

# Sense Accuracy and Calibration

## of the New High-Current PROFET™ family

BTS7002-1EPP, BTS7004-1EPP, BTS7006-1EPP, BTS7008-1EPP  
 High-current PROFET™ 12 V smart high side power switch

### About this document

#### Scope and purpose

This document shows how to understand, use and calibrate the devices of the New High-Current PROFET™ family.

#### Intended audience

Engineers, hobbyists and students who want to understand powerful protected high-side switches for heating or power distribution projects.

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**1 Current Sense**

**1 Current Sense**

The New High-Current protected FET (PROFET™) family was developed to replace relays, fuses and discrete circuits. Due to a selection of protection and diagnostic features in combination with a very low ohmic DMOS power stage this family is particularly suitable for applications such as glow plugs, heating loads, DC motors and for power distribution.

This chapter will provide a brief introduction to the New Smart High-Side Power Switch family diagnosis features, as open load in OFF state, open load in ON state, short circuit to battery and inverse current.

**1.1 Introduction**

The New High-Current PROFET™ family provides as diagnostic feature an analog current sense, that can be used to:

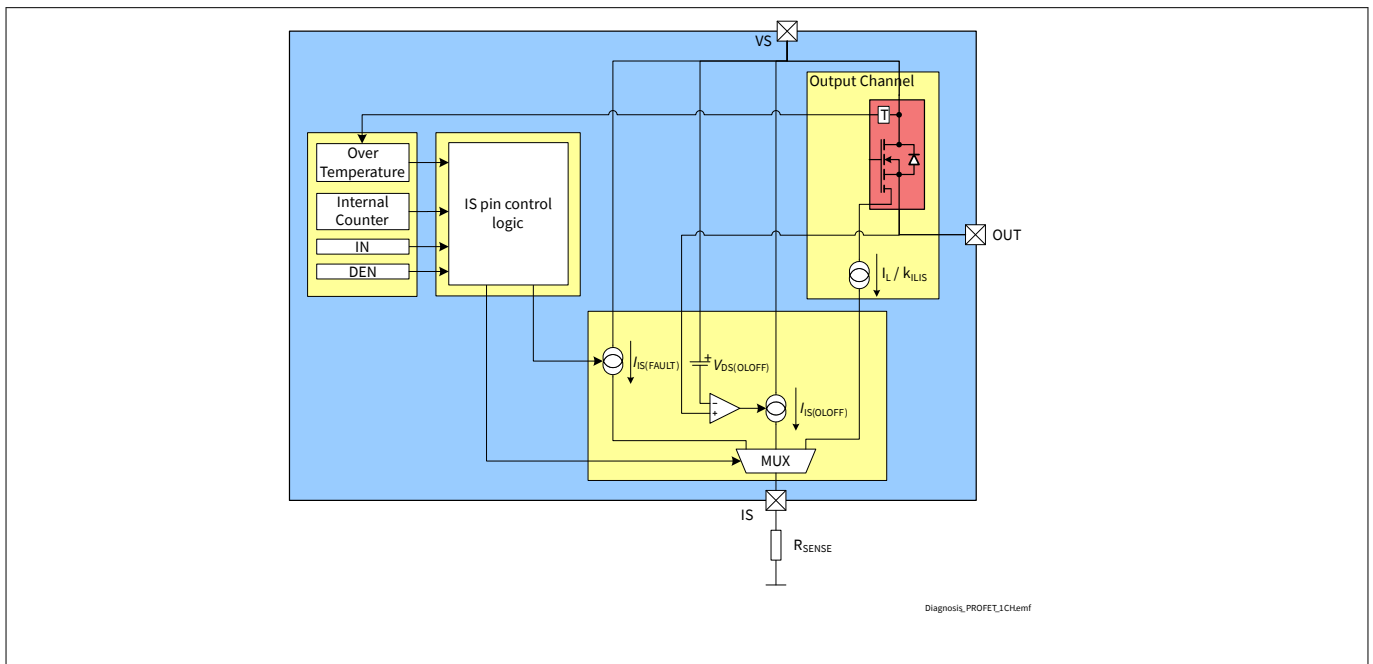
- Monitor the application state as normal, overload, open load, short circuit to ground, short circuit to battery condition, protective switch off (thermal shutdown and overcurrent shutdown);
- Protect the load and the wiring harness;
- Measure the output current for the purpose of controlling the output power.

The parameter used to quantify the accuracy of the current sensing is called  $k_{ILIS}$ , because it is defined as the ratio between the load current  $I_L$  and the sense current  $I_S$ :

$$k_{ILIS} = \frac{I_L}{I_S}$$

The  $k_{ILIS}$  factor is specified with limits that take into account effects due to:

- temperature;
- supply voltage;
- manufacturing process.



**Figure 1 Diagnosis block diagram**

The block diagram, highlighting the diagnosis part for a high-side power switch is illustrated in **Figure 1**.

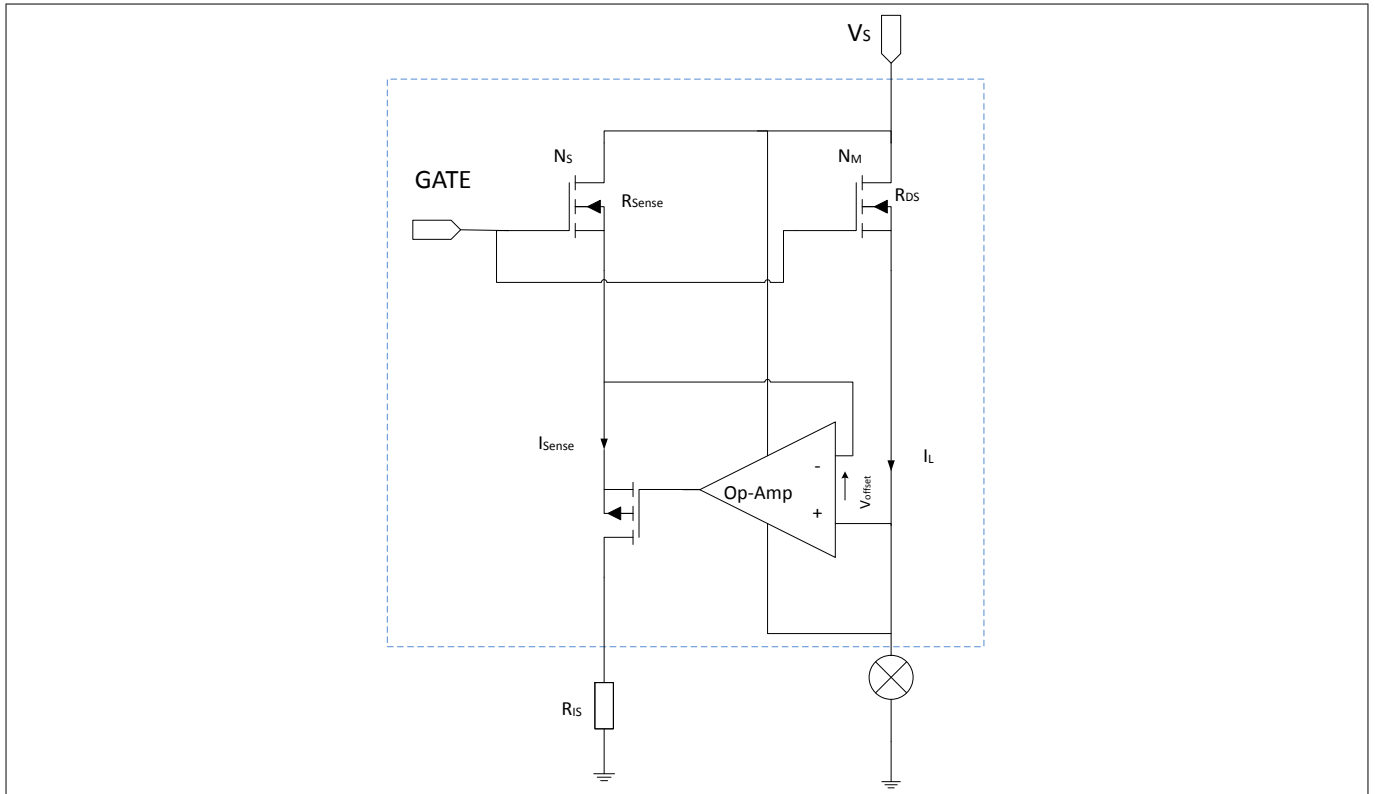
The diagnosis circuitry is controlled by the “Diagnosis Enable” (DEN) pin: when it is set to “high”, the diagnosis is enabled.

**1 Current Sense**

For the new High-Current PROFET™ family additional calibration techniques are supported, whenever the overall specified sense performance does not meet the accuracy required for a particular application.

**1.2 Current Sense circuit**

Ideally the analog current sense diagnosis should reflect the load current without any additional error contribution. However in reality analog current sense diagnosis do always have an inherent inaccuracy associated. In **Figure 2**, the current sense equivalent circuit is shown.



**Figure 2 Current sensing circuit for a conventional high-side power switch**

The following equations show the relation between  $k_{ILIS(ideal)}$  and  $k_{ILIS(real)}$ .

