Current sense and overcurrent accuracy with EiceDRIVER™ APD 2ED4820-EM

About this document

Scope and purpose

This document details how to evaluate the accuracy of the current sense amplifier and the overcurrent feature provided by EiceDRIVER™ APD 2ED4820-EM.

All tables and calculations refer to values in datasheet Rev. 1.00.

Intended audience

HW and SW Engineers who have to integrate 2ED4820-EM in their application.

Table of contents

1 Introduction to EiceDRIVER™ 2ED4820-EM

2ED4820-EM is a gate driver designed for high current 48 V automotive applications, with powerful gate outputs to drive many MOSFETs in parallel in order to minimize the conduction losses. It supports the back-to-back configuration, both common source and common drain structures, thanks to its two gate outputs.
In common source configuration, one gate output can be used to pre-charge highly capacitive loads.
2ED4820-EM generates the supply for the gate outputs based on an integrated one-stage charge pump with external pump and tank capacitors.
2ED4820-EM comes with an SPI interface, for easy configuration, diagnosis and control.
Several protection mechanisms are provided:

- Supply under and overvoltage detection with configurable restart timer
- Charge pump undervoltage detection
- Gate to source undervoltage detection with immediate lock-out to prevent linear mode conduction of the MOSFETs
- Configurable drain to source overvoltage detection, which can also be deactivated
- Configurable overcurrent protection based on an analog current sense amplifier compatible for high-side or low-side shunt topologies
- Internal overtemperature warning and protection

An interrupt pin informs the MCU whenever one of these protections is triggered. Status registers can then be read by the MCU to understand what was the trigger for the notification.
The output of the current sense amplifier can be monitored by the MCU to implement additional protections, such as wire overtemperature.
In addition, 2ED4820-EM enables to implement an open load detection mechanism, checking the source voltage of the MOSFETs with respect to ground in the OFF state.

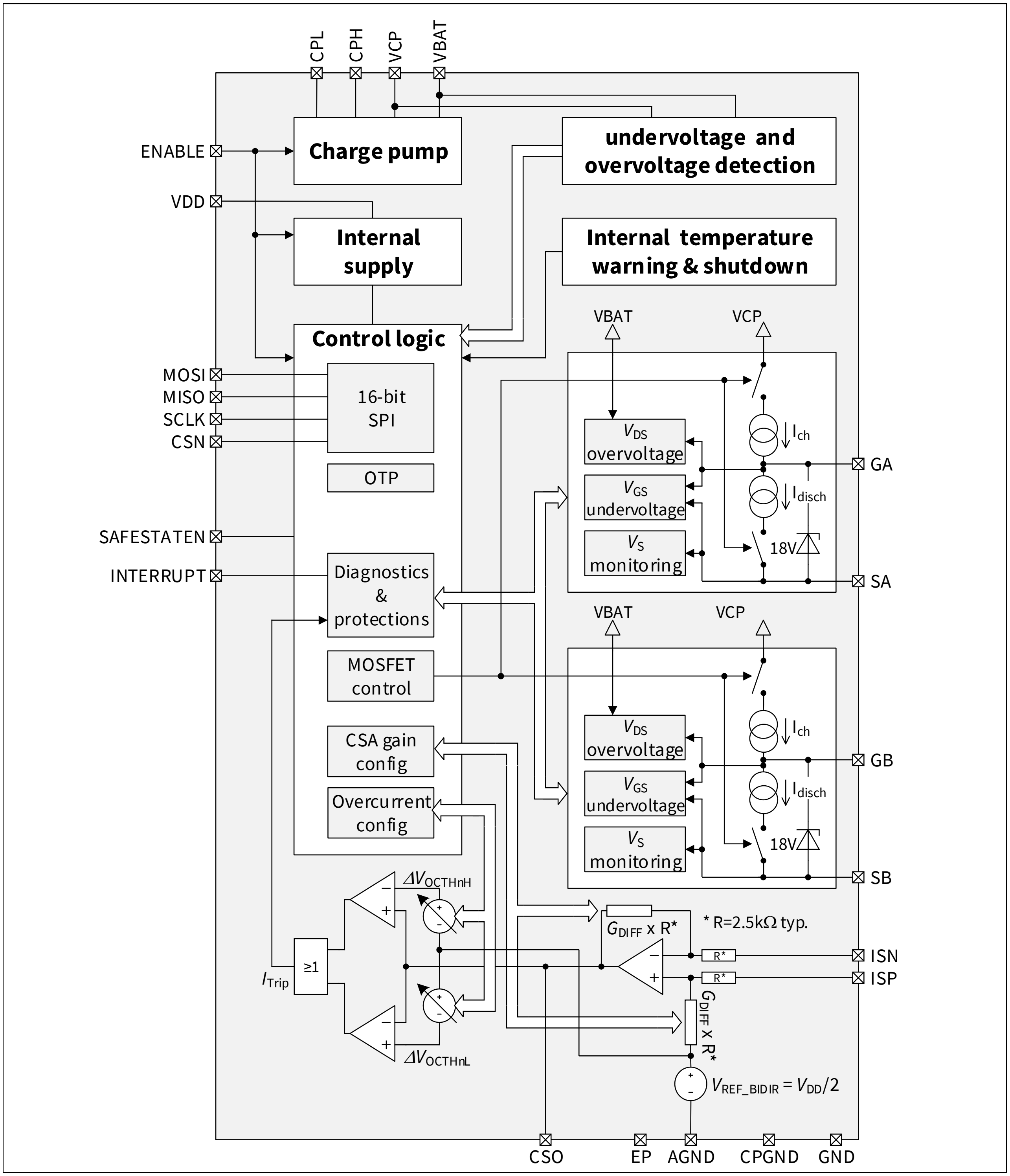

Figure 1 **2ED4820-EM internal block diagram**

2 Current Sense Amplifier

2.1 Output voltage (V_{CSO}) as a function of the amplifier characteristics

The current sense amplifier is based on a well-known differential amplifier structure, with configurable feedback resistors to set the differential gain (G_{DIFF}). This gain value can be changed through an SPI write command.

To implement a bidirectional current sensing, the amplifier is referenced to an internal reference voltage (V_{REF_BIDIR}) which is generated from the voltage applied on the VDD pin: $V_{REF\_BIDIR} = V_{DD} / 2$.

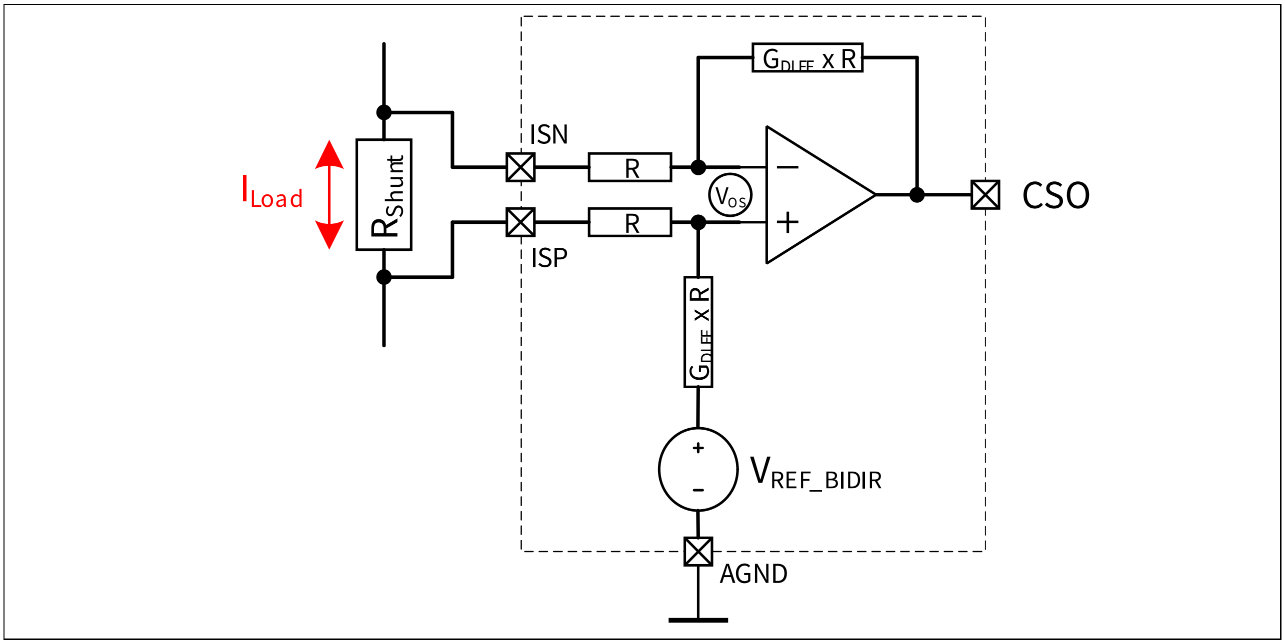

Figure 1 Current sense amplifier internal structure.

Assuming that the amplifier is perfect, the output voltage is defined as:

$$(1)\ \ V_{CSO} = V_{REF\_BIDIR} + [G_{DIFF} \times (V_{ISP} - V_{ISN})]$$

$$(2)\ \ V_{CSO} = V_{REF\_BIDIR} + [G_{DIFF} \times R_{Shunt} \times I_{Load}]$$

The amplifier is not perfect: there is an input offset voltage (V_{OS}), which is also amplified by G_{DIFF}:

$$(3)\ \ V_{CSO} = V_{REF\_BIDIR} + \{G_{DIFF} \times [(V_{ISP} - V_{ISN}) + V_{OS}]\}$$

$$(4)\ \ V_{CSO} = V_{REF\_BIDIR} + \{G_{DIFF} \times [R_{Shunt} \times I_{Load} + V_{OS}]\}$$

The amplifier also exhibits a residual common mode gain (G_{COM}) which amplifies the common mode voltage (V_{COM}) defined as:

$$(5)\ \ V_{COM} = \left|\frac{(V_{ISP}+V_{ISN})}{2} - V_{REF\_BIDIR}\right|$$

The output (CSO) definition is complete when defined as:

$$(6)\ \ V_{CSO} = V_{REF\_BIDIR} + \{G_{DIFF} \times [R_{Shunt} \times I_{Load} + V_{OS}]\} + G_{COM} \times V_{COM}$$

G_{COM} is not defined in the datasheet; an industry-standard value is used instead, called **CMRR** = **C**ommon **M**ode **R**ejection **R**atio. The relationship between CMRR and Common mode gain is defined as:

$$(7)\quad CMRR = 20log\left(\frac{G_{DIFF}}{|G_{COM}|}\right)$$

G_{COM} is therefore calculed from CMRR values provided in the datasheet by the resulting equation:

$$(8)\quad G_{COM} = \pm G_{DIFF} \times 10^{-\left(\frac{CMRR}{20}\right)}$$

Contributors to the error on V_{CSO}

Several parameters contributing to the value of V_{CSO} have an uncertainty, which will influence the current sense accuracy:

Table 1 List of values for the contributors to the error on V_{CSO}, based on datasheet Rev. 1.00.

