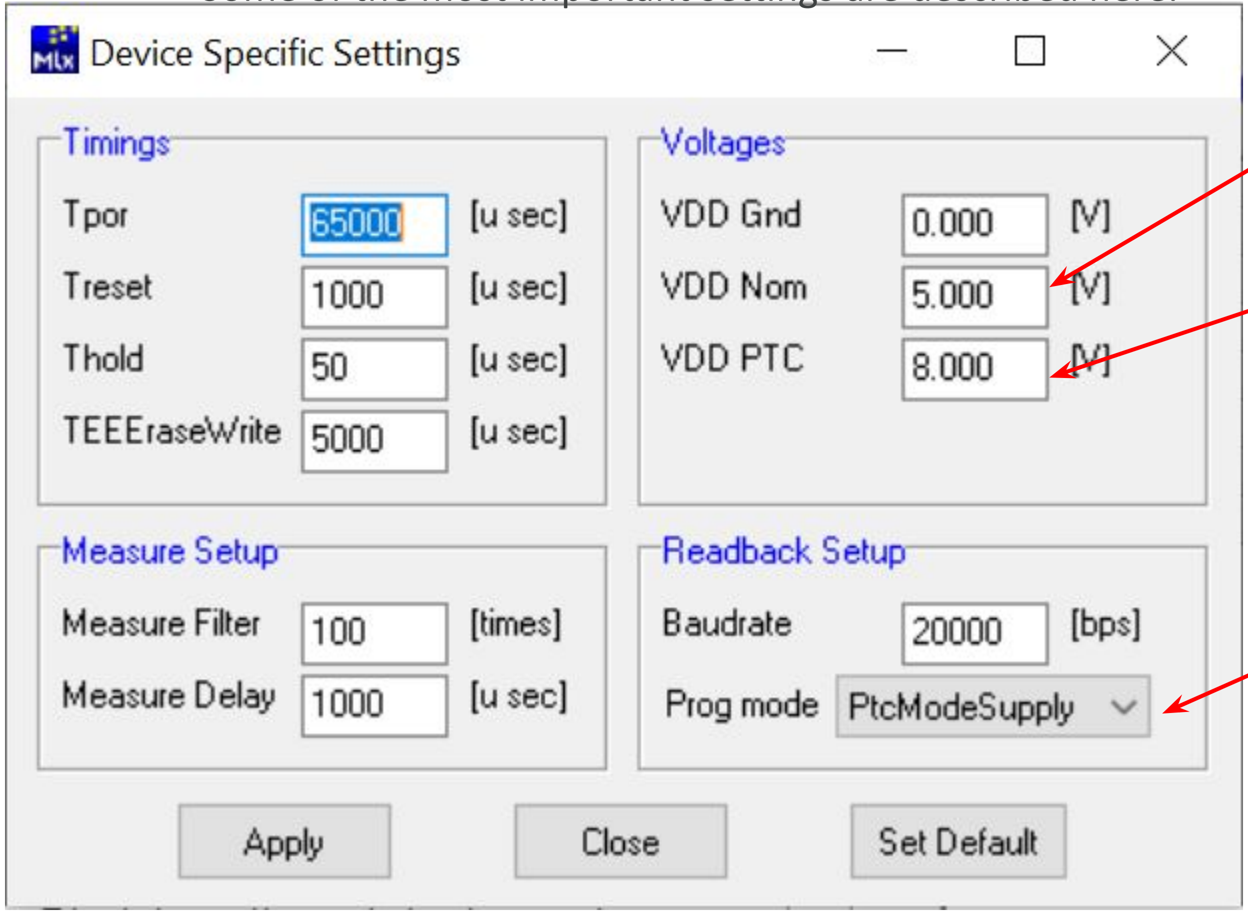
- In the following cases, the datasheet performances are not guaranteed:
  - Sensitivity is outside the datasheet programmable range for a particular part number
  - Supply settings are changed
  - Output mode (ratiometric or fixed) is changed

Multiple Devices

The software can store EEPROM information for up to 16 devices simultaneously. Each device can be selected/enabled with the device selector. However, only 1 device can be physically connected to the OUT1 line of the PTC04. An **external** hardware switch is required for this purpose. The solver will ask the user to switch between the devices at each step of the calibration process.

