ILD2111 - Digital DC/DC Buck Controller IC

.dp digital power 2.0

ILD2111 Design Guide

Application Note

About this document

Scope and purpose

This document is a step-by-step guide to designing high-performance digital DC/DC buck LED controllers using the ILD2111 chip. The design guide clarifies details regarding hardware dimensioning of components around the ILD2111 as well as describing the flexible and powerful options offered by the device parameterization.

Intended audience

This document is intended for anyone who needs to design-in the ILD2111.

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1 Introduction

The ILD2111 is a high-performance digital microcontroller-based DC/DC buck LED controller IC designed as a constant current source. High-precision hysteretic output current regulation is achieved by means of the digital control loops. The driving current can be adjusted with a simple external resistor. The controller typically uses a floating buck topology operating in a Continuous Conduction Mode (CCM). In order to reduce switching losses and increase efficiency, as well as to control the switching frequency over a wide variety of external component's values, input voltage and load variations, a frequency ripple control is introduced. Both internal and external temperature measurements are performed and accompanied by an intelligent temperature protection algorithm with two threshold values. The controller utilizes a variety of protection features, including overpower, open and short load conditions. The ILD2111 is a dimmable device controllable by external PWM signal. An ASSP digital microcontroller-based engine is highly configurable thanks to a comprehensive parameter set providing fine-tuning of operation and protection features. The device can be parameterized through a single pin UART interface at the REF/SC pin by using the .dp vision tool.
The ILD2111 exhibits a high efficiency level over wide input and output ranges as well as high accuracy of ± 5% over the output current range and specified temperature.

The pin configuration of ILD2111 is shown in **Figure 1** and **Table 1**.

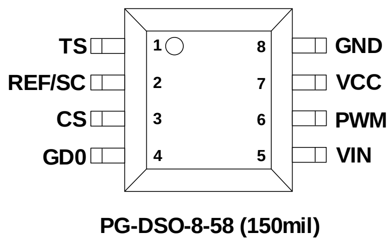


Figure 1 Pin Configuration

Table 1 Pin Definitions and Functions

Symbol	Pin	Type	Function
TS	1	I	**Temperature Sensor** The pin TS is used for external temperature measurement using PTC or an appropriate passive temperature sensor.
REF/SC	2	IO	**Reference/Serial Communication** The pin REF/SC is multiplexed. It is used during startup for reference current sensing via an external RC circuit. Afterwards it serves as a UART serial communication interface.
CS	3	I	**Current Sense** Current measurement on an external shunt resistor.
GD0	4	O	**Gate Driver Output 0** Output for directly driving a Power MOSFET.
VIN	5	I	**Voltage Input** Voltage input measurement. Requires an external series resistor for voltage sensing and current limitation.
PWM	6	I	**PWM Dimming Signal** Input for PWM-based dimming signal.
VCC	7	I	**Positive Voltage Supply** IC power supply
GND	8	O	**Power and Signal Ground**

Figure 2 shows a typical application for ILD2111.

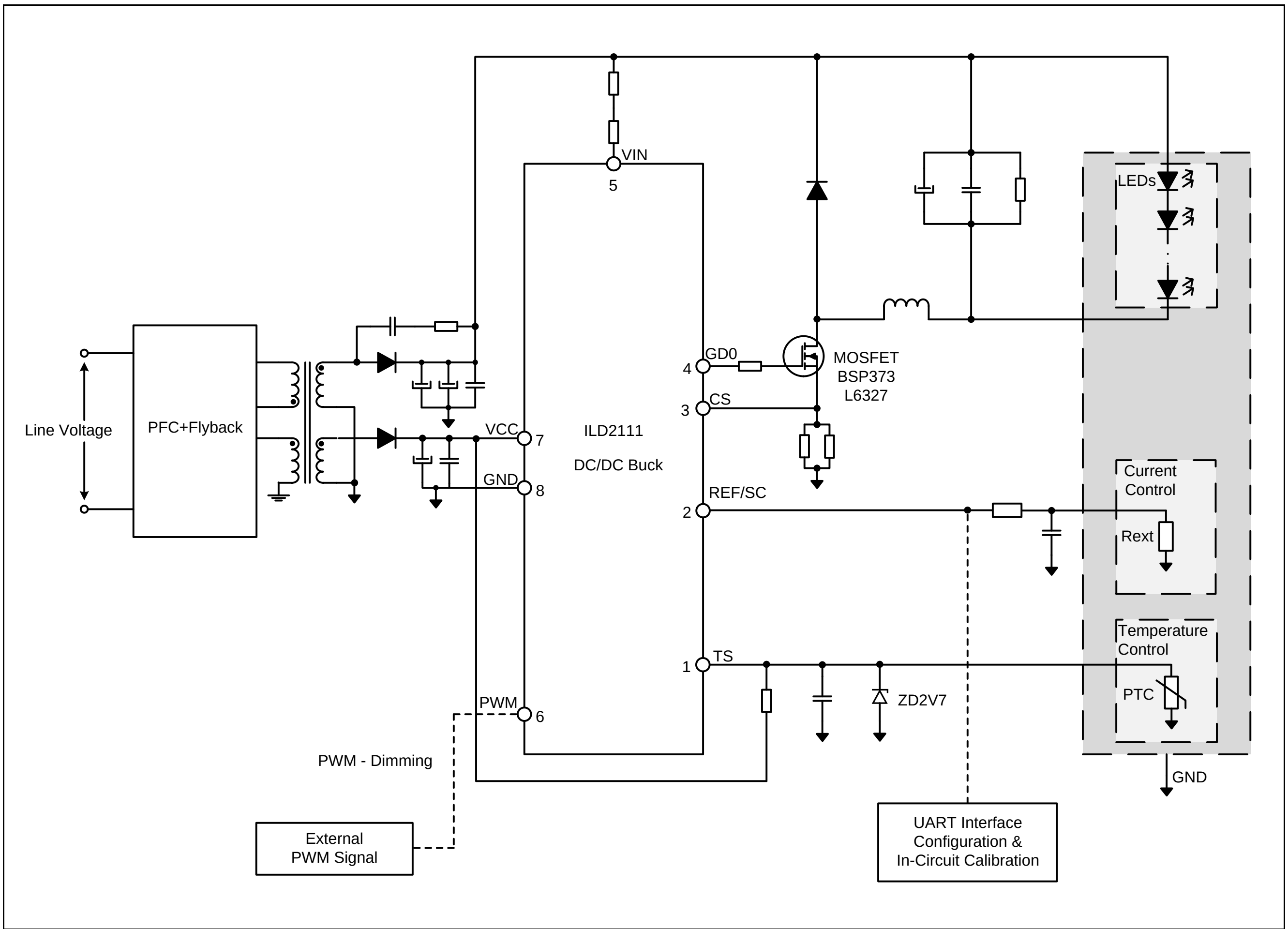


Figure 2 Typical Application

The typical application shown in Figure 2[1] is a two-stage professional lighting system.

The ILD2111 DC/DC buck LED controller IC is used as a second-stage constant output current source and is connected in a floating buck topology. The first stage should provide constant voltage at the input of the ILD2111 and a constant V_{cc} voltage. The primary side is connected to the 1st stage flyback solution with PFC (e.g. TDA4863-2G) for power classes up to 50 W or dual stage PFC + LLC solutions (e.g. ICL5101) for power classes above 50 W.

Figure 3 shows a typical current waveform for the ILD2111 DC/DC buck LED controller operating in continuous conducting mode (CCM).

[1] It is recommended to add some high value resistance (e.g. 10 kΩ) between the gate and the ground (source) of the MOSFET, in order to bias the MOSFET in switched-off state in case the control signal (from GD0) is not connected or is malfunctioning.

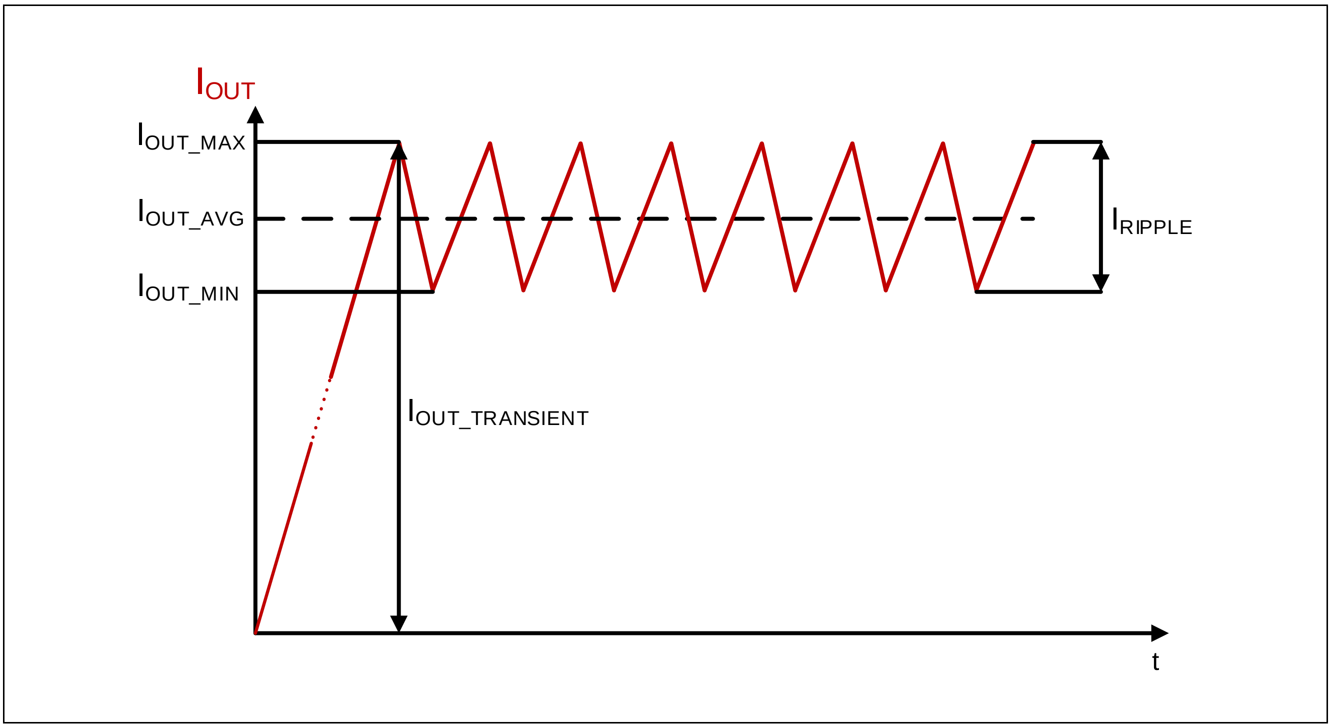


Figure 3 Typical Current Waveform

2 Hardware Recommendations

2.1 System Requirements

The first step in designing a DC/DC buck with the ILD2111 is to determine the system requirements. Parameters that should be defined at the start are shown in **Table 2**. All the values should be defined to fit the desired application needs. Typical values for 20 W SELV converters are given in **Table 2**. These values are used for designing the ILD2111 evaluation board (see [2] for more information).