Parameter symbol		Min	Typ	Max	Uncertainty symbol	Uncertainty	Unit	PRQ in datasheet
V_{OS}		-1.4	0	1.4	δV_{OS}	+/-1.4	mV	PRQ-52
V_{REF_BIDIR}		0.49*V_{DD}	0.5*V_{DD}	0.51*V_{DD}	δV_{REF_BIDIR}	+/-0.01* V_{DD}	V	PRQ-228
G_{DIFF} = 10	G_{DIFF10}	9.8	10	10.2	δG_{DIFF10}	+/-0.2	V/V	PRQ-53
	C_{MRR10}	69			-	-	dB	PRQ-64
	G_{COM10}	-0.003548	0	0.003548	δG_{COM10}	+/-0.003548	V/V	*calculated*
G_{DIFF} = 15	G_{DIFF15}	14.7	15	15.3	δG_{DIFF15}	+/-0.3	V/V	PRQ-77
	C_{MRR15}	72.5			-	-	dB	PRQ-148
	G_{COM15}	-0.003557	0	0.003557	δG_{COM15}	+/-0.003557	V/V	*calculated*
G_{DIFF} = 20	G_{DIFF20}	19.6	20	20.4	δG_{DIFF20}	+/-0.4	V/V	PRQ-78
	C_{MRR20}	75			-	-	dB	PRQ-149
	G_{COM20}	-0.003557	0	0.003557	δG_{COM20}	+/-0.003557	V/V	*calculated*
G_{DIFF} = 25	G_{DIFF25}	24.5	25	25.5	δG_{DIFF25}	+/-0.5	V/V	PRQ-79
	C_{MRR25}	77			-	-	dB	PRQ-150
	G_{COM25}	-0.003531	0	0.003531	δG_{COM25}	+/-0.003531	V/V	*calculated*
G_{DIFF} = 31.5	$G_{DIFF31.5}$	30.87	31.5	32.13	$\delta G_{DIFF31.5}$	+/-0.63	V/V	PRQ-206
	$C_{MRR31.5}$	78.5			-	-	dB	PRQ-210
	$G_{COM31.5}$	-0.003744	0	0.003744	$\delta G_{COM31.5}$	+/-0.003744	V/V	*calculated*
G_{DIFF} = 35	G_{DIFF35}	34.3	35	35.7	δG_{DIFF35}	+/-0.7	V/V	PRQ-207
	C_{MRR35}	79.5			-	-	dB	PRQ-211
	G_{COM35}	-0.003707	0	0.003707	δG_{COM35}	+/-0.003707	V/V	*calculated*
G_{DIFF} = 40	G_{DIFF40}	39.2	40	40.8	δG_{DIFF40}	+/-0.8	V/V	PRQ-208
	C_{MRR40}	81			-	-	dB	PRQ-212
	G_{COM40}	-0.003565	0	0.003565	δG_{COM40}	+/-0.003565	V/V	*calculated*
G_{DIFF} = 47.7	$G_{DIFF47.7}$	46.75	47.7	48.65	$\delta G_{DIFF47.7}$	+/-0.95	V/V	PRQ-209

	$C_{MRR47.7}$	82.5			-	-	dB	PRQ-213
	$G_{COM47.7}$	-0.003577	0	0.003577	$\delta G_{COM47.7}$	+/-0.003577	V/V	calculated

2.2 Computation of the error on the load current

In the system, the 2ED4820-EM current sense output (CSO) is usually connected to an ADC input of a microcontroller.
The MCU computes the load current based on the following equation:

$$(9)\quad I_{LOAD\_Cal\_in\_MCU} = \frac{(V_{CSO} - V_{REF\_BIDIR})}{(G_{DIFF} \times R_{Shu}\quad)}$$

There are two main ways to calculate the error on the load current:

- Worst case tolerance: each contributing parameter is considered in its worst-case condition, which leads to a pessimistic view of the error (the likelihood to have all parameter together in worst-case condition is extremely low)
- Propagation of uncertainty, which leads to a more realistic view of the resulting error.

2.2.1 Worst case tolerance calculation

The maximum output voltage on CSO is calculated based on the equation:

$$(10)\quad V_{CSO\_MAX} = V_{REF\_BIDIR\_MAX} + \left(R_{Shunt} \times I_{Load} + V_{OS\_MAX}\right) \times G_{DIFF\_MAX} + G_{COM\_MAX} \times V_{COM}$$

The minimum output voltage on CSO is calculated based on the equation:

$$(11)\quad V_{CSO\_MIN} = V_{REF\_BIDIR\_MIN} + \left(R_{Shunt} \times I_{Load} + V_{OS\_MIN}\right) \times G_{DIFF\_MIN} + G_{COM\_MIN} \times V_{COM}$$

The MicroControlleur has no access to the internally-defined parameters, $V_{REFBIDIR}$ & G_{DIFF}, so it always computes the Load current based on the typical values for these two parameters.

The maximum load current is calculated based on the equation:

$$(12)\quad I_{Load\_MAX}\ calc\ in\ MCU = \frac{(V_{CSO\_MAX} - V_{REF\_BIDIR\_TYP})}{(G_{DIFF\_TYP} \times R_{Shu}\quad)}$$

$$(13)\quad = \frac{\left((R_{Shunt} \times I_{Load} + V_{OS\_MAX}) \times G_{DIFF\_MAX} + G_{COM\_MAX} \times V_{COM} + (V_{REF\_BIDIR\_MAX} - V_{REF\_BIDIR\_TYP})\right)}{(G_{DIFF\_TYP} \times R_{Shunt})}$$

The minimum load current is calculated based on the equation:

$$(14)\quad I_{Load\_MIN}\ calc\ in\ MCU = \frac{(V_{CSO\_MIN} - V_{REF\_BIDIR\_TYP})}{(G_{DIFF\_TYP} \times R_{Shunt})}$$

$$(15)\quad = \frac{\left((R_{Shunt} \times I_{Load} + V_{OS\_MIN}) \times G_{DIFF\_MIN} + G_{COM\_MIN} \times V_{COM} + (V_{REF\_BIDIR\_MIN} - V_{REF\_BIDIR\_TYP})\right)}{(G_{DIFF\_TYP} \times R_{Shunt})}$$

0 show the computed values for one concrete example:

V_{DD} = 5 V, R_{Shunt} = 200 µΩ, G_{DIFF} = 47.7 and V_{COM} = 2.5 V (low-side sense)

Table 2 Error on the Load current as calculated in the MCU, based on worst case methodology:

I_{Load}	12.5 A	25 A	50 A	75 A	100 A	150 A	200 A
V_{CSO_MIN}	2.493 V	2.609 V	2.843 V	3.077 V	3.311 V	3.778 V	4.246 V
V_{CSO_TYP}	2.619 V	2.739 V	2.977 V	3.216 V	3.454 V	3.931 V	4.408 V
V_{CSO_MAX}	2.749 V	2.870 V	3.114 V	3.357 V	3.600 V	4.087 V	4.573 V
I_{Load_MIN} calculated in MCU	-0.78 A	11.46 A	35.96 A	60.46 A	84.96 A	133.96 A	182.96 A
I_{Load_MAX} calculated in MCU	26.07 A	38.82 A	64.32 A	89.82 A	115.32 A	166.32 A	217.32 A
Error on I_{Load_MIN} vs I_{Load}	-106 %	-54.2 %	-28.1 %	-19.4 %	-15.0 %	-10.7 %	-8.5 %
Error on I_{Load_MAX} vs I_{Load}	108.5 %	55.3 %	28.6 %	19.8 %	15.3 %	10.9 %	8.7 %

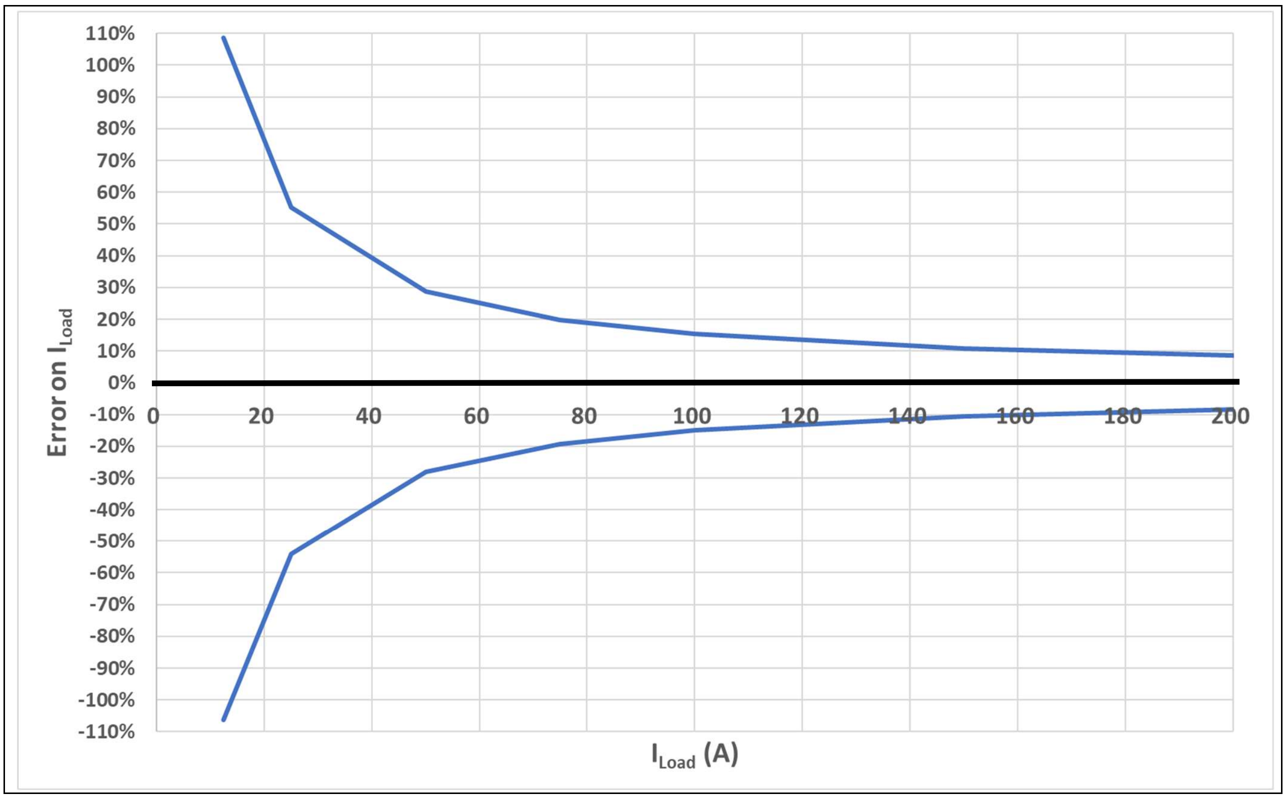

Figure 2 Graphical view of the error on the Load current as calculated in the MCU.

2.2.2 Uncertainty propagation calculation

Rationale for this calculation method: assuming that all independent parameters can be simultaneously in the worst-case condition (all in maximum or all in minimum value) is very pessimistic statistically speaking.

To illustrate it, the well-known gaussian distribution in Figure 3 shows that when parameters are defined with +/-6σ, it means that 99.999998% of the samples are inside the limits, 3.4ppm (part per million) are outside. Considering 2 parameters which are independent, the likelihood to have them both in worst case (+/-6σ) at the same time is ultra low: only 0.01ppb (part per billion) !