If the voltage across the input pins of Op-Amp ( $V_{offset}$ ) is not taken into account, the relation between the voltage across the MOSFET of the current mirror  $V_M$ , and the voltage across the power MOSFET  $V_P$  will be:

$$V_M = V_P$$

$$I_{IS} \cdot R_M = I_L \cdot R_P$$

$$\frac{N_P}{N_M} = \frac{R_M}{R_P} = \frac{I_L}{I_{IS}} = k_{ILIS(ideal)}$$

Where  $R_M$  is the on resistance of the MOSFET of the current mirror with  $N_M$  cells;  $R_P$  is the on resistance of the power MOSFET with  $N_P$  dimension.

Including the Op-Amp contribution:

$$V_M \pm V_{offset} = V_P$$

$$I_{IS} \cdot R_M \pm V_{offset} = I_L \cdot R_P$$

$$\frac{1}{I_L \cdot R_P \pm V_{offset}} = \frac{1}{I_{IS} \cdot R_M}$$

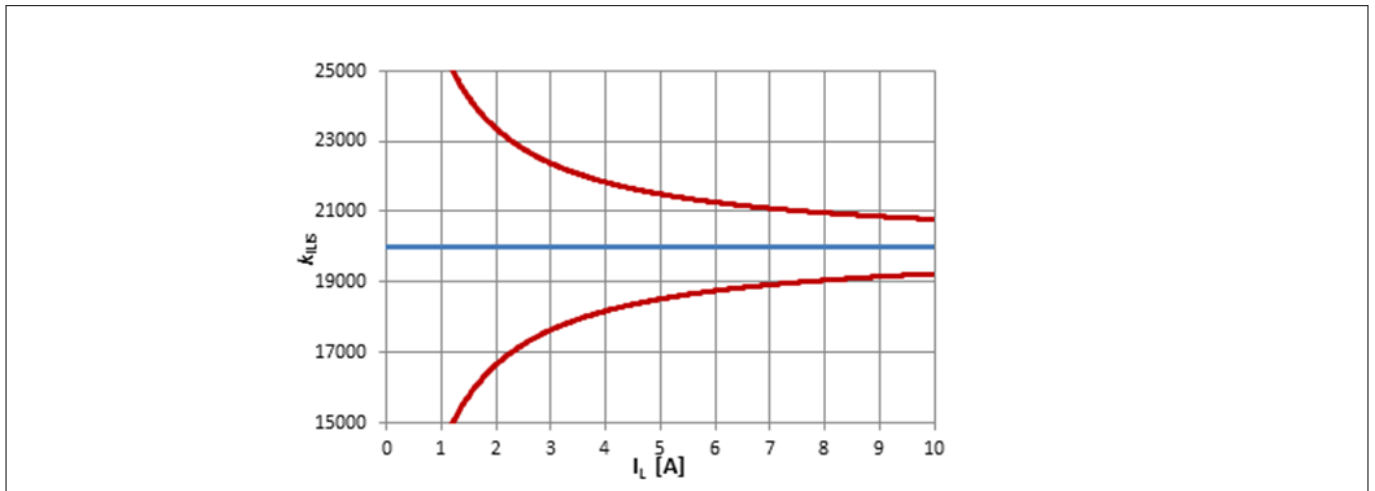
$$\frac{I_L \cdot R_M}{I_L \cdot R_P \pm V_{offset}} = \frac{I_L}{I_{IS}} = k_{ILIS(real)}$$

**1 Current Sense**

$$k_{ILIS(real)} = \frac{I_L \cdot R_M}{I_L \cdot \left( R_P \pm \frac{V_{offset}}{I_L} \right)} = \frac{R_M}{R_P} \cdot \frac{1}{1 \pm \frac{V_{offset}}{R_P \cdot I_L}}$$

$$k_{ILIS(real)} = k_{ILIS(ideal)} \cdot \frac{1}{1 \pm \frac{V_{offset}}{R_P \cdot I_L}}$$

As result of the previous equations, the relation of  $I_L$  and  $k_{ILIS}$  is plotted in **Figure 3**. Ideally the relationship between the sense current  $I_{IS}$  and the load current  $I_L$  is linear and their ratio is constant and equal to  $k_{ilis(ideal)}$ , as the blue curve shows. When the Op-Amp is introduced, depending on its positive or negative internal offset voltage, the current sense accuracy, shown in the red curve is deteriorate especially at lower load currents.



**Figure 3 Example of current sense vs. load current**

**1.3 Diagnosis in ON State**

A current proportional to the load current (ratio  $k_{ILIS} = I_L / I_{IS}$ ) is provided at pin IS when the following conditions are fulfilled:

- the power output stage is switched ON with  $V_{DS} < 2 V$ ;
- the diagnosis is enabled (DEN level = “high”);
- no fault (overtemperature and over load condition) is present or was present and not cleared yet.

$I_{IS}$  increases linearly with  $I_L$  output current until it reaches the saturation current  $I_{IS(SAT)}$ .

If the load is in under load condition (i.e. output voltage limitation condition) and the output current is higher than  $I_{L(OL)}$ ,  $I_{IS}$  will be  $I_{IS(EN)} < I_{IS} < I_{L(NOM)}/k_{ILIS}$ , as shown in the pointed area of **Figure 4** (see **Accuracy at low current** for further details). In under load condition the device can distinguish  $I_{L(OL)min}$  from  $I_{L(OL)max}$ .

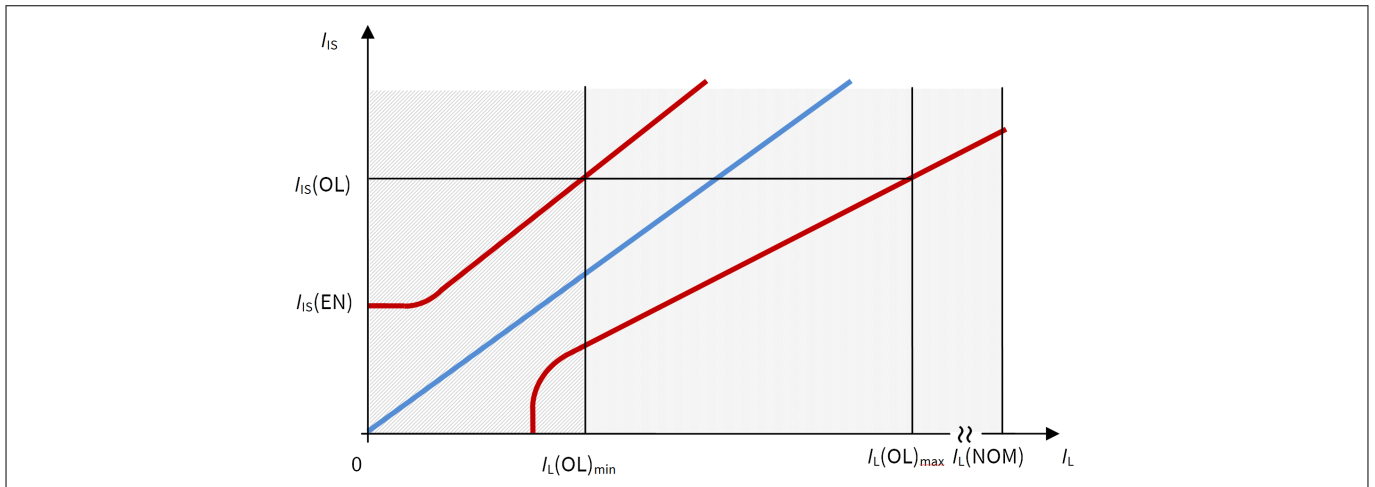
If the load is in open load condition ( $I_L$  close to 0 A and  $V_{out}$  close to  $V_s$ ) and the output load current is smaller than  $I_{L(OL)}$  and the maximum sense current  $I_{IS(EN)}$  measureable is specified (as shown in the striped area of **Figure 4**). This  $I_{IS(EN)}$  value is specified in the datasheet for  $T_j \leq 85^\circ C$  (P\_9.6.0.3) and for  $T_j = 150^\circ C$  (P\_9.6.0.4).

The open load output current range is specified in the datasheet measuring the sensing current  $I_{IS}$ , when it is equal to 4  $\mu A$ . Assuming  $R_{SENSE} = 1.2 k$ ,  $V_{SENSE}$  is 4.8 mV, and this is considered as the minimum value that a microcontroller ( $\mu C$ ) can measure in order to use this diagnosis feature.

This condition is shown in **Figure 4**. The blue line represents the ideal  $k_{ILIS}$  line, while the red lines show the behavior of a typical product.

An external RC filter between IS pin and the  $\mu C$  ADC input pin is recommended to reduce signal ripple and oscillations (a minimum time constant of 1  $\mu s$  for the RC filter is recommended).