Table 2 Main System Requirements

Symbol	Typical Value	Unit	Comment
V_{IN_MAX}	75	V	Maximum possible voltage at input; hardware requirement
$V_{IN\_MAX\_MEAS}$	66	V	Maximum possible measured input voltage
$V_{IN\_MAX\_OPER}$	65	V	Maximum operating input voltage
$V_{IN\_MIN\_OPER}$	40	V	Minimum operating input voltage
$I_{OUT\_AVG\_MIN}$	250	mA	Minimum average output current
$I_{OUT\_AVG\_MAX}$	800	mA	Maximum average output current
ΔI_L	30	%	Maximum inductor current ripple as a percentage of output current
P_{OUT_MAX}	23	W	Maximum output power
V_{cc}	15	V	IC supply voltage
T_{ETP_MAX}	110	˚C	Maximum measured external temperature of light element
f_{SW_MIN}	30	kHz	Minimum switching frequency
f_{SW_MAX}	250	kHz	Maximum switching frequency
f_{EPWM_MIN}	0.1	kHz	Minimum input external PWM signal frequency
f_{EPWM_MAX}	1	kHz	Maximum input external PWM signal frequency

2.2 Mandatory Functionality

2.2.1 Selecting the Input Voltage Measurement Resistor

The input voltage is sensed at the VIN pin. The basic input voltage measurement circuit is shown in **Figure 4**.

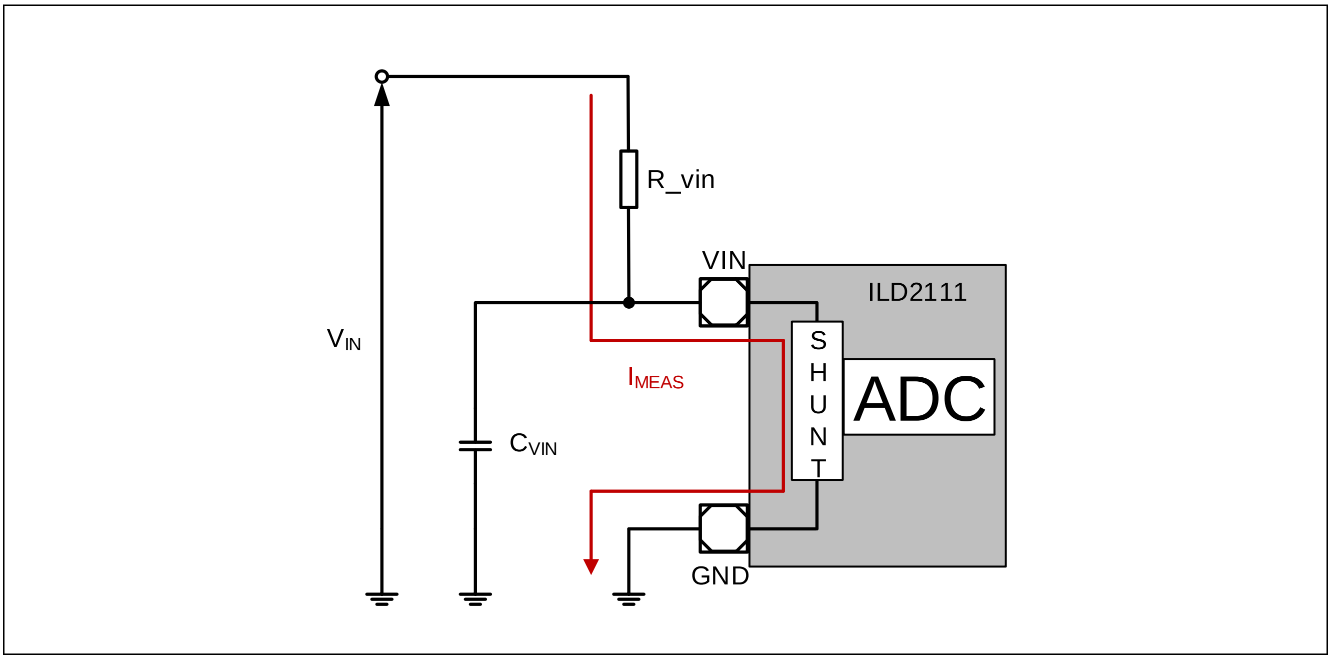


Figure 4 Input Voltage Measurement Schematic

The input voltage measurement external resistor R_vin is calculated using the following equation:

$$R\_vin = \frac{V_{IN\_MAX\_MEAS}}{0.75 \cdot I_{MEAS}} - R_{SHUNT} \quad (1)$$

The values of I_{MEAS} and R_{SHUNT} are determined by selecting the input voltage measurement range. There are two implemented measurement ranges related to the VIN pin. They are called current ranges because they use selection of an internal shunt resistor, where an ADC measures the shunt resistor current indirectly by measuring a voltage drop across the shunt resistor.

Nominal shunt values for an appropriate current range are as follows:

1. Current range 00_b – I_{MEAS} = 209 µA, R_{SHUNT} = 6690 Ω.
2. Current range 01_b – I_{MEAS} = 1.6 mA, R_{SHUNT} = 1490 Ω.

The current range is defined by the parameter Vin_current_range (see **Table 14**).

The input voltage range will influence selection of the current measurement range and the external resistor R_vin. Lower values of the shunt resistors (current range 01_b) are preferable due to higher noise immunity and for lower V_{IN} voltages, but designers also have to take into account power losses in this circuitry, especially for high V_{IN} voltages when the current range 00_b is preferred.

According to **Table 2**, for $V_{IN\_MAX\_MEAS}$ = 66 V, with a selected current range 01_b where I_{MEAS} = 1.6 mA, R_vin is therefore calculated as follows:

$$R\_vin = \frac{V_{IN\_MAX\_MEAS}}{0.75 \cdot I_{MEAS}} - R_{SHUNT} = 53.5\ k\Omega \qquad (2)$$

The recommendation is to use two identical resistors instead of one for R_vin due to the power dissipation reduction for each resistor. If the calculated resistor is not available, use the one with the higher value. For the calculated case, two 27 kΩ resistors should be used. Each of two resistors should be able to withstand power dissipation. In this case, each of them (designated as R_vin_1(2)) will dissipate at most:

$$P_{DISSIPATION} = R\_vin\_1(2) \cdot I_{MEAS}^2 = 69\ mW \qquad (3)$$

For example, it is also possible to use the other current range (00_b). In this case, the device would be less immune to noise, but it would have lower power dissipation in the R_vin resistor. The new value of R_vin should be calculated by using equation **(1)** and appropriate I_{MEAS} and R_{SHUNT} values for the current range 00_b. The new rounded value of R_vin would be 420 kΩ and splitting it up into two 210 kΩ resistors the maximal power dissipation in each resistor would be 9 mW.

It is mandatory to use the C_{VIN} capacitor to filter conductive and electromagnetic interference caused by the converter switching operation. The recommended value for C_{VIN} is at least 100 nF.

2.2.2 Selecting an Inductor

Due to the broad range of possible setups (external components as well as internal parameters), the calculation of an inductor is not a straightforward task. A maximum switching frequency is used as the main criterion for inductor selection. All other values are chosen such that they provide the worst case for the switching frequency (e.g. maximum input voltage, duty factor of 0.5, etc.).

The following equation is used for calculating the inductor value:

$$L = \frac{(V_{IN} - V_{OUT}) \cdot D}{I_{RIPPLE} \cdot f_{SW}} = V_{IN} \cdot \frac{(1-D) \cdot D}{I_{RIPPLE} \cdot f_{SW}} \qquad (4)$$

In order to provide the worst case for the maximum selected frequency, the values used for calculating the inductor are as follows:

Maximum input voltage (see **Table 2**) – $V_{IN\_MAX\_OPER}$ = 65 V

Maximum switching frequency (see **Table 2**) – f_{SW} = 250 kHz

Duty cycle – D = 50%.

The inductor current ripple $\Delta I_{LRIPPLE}$, for a minimum input current $I_{OUT\_AVG\_MIN}$ is calculated as:

$$I_{RIPPLE} = I_{OUT\_AVG\_MIN} \cdot \frac{\Delta I_L}{100} = 75\ mA \qquad (5)$$

The minimum inductor value is then calculated as follows:

$$L_{MIN} = 870\ \mu H \qquad (6)$$

The inductor peak current is calculated using the following equation:

$$I_{Lpeak} = I_{OUT\_AVG\_MAX} + \frac{1}{2} \cdot \frac{I_{OUT\_AVG\_MAX} \cdot \Delta I_L}{100} = 920\, mA \tag{7}$$

The inductor must be selected so that it can sustain the calculated peak current without saturation. It is recommended to select an inductor with a 30% higher saturation current than the calculated peak current. In this case, an inductor with a saturation current higher than 1.2 A should be selected.

2.2.3 Selecting the Freewheeling Diode

When selecting a freewheeling diode for DC/DC buck converters, four parameters should be carefully considered: forward voltage drop (V_F), reverse (breakdown) voltage (V_R), average forward current ($I_{F(AV)}$) and maximum power dissipation (P_D).

Schottky diodes are preferred and are the recommended choice. They are characterized by low forward voltage drops (V_F), which reduce the power dissipation considerably. Additionally, faster responses compared to standard silicon diodes reduce diode switching losses.

The average forward current ($I_{F(AV)}$) required is calculated using the following equation:

$$I_{F(AV)} = I_{OUT\_AVG\_MAX} \cdot (1 - D) \tag{8}$$

According to **Table 2**, for a worst case scenario ($I_{OUT\_AVG\_MAX}$ = 800 mA and D = 0.01), the average forward current required is:

$$I_{F(AV)} = 800\, mA \tag{9}$$

A diode with an average forward current of a minimum of 1 A should be selected.

The maximum diode reverse voltage (V_R) should be higher than the maximum input voltage (V_{IN_MAX}, see **Table 2**). For the case defined in **Table 2**, a Schottky diode with a maximum reverse voltage of 100 V or higher should be selected.

The diode power dissipation while conducting is calculated using the following equation:

$$P_D = I_F \cdot V_F \tag{10}$$

Accordingly, the maximum power dissipation while conducting is determined for the maximum possible forward current (I_{F_MAX}) and forward voltage drop across the diode for that particular current, which should be found in the datasheet of the selected diode.

2.2.4 Selecting the MOSFET

When selecting a MOSFET for DC/DC buck converters, several important parameters should be considered:

I_D – Maximum continuous drain current

BV_{DS} – Breakdown drain source voltage

$R_{DS(on)}$ – Drain source ON-state resistance

Q_G – Total gate charge and

V_{GS} – Maximum gate source voltage.