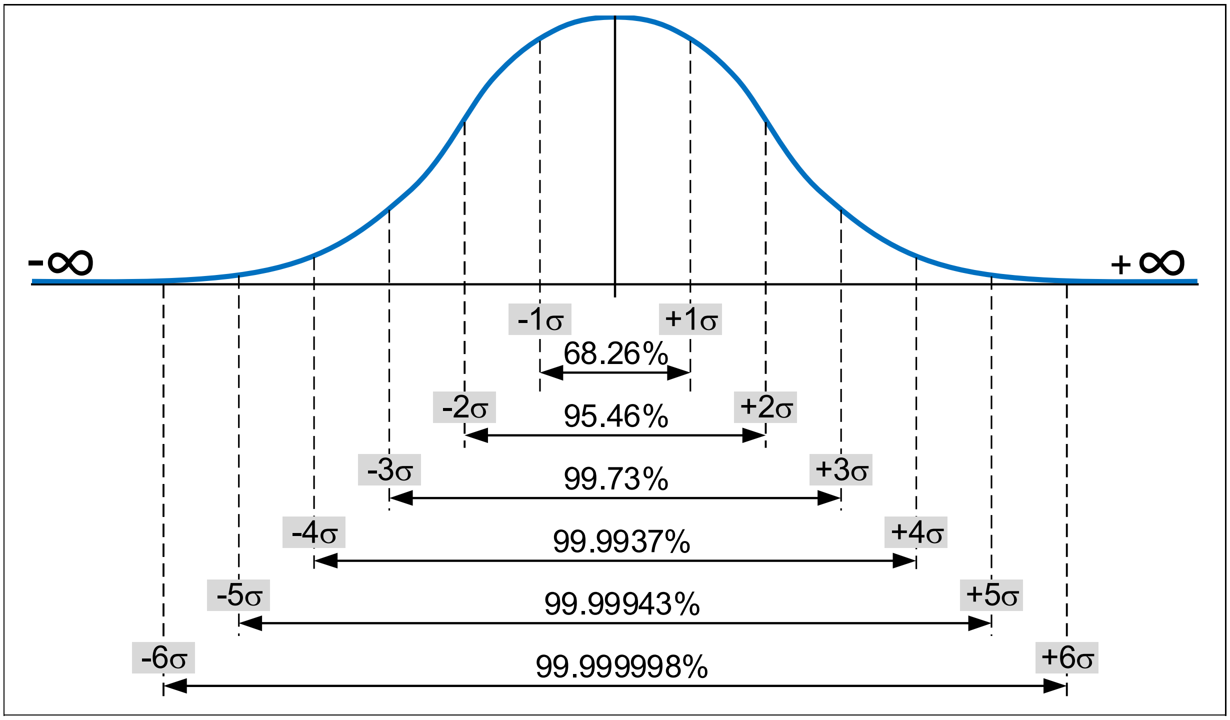

Figure 3 Gauss distribution.

The parameters influencing the uncertainty on the voltage on CSO and the resulting Load current computation in the microcontroller are all independent, it is then very pessimistic to consider all of them in worst case simultaneously.

The popular approach to estimate the error on a measurement in a more realistic way is known as the "Propagation of uncertainty".

Assuming that a measurement 'M' relies on 3 different parameters: x, y and z, each of them having an uncertainty of δx, δy and δz, the resulting uncertainty on 'f' is defined as:

$$(16)\ \delta M(x,y,z) = \sqrt{\left(\frac{\partial M}{\partial x}\delta x\right)^2 + \left(\frac{\partial M}{\partial y}\delta y\right)^2 + \left(\frac{\partial M}{\partial z}\delta z\right)^2}$$

The voltage measured on the CSO pin relies on 4 parameters internal to 2ED4820-EM: V_{REF_BIDIR}, G_{DIFF}, V_{OS} and G_{COM}. Each of these parameters has an uncertainty: δV_{REF_BIDIR}, δG_{DIFF}, δV_{OS} and δG_{COM}. The uncertainty on V_{CSO} can then be defined as:

$$(17)\ \partial V_{CSO} = \sqrt{\left(\frac{\partial V_{CSO}}{\partial V_{REF\_BIIR}}\partial V_{REF\_BIDIR}\right)^2 + \left(\frac{\partial V_{CSO}}{\partial G_{DIFF}}\partial G_{DIFF}\right)^2 + \left(\frac{\partial V_{CSO}}{\partial V_{OS}}\partial V_{OS}\right)^2 + \left(\frac{\partial V_{CSO}}{\partial G_{COM}}\partial G_{COM}\right)^2}$$

Deriving V_{CSO} for each of the 4 parameters:

$$(18)\ V_{CSO} = V_{REF\_BIDIR} + \{G_{DIFF} \times [R_{Shun} \times I_{Load} + V_{OS}]\} + G_{COM} \times V_{COM}$$

We get:

$$(19)\ \frac{\partial V_{CSO}}{\partial V_{REF\_BIDIR}} = 1$$

$$(20)\ \frac{\partial V_{CSO}}{\partial G_{DIFF}} = R_{Shunt} \times I_{Load} + V_{OS}$$

$$(21)\ \frac{\partial V_{CSO}}{\partial V_{OS}} = G_{DIFF}$$

$$(22)\ \frac{\partial V_{CSO}}{\partial G_{COM}} = V_{COM}$$

The uncertainty on V_{CSO} becomes then:

$$(23)\ \partial V_{CSO} = \sqrt{(\partial V_{REF\_BIDIR})^2 + ((R_{Shunt} \times I_{Load} + V_{OS}) \times \partial G_{DIFF})^2 + (G_{DIFF} \times \partial V_{OS})^2 + (V_{COM} \times \partial G_{COM})^2}$$

The microcontroller will compute the load current from the voltage on CSO pin according to the following equation:

$$(24)\ I_{Load\ calc\ in\ MCU} = \frac{(V_{CSO} - V_{REF\_BIDIR\_TYP})}{G_{DIFF\_TYP} \times R_{Shun}}$$

Deriving $I_{Load\ calc\ in\ MCU}$ against V_{CSO}:

$$(25)\ \frac{\partial I_{Load\ calc\ in\ MCU}}{\partial V_{CSO}} = \frac{1}{G_{DIFF\_TYP} \times R_{Shunt}}$$

The uncertainty on $I_{Load\ calc\ in\ MCU}$ is therfore:

$$(26)\ \partial I_{Load\ calc\ in\ MCU} = \frac{\partial V_{CSO}}{G_{DIFF\_TYP} \times R_{Shunt}}$$

$$= \frac{1}{G_{DIFF\_TYP} \times R_{Shun}} \times \sqrt{(\partial V_{REF\_BIDIR})^2 + ((R_{Shunt} \times I_{Load} + V_{OS}) \times \partial G_{DIFF})^2 + (G_{DIFF} \times \partial V_{OS})^2 + (V_{COM} \times \partial G_{COM})^2}$$

Considering the same concrete example: V_{DD} = 5 V, R_{Shunt} = 200 µΩ, G_{DIFF} = 47.7 and V_{COM} = 2.5 V (low-side sense), **Table 3** shows the resulting error on the sense current:

Table 3 Error on the Load current as calculated in the MCU, based on uncertainty propagation:

I_{Load}	12.5 A	25 A	50 A	75 A	100 A	150 A	200 A
δI_{Load_MIN} calculated in MCU	-8.80 A	-8.82 A	-8.87 A	-8.95 A	-9.05 A	-9.34 A	-9.72 A
δI_{Load_MAX} calculated in MCU	8.80 A	8.82 A	8.87 A	8.95 A	9.05 A	9.34 A	9.72 A
Error of δI_{Load_MIN} vs I_{Load}	-70.4 %	-35.3 %	-17.7 %	-11.9 %	-9.1 %	-6.2 %	-4.9 %
Error of δI_{Load_MAX} vs I_{Load}	70.4 %	35.3 %	17.7 %	11.9 %	9.1 %	6.2 %	4.9 %

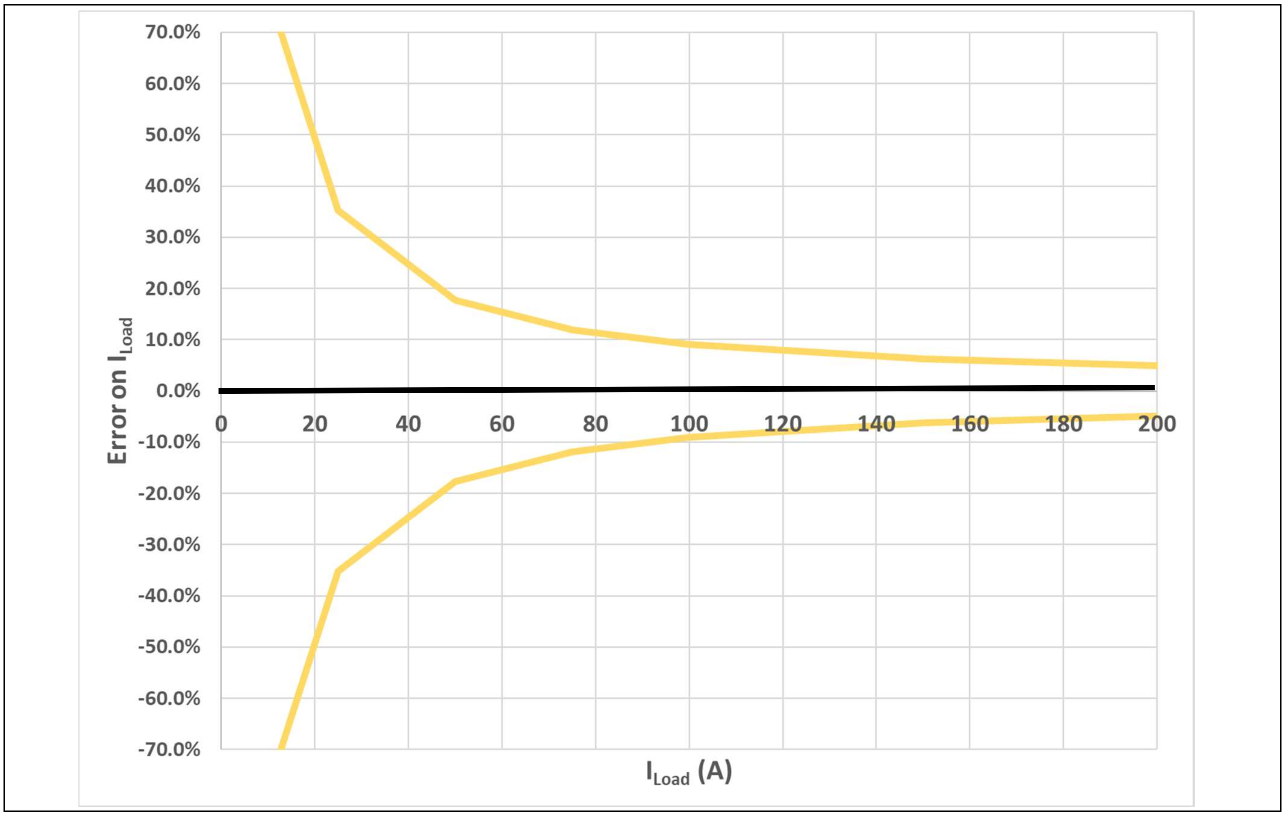

Figure 4 **Graphical view of the error on the Load current as calculated in the MCU (uncertainty propagation).**