Settings

Some of the most important settings are described here.



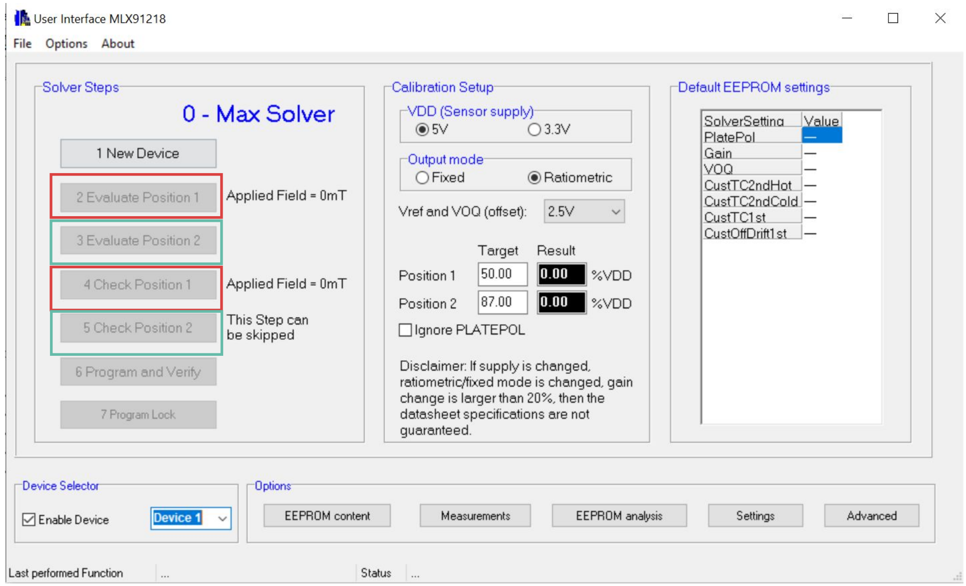
nominal chip supply (Vdd)