The maximum continuous drain current (I_D) should be higher than the maximum output current of the DC/DC buck converter. The maximum output current is calculated using the following equation:

$$I_{OUT\_MAX} = I_{OUT\_AVG\_MAX} + \frac{I_{RIPPLE}}{2} = 920\ mA \tag{11}$$

With $I_{OUT\_AVG\_MAX}$ as the maximum possible average output current defined in **Table 2**, I_{RIPPLE} is defined as:

$$I_{RIPPLE} = I_{OUT\_AVG\_MAX} \cdot \frac{\Delta I_L}{100} = 240\ mA \tag{12}$$

The breakdown voltage BV_{DS} has to be higher than the expected peak voltage on MOSFET. In floating output buck topologies, the expected peak voltage is equal to the input voltage V_{IN} (see **Table 2**). Therefore, the breakdown drain source voltage BV_{DS} should be higher than the maximum input voltage (V_{IN_MAX}, defined in **Table 2**).

$R_{DS(on)}$ and Q_G should be as low as possible to reduce conduction and switching losses in the MOSFET. It is important to notice that $R_{DS(on)}$ depends on V_{GS} (higher V_{GS}, lower $R_{DS(on)}$).

The maximum gate source voltage should be higher than the maximum output voltage at the GD0 pin on the ILD2111 chip. The output voltage range at GD0 is defined in the ILD2111 Data Sheet (see **[1]**) and its maximum value is $V_{GD0\_OUT\_MAX}$ = 15 V.

For a system with requirements presented as an example in **Table 2**, the MOSFET BSP716N from Infineon could be selected. Its key parameters are given in the following table **(Table 3)**.

Table 3 Key BSP716N MOSFET Parameters

Parameter	Value	Unit	Description
I_{D_MAX}	2.3	A	Maximum continuous drain current
BV_{DS_MIN}	75	V	Minimum drain source breakdown voltage
$R_{DS(on)\_MAX}$	180	mΩ	Maximum drain source on-state resistance
Q_{G_MAX}	13.1	nC	Maximum total gate charge
V_{GS}	±20	V	Gate source voltage range

Infineon Technologies AG has a broad product portfolio of MOSFET’s. Once the technical MOSFET parameters are determined, please contact your Infineon Technologies representative or visit www.infineon.com for support and more information.

2.2.5 Selecting a Current Sense Resistor

A current sense resistor is used for output current measurement. A schematic diagram is shown in **Figure 5**.

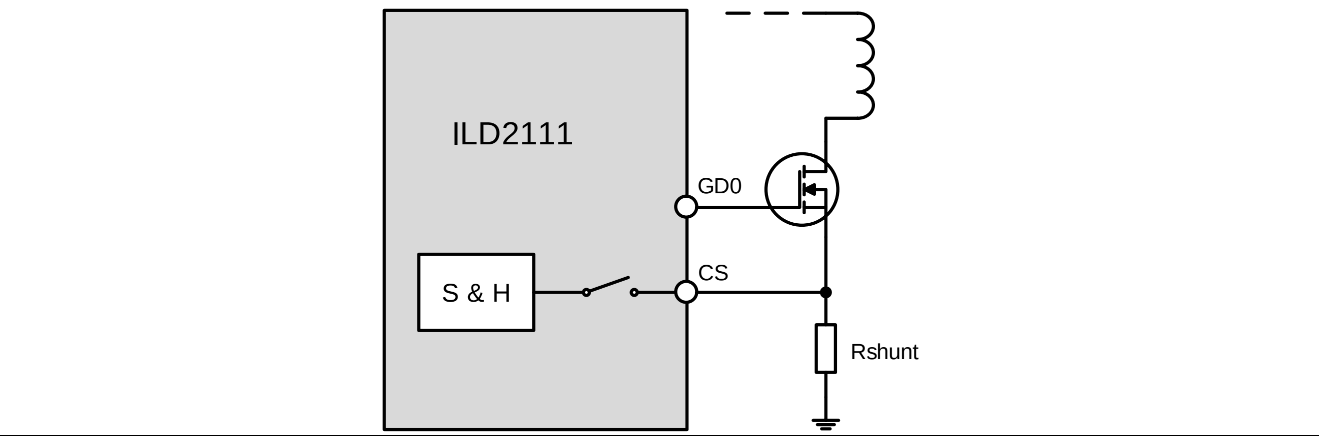


Figure 5 Current Sense Resistor (R_{SHUNT})

To calculate the current sense resistance (R_{SHUNT}) it is necessary to define the maximum voltage level at the current sense pin ($V_{OCP1(RANGE)}$) and the maximum output current (I_{OUT_MAX}):

$$R_{SHUNT} = \frac{V_{OCP1(RANGE)}}{I_{OUT\_MAX}} \quad (13)$$

The maximum voltage level at the current sense pin $V_{OCP1(RANGE)}$ depends on the configuration of the current sense pin, which is accomplished by configuring the parameter Current_sense_OCP1 (see **Table 15**). Two current sense ranges are defined:

1. Current sense range 10_b – RANGE = 0 V – 0.6 V, $V_{OCP1(10)}$ = 0.6 V
2. Current sense range 11_b – RANGE = 0 V – 0.4 V, $V_{OCP1(11)}$ = 0.4 V

The maximum output current is calculated using the following equation:

$$I_{OUT\_MAX} = I_{OUT\_AVG\_MAX} + \frac{I_{RIPPLE}}{2} = 920\ mA \quad (14)$$

With $I_{OUT\_AVG\_MAX}$ as the maximum possible output current from the range defined in **Table 2**, I_{RIPPLE} is defined as follows:

$$I_{RIPPLE} = I_{OUT\_AVG\_MAX} \cdot \frac{\Delta I_L}{100} = 240\ mA \quad (15)$$

If we select a current sense range where $V_{OCP1(10)}$ = 0.6 V, R_{SHUNT} is calculated as follows:

$$R_{SHUNT} = \frac{V_{OCP1(10)}}{I_{OUT\_MAX}} = 0.65\ \Omega \quad (16)$$

It is possible to use two or more resistors connected in parallel. For these settings, two 1.2 Ω resistors in parallel should be used. It is recommended, if possible, to select a current sense range which will result in a higher value of the shunt resistor. This is important due to higher noise immunity of current readings. On the other hand, for higher output currents, this will increase power dissipation at the shunt resistor.

2.2.6 Reference Current Set

The reference current value is obtained by measurement, using the value of the external resistor R_iset connected to the pin 'REF/SC' together with the capacitor C_ref via the discharge time of the capacitor (see **Figure 6**[1]). Depending on the resistance of the resistor R_iset, the appropriate reference current (stored in the predefined table) is used as a reference for the output current.

It is highly recommended to use a ceramic capacitor C_filt to filter noise caused by the converter switching operation. It is mainly used to suppress noise for ADC measurement as well as UART communication. The typical value for C_filt is 100 pF. However, UART communication (see **Figure 6**) problems at higher output currents and higher temperatures may occur. If this is the case, it is recommended to increase the value of the capacitor C_filt (for example, to the value of 200 pF). On the other hand, it should be borne in mind that if the C_filt capacitor value is increased, it will influence the reference current setting procedure. In order to avoid this effect and to obtain proper behavior of the reference current setting procedure, the parameter setting needs to be adapted.

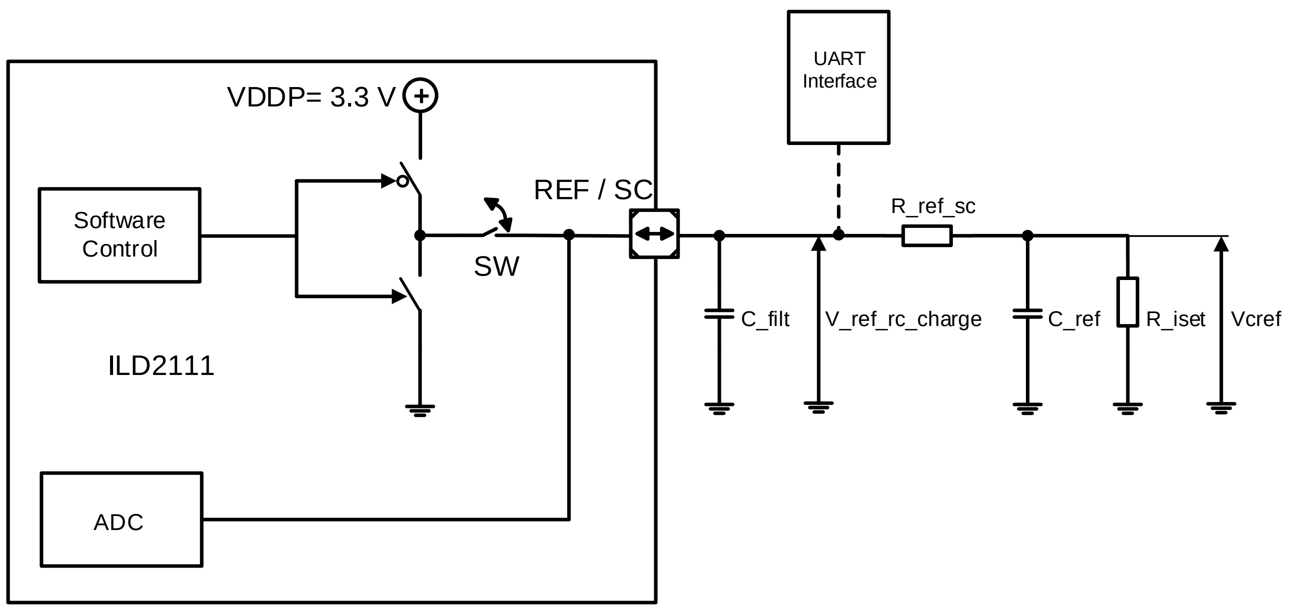


Figure 6 Charging and Discharging of the C_ref Capacitance Depending on the Switch State

When the internal switch SW is turned on for a short period of time, as defined by the parameter RC_CAP_CHARGE_TIME (see [1]), the C_ref is fully charged to Vcref, where this voltage depends on the internal VDDP voltage and voltage divider R_ref_sc – R_iset.

R_ref_sc is used for decoupling the reference current measurement circuitry and serial UART communication. Care must be taken to ensure that the ratio of R_iset to R_ref_sc is sufficient to have a low impact on Vcref. Otherwise, it has to be included in the time thresholds calculation. When the switch is turned off, the C_ref discharges through the external resistor R_iset. The discharging time of the capacitor C_ref depends on the value of the external resistor. During the discharging interval, the ADC monitors the

[1] Shortening REF/SC pin to ground, V_{cc} or any other pin as well as disconnection of this pin from the external circuitry will (may) disable communication and heavily influence reference current selection.

pin voltage while the internal timer is measuring the discharging time. When the capacitor voltage drops below the programmed threshold level V_adc_th (defined by the parameter RC_DISCHARGE_ADC_TH, see [1]), the internal timer value is latched and is used to determine the reference current from the predefined table.