**1 Current Sense**

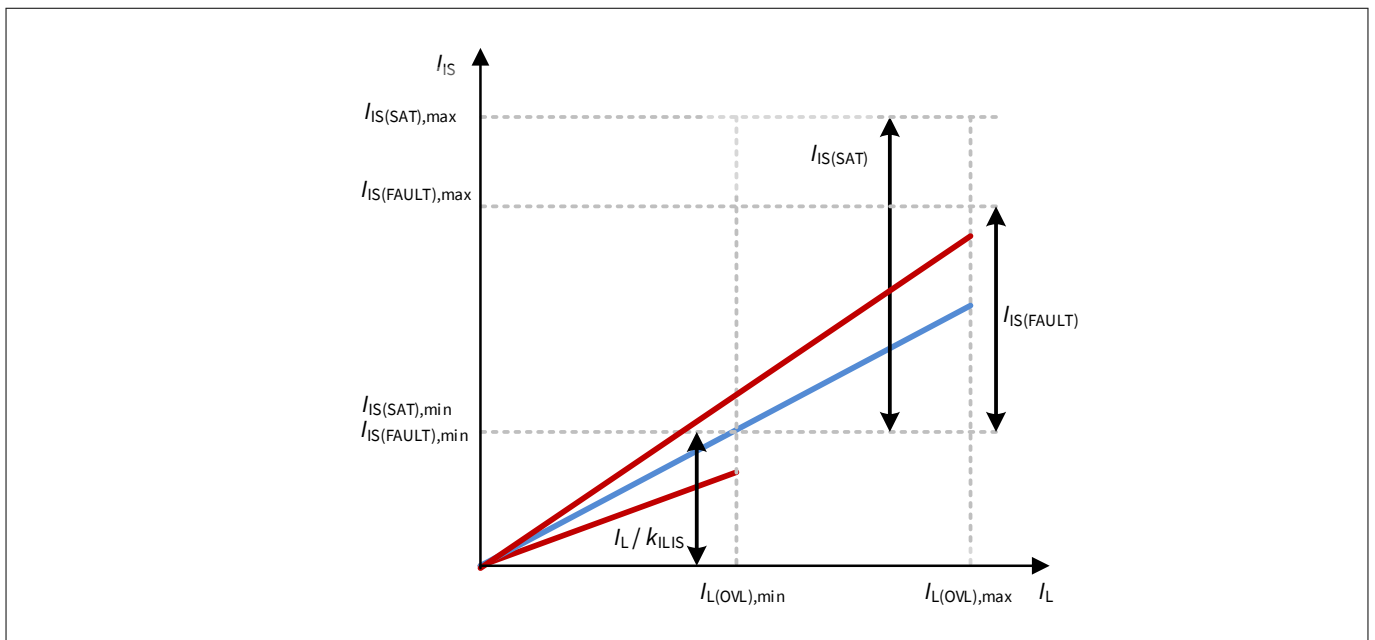


**Figure 4 Current sense ratio in open load at ON condition**

A protection event like overtemperature or overload can trigger a protection mechanism. If DEN is set to “high” and a protection event occurs, the value of the internal latch changes from 0 to 1 and, the IS pin provides a current equal to  $I_{IS(FAULT)}$ , and the affected device is switched OFF.

The switch can be unlatched using the IN pin or using the DEN pin.

**Figure 5** shows the relation between  $I_{IS} = I_L/k_{ILIS}$ ,  $I_{IS(SAT)}$  and  $I_{IS(FAULT)}$ , considering their possible ranges.

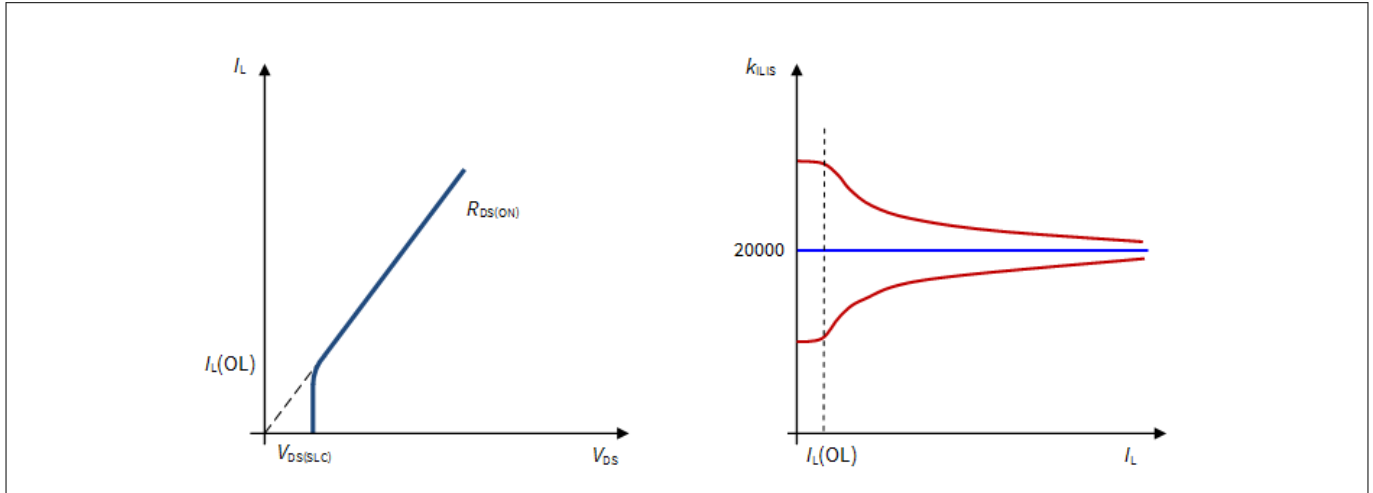


**Figure 5 SENSE behavior - overview**

**1 Current Sense**

**1.3.1 Accuracy at low current**

To realize a more accurate current sense function, especially at low current load, the output voltage limitation is implemented, monitoring  $V_{DS}$ .



**Figure 6 Power MOSFET characteristic and current sense ratio with output voltage limitation**

When the output current  $I_L$  decreases, while the channel is diagnosed (DEN pin set to “high”) bringing  $V_{DS}$ , equal or lower than  $V_{DS(SLC)}$ , the output DMOS gate is partially discharged, due to a circuitry that controls the gate. This increases the output resistance  $R_{DS(ON)}$  so that  $V_{DS} = V_{DS(SLC)}$ , even for very small output currents.

The  $V_{DS}$  increase allows the Op-Amp, present in the current sensing circuitry to work more efficiently, providing better  $k_{ILIS}$  accuracy for output current in the low range.

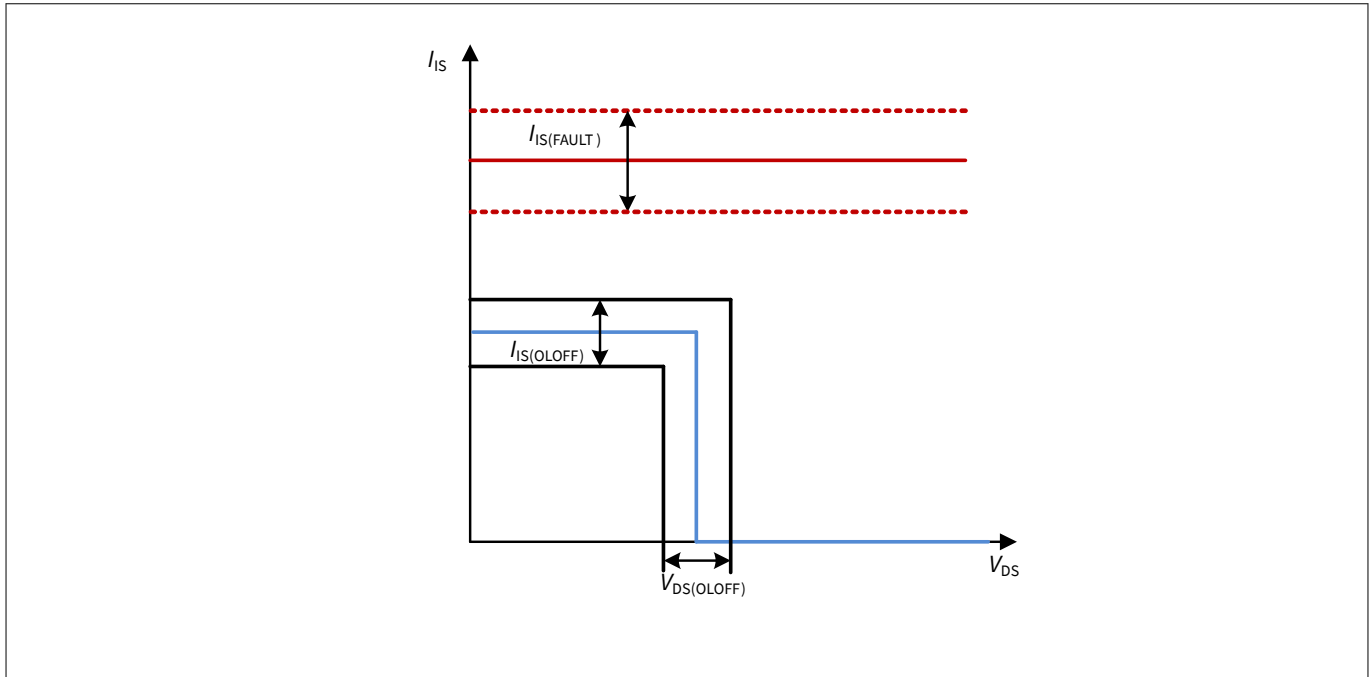
By controlling the voltage drop  $V_{DS}$ , the negative effect of the Op-Amp offset voltage  $V_{offset}$  is reduced and the sense accuracy is improved at small load currents as shown in [Figure 6](#).

*Note: For more information about the output voltage limitation please check the output voltage limitation paragraph in data sheet: [BTS7002-1EPP Data Sheet single-channel](#), [BTS7004-1EPP Data Sheet single-channel](#), [BTS7006-1EPP Data Sheet single-channel](#), [BTS7008-1EPP Data Sheet single-channel](#).*

**1.4 Diagnosis in OFF state**

If the diagnosis is enabled (DEN='high'), the diagnosis feature can be provided even if the power output stage is in OFF state. This mechanism is possible only measuring the drain-source voltage and compare it with a threshold voltage: condition of missing load, or short circuit to battery can be detected.