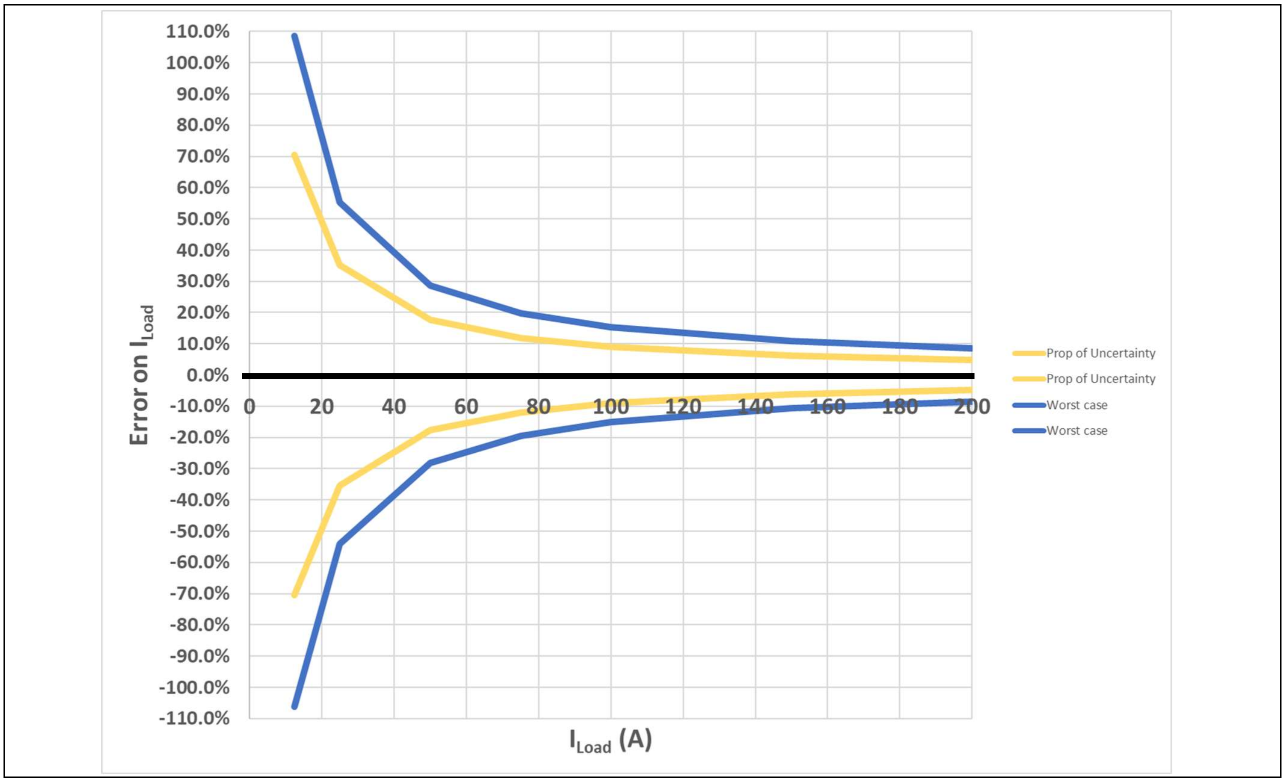

Figure 5 **Graphical comparison of the 2 methods to calculate the error.**

3 Overcurrent protection

3.1 Implementation of the overcurrent detection

To detect overcurrent, whatever the current direction (charge or discharge), the current sense amplifier output is connected to a window comparator:

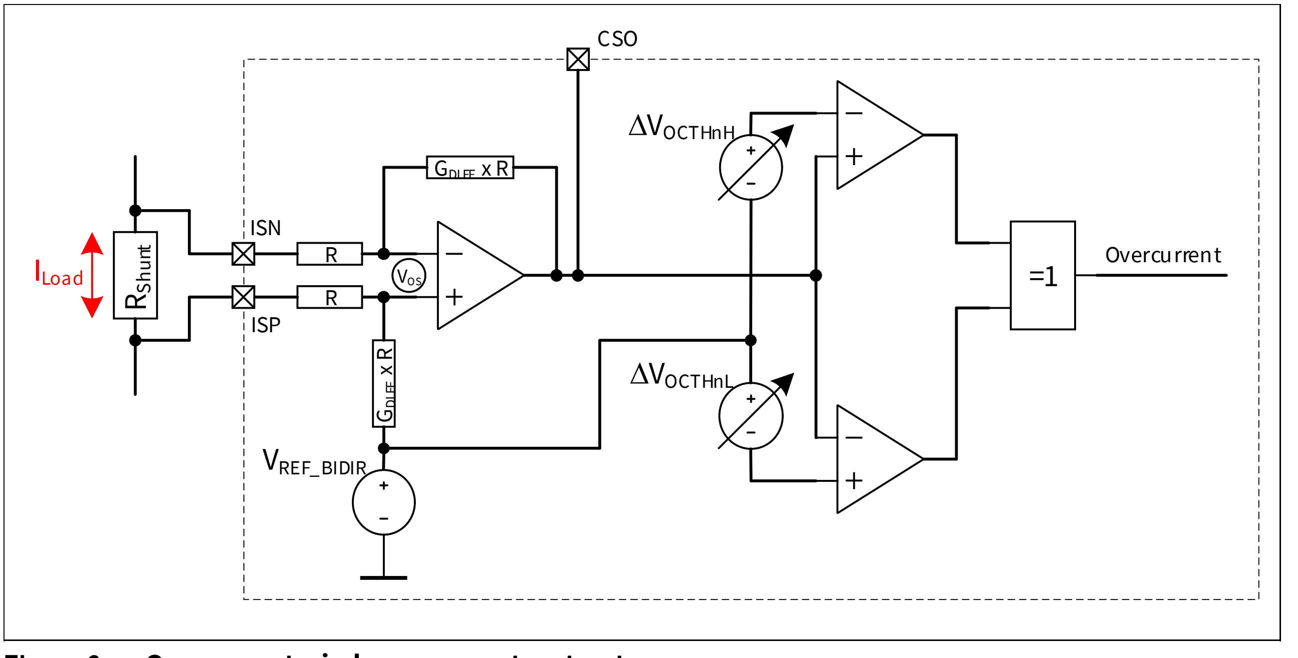

Figure 6 Overcurrent window comparator structure.

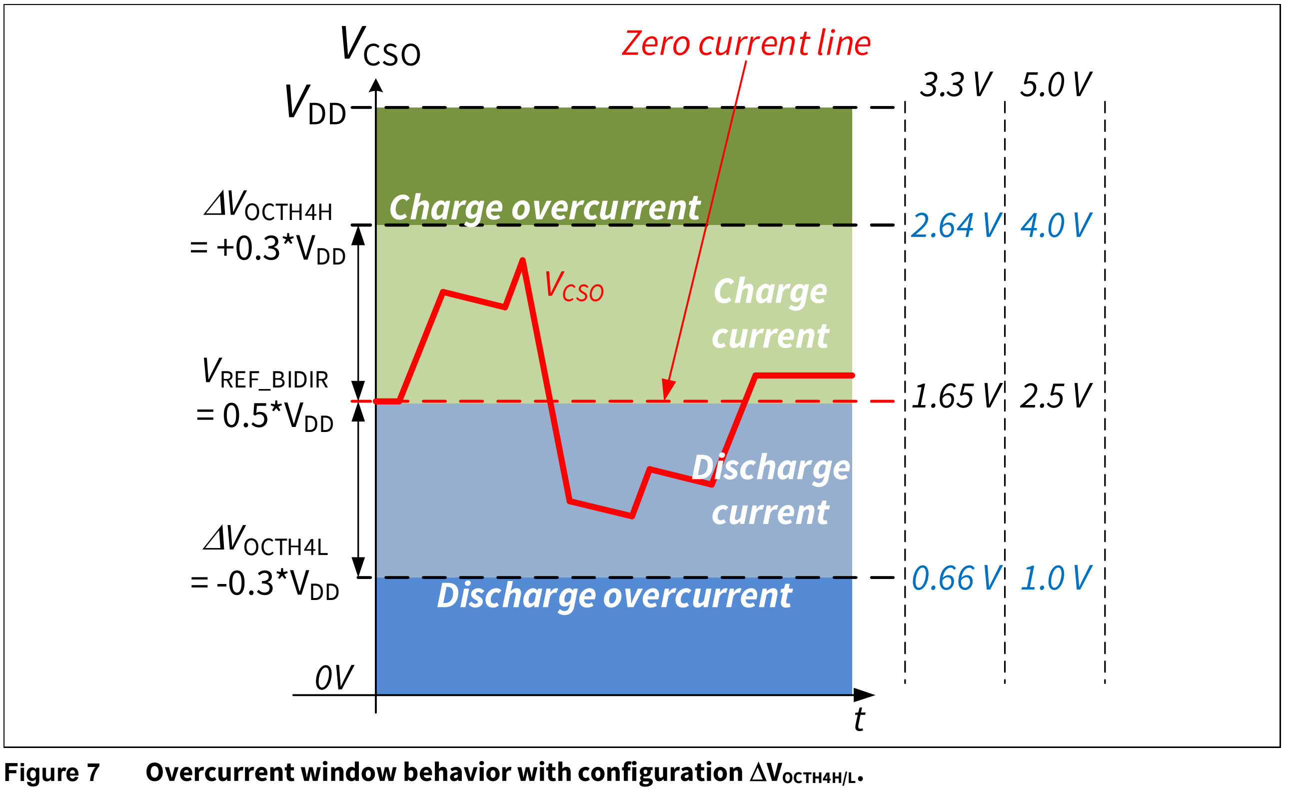

Figure 7 Overcurrent window behavior with configuration $\Delta V_{OCTH4H/L}$.

Assuming that the amplifier and the comparator are perfect, an overcurrent fault is triggered if the load current $I_{Load\_OC\_H/L}$ is such that:

$$(27)\ \left|\Delta V_{OCTHnH/L}\right| = \left|V_{CSO} - V_{REF\_BIDIR}\right|$$

$$(28)\ \Delta V_{OCTHnH} = G_{DIFF} \times R_{Shunt} \times I_{Load\_OC\_H}$$

$$(29)\ \Delta V_{OCTHnL} = G_{DIFF} \times R_{Shunt} \times I_{Load\_OC\_L}$$

The structure is symmetrical, $|\Delta V_{OCTHnH}| = |\Delta V_{OCTHnL}|$ and $|I_{Load\_OC\_H}| = |I_{Load\_OC\_L}|$. In the coming analysis, only $I_{Load\_OC\_H}$ is considered for simplicity.

$$(30)\ I_{Load\_OC\_H} = \frac{\Delta V_{OCTHnH}}{G_{DIFF} \times R_{Shunt}}$$

Playing with the gain (G_{DIFF}) and window (ΔV_{OCTHnH}) settings, it is possible to configure many different overcurrent values as shown in **Table 4** and **Figure 8** where the shunt value is R_{Shunt} = 200 µΩ and VDD = 5 V:

Table 4 Value of the overcurrent ($I_{Load\_OC\_H}$) for all gain (G_{DIFF}) and window (ΔV_{OCTHnH}) settings:

G_{DIFF}	ΔV_{OCTH1H}	ΔV_{OCTH2H}	ΔV_{OCTH3H}	ΔV_{OCTH4H}
10	263 A	525 A	635 A	760 A
15	175 A	350 A	423 A	507 A
20	131 A	263 A	318 A	380 A
25	105 A	210 A	254 A	304 A
31.5	83 A	167 A	202 A	241 A
35	75 A	150 A	181 A	217 A
40	66 A	131 A	159 A	190 A
47.7	55 A	110 A	133 a	159 A

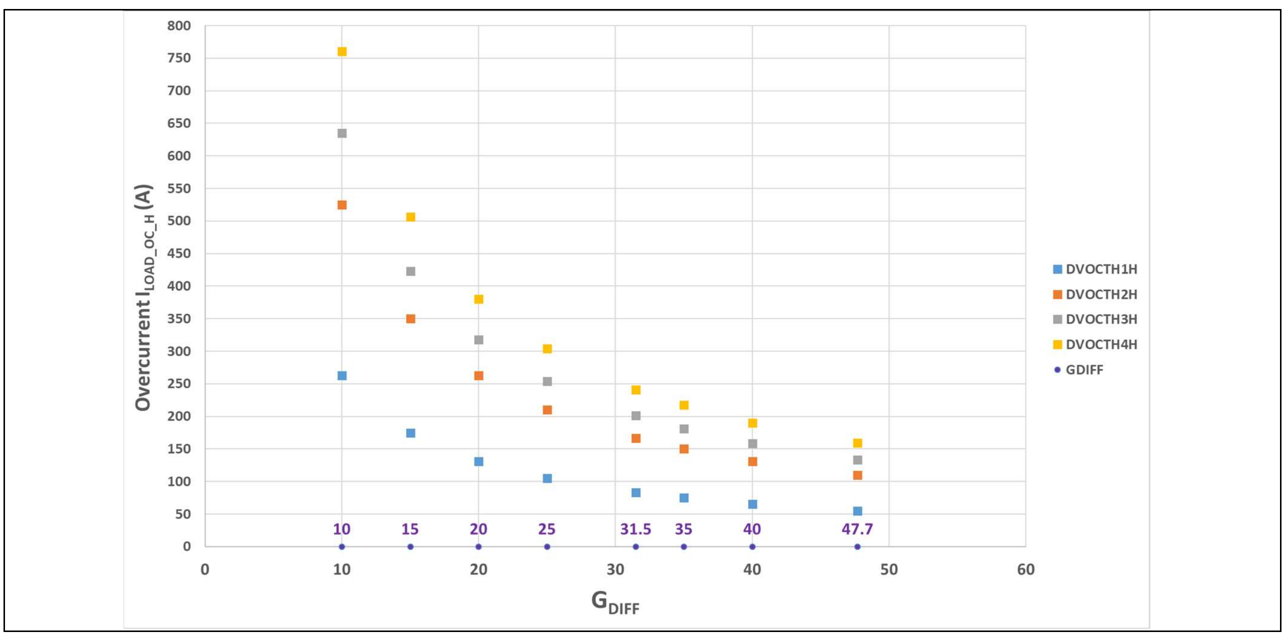

Figure 8 Configurable overcurrent values playing with gain (G_{DIFF}) and window (ΔV_{OCTHnH}).