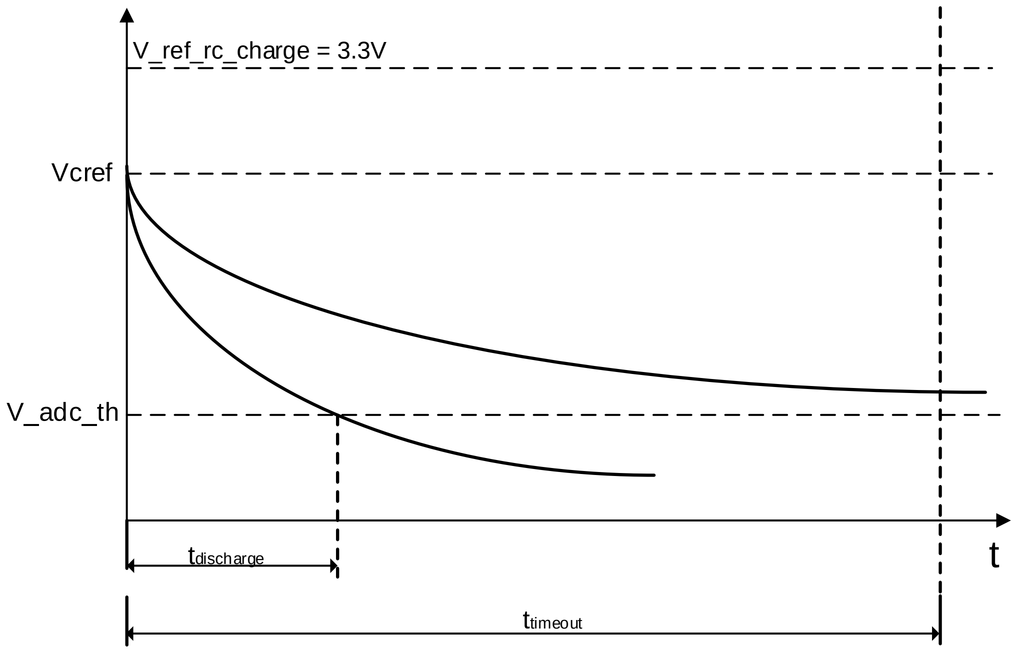


Figure 7 C_ref Discharging Interval Determined by the Referent Resistor Value

The charging voltage Vcref is calculated as follows:

$$Vcref = \frac{R\_iset}{R\_iset + R\_ref\_sc} \cdot V\_ref\_rc\_charge \tag{17}$$

The equation for V_adc_th is:

$$V\_adc\_th = Vcref \cdot e^{-\frac{t_{discharge}}{R\_iset \cdot C\_ref}} \tag{18}$$

Therefore:

$$t_{discharge} = R\_iset \cdot C\_ref \cdot ln\frac{Vcref}{V\_adc\_th} \tag{19}$$

If a lower voltage threshold is not reached after the predefined timeout period $t_{timeout}$ (defined by the parameter RC_MEASUREMENT_TIMEOUT, see [1]), the reference current determination process ends and the last value from the current table is taken as the reference (i.e. 250 mA). Component values and their tolerances must provide unique thresholds in order to enable appropriate detection (see **Figure 8**).

More accurate equations will be obtained if typical component tolerance values are included[1].

The following are assumed:

1. Maximum reference resistance: R_iset_max (n) = R_iset (n) + 1%R_iset (n)
2. Minimum reference resistance: R_iset_min (n) = R_iset (n) - 1%R_iset (n)
3. Maximum reference capacitance: C_ref_max = C_ref + 2%C_ref
4. Minimum reference capacitance: C_ref_min = C_ref - 2%C_ref

Therefore, the minimum and maximum discharging times are given by:

$$T\_RC\_(n)\_min = R\_iset\_min(n) \cdot C\_ref\_min \cdot ln\frac{Vcref\_min(n)}{V\_adc\_th} \quad (20)$$

and

$$T\_RC\_(n)\_max = R\_iset\_max(n) \cdot C\_ref\_max \cdot ln\frac{Vcref\_max(n)}{V\_adc\_th} \quad (21)$$

where n is the ordinal number of the resistor, and Vcref_min and Vcref_max are the minimum and maximum voltage values of charged capacitance respectively:

$$Vcref\_min = \frac{R\_iset\_min}{R\_iset\_min + R\_ref\_sc} \cdot V\_ref\_rc\_charge \quad (22)$$

and

$$Vcref\_max = \frac{R\_iset\_max}{R\_iset\_max + R\_ref\_sc} \cdot V\_ref\_rc\_charge \quad (23)$$

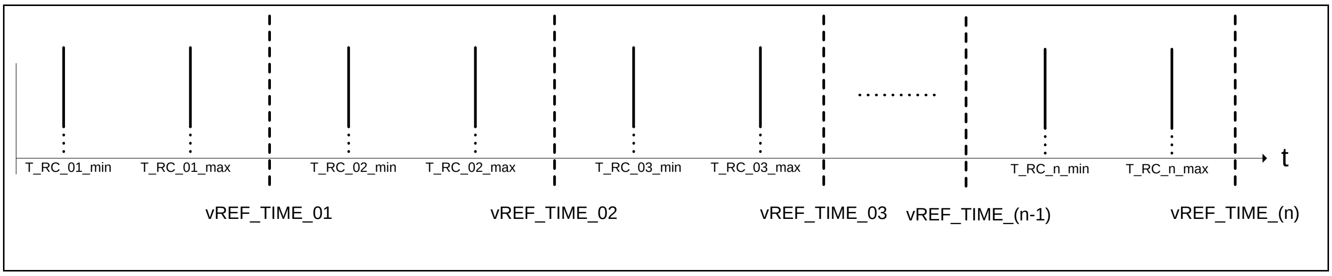


Figure 8 Time Constant vREF_TIME_n Threshold Calculations

[1] The reference resistance R_ref_sc is used to decouple the UART interface and current set resistance R_iset due to multiplexed functionality of the REF/SC pin. In this case, the tolerance of the R_ref_sc resistance is not taken into account (its tolerance is ignored).

As shown above, the discharging time threshold is obtained as:

$$vREF\_TIME\_n = \frac{T\_RC\_n\_max + T\_RC\_(n+1)\_min}{2} \quad (24)$$

The last discharge time threshold is given by:

$$vREF\_TIME\_n = \frac{3 \cdot T\_RC\_n\_max - T\_RC\_n\_min}{2} \quad (25)$$

The measured discharge time – $t_{discharge}$ is compared with the calculated thresholds, ranging from the smallest, and – based on that – it will be determined which reference resistor is detected. For example, if the measured discharge time is greater than vREF_TIME_01, vREF_TIME_02, vREF_TIME_03 and smaller than vREF_TIME_04, the 4th reference resistor from the list will be chosen (see **Table 4**).

The components (R_iset, C_ref) must be carefully selected to avoid overlapping time intervals, as otherwise an appropriate threshold could not be calculated to provide unique detection. For example, if the resistance values are too close together (including tolerances), discharge time intervals will overlap, and calculated thresholds will be set inside the overlapped area, but it cannot be guaranteed that the same current will be selected in different production series (see **Figure 9**).

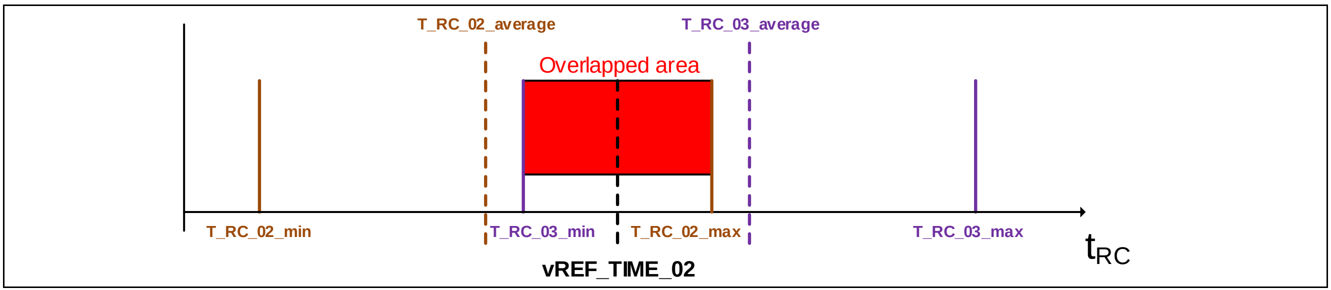


Figure 9 Overlapping Discharge Time Intervals

For typical applications (see **Table 2**) which cover an output current ranging from 250 mA to 800 mA (with 50 mA steps), reference resistor values for the specific current values (assuming C_ref = 10 nF and threshold voltage value of V_adc_th = 0.6075 V) are given in **Table 4**. Resistors that are used belong to the series E96 with a variation (tolerance) of 1%. The reference pin serial resistor is R_ref_sc = 3.3 kΩ. The recommended capacitor C_ref tolerance should be ≤ 2%[1]. The recommended C_Ref capacitor type is zero drift CoG (NPO).

The output currents can be configured up to 3000 mA, however the ratio between the maximum and minimum currents has to be equal to or less than 4 (I_REF_max / I_REF_min ≤ 4). For example, if the minimum reference current is 250 mA, the maximum reference current from the range should not exceed 1000 mA.

Only tolerances of external components were taken into account for the calculations given in this document. For full analysis, internal VDDP voltage and ADC tolerances as well as REF / SC pin leakage currents should be also taken into account. For more information on these values, please refer to the section "Electrical Characteristics" in the ILD2111 data sheet document (see **[1]**).

[1] For different component tolerances, different discharge times will be obtained by equations. Resistor values in **Table 4** are taken as examples. For different applications (different output currents and output power), different values of the external resistors can be taken.

Table 4 Reference Resistor Values – Example

Ordinal Number	I_REF_n [mA]	R_iset [kΩ]	vREF_TIME_n [µs]
1	800	2.15	80
2	750	10.00	180
3	700	15.00	280
4	650	21.50	430
5	600	33.20	620
6	550	43.20	800
7	500	53.60	970
8	450	63.40	1130
9	400	71.50	1290
10	350	82.50	1460
11	300	90.90	1610
12	250	100.00	1890

Reference current determination happens only during the chip's initial startup and after the load is disconnected – an open output is detected. During normal buck operation, the REF/SC pin is used as a communication port.

Although, typically, the application uses less than 16 reference currents, all parameters (REF_CURRENT_01 – REF_CURRENT_16, see [1]) must be filled (arranged) in 4 groups, using copies with same reference current. It is assumed that approximately the same currents have approximately the same parameters. Thereafter, all reference currents and appropriate reference times (REF_TIME_01 – REF_TIME_16) need to be allocated to the groups by the user. The currents from the same group will have the same minimum and maximum switching frequency limits and minimum and maximum current ripple limits as well. In the event that only one reference current parameter is set to zero, the parameter configuration will be invalid and the converter will not start.