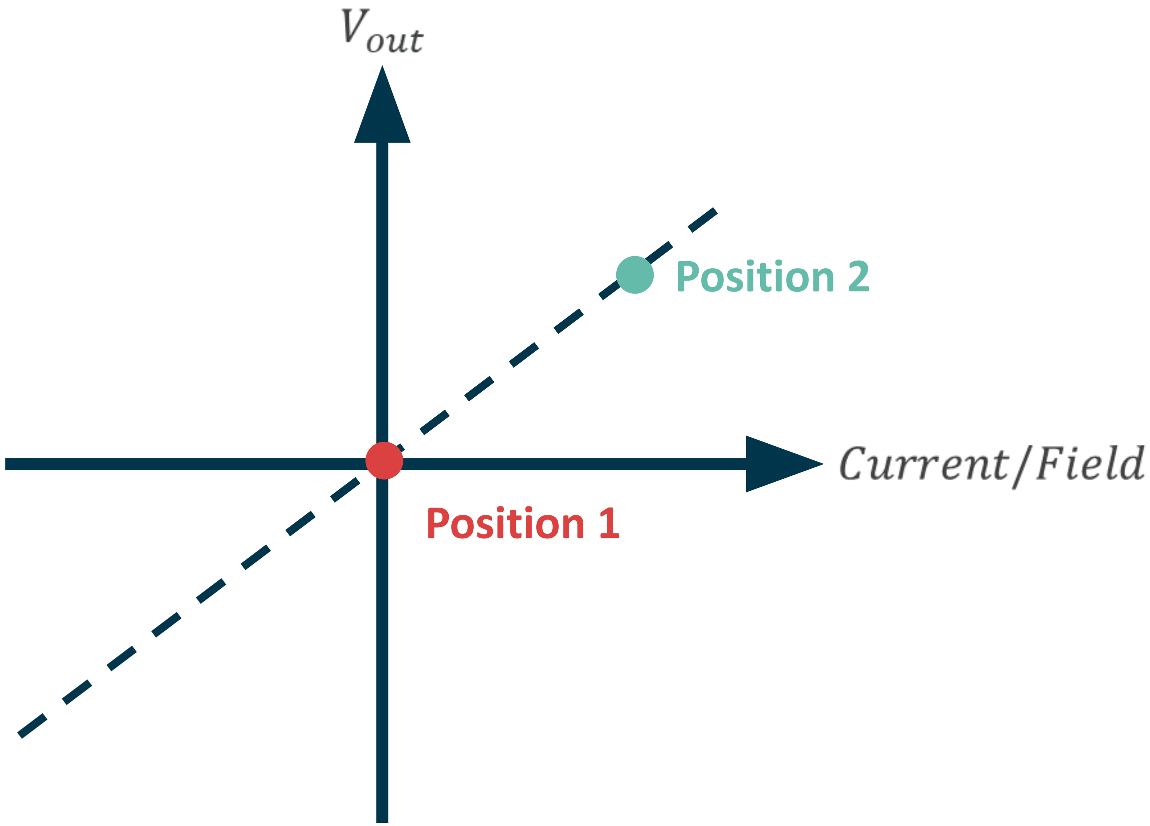
voltage level for «PtcMode» programming

select **programming mode**:

- PtcModeSupply: use Vdd=8V to put chip in communication mode
- MUSTMode: use MUST/test pin to communicate (at nominal Vdd)
- PtcModeVref: use Vref/Out pin to communicate (at nominal Vdd)

0-Max Solver





Concept: The solver starts from the preset gain.

Two reference positions are needed for offset and gain parameters calibration:

Position 1: Zero current/field

Position 2: Positive reference current/field

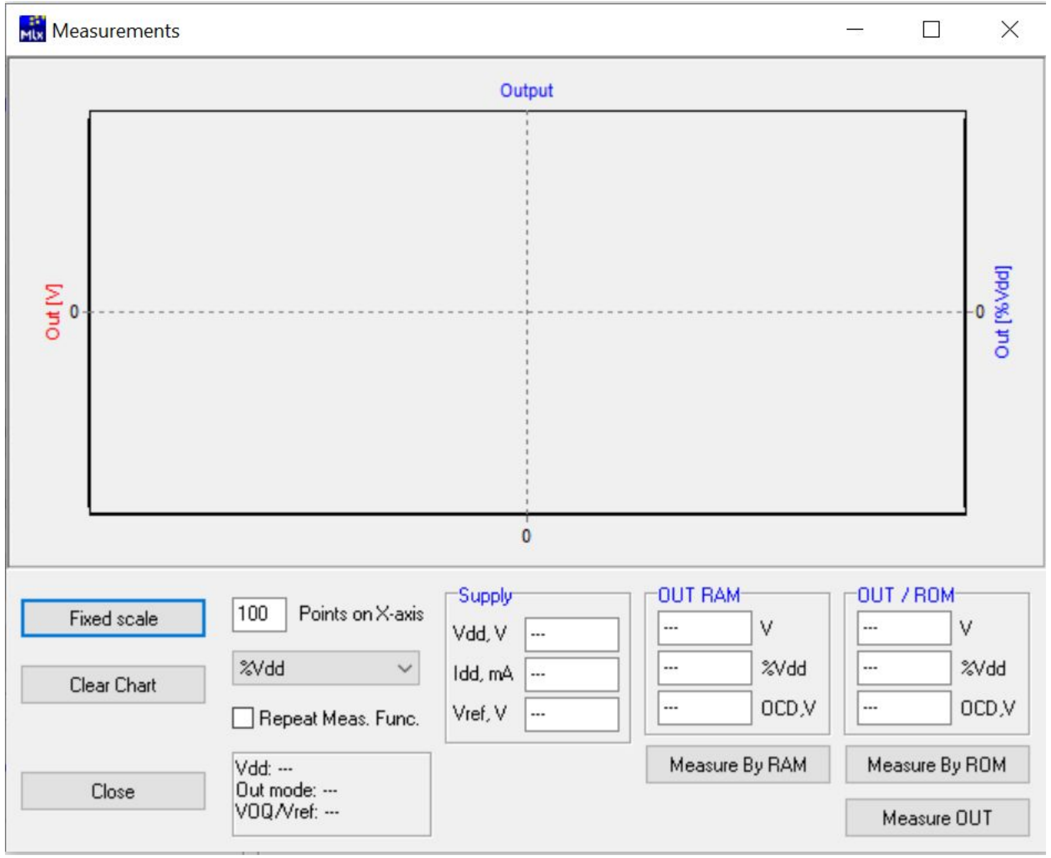
Program Lock: The program lock button, if pressed, will lock the eeprom and disable any possibility of re-programming the sensor. **If subsequent programming is needed, do not press this button.**