The amplifier is not perfect: there is an input offset voltage (V_{OS}), which is also amplified by G_{DIFF}:

$$(31)\ \Delta V_{OCTHnH} = G_{DIFF} \times \left[R_{Shun} \times I_{Load\_OC\_H} + V_{OS}\right]$$

The amplifier also exhibits a residual common mode gain (G_{COM}) which amplifies the common mode voltage (V_{COM}, see **Output voltage (VCSO) as a function of the**):

$$(32)\ \Delta V_{OCTHnH} = G_{DIFF} \times \left[R_{Shunt} \times I_{Load\_OC\_H} + V_{OS}\right] + G_{COM} \times V_{COM}$$

$$(33)\ \Delta V_{OCTHnH} = G_{DIFF} \times R_{Shunt} \times I_{Load\_OC\_H} + V_{OS} \times G_{DIFF} + G_{COM} \times V_{COM}$$

$$(34)\ G_{DIFF} \times R_{Shunt} \times I_{Load\_OC\_H} = \Delta V_{OCTHnH} - V_{OS} \times G_{DIFF} - G_{COM} \times V_{COM}$$

$$(35)\ I_{Load\_OC\_H} = \frac{1}{G_{DIFF} \times R_{Shun}}\left[\Delta V_{OCTHnH} - V_{OS} \times G_{DIFF} - G_{COM} \times V_{COM}\right]$$

$$(36)\ I_{Load\_OC\_H} = \frac{1}{G_{DIFF} \times R_{Shunt}}\left[\Delta V_{OCTHnH} - G_{COM} \times V_{COM}\right] - \frac{V_{OS}}{R_{Shunt}}$$

3.2 Contributors to the error on the overcurrent $I_{Load\_OC\_H}$

Several parameters contributing to the value of $I_{Load\_OC\_H}$ have an uncertainty, which will influence the overcurrent accuracy:

Table 5 List of values for the contributors to the error on V_{CSO}, based on datasheet Rev. 1.00

Parameter symbol		Min	Typ	Max	Uncertainty symbol	Uncertainty	Unit	PRQ in datasheet
V_{OS}		-1.4	0	1.4	δV_{OS}	+/-1.4	mV	PRQ-52
ΔV_{OCTH1H}		0.095*V_{DD}	0.105*V_{DD}	0.115*V_{DD}	$\delta\Delta V_{OCTH1H}$	0.05	V	PRQ-531
ΔV_{OCTH2H}		0.199*V_{DD}	0.199*V_{DD}	0.199*V_{DD}	$\delta\Delta V_{OCTH2H}$	0.055	V	PRQ-533
ΔV_{OCTH3H}		0.243*V_{DD}	0.254*V_{DD}	0.265*V_{DD}	$\delta\Delta V_{OCTH3H}$	0.055	V	PRQ-535
ΔV_{OCTH4H}		0.293*V_{DD}	0.304*V_{DD}	0.315*V_{DD}	$\delta\Delta V_{OCTH4H}$	0.055	V	PRQ-537
G_{DIFF} = 10	G_{DIFF10}	9.8	10	10.2	δG_{DIFF10}	+/-0.2	V/V	PRQ-53
	C_{MRR10}	69			-	-	dB	PRQ-64
	G_{COM10}	-0.003548	0	0.003548	δG_{COM10}	+/-0.003548	V/V	*calculated*
G_{DIFF} = 15	G_{DIFF15}	14.7	15	15.3	δG_{DIFF15}	+/-0.3	V/V	PRQ-77
	C_{MRR15}	72.5			-	-	dB	PRQ-148
	G_{COM15}	-0.003557	0	0.003557	δG_{COM15}	+/-0.003557	V/V	*calculated*
G_{DIFF} = 20	G_{DIFF20}	19.6	20	20.4	δG_{DIFF20}	+/-0.4	V/V	PRQ-78
	C_{MRR20}	75			-	-	dB	PRQ-149
	G_{COM20}	-0.003557	0	0.003557	δG_{COM20}	+/-0.003557	V/V	*calculated*
G_{DIFF} = 25	G_{DIFF25}	24.5	25	25.5	δG_{DIFF25}	+/-0.5	V/V	PRQ-79
	C_{MRR25}	77			-	-	dB	PRQ-150
	G_{COM25}	-0.003531	0	0.003531	δG_{COM25}	+/-0.003531	V/V	*calculated*
	$G_{DIFF31.5}$	30.87	31.5	32.13	$\delta G_{DIFF31.5}$	+/-0.63	V/V	PRQ-206

G_{DIFF} = 31.5	**$C_{MRR31.5}$**	78.5			**-**	-	dB	PRQ-210
	$G_{COM31.5}$	-0.003744	0	0.003744	**$\delta G_{COM31.5}$**	+/-0.003744	V/V	*calculated*
G_{DIFF} = 35	**G_{DIFF35}**	34.3	35	35.7	**δG_{DIFF35}**	+/-0.7	V/V	PRQ-207
	C_{MRR35}	79.5			**-**	-	dB	PRQ-211
	G_{COM35}	-0.003707	0	0.003707	**δG_{COM35}**	+/-0.003707	V/V	*calculated*
G_{DIFF} = 40	**G_{DIFF40}**	39.2	40	40.8	**δG_{DIFF40}**	+/-0.8	V/V	PRQ-208
	C_{MRR40}	81			**-**	-	dB	PRQ-212
	G_{COM40}	-0.003565	0	0.003565	**δG_{COM40}**	+/-0.003565	V/V	*calculated*
G_{DIFF} = 47.7	**$G_{DIFF47.7}$**	46.75	47.7	48.65	**$\delta G_{DIFF47.7}$**	+/-0.95	V/V	PRQ-209
	$C_{MRR47.7}$	82.5			**-**	-	dB	PRQ-213
	$G_{COM47.7}$	-0.003577	0	0.003577	**$\delta G_{COM47.7}$**	+/-0.003577	V/V	calculated

3.3 Computation of the error on the overcurrent

There are two main ways to calculate the error on the overcurrent:

- Worst case tolerance: each contributing parameter is considered in its worst-case condition, which leads to a pessimistic view of the error
- Propagation of uncertainty, which leads to a more realistic view of the resulting error.

3.3.1 Worst case tolerance calculation

The maximum value of the overcurrent is calculated based on the equation:

$$(37)\quad I_{Load\_OC\_H\_MAX} = \frac{1}{G_{DIFF\_MIN} \times R_{Shunt}} \left[\Delta V_{OCTHnH\_MAX} - G_{COM\_MIN} \times V_{COM}\right] - \frac{V_{OS\_MIN}}{R_{Shunt}}$$

The minimum value of the overcurrent is calculated based on the equation:

$$(38)\quad I_{Load\_OC\_H\_MIN} = \frac{1}{G_{DIFF\_MAX} \times R_{Shunt}} \left[\Delta V_{OCTHnH\_MIN} - G_{COM\_MAX} \times V_{COM}\right] - \frac{V_{OS\_MAX}}{R_{Shunt}}$$

0 shows the computed values for one concrete example:

V_{DD} = 5 V, ΔV_{OCTH4H} = 0.3xVDD = 1.5 V, R_{Shunt} = 200 µΩ and V_{COM} = 2.5 V (low-side sense)

Table 6 Error on the overcurrent:

G_{DIFF}	$I_{Load\_OC\_H}$ Min (A)	$I_{Load\_OC\_H}$ Min (%)	$I_{Load\_OC\_H}$ Typ (A)	$I_{Load\_OC\_H}$ Max (A)	$I_{Load\_OC\_H}$ Max (%)
10	706.8	-7.0%	760	815.1	7.2%
15	468.9	-7.5%	507	545.7	7.7%
20	349.9	-7.9%	380	411.1	8.2%
25	278.5	-8.4%	304	330.2	8.6%
31.5	219.5	-9.0%	241	263.6	9.3%
35	196.9	-9.3%	217	237.9	9.6%
40	171.4	-9.8%	190	209.0	10.0%
47.7	142.6	-10.5%	159	176.4	10.7%

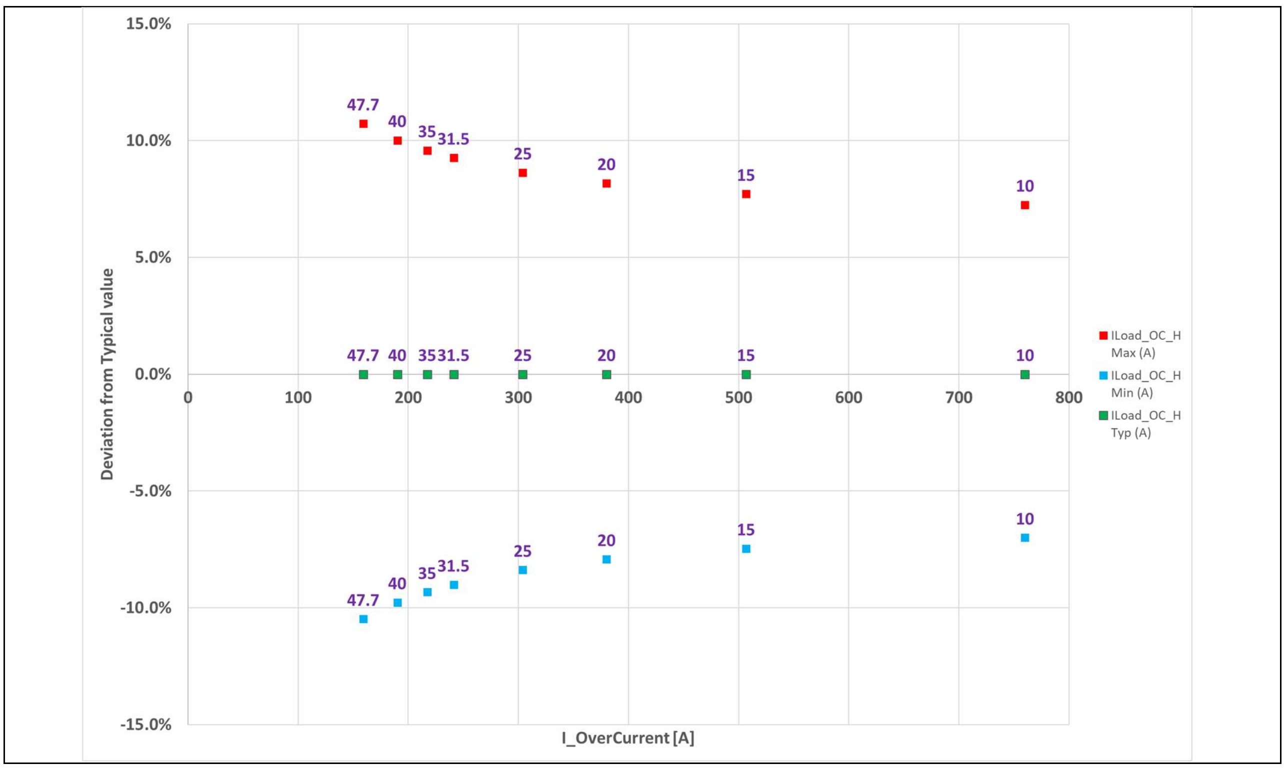

Figure 9 Graphical view of the error on the overcurrent for all gains with ΔV_{OCTH4H} = 0.3xVDD.