One possible arrangement is given below in **Table 5**.

Table 5 Example of Reference Current Arrangement

Group Number	Reference Current
1.	800 mA, 750 mA, 700 mA
2.	650 mA, 600 mA, 550 mA
3.	500 mA, 450 mA, 400 mA
4.	350 mA, 300 mA, 250 mA

2.3 Optional Functionality

2.3.1 Selecting the Input Capacitor

Input capacitors are used to filter input voltage noise and maintain input voltage stability during output surges in peak current. It is recommended to use capacitors with low equivalent series resistance (ESR) to reduce losses.

Two capacitors should be used at the input of the converter: a ceramic capacitor to filter noise and reduce EMI on the board and a bulk capacitor to maintain input voltage stability when output surges past peak current.

To determine the ceramic capacitor value, use the following equation:

$$C_C = \frac{I_{OUT} \cdot D \cdot (1-D)}{f_{SW} \cdot \Delta V_{pp}} \quad (26)$$

In this equation there is a dependency between the duty (D) and switching frequency (f_{SW}), hence the worst case cannot be easily determined. If equation **(4)** is combined with **(26)**, an equation with independent parameters is obtained:

$$C_C = \frac{I_{OUT} \cdot L \cdot I_{RIPPLE}}{V_{IN} \cdot \Delta V_{pp}} \quad (27)$$

Using the previous equation, the minimum required ceramic capacitance (C_{CMIN}) is determined.

ΔV_{pp} represents the maximum peak–to-peak voltage allowed. Let us assume its value to be 100 mV. The average output current should be at the maximum value $I_{OUT\_AVG\_MAX}$ = 800 mA (see **Table 2**). I_{RIPPLE} is assumed to be 30% of the maximum current. With this input value, the minimum required ceramic capacitance is 25.7 μF.

For example, one capacitor with 22 μF, nearest to the standard capacitance, and a voltage rating of 100 V could be used, or several capacitors connected in parallel, each with a voltage rating of 100 V (for example, two capacitors with a standard capacitance of 10 μF). The recommendation is to use MLCC (Multi-Layered Ceramic Capacitors) with an X7R- or X5R-type dielectric. This capacitor should be placed as close as possible to the ILD2111 chip to reduce stray inductance. Since such high capacitance and high voltage ratings of the ceramic capacitors are an expensive solution, a pragmatic engineering approach is to combine a low ESR aluminum electrolytic or tantalum capacitor with a small value ceramic capacitor (100-220 nF). Furthermore, this electrolytic capacitor can also take the role of the bulk capacitor.

The minimum required bulk capacitance value is calculated approximately using the following equation:

$$C_B = \frac{1.21 \cdot I_{OUT\_TRANSIENT}^2 \cdot D^2 \cdot L_{STRAY}}{\Delta V_{pp}^2 \cdot \eta^2} \quad (28)$$

In this equation, ΔV_{pp} represents the maximum peak-to-peak ripple voltage allowed. $I_{OUT\_TRANSIENT}$ is the output transient current, D is the duty cycle and η is the efficiency. L_{STRAY} represents the series inductance due to PCB layout and capacitor leads.

To calculate the minimum required bulk capacitance, the following values were used:

ΔV_{pp} = 100 mV – assumed value

η = 0.95 – assumed value

L_{STRAY} = 100 nH – should be no less than 50 nH

D = 90% - maximum duty cycle

The maximum output transient current is calculated using values from **Table 2** and the following equation:

$$I_{OUT\_TRANSIENT} = I_{OUT\_AVG\_MAX} + \frac{1}{2} \cdot I_{OUT\_AGV\_MAX} \cdot \frac{\Delta I_L}{100} = 920\ mA \quad (29)$$

Therefore, the minimum required bulk capacitance is:

$$C_{BMIN} = 9.2\ \mu F \quad (30)$$

The electrolytic capacitor nearest to the standard capacitance value has 10 μF. A low ESR aluminum electrolytic or tantalum capacitor should be used. Another important parameter for this type of capacitor is the voltage rating. The maximum input voltage V_{IN_MAX} is defined in **Table 2**; the capacitor voltage rating should be higher than V_{IN_MAX}. For the specification given in **Table 2**, the capacitor voltage rating should be 100 V or higher.

2.3.2 Selecting the Output Filter

An output capacitor is used to reduce LED current ripple and also to reduce output voltage ripple. It is advisable to use at least ceramic capacitors as output filters.

First of all, the capacitor impedance is determined and then, based on the minimum switching frequency and capacitor impedance values, the output capacitor value is calculated.

Output capacitor impedance is calculated using the following equation:

$$Z_C = \frac{\Delta I_D}{\Delta I_L - \Delta I_D} \cdot n \cdot r_D \quad (31)$$

Next, the output capacitor value is calculated:

$$C_o = \frac{1}{2 \cdot \pi \cdot f_{SW\_MIN} \cdot Z_c} \quad (32)$$

These symbols were used in previous equations:

C_O – Output capacitor value

ΔI_D – Desired LED current ripple

ΔI_L – Inductor ripple

f_{SW_MIN} – Minimum switching frequency

r_D – Dynamic LED resistance

n – Number of LED diodes connected at the output

Z_C – Capacitor impedance at the specified frequency.

For the system requirements given in **Table 2**, the required output capacitor impedance is:

$$Z_C = \frac{\Delta I_D}{\Delta I_L - \Delta I_D} \cdot n \cdot r_D = \frac{25}{240-25} \cdot 8 \cdot 1 = 0.93\ \Omega \quad (33)$$

It is assumed that 8 LED diodes are connected at the output and that each of them has a dynamic resistance r_D of 1 Ω. The inductor current ripple is 240 mA peak to peak and the desired LED current ripple is ± 5% of the minimum average current ($I_{OUT\_AVG\_MIN}$ = 250 mA, see **Table 2**).

Subsequently, the required minimum output capacitor is calculated as follows:

$$C_{O(MIN)} = \frac{1}{2 \cdot \pi \cdot f_{SW\_MIN} \cdot Z_C} = 5.7\ \mu F \quad (34)$$

The minimum required output capacitor is calculated using the minimum switching frequency defined in **Table 2**.

The output capacitor should be a ceramic type with an ESR that is as low as possible. Is is preferred to use MLCC (Multi-Layered Ceramic Capacitors) with an X7R- or X5R-type dielectric. Because of this fact, the equivalent series resistance of the output capacitor was neglected in the equation for capacitor impedance. It is possible to connect more than one capacitor in parallel, as is shown in **Figure 10**.

Additionally, it is recommended to use a common mode choke as the output filter (beside the output capacitor). It is used to suppress common mode electromagnetic interference (EMI) currents (common mode noise) and to reduce the influence of parasitic capacitance between LED traces and the heat sink. The recommended value for the common mode choke is 2 x 100 µH (L in **Figure 10**).

An example of an output filter schematic is shown in **Figure 10**.

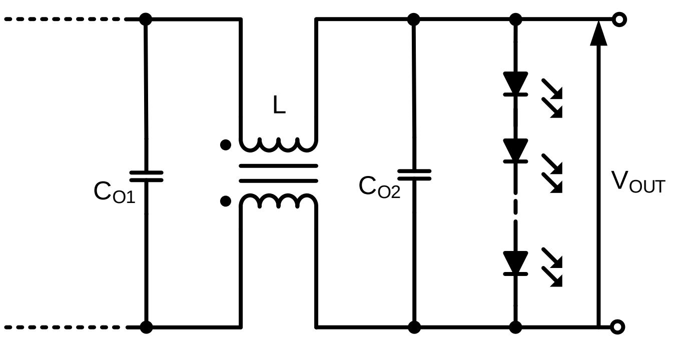


Figure 10 Output Filter Schematics Example

2.3.3 External Temperature Sensor

External temperature-based protection uses a PTC resistor connected to the TS pin and GND. The external temperature is meant to reduce the output current (with PWM modulation) whenever the temperature of the light element increases. The external temperature measurement diagram is shown in **Figure 11**.

The voltage at the TS pin (V_{TS}) is calculated as follows:

$$V_{TS} = Vcc \cdot \frac{R_{PTC}}{R\_TS\_pull\_up + R_{PTC}} \tag{35}$$

The maximum voltage at the TS pin (V_{TS}) for the maximum measured temperature (T_{ETP} = 110 °C) defined in **Table 2** is 1.5 V. For the PTC sensor KTY81-210PTC, the resistance R_{PTC} at temperature T_{ETP} is R_{PTC} = 3607 Ω. The voltage V_{cc} is considered as a reference value (also the expected maximum value). Due to the fact that V_{cc} may vary, the external temperature measurement is compensated by FW based on V_{cc} measurement for the change in V_{cc}. V_{cc} is measured by ADC. Using the previous equation and all provided data, the pull-up resistor R_TS_pull_up is determined with the following equation:

$$R\_TS\_pull\_up = R_{PTC} \cdot \left(\frac{Vcc}{V_{TS}} - 1\right) = 32.5\ k\Omega \tag{36}$$

It is recommended to use a zener diode at the TS pin to prevent voltage from rising higher than 3.3 V and damaging the chip. For this purpose, diodes with zener voltages of 2.7 V or 3.3 V could be used. Additionally, a capacitor C (100 nF) should be used as a noise filter.

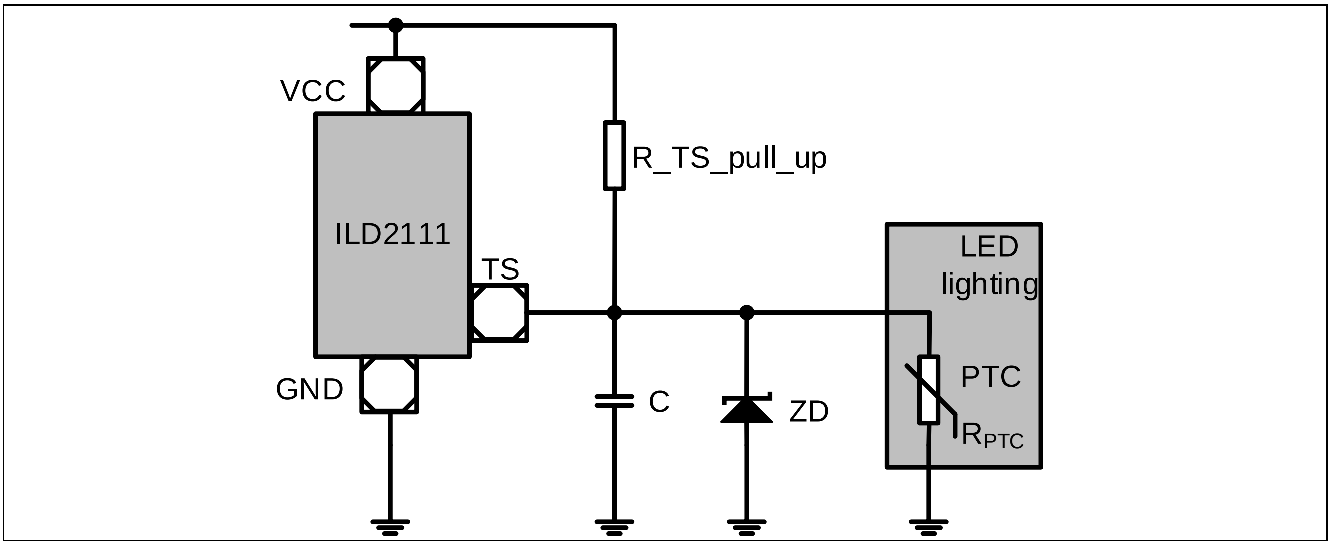


Figure 11 External Temperature Measurement Schematics

There is no dedicated protection against open/short conditions of the external temperature sensor. In the case that an open condition during start-up is detected, the sensor will be disregarded. If the sensor disconnects during operation, the IC will restart due to Over Temperature Error (OTE) and – due to a subsequent start-up – will disregard the sensor.