- ✚ High accuracy for offset trimming
- ℹ More sensitive to hysteresis and saturation

Melexis INSPIRED ENGINEERING

Measurements window

This window allows to monitor sensor supply and output. It is good practice to check that VDD and IDD are in the expected range before starting to program the sensor.

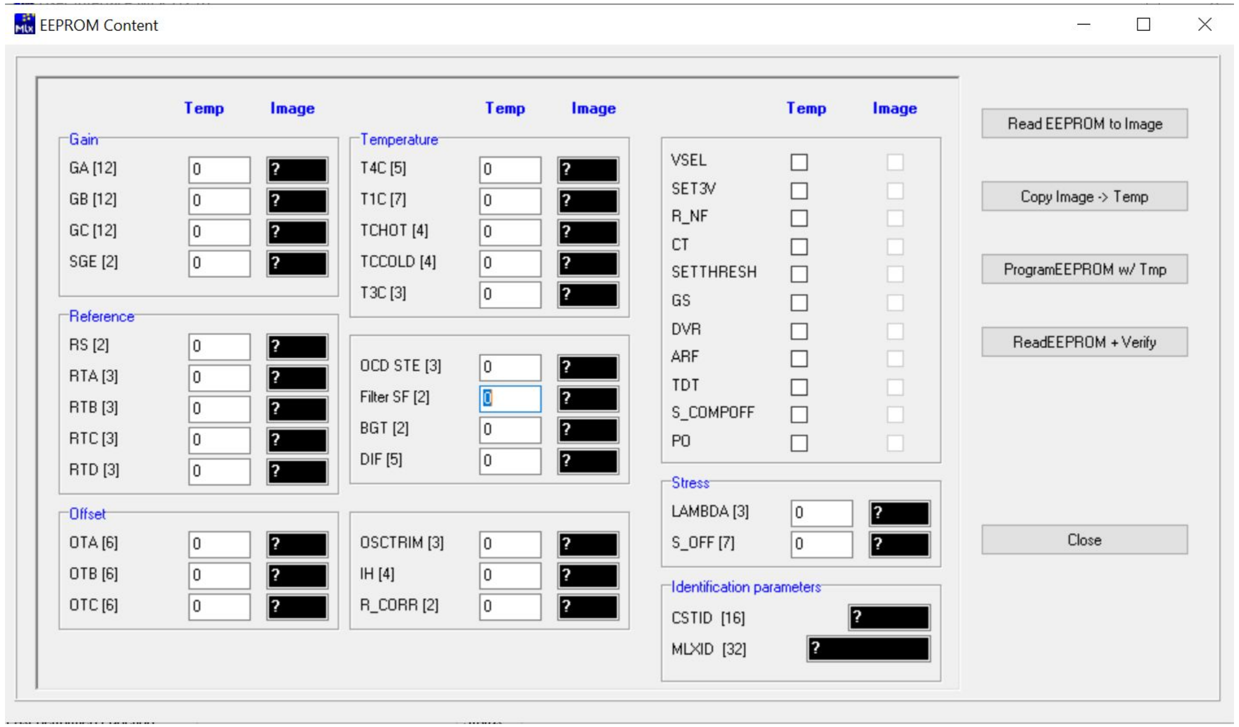


measure by RAM
program RAM with values from the TEMP register, then measure output

measure by ROM
reset device to program RAM with EEPROM values, then measure output

measure OUT
perform single measurement

EEPROM window



To change the value of one or several EEPROM parameter(s), always perform the following steps:

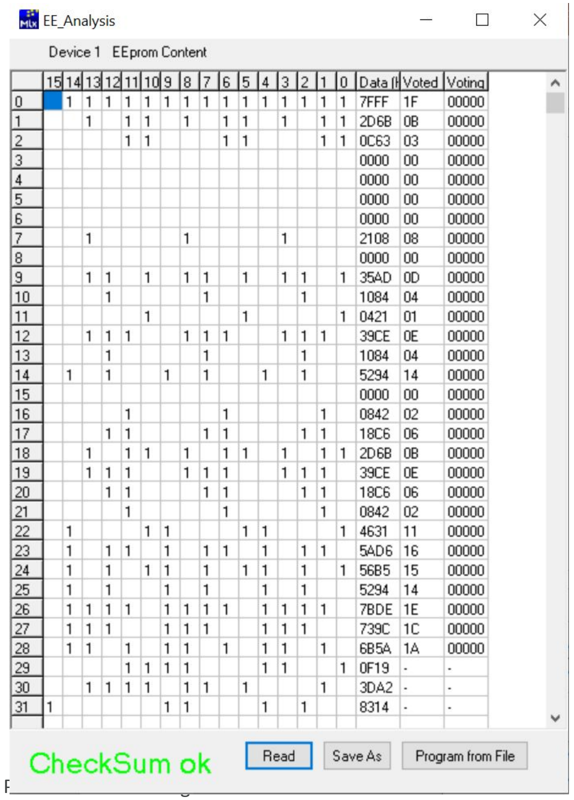
⟶ read EEPROM to Image
⟶ copy Image to Temp
⟶ edit the Temp value(s)
⟶ program EEPROM with Temp
⟶ read EEPROM and verify

The final verification step is required to readback the updated CRC code.

EEPROM Lock

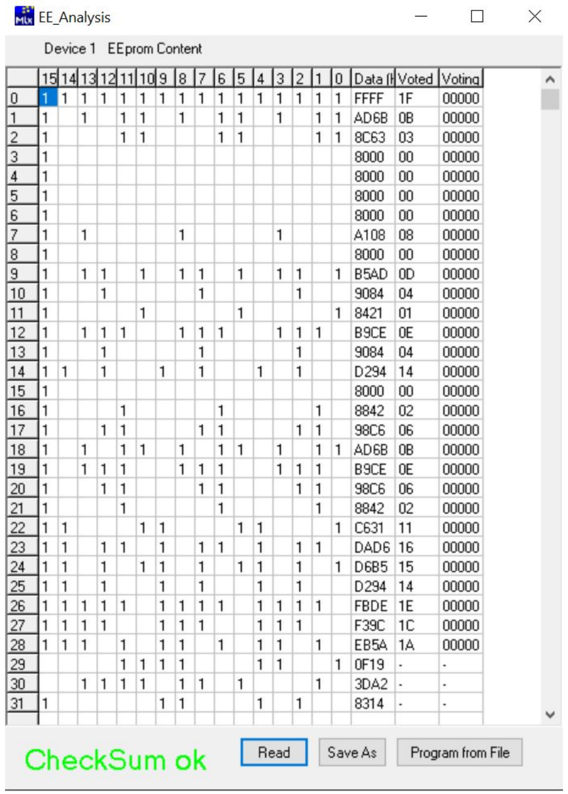
- EEPROM lock is writing the MSB of each word, blocking any subsequent writing on the EEPROM