3.3.2 Uncertainty propagation calculation

The rationale for this calculation methodis described here: **Uncertainty propagation calculation**.

The overcurrent relies on 4 parameters internal to 2ED4820-EM: G_{DIFF}, V_{OS} and G_{COM}. Each of these parameters has an uncertainty: δG_{DIFF}, δV_{OCTHnH}, δV_{OS} and δG_{COM}. The uncertainty on V_{CSO} can then be defined as:

$$(39)\quad \partial I_{Load\_OC\_H} = \sqrt{\left(\frac{\partial I_{Load\_OC\_H}}{\partial G_{DIFF}}\partial G_{DIFF}\right)^2 + \left(\frac{\partial I_{Load\_OC\_H}}{\partial \Delta V_{OCTHnH}}\partial \Delta V_{OCTHnH}\right)^2 + \left(\frac{\partial I_{Load\_OC\_H}}{\partial V_{OS}}\partial V_{OS}\right)^2 + \left(\frac{\partial I_{Load\_OC\_H}}{\partial G_{COM}}\partial G_{COM}\right)^2}$$

Deriving $I_{Load\_OC\_H}$ for each of the 4 parameters:

$$(40)\quad I_{Load\_OC\_H} = \frac{1}{G_{DIFF} \times R_{Shun}} [\Delta V_{OCTHnH} - G_{COM} \times V_{COM}] - \frac{V_{OS}}{R_{Shunt}}$$

We get:

$$(41)\quad \frac{\partial I_{Load\_OC\_H}}{\partial G_{DIFF}} = -\frac{(\Delta V_{OCTHnH} - G_{COM} \times V_{COM})}{R_{Shunt} \times G_{DIFF}{}^2}$$

$$(42)\quad \frac{\partial I_{Load\_OC\_H}}{\partial \Delta V_{OCTHnH}} = \frac{1}{R_{Shunt} \times G_{DIFF}}$$

$$(43)\quad \frac{\partial I_{Load\_OC\_H}}{\partial V_{OS}} = \frac{-V_{COM}}{R_{Shunt} \times G_{DIFF}}$$

$$(44)\quad \frac{\partial I_{Load\_OC\_H}}{\partial G_{COM}} = \frac{-1}{R_{Shunt}}$$

The uncertainty on $I_{Load\_OC\_H}$ becomes:

$$(45)\quad \partial I_{Load\_OC\_H} = \sqrt{\left(\frac{(\Delta V_{OCTHnH} - G_{COM} \times V_{COM})}{R_{Shunt} \times G_{DIFF}{}^2} \partial G_{DIFF}\right)^2 + \left(\frac{1}{R_{Shunt} \times G_{DIFF}} \partial \Delta V_{OCTHnH}\right)^2 + \left(\frac{-V_{COM}}{R_{Shunt} \times G_{DIFF}} \partial V_{OS}\right)^2 + \left(\frac{-1}{R_{Shunt}} \partial G_{COM}\right)^2}$$

Considering the same concrete example: V_{DD} = 5 V, ΔV_{OCTH4H} = 0.3xVDD = 1.5 V, R_{Shunt} = 200 µΩ and V_{COM} = 2.5 V (low-side sense) **Table 7** shows the error on the overcurrent:

Table 7 Error on the overcurrent:

G_{DIFF}	$\delta I_{Load\_OC\_H}$ Min (A)	$\delta I_{Load\_OC\_H}$ Min (%)	$I_{Load\_OC\_H}$ Typ (A)	$\delta I_{Load\_OC\_H}$ Max (A)	$\delta I_{Load\_OC\_H}$ Max (%)
10	-32.5	-4.3%	760	32.5	4.3%
15	-22.3	-4.4%	507	22.3	4.4%
20	-17.3	-4.6%	380	17.3	4.6%
25	-14.5	-4.8%	304	14.5	4.8%
31.5	-12.3	-5.1%	241	12.3	5.1%
35	-11.5	-5.3%	217	11.5	5.3%
40	-10.6	-5.6%	190	10.6	5.6%
47.7	-9.7	-6.1%	159	9.7	6.1%

Figure 10 Graphical view of the error on the overcurrent for all gains with ΔV_{OCTH4H} = 0.3xVDD.

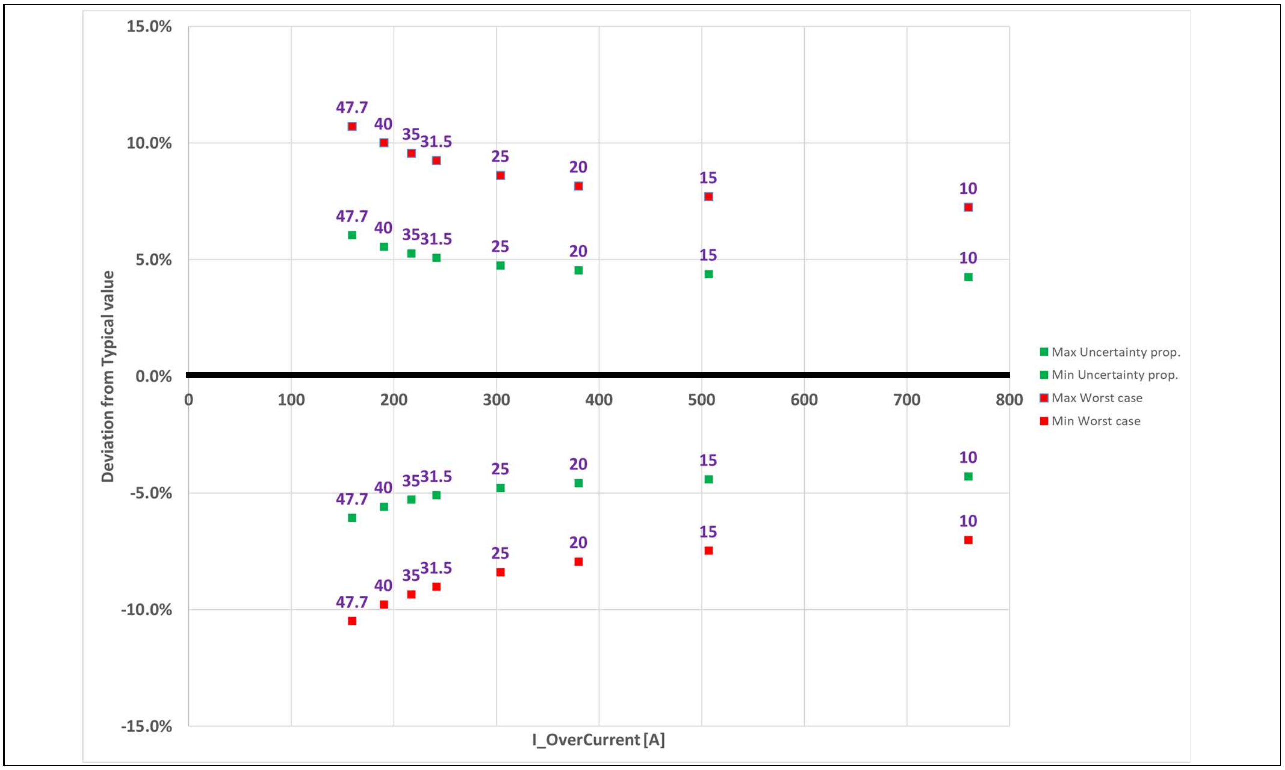

Figure 11 Graphical comparison of the 2 methods to calculate the error.

4 Excel worksheets

An excel file is available to complement the present application note:

`Infineon-Current_sense_and_overcurrent_accuracy_with_EiceDRIVER_APD_2ED4820-EM-AN-v01_00-EN.xlsx`

It provides 5 worksheets, to compute the accuracy which can be achieved with EiceDRIVER™ APD 2ED4820-EM.

4.1 CSO accuracy with Worst Case calculation methodology

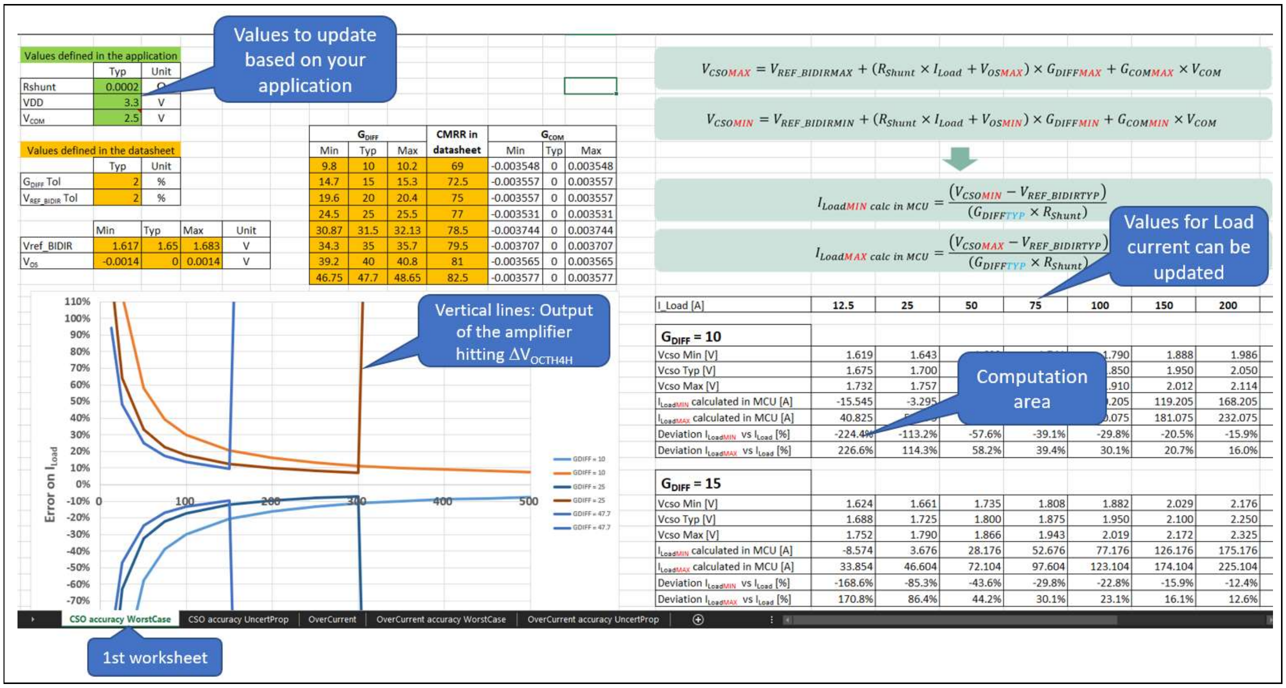

Figure 12 Overview of the 1st worksheet, computing accuracy on CSO using worst case methodology.