2.3.4 External PWM Dimming

An external PWM signal is supplied to the ILD2111 at the PWM input pin. As a consequence, the external PWM duty cycle and period can be measured on it and processed further.

It is recommended to supply the external PWM signal through an optocoupler as shown in **Figure 12**.

When using an optocoupler to feed external PWM signals to ILD2111 it is important to select an appropriate optocoupler.

The following are important parameters to be considered:

I_F – Input forward current

V_F – Input forward voltage

V_R – Input reverse voltage

CTR – Current transfer ratio

f_{CO} – Cut-off frequency

$I_{C(MAX)}$ – Maximum collector current

$V_{CE(MAX)}$ – Maximum collector emitter voltage.

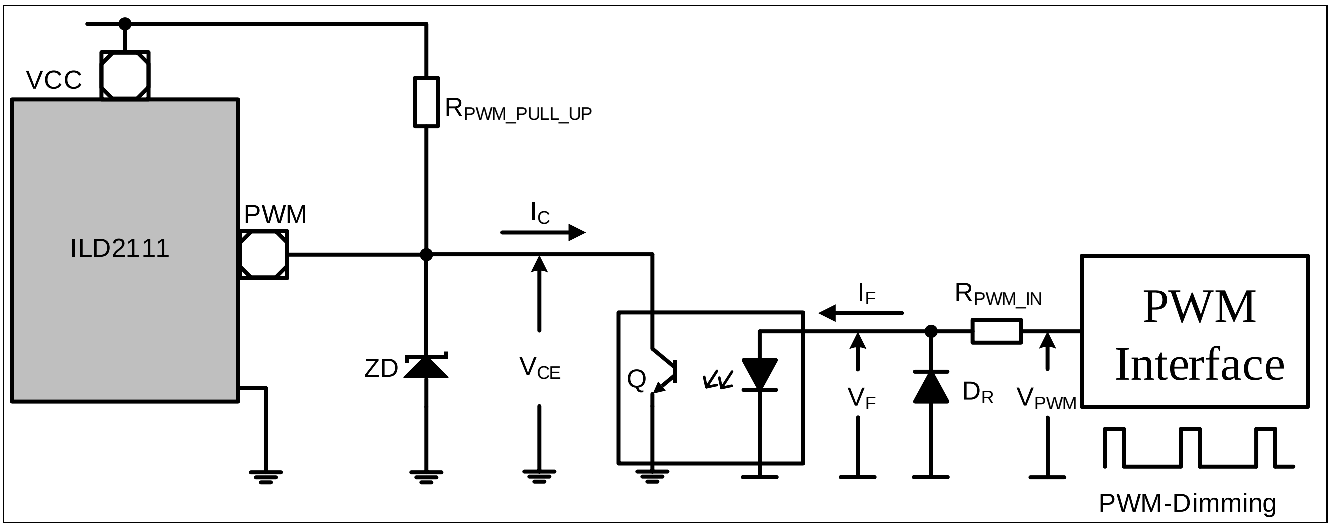


Figure 12 External PWM Dimming Interface Schematic

The input forward current and input forward voltage are parameters important for calculation of the R_{PWM_IN} resistor. The resistor R_{PWM_IN} is calculated using the following equation:

$$R_{PWM\_IN} = \frac{V_{PWM(MAX)} - V_F(I_F)}{I_F} = 880\ \Omega \tag{37}$$

The current transfer ratio CTR represents the ratio of the output current (I_C) to the input current (I_F); it is usually expressed as a percentage. It is necessary to take into account that CTR is highly dependent on the forward current (I_F) and ambient temperature. Therefore, the input forward current should be selected such that the current transfer ratio CTR is the highest. This is usually the case for an input forward current of 10 mA; the input forward voltage on that current is 1.2 V for gallium arsenide diodes. The minimum value of the R_{IN} resistor is calculated using the maximum input forward current $I_{F(MAX)}$ and appropriate forward voltage for the particular current, which can be determined from the corresponding V_F (I_F) graph available in the datasheet of the selected optocoupler.

Sometimes there is a possibility to have the input PWM voltage (V_{PWM}) reversed (due to connection of the wrong cables). If the maximum input reverse voltage ($V_{R(MAX)}$) of the LED is low, there is a risk of damaging the optocoupler. Since the optocoupler input LEDs usually have low reverse voltage, the optocoupler must be protected. This is done by connecting a reverse polarized diode directly across the input LED (see **Figure 12**).

The cut-off frequency f_{CO} represents the highest signal frequency that can be transferred through the optocoupler. The maximum frequency of the external PWM signal is 1 kHz and the cut-off frequency should be higher than that value. Typically, the cut-off frequency of the optocoupler is significantly higher than 1 kHz.

The maximum collector emitter voltage ($V_{CE(MAX)}$) limits the maximum supply voltage (V_{cc}, see **Figure 12**). The current through the output of the optocoupler should not exceed the maximum collector current ($I_{C(MAX)}$).

The pull-up resistance at the output of the optocoupler is calculated using the following equation:

$$R_{PWM\_PULL\_UP} = \frac{Vcc - V_{CE}(I_F, I_C)}{I_C(I_F, CTR)} = 1.48\ k\Omega \quad (38)$$

The values of the collector emitter voltage and collector current are determined from graphs available in the datasheet of the selected optocoupler. First, the collector current is calculated by multiplying the input forward current and CTR (current transfer ratio). Then V_{CE} is estimated from the graph for this input forward current and the calculated collector current, and finally, $R_{PWM\_PULL\_UP}$ is calculated.

It is important to notice that the output signal of the optocoupler is inverted compared to the input PWM signal.

2.3.5 ILD2111 IC Supply

The ILD2111 IC needs a supply voltage (V_{cc}) in the range from 11 V to 22 V in order to work properly (see **[1]**). A typical value of V_{cc} is 15 V (see **Table 2**).

When burning parameters to OTP memory, the V_{cc} voltage needs to be lower and be kept in a narrow range (see **[1]**). Consequently, any programming interface (e.g. .dp Interface Gen2) needs to have direct connection to the pin VCC. Any voltage drop (e.g. diode in series) in the VCC path from the programming interface to the IC may result in an OTP programming fault.

In order to filter V_{cc} voltage better and reduce noise to a minimum, a ceramic capacitor with a value of 100 nF should be connected as close as possible to the VCC and GND pins. Depending on how the ILD2111 is supplied, it is also recommended to insert an additional capacitor (ceramic or tantalum) with higher capacitance (1 – 10 µF). Voltage ratings of selected capacitors should be higher than the maximum V_{cc} voltage.

2.4 PCB Board Design Guidelines

When it comes to the PCB board layout, it is very important to follow a few simple guidelines in order to reduce electromagnetic emission and maintain voltage stability.

The V_{cc} decoupling capacitor should be placed as close as possible to the IC's VCC and GND pins (C_{VCC}, see **Figure 13**). Also, the C_{VIN} capacitor (see Section **2.3.1**) should be placed as close as possible to the VIN pin (see the light blue line in **Figure 13**).

The power ground and signal ground should be held separately and connected to the input ceramic capacitor (see purple line in **Figure 13**). The power path consists of input capacitors, output capacitor, output LED array, inductance, free-wheeling diode, MOSFET and shunt resistors. All of these components should be connected with the shortest possible PCB traces to reduce the length of the power path (see red and orange lines in **Figure 13**).

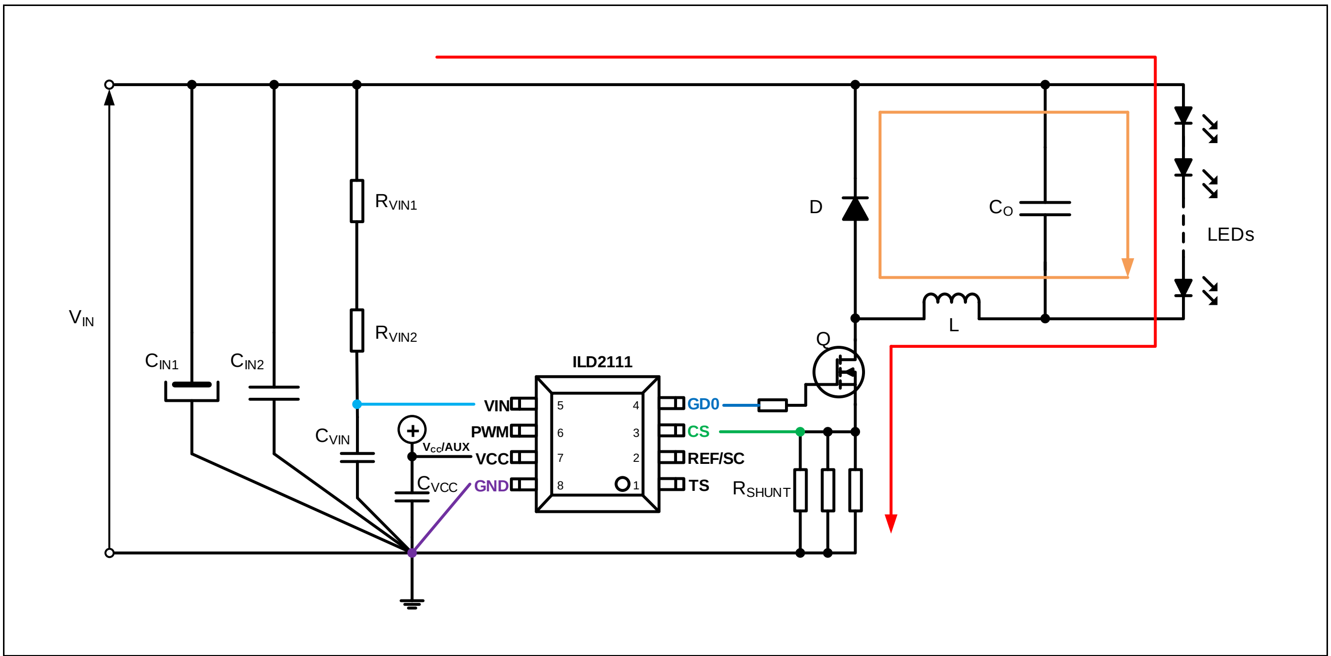


Figure 13 Important Connections/Paths in ILD2111 DC/DC Buck Converter

When connecting more than one shunt resistor in parallel, use the connection as shown in **Figure 14**, because in this case all current paths are the same length. Do <u>not</u> connect shunt resistors as shown in **Figure 15**.