**1 Current Sense**



**Figure 7**  $I_{IS}$  in OFF state

Also in OFF state a current  $I_{IS(FAULT)}$  can be provided, if a fault condition was detected in the previous ON state, and if the internal latch is “1”. A fault current  $I_{IS(FAULT)}$  will appear by IS pin, regardless of drain-source or output voltage, as long as DEN='high'.

If  $V_{DS} \leq V_{DS(OLOFF)}$ , an open load condition will be detected, and only after a waiting time of  $t_{IS(OLOFF)}$ , a sense current  $I_{IS(OLOFF)}$  will be provided. The  $t_{IS(OLOFF)}$  is defined as the time between the falling edge of the input pin IN and the sensing at pin IS for open load in OFF diagnosis. This situation will occur only if the internal latch is “0”, otherwise the IS pin will provide a fault current  $I_{IS(FAULT)}$ .

In **Figure 7** the relationship between  $I_{IS(OLOFF)}$  and  $I_{IS(FAULT)}$  as functions of  $V_{DS}$  are shown. It is important to notice that the two currents do not overlap in order to differentiate between open load in OFF and Fault condition.

With this, the complete diagnosis state of the device can be detected in OFF state which allows the  $\mu C$  software to be non-time critical reading and diagnosing the sense pin:

- $I_{IS}$  = “low” nominal condition;
- $I_{IS(OLOFF)}$  open load or short circuit to  $V_S$  or inverse current (if no  $I_{IS(FAULT)}$  are present);
- $I_{IS(FAULT)}$  short circuit to GND or overtemperature from previous ON state.

**2 Error calculation**

**2 Error calculation**

In this chapter the mathematical procedure for the inaccuracy or error calculation are explained.

For the New High-Current PROFET™ family the relation between the load current  $I_L$  and the sense current  $I_{IS}$  is described through the relation:

$$I_{IS} = \frac{1}{k_{ILIS}} \cdot I_L$$

**Equation 1**

It is possible to compare this relation with the formula for a straight line:

$$y = m \cdot x + b$$

**Equation 2**

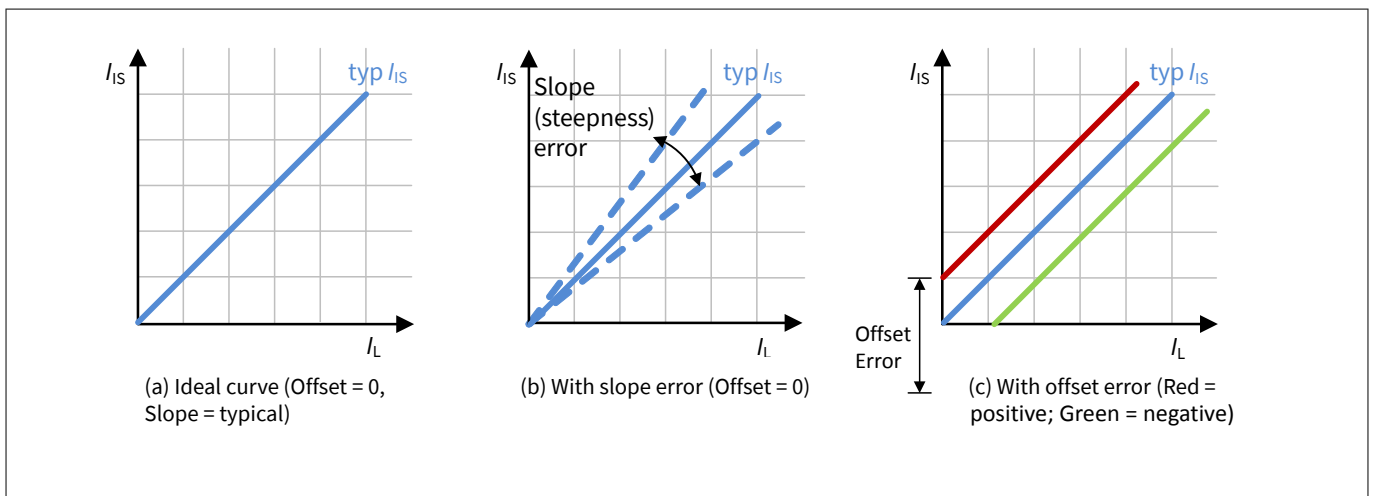
In which x is the independent variable, y is the dependent variable, m is the slope and b is the intercept with the y axis, or offset.

Comparing Equation 1 and Equation 2, it is possible to notice that  $I_L$  acts as independent variable,  $I_{IS}$  as dependent variable,  $k_{ILIS}$  is the slope, and there is no offset, because, assuming the ideal relation, the line will cross the zero-value.

The relationship between the sense current  $I_{IS}$  and the load current  $I_L$  should be linear with a fixed angular coefficient, as shown in **Figure 8a**. In reality, inaccuracy can occur, in particular a slope (steepness) error and an offset, or combinations of both errors can show up. The slope error (in **Figure 8b**) is dependent on part-to-part production variation, and its effects are more pronounced at higher load currents.

The sense offset error (in **Figure 8c**) is caused by an internal amplifier offset voltage. It is strongly dependent on production variation and the operating temperature of the device. The effects of the offset are more pronounced at lower load currents.

Positive offset errors will result in a current at the IS pin, without a load current flowing. Negative offset errors will result in no current at the IS pin (theoretical negative sense current), even though load current is flowing. The sense functionality below a certain load current threshold will be disabled. Load currents at this threshold or below will result in no sense current at the IS pin.



**Figure 8 Relationship between  $I_{IS}$  and  $I_L$  in conventional devices**

At this point the error measurements can be introduced, in order to value in which limits the x value may vary, assuming a certain y value is read. This procedure is applied only at the case shown in **Figure 8b**, only slope error present, because it is done in the hypothesis that any offset error is present.



**2 Error calculation**

The typical straight line is described by the relation:

$$y = m_{TYP} \cdot x$$

**Equation 3**

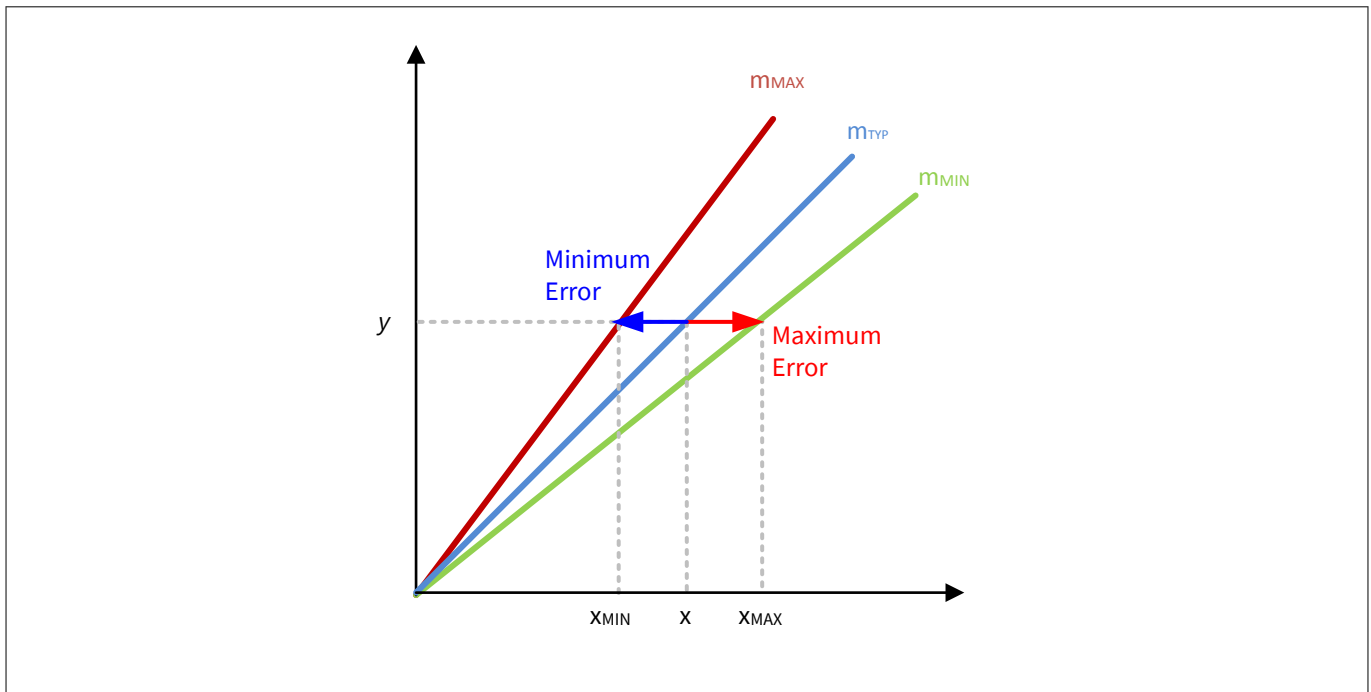
If slope errors are considered, two other lines will be present, defined by the equations:

$$y = m_{MAX} \cdot x$$

**Equation 4**

$$y = m_{MIN} \cdot x$$

**Equation 5**



**Figure 9 Graphic representation of minimum and maximum error**

Assuming that a y-value is read, all x-values between  $x_{MIN}$  and  $x_{MAX}$  could be real as shown in **Figure 9**. The difference between  $x$  and  $x_{MIN}$  and  $x$  and  $x_{MAX}$  are defining the minimum and maximum absolute errors:

$$MinAbsErr = x_{MIN} - x = \frac{y}{m_{MAX}} - x = \left( \frac{m_{TYP}}{m_{MAX}} - 1 \right) \cdot x$$

**Equation 6**

$$MaxAbsErr = x_{MAX} - x = \frac{y}{m_{MIN}} - x = \left( \frac{m_{TYP}}{m_{MIN}} - 1 \right) \cdot x$$

**Equation 7**

The minimum absolute error and the maximum absolute error represent the possible x-spreading, introduced by slope inaccuracy.