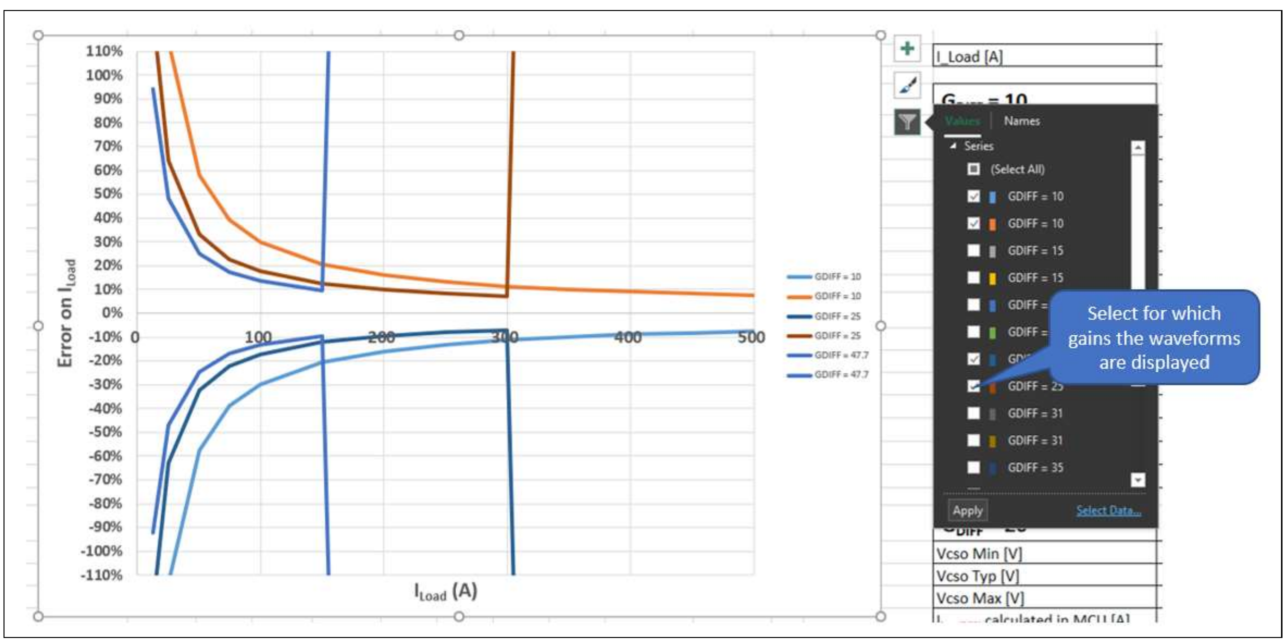

Figure 13 How the select the waveforms displayed on the graph (sorted by gain).

4.2 CSO accuracy with uncertainty propagation methodology

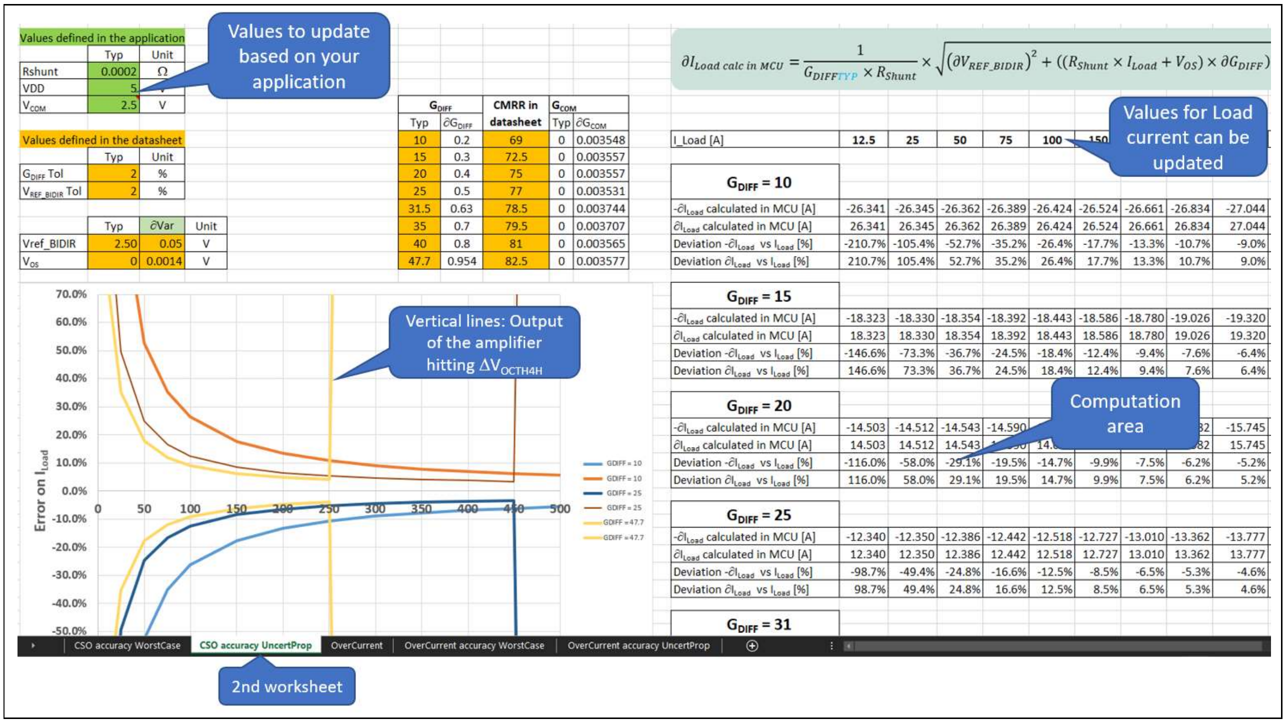

Figure 14 Overview of the 2nd worksheet, computing accuracy on CSO using uncertainty propagation.

4.3 Overcurrent settings

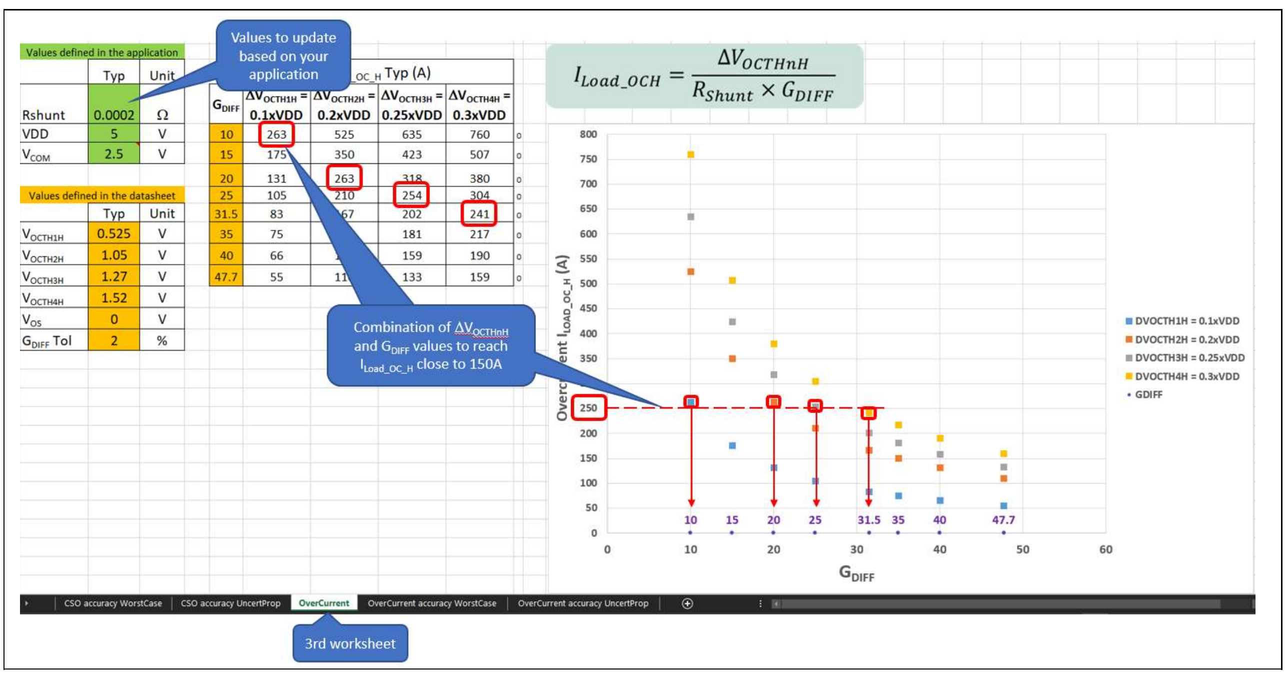

Figure 15 Overview of overcurrent settings offered by EiceDRIVER™ APD 2ED4820-EM.

4.4 Overcurrent accuracy with Worst Case calculation methodology

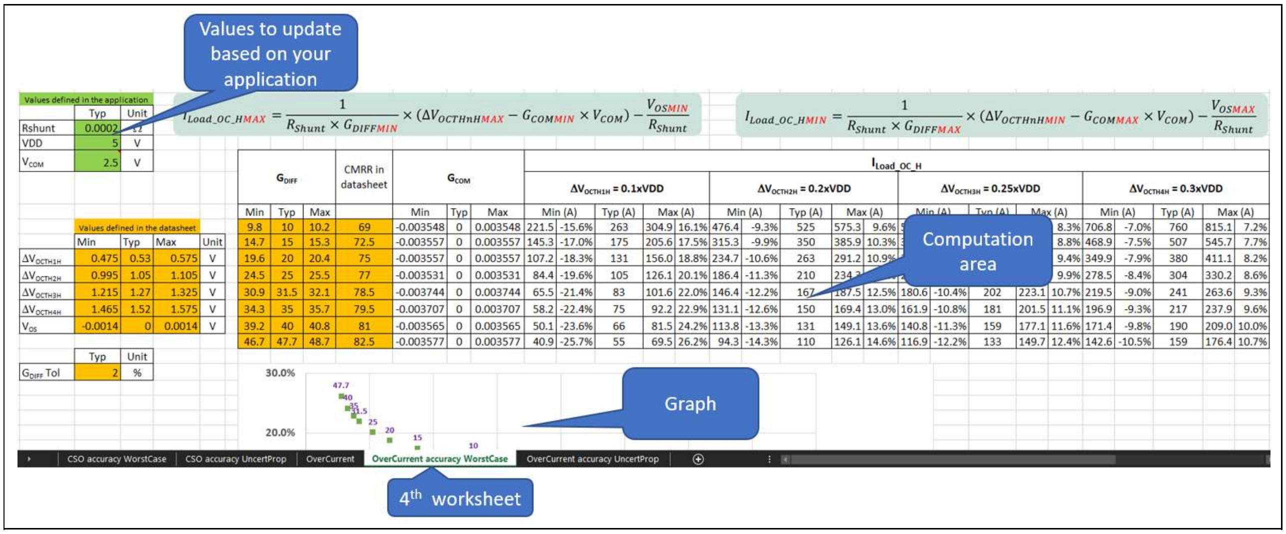

Figure 16 Overview of the 4th worksheet, computing overcurrent accuracy using worst case method.

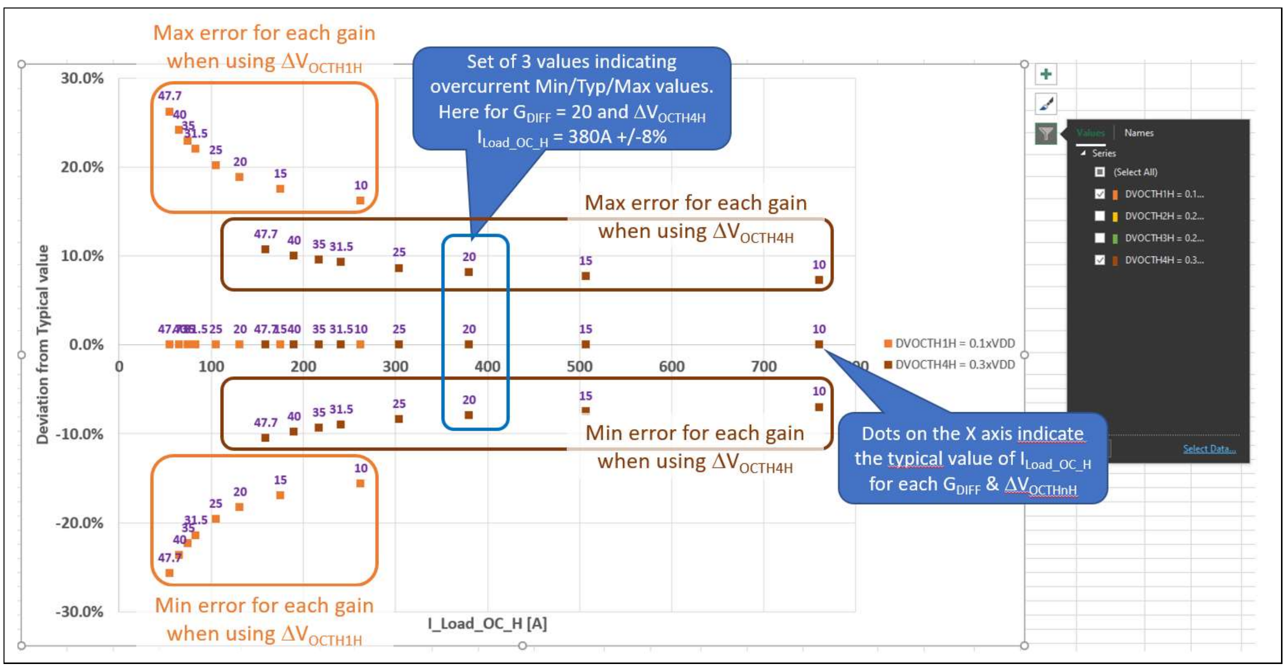

Figure 17 How to read the graph.