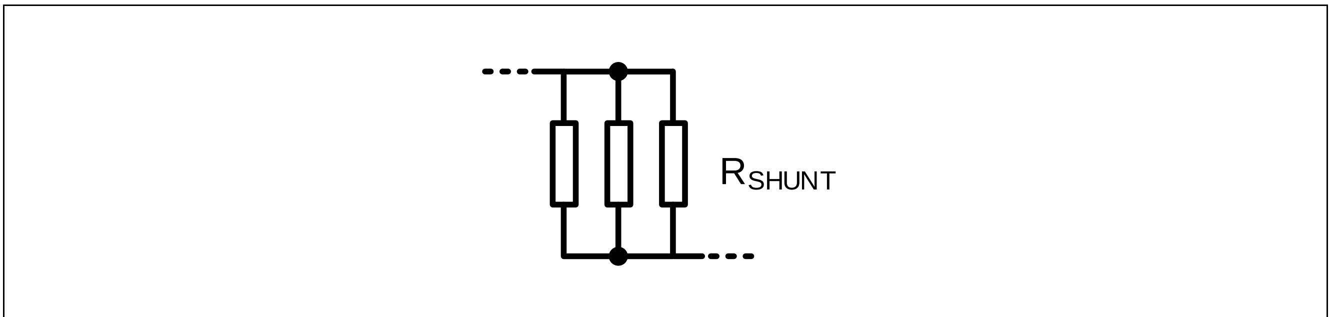


Figure 14 Correct Shunt Resistors Layout

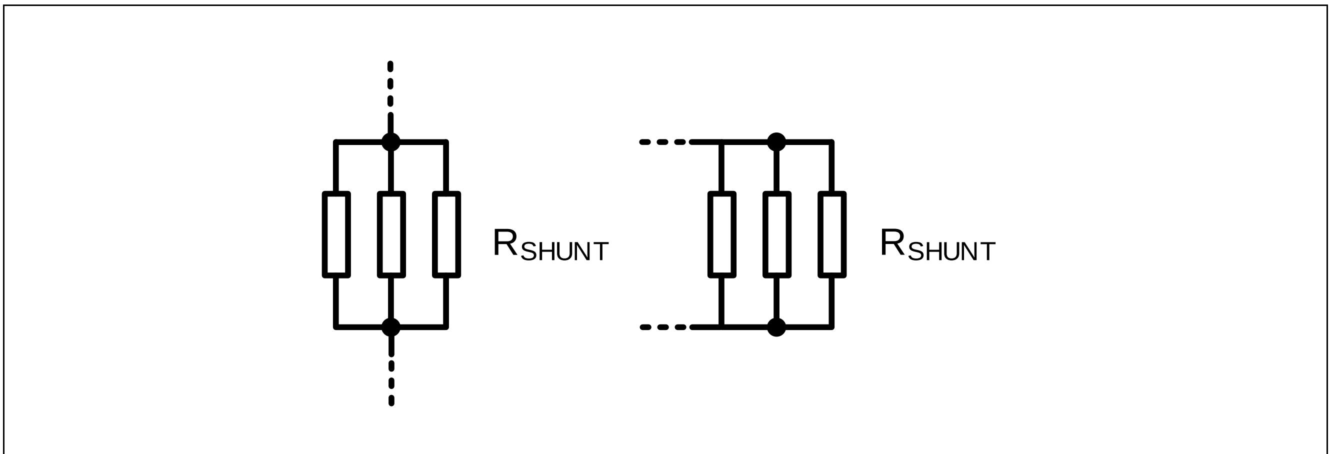


Figure 15 Wrong Shunt Resistors Layout

3 Device Parameter Settings

The ILD2111 provides a generic firmware version that includes all parameters set to zero. The parameter values need to be modified according to the desired application.

After finishing calculations of the hardware components for an ILD2111 DC/DC buck converter, the user has to configure all the parameters, which are specified by the hardware environment and the customer's requirements. This is done by using the .dp vision tool, an innovative and user-friendly graphical user interface (GUI). After entering all the data (parameters), the .dp vision tool will automatically calculate all other relevant parameters, after which the user will be able to test and burn the complete application.

A complete list of available parameters in the ILD2111 can be found in the ILD2111 Data sheet (see **[1]**). Relevant information on using the .dp vision tool is available in the .dp Vision User Manual (see **[3]**) and in the ILD2111 Application Note (see **[2]**).

A few examples of how to set up a configuration file for calculated values are described in the following subsections.

3.1 Design Parameters

The ILD2111 evaluation system comes along with a verified parameter setting, which can be used as a reference (see **[2]**).

There are many possible ways of configuring parameters. Since there is no right or wrong way, the most direct way is the one described. Simply start filling parameters as they are displayed in the .dp vision tool. Please use the configuration file for the ILD2111 evaluation board as a reference (see **[2]**).

The process of filling the parameters is described in the following sections. Each parameter is described in a separate table (their contents are provided in accordance with **Table 6**).

Table 6 Parameter Tables Description

Parameter	Parameter name.
Description	Detailed description of the parameter and its function.
Unit	Unit in which the parameter is stored.
Example Value	Value of the parameter which is calculated or selected in the example presented in this document.
Min	Minimum possible value of the parameter.
Max	Maximum possible value of the parameter.
Input Type	Information in which way the parameter is entered in the .dp vision tool. Either the value is filled in directly or it is selected from a list of predefined possible values.
Input Details	More information about the input value to be set.

3.1.1 Hardware Configuration Parameters

The hardware configuration represents hardware component values that are calculated and assembled on the specified application board (for example R_{VIN}, R_TS_pull_up, C_ref, etc.) and chip-specific hardware features that can be configured for the custom application. For some parameters, the value needs to be filled in and for others the value can be selected from a drop-down menu.

The values that are shown in the default configuration .csv comply with the hardware component values of the ILD2111 evaluation board (see **[2]**).

Table 7 Reference Capacitor

Parameter	C_ref
Description	This capacitor is used as a reference for the I-set procedure.
Unit	nF
Example Value	10.00
Min	0
Max	-
Input Type	Enter the desired value.
Input Details	For more information, please refer to Section **2.2.6**.

Table 8 Reference Resistance

Parameter	R_ref_sc
Description	This resistor is used to decouple the UART interface and current set resistance R_iset due to multiplexed functionality of the REF/SC pin.
Unit	kΩ
Example Value	3.30
Min	0
Max	-
Input Type	Enter the desired value.
Input Details	For more information, please refer to Section **2.2.5**.

Table 9 Input Voltage External Resistor

Parameter	R_vin
Description	Input voltage of the external resistor. Its value is determined based on the maximum input voltage to be measured and the selected Vin current range (parameter Vin_current_range, see **Table 14**).
Unit	Ω
Example Value	60000.00
Min	0
Max	-
Input Type	Enter the desired value.
Input Details	For more information on how R_vin is calculated, please refer to Section **2.2.1** and equation **(2)**.

Table 10 Current Sense Shunt Resistor

Parameter	R_current_sense
Description	Current sense shunt resistor used for current measurement. Its value depends on the selected current sense range (parameter Current_sense_OCP1, see **Table 15**).
Unit	Ω
Example Value	0.650
Min	0
Max	-
Input Type	Enter the desired value.
Input Details	For more information on how R_current_sense is calculated, please refer to Section **2.2.5** and equation **(16)**.

Table 11 Pull-up Resistor on TS Pin

Parameter	R_TS_pull_up
Description	Pull-up resistor on TS pin which is used for the external temperature measurement procedure. Its value is selected such that the ADC range matches the desired temperature range, based on the resistance of the PTC sensor at a particular maximum temperature.
Unit	Ω
Example Value	32500.00
Min	0
Max	-
Input Type	Enter the desired value.
Input Details	For more information on how R_TS_pull_up is calculated, please refer to Section **2.3.3** and equation **(36)**.

Table 12 Tolerance of the Reference Capacitor

Parameter	C_ref_tolerance
Description	Tolerance of the reference capacitor.
Unit	%
Example Value	5
Min	0
Max	-
Input Type	Enter the desired value.
Input Details	Narrow range of I-set resistors can be achieved with the lower tolerances. With the higher tolerances, larger spacing between the resistor values is necessary in order to secure proper current selection overall uncertainties.

Table 13 Tolerance of the Reference I-Set Resistor

Parameter	R_iset_tolerance
Description	Tolerance of the reference I-set resistor.
Unit	%
Example Value	1
Min	0
Max	-
Input Type	Enter the desired value.
Input Details	Narrow range of I-set resistors can be achieved with the lower tolerances. With the higher tolerances, larger spacing between the resistor values is necessary in order to secure proper current selection overall uncertainties. It is recommended to use resistor values that are as accurate as possible (recommended tolerance is 1%).

Table 14 Input Voltage Measurement Current Range

Parameter	Vin_current_range
Description	Input voltage measurement current range. By changing V_{IN} current range, different I_{MEAS} current values are selected.
Unit	mA
Example Value	1.600
Min	0.209
Max	1.600
Input Type	Predefined values are available in the drop-down menu. Possible choices are 1.6 mA and 0.209 mA.
Input Details	There are two implemented measurement ranges related to the VIN pin – 1.6 mA and 0.209 mA. Based on the choice of range, a different internal shunt resistor is selected, where the ADC measures the shunt resistor current indirectly by measuring the voltage drop across the shunt resistor. For more information, please refer to Section **2.2.1**.

Table 15 Current Sense Range

Parameter	Current_sense_OCP1
Description	Current sense range. Input voltage range for CS pin is selected. The selected value defines the maximum value of the OCP1 voltage level.
Unit	V
Example Value	0.6
Min	0.4
Max	0.6
Input Type	Predefined values are available from the drop-down menu. Possible choices are 0.6 V and 0.4 V.
Input Details	There are two possible current sense ranges: 0.4 V and 0.6 V. It is recommended, if possible, to select the current sense range which will result in a higher value of the shunt resistor. This is important due to higher noise immunity of the current readings. On the other hand, a higher value of the shunt resistor will increase power dissipation on it. For more information, please refer to Section **2.2.5**.