**2 Error calculation**

Normalizing for the  $x$  the minimum absolute error and the maximum absolute error, the minimum relative error and the maximum relative error can be obtained:

$$MinRelErr = \frac{x_{MIN}^{-x}}{x} = \frac{y}{m_{MAX} \cdot x} - 1 = \frac{m_{TYP}}{m_{MAX}} - 1$$

**Equation 8**

$$MaxRelErr = \frac{x_{MAX}^{-x}}{x} = \frac{y}{m_{MIN} \cdot x} - 1 = \frac{m_{TYP}}{m_{MIN}} - 1$$

**Equation 9**

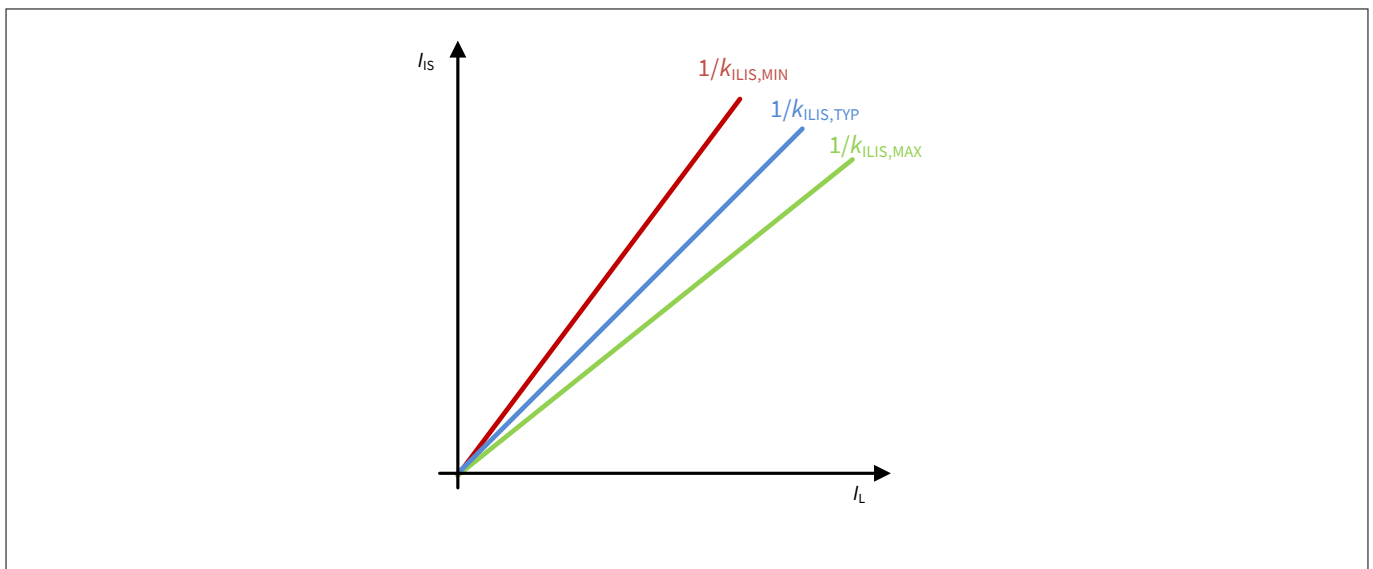
The minimum relative error and the maximum relative error represent also the possible  $x$ -spreading, introduced by slope inaccuracy, but it is weighted for the  $x$  itself.

**2.1 “Default” performance**

In the New High-Current PROFET™ family datasheet the typical  $k_{ILIS}$  parameters is specified for a load current range. The maximum and minimum values are also defined fixing the inaccuracy range. These inaccuracies are decreasing with increasing the load current, therefore for low current the inaccuracy range is broader than the high current range.

In **Figure 4**, the behavior of  $I_{IS}$  curve is shown and it has been already described. In order to simplify this argument the following assumptions will be taken in account:

- At low current ( $< I_{L(OL)}$ ) the relation  $I_{IS} = I_L/k_{ILIS}$  is still valid;
- The slope of  $I_{IS}$  curve can vary from a limiting upper line to a limiting lower line according to  $k_{ILIS}$  range as defined datasheet.



**Figure 10 Simplified representation for the  $I_{IS}$  as function of  $I_L$**

These assumptions are applied and shown in **Figure 10**.

The “Electrical Characteristics: Diagnosis –  $x$  mΩ” Table of the datasheet section “Diagnosis Power Output Stage –  $x$  mΩ” contains the “default” diagnosis performances for the New High-Current PROFET™ family. Focusing on the BTS7004-1EPP,  $k_{ILIS}$  is specified for load currents from 200 mA up to 15 A.

From the parameters in the datasheet it is possible to derive:

**2 Error calculation**

- The typical slop  $m_{TYP}$  as:

$$m_{TYP} = 1/k_{ILIS, TYP}$$

- The maximum slope  $m_{MAX}$  as:

$$m_{MAX} = 1/k_{ILIS, MIN}$$

- The minimum slope  $m_{MIN}$  as:

$$m_{MIN} = 1/k_{ILIS, MAX}$$

These slope parameters are describing the limiting lower line and the limiting upper line of the measurable load current range.

Applying the New High-Current PROFET™ family parameters to Equation 6 / 9 results in the following equations:

$$MinAbsErr = \left( \frac{m_{TYP}}{m_{MAX}} - 1 \right) \cdot I_L$$

**Equation 10**

$$MaxAbsErr = \left( \frac{m_{TYP}}{m_{MIN}} - 1 \right) \cdot I_L$$

**Equation 11**

$$MaxRelErr = \frac{m_{TYP}}{m_{MIN}} - 1$$

**Equation 12**

$$MinRelErr = \frac{m_{TYP}}{m_{MAX}} - 1$$

**Equation 13**

It is worth noting that the maximum relative error and the minimum relative error, with these assumptions, are depending only on the ratio between the slopes.

In **Table 1** the results for the “default” current sense performance are shown for the BTS7004-1EPP, for load current  $I_L$  from 200 mA to 15 A.

In term of accuracy it can be seen that the “default” accuracy reaches at nominal current ( $I_L = 15$  A) 8%, that is the minimum value. Furthermore, the Maximum Relative Error and the Minimum Relative Error are decreasing when increasing the load current, because relative  $k_{ILIS}$  accuracy improves at “high” current.

**Table 1**

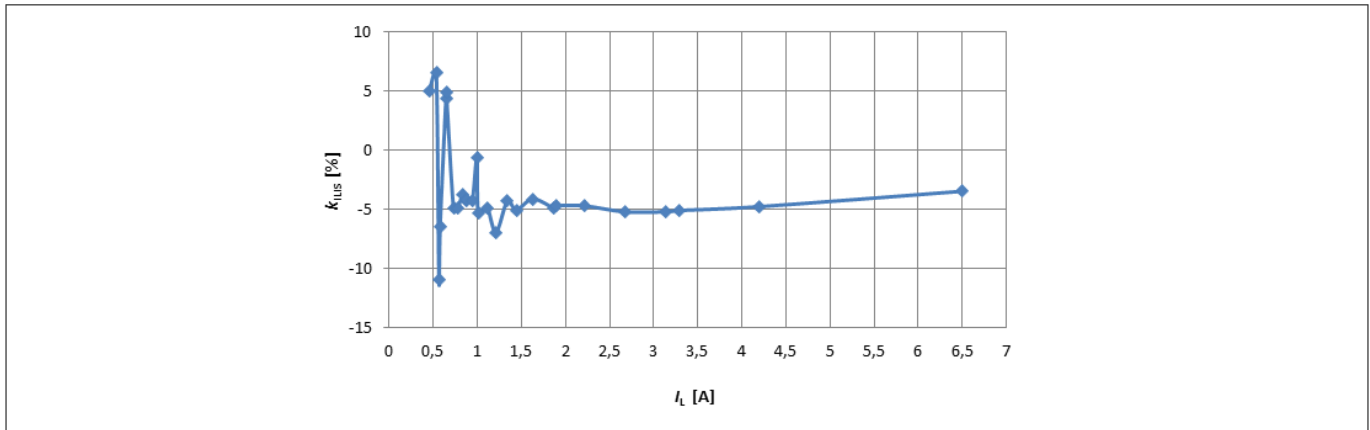
$I_L$ [A]	Maximum absolute error [A]	Maximum relative error [%]	Minimum absolute error [A]	Minimum relative error [%]
0.05	0.03	65	-0.03	-65
0.2	0.13	65	-0.13	-65
0.45	0.25	55	-0.25	-55
2	0.80	40	-0.80	-40