4.5 Overcurrent accuracy with uncertainty propagation method

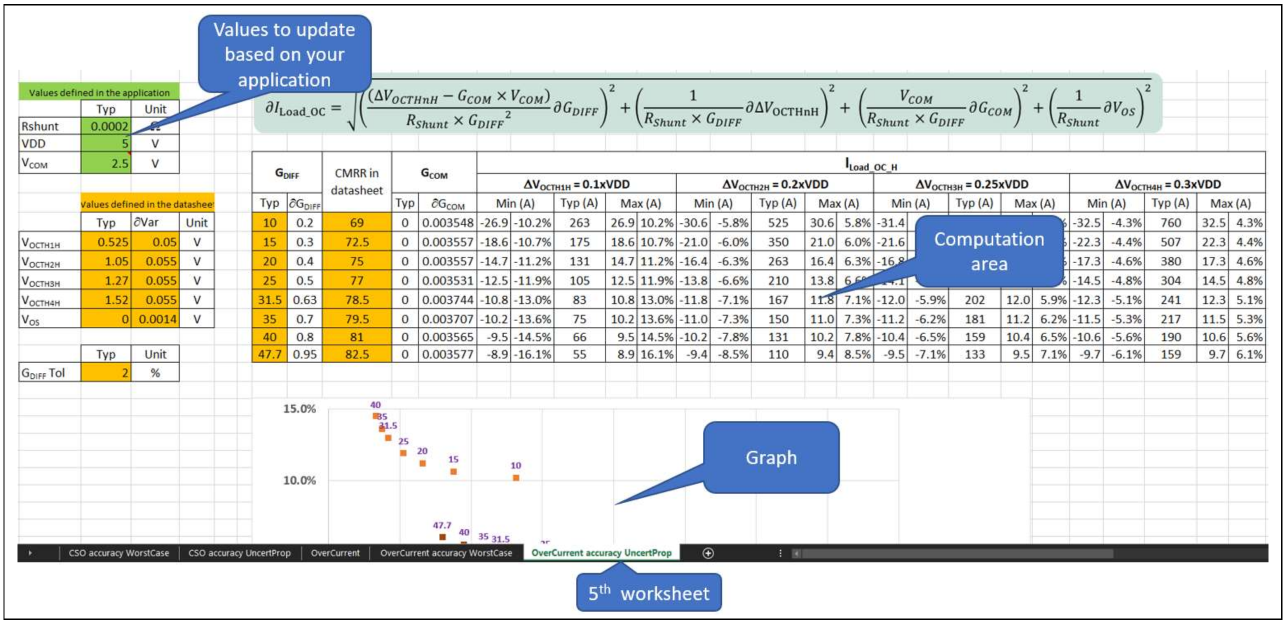

Figure 18 Overview of the 5th worksheet, computing overcurrent accuracy using uncertainty propagation.

5 Choosing the best setting to improve the accuracy

5.1 Parameters impacting the accuracy

To improve the accuracy, there are three parameters which can be configured at the application level:

- The shunt value, R_{Shunt}
- The shunt connexion, either in low-side or high-side, impacting the common mode
- The logic supply VDD

There are also 2 parameters configured over SPI in the EiceDRIVER™ APD 2ED4820-EM:

- The gain of the amplifier, G_{DIFF}
- The window of the overcurrent comparator, ΔV_{OCTHnH}

Table 8 and **Table 9** analyze the impact of these parameters on the current sense output, CSO, and on the overcurrent.

Table 8 Parameters impacting the CSO current sense output accuracy

Parameter	Trend	Comment
G_{DIFF}	Use high gain values	High gains can be used at low current but the overcurrent can be triggered at higher currents => switch then to a lower gain
VDD	5 V better than 3.3 V	5 V VDD enables to use high gains for medium currents without saturating the CSO output.
V_{COM}	Low side shunt better than high side	Low side shunt configuration significantly reduces the effect of the Common Mode Rejection Ratio (CMRR)

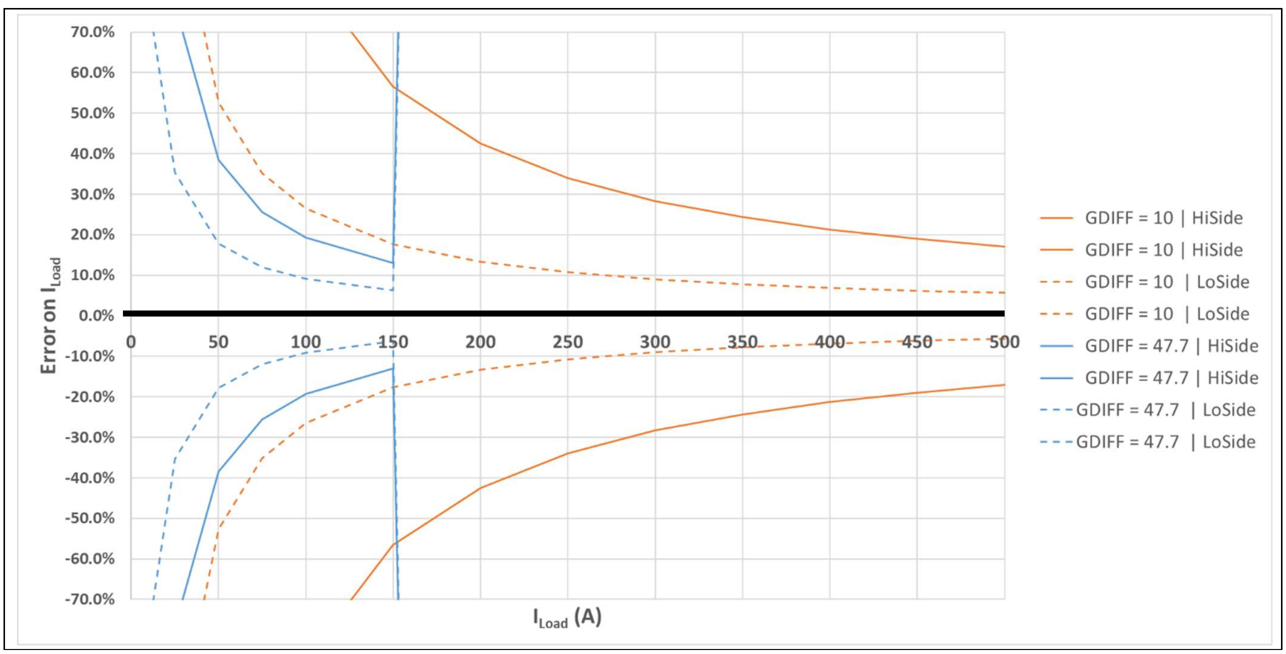

Figure 19 Impact of the Shunt connection (low side, V_{COM} = 2.5 V, vs high side, V_{COM} = 45.5 V) on the current sense accuracy.

Table 9 Parameters impacting the overcurrent accuracy

Parameter	Trend	Comment
G_{DIFF}	Use low gain values	The trend here is opposite to the trend on current sense output: overcurrent is a single point, at high current only, while CSO current sense covers a broad range of current.
VDD	5 V better than 3.3 V	5 V enlarges the windows ΔV_{OCTHnH} thus reducing the impact of the offsets.
ΔV_{OCTHnH}	ΔV_{OCTH4H} as best choice	The bigger the window, the lower the impact of the offsets
V_{COM}	Low side shunt better than high side	Low side shunt configuration significantly reduces the effect of the Common Mode Rejection Ratio (CMRR)

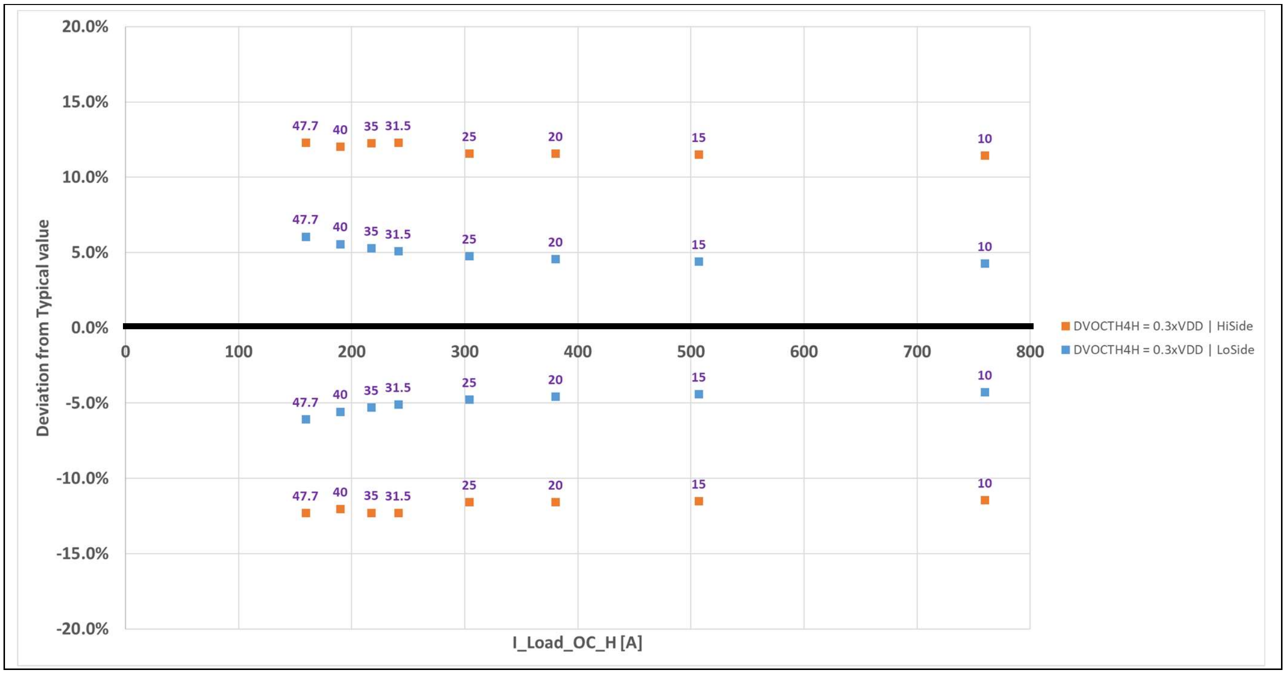

Figure 20 Impact of the Shunt connection (low side, V_{COM} = 2.5 V, vs high side, V_{COM} = 45.5 V) on the overcurrent accuracy.

Revision history

Document version	Date of release	Description of changes
Rev 1.0	2021-01-20	First version, based on datasheet Rev 1.00

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