Unlocked EEPROM



	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	Data (H	Voted	Voting
0		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7FFF	1F	00000
1			1		1	1		1		1	1		1		1	1	2D6B	0B	00000
2					1	1				1	1				1	1	0C63	03	00000
3																	0000	00	00000
4																	0000	00	00000
5																	0000	00	00000
6																	0000	00	00000
7			1					1					1				2108	08	00000
8																	0000	00	00000
9			1	1		1		1	1		1		1	1		1	35AD	0D	00000
10				1					1					1			1084	04	00000
11						1					1					1	0421	01	00000
12			1	1	1			1	1	1			1	1	1		39CE	0E	00000
13				1					1					1			1084	04	00000
14		1		1			1		1			1		1			5294	14	00000
15																	0000	00	00000
16					1					1					1		0842	02	00000
17				1	1				1	1				1	1		18C6	06	00000
18			1		1	1		1		1	1		1		1	1	2D6B	0B	00000
19			1	1	1			1	1	1			1	1	1		39CE	0E	00000
20				1	1				1	1				1	1		18C6	06	00000
21					1					1					1		0842	02	00000
22		1				1	1				1	1				1	4631	11	00000
23		1		1	1		1		1	1		1		1	1		5AD6	16	00000
24		1		1		1	1		1		1	1		1		1	56B5	15	00000
25		1		1			1		1			1		1			5294	14	00000
26		1	1	1	1		1	1	1	1		1	1	1	1		7BDE	1E	00000
27		1	1	1			1	1	1			1	1	1			739C	1C	00000
28		1	1		1		1	1		1		1	1		1		6B5A	1A	00000
29					1	1	1	1				1	1			1	0F19	-	-
30			1	1	1	1		1	1		1				1		3DA2	-	-
31	1						1	1				1		1			8314	-	-

Locked EEPROM



	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	Data (H	Voted	Voting
0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	FFFF	1F	00000
1	1		1		1	1		1		1	1		1		1	1	AD6B	0B	00000
2	1				1	1				1	1				1	1	8C63	03	00000
3	1																8000	00	00000
4	1																8000	00	00000
5	1																8000	00	00000
6	1																8000	00	00000
7	1		1					1					1				A108	08	00000
8	1																8000	00	00000
9	1		1	1		1		1	1		1		1	1		1	B5AD	0D	00000
10	1			1					1					1			9084	04	00000
11	1					1					1					1	8421	01	00000
12	1		1	1	1			1	1	1			1	1	1		B9CE	0E	00000
13	1			1					1					1			9084	04	00000
14	1	1		1			1		1			1		1			D294	14	00000
15	1																8000	00	00000
16	1				1					1					1		8842	02	00000
17	1			1	1				1	1				1	1		98C6	06	00000
18	1		1		1	1		1		1	1		1		1	1	AD6B	0B	00000
19	1		1	1	1			1	1	1			1	1	1		B9CE	0E	00000
20	1			1	1				1	1				1	1		98C6	06	00000
21	1				1					1					1		8842	02	00000
22	1	1				1	1				1	1				1	C631	11	00000
23	1	1		1	1		1		1	1		1		1	1		DAD6	16	00000
24	1	1		1		1	1		1		1	1		1		1	D6B5	15	00000
25	1	1		1			1		1			1		1			D294	14	00000
26	1	1	1	1	1		1	1	1	1		1	1	1	1		FBDE	1E	00000
27	1	1	1	1			1	1	1			1	1	1			F39C	1C	00000
28	1	1	1		1		1	1		1		1	1		1		EB5A	1A	00000
29					1	1	1	1				1	1			1	0F19	-	-
30			1	1	1	1		1	1		1				1		3DA2	-	-
31	1						1	1				1		1			8314	-	-

Back-end (MCU level) Calibration

MCU Correction Concept

- **Best Suited for:** multi-sensors applications, i.e. on power distribution units, where typically 12 to 24 sensors are on the same PCB in order to monitor the current of each channel.

All Melexis current sensors are factory-calibrated over temperature!

- **The concept :**
  - assemble the factory-calibrated sensors on each channel
  - apply a reference current (for which a precise output is targeted) on each channel and store the output of each sensor
  - compare the obtained output to the reference one and calculate the required corrective factor
  - store and apply the corrective factor in the MCU

Melexis

INSPIRED ENGINEERING

We Engineer The Sustainable Future

Melexis
INSPIRED ENGINEERING