**2 Error calculation**

**Table 1 (continued)**

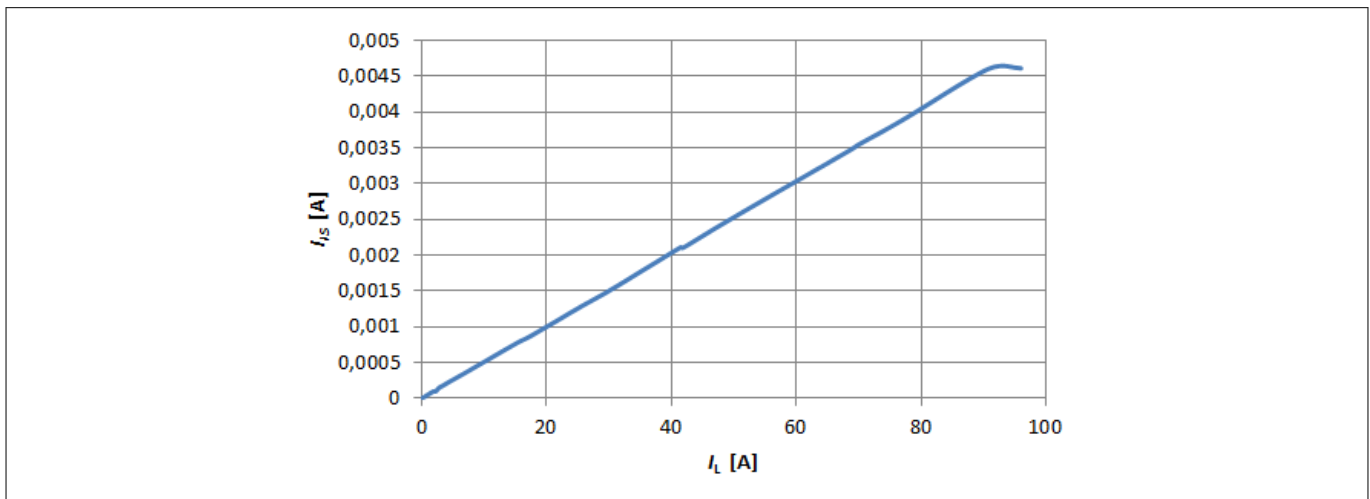
$I_L$ [A]	Maximum absolute error [A]	Maximum relative error [%]	Minimum absolute error [A]	Minimum relative error [%]
5.5	1.32	24	-1.32	-24
10	0.80	8	-0.80	-8
15	1.20	8	-1.20	-8

It could be interesting to analyze the accuracy across Low Current and Nominal Current range, in particular from  $I_L = 450$  mA to  $I_L = 6.5$  A.



**Figure 11  $k_{ILIS}$  measurements results across low and nominal current range at different  $T_j$  and  $V_{bb}$**

In **Figure 11** measurement results are shown. These measurements have been conducted at  $T_j = 25^\circ\text{C}$  and with a supply voltage  $V_s = 13.5$  V. The  $k_{ILIS}$  accuracy is still confined in range of accuracy defined in the datasheet. It could be also interesting to note how the  $k_{ILIS}$  behaves if a current range, above the nominal, is investigated.



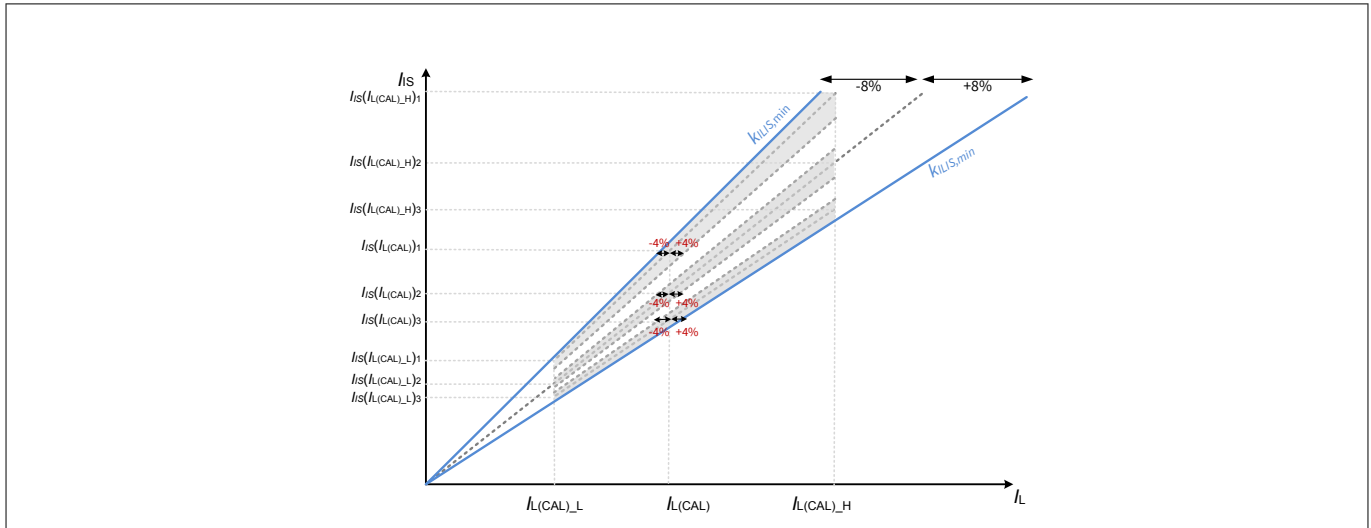
**Figure 12  $k_{ILIS}$  measurements results at high current range**

In **Figure 12** measurement results are shown. These measurements have been conducted at  $T_j = 25$ , with a supply voltage  $V_s = 13.5$  V. This behavior proves the  $I_{IS(SAT)}$ : behavior shows the accuracy of the sense current up to the saturation level.

**2 Error calculation**

**2.2 1-Point calibration performance**

One option to improve the current sense performance is the 1-Point calibration, obtaining tighter limits of accuracy if compared to the “default” overall sense performance. The one point calibration offers the lowest measurement effort of all possible calibration options.



**Figure 13  $k_{ILIS}$  parameter for the BTS7004-1EPP**

**Figure 13** shows the  $k_{ILIS}$  parameter for the BTS7004-1EPP, when the 1-Point calibration is used on three different samples in the range delimited by  $I_{L(CAL)_L}$  and  $I_{L(CAL)_H}$ , the sense accuracy can be tightened from 8% to 4% for definite load currents.

The idea behind the 1-Point calibration in mathematical terms is:

- Fix  $x_1$ ;
- Identify the point  $(x_1, y_1)$ ;
- Calculate m as:

$$m = \frac{y_1}{x_1}$$

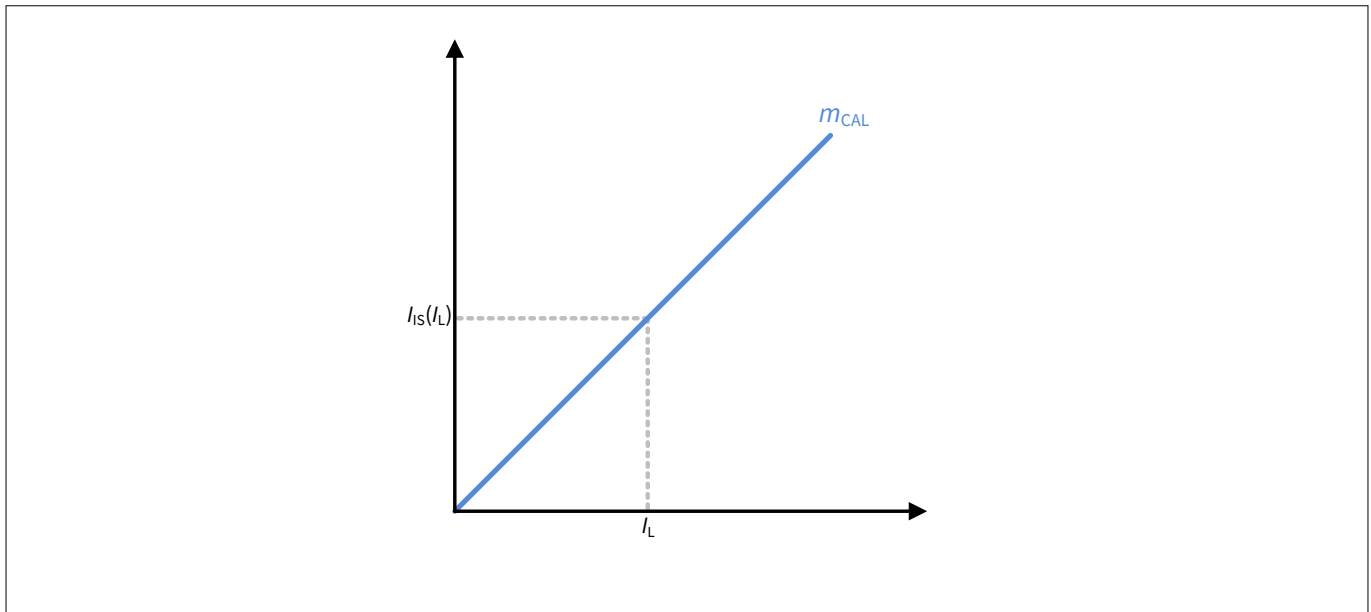
This procedure can be extrapolate from Equation 1, in the hypothesis that the straight line crosses that zero-value, therefore  $b = 0$ . This situation is shown in **Figure 14**.

In the real case, 1-Point calibration procedure is based of the following steps:

- Fix  $I_L$ ;
- Measure  $I_{IS}(I_L)$ ;
- Calculate m as:

$$m_{CAL} = \frac{I_{IS}(I_L)}{I_L}$$

**2 Error calculation**



**Figure 14 Schematic representation of 1-Point calibration procedure for a generic  $I_L$ - $I_{IS}$  line**

To measure current sense at very low current gate back regulation is present.

For this reason the problem is split in two parts: low current and nominal current.

Once  $m_{CAL}$  is calculated, variation effects should be taken into account. In the datasheet the parameters  $\Delta k_{ILIS(OL)}$  (Sense Current Derating with Low Current Calibration) and  $\Delta k_{ILIS(NOM)}$  (Sense Current Derating with Nominal Current Calibration) are specified. Measuring the sense current  $I_{IS}$  after calibration, it is possible to calculate the load current  $I_L$  with the accuracy defined by the Sense Current Derating parameters.

In order to quantify the 1-Point calibration accuracy, the calculation of the maximum absolute and minimum absolute error is carried out. Equations 10-13 can be used for this purpose if  $m_{TYP}$  is replaced with  $m_{CAL}$ ;  $m_{MIN}$  and  $m_{MAX}$  can be calculated as following:

$$m_{MIN} = \frac{m_{CAL}}{1 + \max(\Delta k_{ILIS})}$$

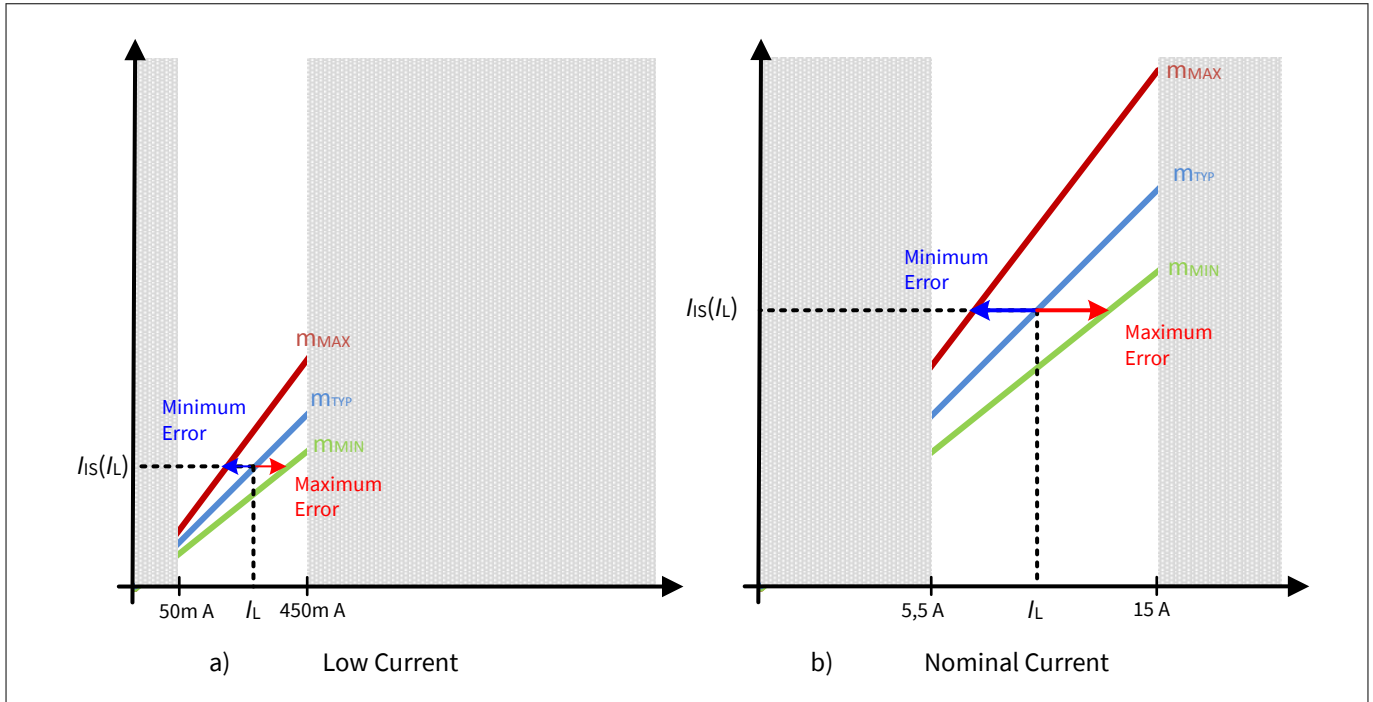
$$m_{MAX} = \frac{m_{CAL}}{1 - \min(\Delta k_{ILIS})}$$

Where  $\Delta k_{ILIS}$  is intended as  $\Delta k_{ILIS(OL)}$  for low current range and  $\Delta k_{ILIS(NOM)}$  for nominal current range.

For the BTS7004-1EPP, the considered low current range starts from 50 mA to 450 mA, and the nominal current range goes from 5.5 A to 15 A.

**Figure 15** shows a graphic representation of Maximum Absolute Error and Minimum Absolute Error for low and nominal currents, for the BTS7004-1EPP.

**2 Error calculation**



**Figure 15** Graphic representation of minimum and maximum error for low and nominal current ranges

**Table 2** shows maximum and minimum absolute errors and maximum and minimum relative errors for low current ranges for the BTS7004-1EPP with a calibration current  $I_L = 0.2$  A.

**Table 3** shows maximum and minimum absolute errors and maximum and minimum relative errors for nominal current ranges for the BTS7004-1EPP with a calibration current  $I_L = 10$  A.

It is possible to compare the results from **Table 2** and **Table 3** with the results showed in **Table 1**. For both Low Current Range and for Nominal Current Range the calibration 1-Point calibration improves the accuracy compared to the “default” performance.

The same comments done for the “default” performances are valid for the 1-Point calibration performance:

- The minimum value is reached at nominal current ( $I_L = 15$  A) 4%;
- The Maximum Relative Error and the Minimum Relative Error are decreasing increasing the load current.

**Table 2**

$I_L$ [A]	Maximum absolute error [A]	Maximum relative error [%]	Minimum absolute error [A]	Minimum relative error [%]
0.05	-1.50E-02	-30	1.50E-02	30
0.2	-6.00E-02	-30	6.00E-02	30
0.45	-1.35E-01	-30	1.35E-01	30

**Table 3**

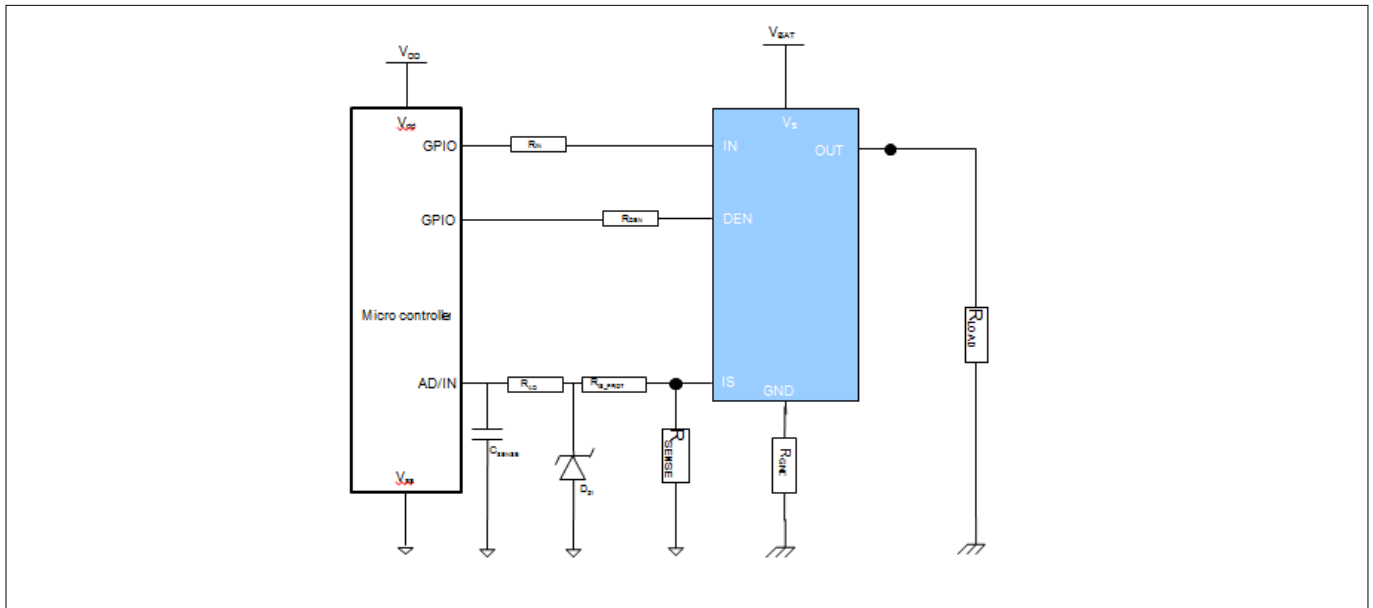
$I_L$ [A]	Maximum absolute error [A]	Maximum relative error [%]	Minimum absolute error [A]	Minimum relative error [%]
5.5	-0.22	-4	0.22	4
10	-0.4	-4	0.4	4
15	-0.6	-4	0.6	4

**3 Practical procedure**

From another point of view, the previous results represent the accuracy which, measuring the sense current  $I_{IS}$ , it is possible to know the load current  $I_L$ . After the 1-Point calibration, measuring a sense current  $I_{IS}$ , it is possible to obtain a load current value with a derating of  $\pm 4\%$ .

**3 Practical procedure**

In this paragraph the calibration techniques previously discussed are presented in terms of practical example.



**Figure 16 Simplified example of an application circuit, focused on the diagnostic function**

In a general application, a microcontroller is used in order to monitor the sense current  $I_{IS}$ . The  $\mu C$  is able to read voltage through the ADC ports, therefore it measures the voltage  $V_{IS}$  across the sense resistor  $R_{SENSE}$ , as shown in **Figure 16**.

*Note: This is a very simplified example of an application circuit focusing on sense accuracy. The function must be verified in the real application. Further application hints can be found in the datasheet in the paragraph “Application Information”.*

The voltage  $V_{IS}$  is seen by the ADC input in the microcontroller as:

$$V_{IS} = R_{SENSE} \cdot I_{IS}$$

**Equation 14**

$$I_L = k_{ILIS,TYP} \cdot I_{IS} = k_{ILIS,TYP} \cdot \frac{V_{IS}}{R_{SENSE}}$$

**Equation 15**

Where  $k_{ILIS,TYP}$  is the typical value for the  $k_{ILIS}$  specified in the data sheet for a fixed load current  $I_L$ . In case of 1-Point calibration, the load current  $I_L$  can be calculate as:



**3 Practical procedure**

$$I_L = k_{ILIS,CAL} \cdot I_{IS}(I_L) = k_{ILIS,CAL} \cdot \frac{V_{IS}(I_L)}{R_{SENSE}}$$

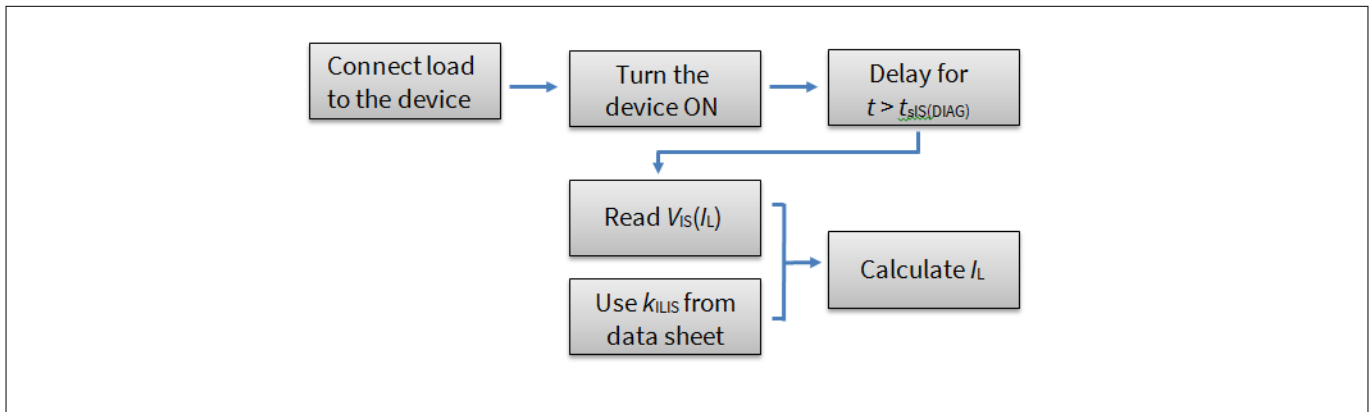
**Equation 16**

Where  $k_{ILIS,CAL}$  is calculated as the ratio between the fixed load current  $I_L$  and the measured  $I_{IS}$ .

**3.1 “Default” behavior**

This procedure is the least expensive in terms of time and manufacturing effort, but it is the least accurate. This option does not require that any value should be stored, instead it needs the knowledge of values as  $k_{ILIS}$ , specified in the data sheet.

The term “device”, used in the flowchart in [Figure 17](#), refers to the high-side switch tested.



**Figure 17 Manufacturing procedure for the default behavior**

After a load is connected, the device can be switched ON, but a time delay of  $t_{sIS(DIAG)}$  is needed before the voltage  $V_{IS}$  is read by the microcontroller. This time delay is defined as:

$$t_{sIS(DIAG)} \leq 3 \cdot (t_{ON\_MAX} + t_{sIS(ON)\_MAX})$$

Where  $t_{ON\_MAX}$  is the maximum switch ON time, and  $t_{sIS(ON)\_MAX}$  is the maximum sense settling time with Nominal Load Current Stable.

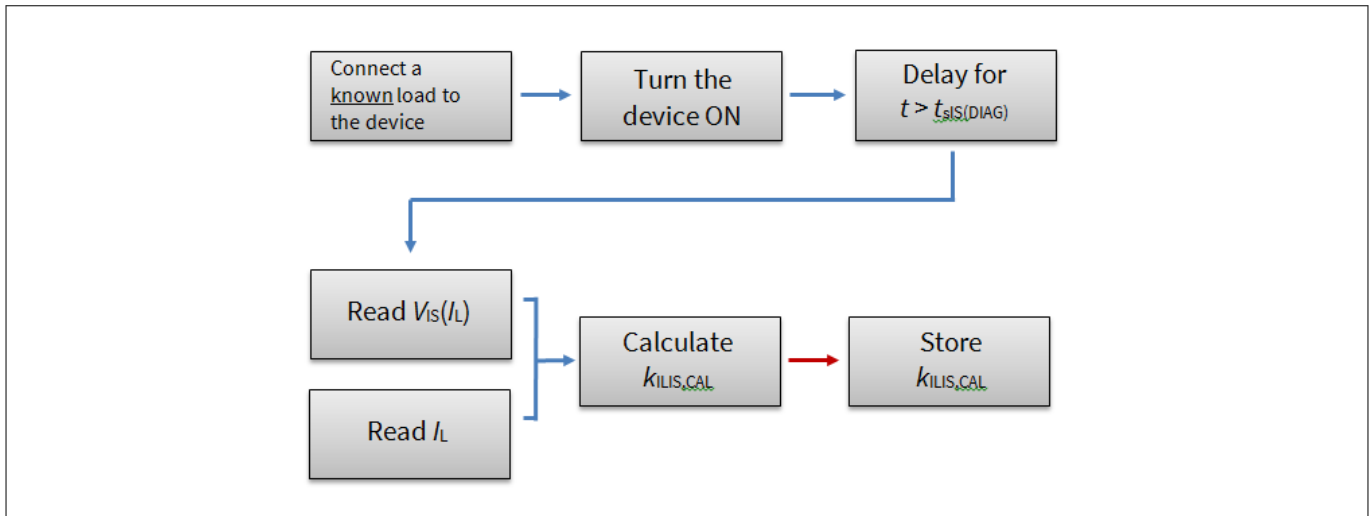
Using the  $k_{ILIS}$  value from the data sheet, after  $V_{IS}$  reading, the load current  $I_L$  can be calculate using Equation 15.

Comparing then the obtained  $I_L$  value with threshold limits, load condition can be determine (e.g. Nominal, Over Load, Short-circuit to  $V_s$ , etc.).

**3.2 1-Point calibration**

1-Point calibration practical test is usually carried out at temperature of 25°C. It is based on the measurement of  $V_{IS}(I_L)$ , that is the voltage across the sense resistor  $R_{SENSE}$ , when a load current  $I_L$  is previously chosen. [Figure 18](#) shows the procedure for 1-Point calibration.

**4 Conclusion**



**Figure 18 Manufacturing procedure for 1-Point calibration**

After a known load is connected, the device can be switched ON, but a time delay of  $t_{sIS(DIAG)}$  is needed to be wait, before the voltage  $V_{IS}$  is read by the microcontroller. The parameter  $k_{ILIS,CAL}$  can be calculated and store in NVM (non-volatile memory).

The next measurements are going to use this  $k_{ILIS,CAL}$  value in order to calculate  $I_L$ : the flowchart in [Figure 17](#) can be used, using  $k_{ILIS,CAL}$  instead of  $k_{ILIS,TYP}$ .

The obtained  $I_L$  value can be compared with the nominal current or with threshold limits, in order to determine load conditions.

*Note: Note: The accuracy of the measurement depends on several components of the system, e.g.: sense resistor, AD-converter of microcontroller, known load.*

**4 Conclusion**

The New Smart High-Side Power Switch family provides protection functions and diagnosis.

For diagnosis purpose, it provides a sense current signal ( $I_{IS}$ ) at pin IS in order to detect:

- Proportional load current sense;
- Open load in ON and OFF state;
- Short circuit to ground and battery.

A current proportional to the load current (ratio  $k_{ILIS} = I_L/I_{IS}$ ) is provided at pin  $I_S$  with a “default” accuracy. The sense current accuracy tolerance/spread widens at lower load currents.

If the default accuracy does not fulfill the application requirements, 1-Point calibration can performed. 1-Point calibration is the easiest calibration technique in terms of manufacturing effort.

With the New High Current PROFET™, Infineon Technologies offers protected high side switch with very good current measurement accuracy.

**Revision history**

Document version	Date of release	Description of changes
1.1	2018-02-14	Editorial changes, typos corrected.
1.0	2018-01-22	Initial release.

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