Table 16 Output Gate-Driver Voltage

Parameter	GD_voltage[1]
Description	Output gate-driver voltage (V_{GDH}). Select a voltage at which the MOSFET is fully switched on. Output gate-driver voltage is limited by the V_{cc} voltage[2].
Unit	V
Example Value	15.0
Min	4.5
Max	15.0
Input Type	Predefined values are available from the drop-down menu. Possible choices in V are: 4.5, 6.0, 7.5, 9.0, 10.5, 12.0, 13.5, 15.0
Input Details	The input value depends on the MOSFET specification (see Section **2.2.4**).

[1] When the MOSFET is in the off state, the Gate Driver (GD) output is securely pulled to a low voltage for preventive reasons (unwanted switch-on).

[2] The selected gate driver voltage should be set to a value below the actual V_{cc} voltage level. If the selected GD voltage is above the actual V_{cc} value, the GD output voltage cannot reach the selected value.

Table 17 Output Gate-Driver Current

Parameter	GD_current
Description	Output gate-driver current (I_{GD}).
Unit	mA
Example Value	118
Min	30
Max	118
Input Type	Predefined values are available from the drop-down menu. Possible choices in mA are: 30, 33, 35, 38, 41, 45, 49, 53, 57, 62, 67, 73, 79, 85, 93, 100, 109, 118.
Input Details	The input value depends on the specification of the MOSFET. Higher currents switch on the MOSFET faster (less switching losses), but create a higher level of EMI.

3.1.2 Protections

Protections represent parameters related to protection of the device. Parameters available in this part of the configuration are described in detail in the following tables.

Table 18 V_{cc} Voltage Compensation Feature Control

Parameter	ETP_comp_Vcc
Description	V_{cc} voltage compensation for external temperature measurement enabled/disabled.
Unit	-
Example Value	Enabled
Min	-
Max	-
Input Type	Predefined values are available from the drop-down menu. Possible choices are: Enabled or Disabled.
Input Details	If a ratiometric sensor (output proportional to supply voltage) is used (like PTC), compensation is necessary in order to cancel supply change effects. If the sensor outputs do not depend on supply voltage, this parameter should be disabled.

Table 19 External Temperature Protection Feature Control

Parameter	ETP_enable
Description	External temperature protection feature enabled/disabled.
Unit	-
Example Value	Enabled
Min	-
Max	-
Input Type	Predefined values are available from the drop-down menu. Possible choices are: Enabled or Disabled.
Input Details	If an external sensor is used, this feature should be enabled and vice versa.

Table 20 V_{IN} Minimum Start Voltage

Parameter	Vin_min_start
Description	Lowest possible input voltage V_{IN} for the controller to start generating output current. If the input voltage is lower than Vin_min_start parameter during start-up, the controller will not generate output current. The converter will start generation when the voltage becomes higher than the Vin_min_start parameter.
Unit	V
Example Value	45.00
Min	0
Max	-
Input Type	Enter the desired value.
Input Details	Provide a value higher than Vin_min_oper (see **Table 21**) in order to deal with eventual drops in input voltage due to turn-on and consequential load changes.

Table 21 V_{IN} Minimum Operational Voltage

Parameter	Vin_min_oper
Description	Lowest possible input voltage V_{IN} allowed during operation. If the input voltage becomes lower than the Vin_min_oper parameter during operation, the controller will report an error. The converter will start again when the voltage becomes higher than Vin_min_start (see **Table 20**) parameter.
Unit	V
Example Value	40.00
Min	0
Max	-
Input Type	Enter the desired value.
Input Details	Provide minimum value of input voltage.

Table 22 V_{IN} Maximum Start Voltage

Parameter	Vin_max_start
Description	Highest possible input voltage V_{IN} for the controller to start generating output current. If the input voltage is higher than the Vin_max_start parameter during start-up, the controller will not generate output current. The converter will start generation when the voltage becomes lower than the Vin_min_start parameter.
Unit	V
Example Value	60.00
Min	0
Max	-
Input Type	Enter the desired value.
Input Details	Provide a value lower than Vin_max_oper (see **Table 23**) in order to deal with eventual overshoots in input voltage due to turn-on and consequential load changes.

Table 23 V_{IN} Maximum Operational Voltage

Parameter	Vin_max_oper
Description	Highest possible input voltage V_{IN} allowed during operation. If the input voltage becomes higher than the Vin_max_oper parameter during operation, the controller will report an error. The converter will start again when the voltage becomes lower than the Vin_max_start (see **Table 22**) parameter.
Unit	V
Example Value	65.00
Min	0
Max	-
Input Type	Enter the desired value.
Input Details	Provide maximum value of the input voltage.

Table 24 Minimum Output Voltage

Parameter	Vout_min
Description	Output voltages lower than this value will trigger undervoltage protection. Short output conditions are also detected.
Unit	V
Example Value	8.00
Min	0
Max	-
Input Type	Enter the desired value.
Input Details	Minimum output voltage is limited by the desired minimum number of LEDs connected to the output of the device and their forward voltage drop.

Table 25 Maximum Output Voltage

Parameter	Vout_max
Description	Output voltages higher than this value will trigger output overvoltage protection.
Unit	V
Example Value	40.00
Min	0
Max	-
Input Type	Enter the desired value.
Input Details	Maximum output voltage should be at least 5 V lower than the lowest possible input voltage, which is defined by the parameter Vin_min_oper (see **Table 21**).

Table 26 Maximum Output Power

Parameter	Pout_max
Description	Output power higher than this value will trigger output overpower protection.
Unit	W
Example Value	23.00
Min	0
Max	-
Input Type	Enter the desired value.
Input Details	Maximum output power is defined as a requirement in the main system requirements table (see **Table 2**).

Table 27 Maximum Error Reference Current

Parameter	Err_refcurrent_max
Description	Maximum hysteretic value of the shutdown output current (ERROR CURRENT, see **Figure 16**).
Unit	mA
Example Value	131
Min	0
Max	-
Input Type	Enter the desired value.
Input Details	Err_refcurrent_min (see **Table 28**) should provide a ripple current such that the switching frequency is below the maximum for any applicable V_{IN}/V_{OUT} condition.

Table 28 Minimum Error Reference Current

Parameter	Err_refcurrent_min
Description	Minimum hysteretic value of shutdown output current (ERROR CURRENT, see **Figure 16**).
Unit	mA
Example Value	20
Min	0
Max	-
Input Type	Enter the desired value.
Input Details	Should be at least 4 current LSBs. For example: (Current_sense_OCP1 / (R_current_sense · 255)) · 4

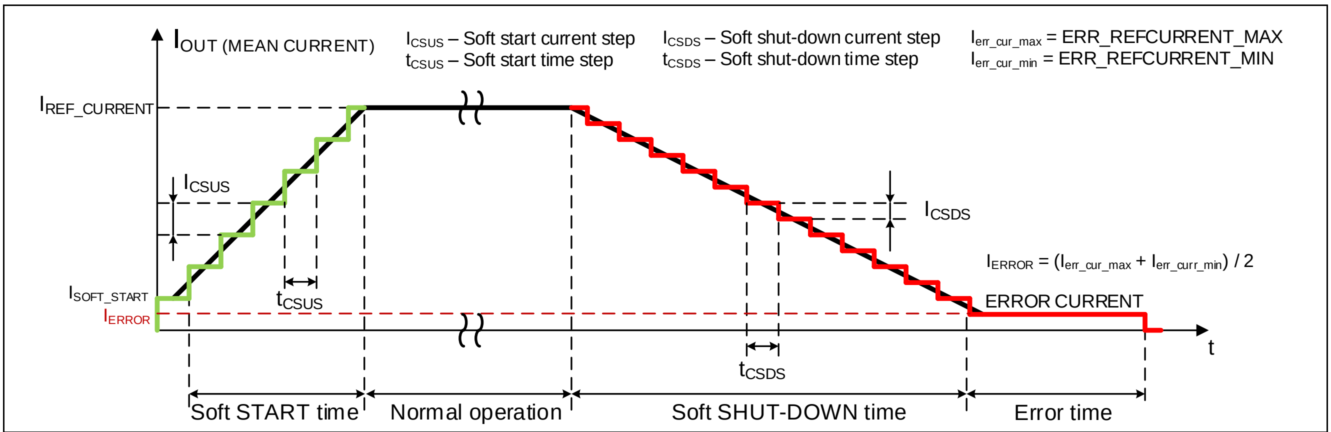


Figure 16 Soft Start and Soft Shutdown Definitions

3.1.3 Temperature Guard

For temperature protection, it is necessary to enter the values of temperature thresholds that define the device's behavior regarding operating temperature conditions (see **[2]**, **[3]**). Increment and decrement time steps should be defined as well as a reference V_{cc} power supply value to be used for external temperature measurement compensation[1]. Available parameters are described in the following tables.

Table 29 Internal Temperature Hot Threshold

Parameter	ITP_temperature_hot
Description	Hot temperature threshold for internal sensor (see **Figure 17**).
Unit	°C
Example Value	120
Min	-40
Max	150
Input Type	Enter the desired value.
Input Details	Internal temperature value at which the device starts reducing output current.

[1] For more details on how temperature protection is handled, please refer to the ILD2111 data sheet **[1]**.

Table 30 Internal Temperature Critical Threshold

Parameter	ITP_temperature_critical
Description	Critical temperature threshold for internal sensor (see **Figure 17**).
Unit	°C
Example Value	123
Min	-40
Max	150
Input Type	Enter the desired value.
Input Details	Internal temperature value at which the device stops generating output current.

Table 31 External Temperature Hot Threshold

Parameter	ETP_temperature_hot
Description	Hot temperature threshold for external sensor (see **Figure 18**).
Unit	V
Example Value	1.27
Min	0
Max	1.6
Input Type	Enter the desired value.
Input Details	This value should be calculated based on the sensor used. For more information, please refer to Section **2.3.3** and equation **(35)**.

Table 32 External Temperature Critical Threshold

Parameter	ETP_temperature_critical
Description	Critical temperature threshold for external sensor (see **Figure 18**).
Unit	V
Example Value	1.37
Min	0
Max	1.6
Input Type	Enter the desired value.
Input Details	This value should be calculated based on the sensor used. For more information, please refer to Section **2.3.3** and equation **(35)**.

Table 33 Internal Temperature Protection Time Step for Current Increasing

Parameter	ITP_PWM_inc_time_step
Description	Internal temperature protection time step for increasing current (change of internal PWM duty, see **Figure 17**).
Unit	s
Example Value	10
Min	1
Max	100
Input Type	Enter the desired value.
Input Details	Resolution is 1 s. It is usually paired with the parameter ITP_PWM_dec_time_step (see **Table 34**).

Table 34 Internal Temperature Protection Time Step for Current Decreasing

Parameter	ITP_PWM_dec_time_step
Description	Internal temperature protection time step for decreasing current (change of internal PWM duty, see **Figure 17**).
Unit	s
Example Value	10
Min	1
Max	100
Input Type	Enter the desired value.
Input Details	Resolution is 1 s. It is usually paired with the parameter ITP_PWM_inc_time_step (see **Table 33**).

Table 35 External Temperature Protection Time Step for Current Increasing

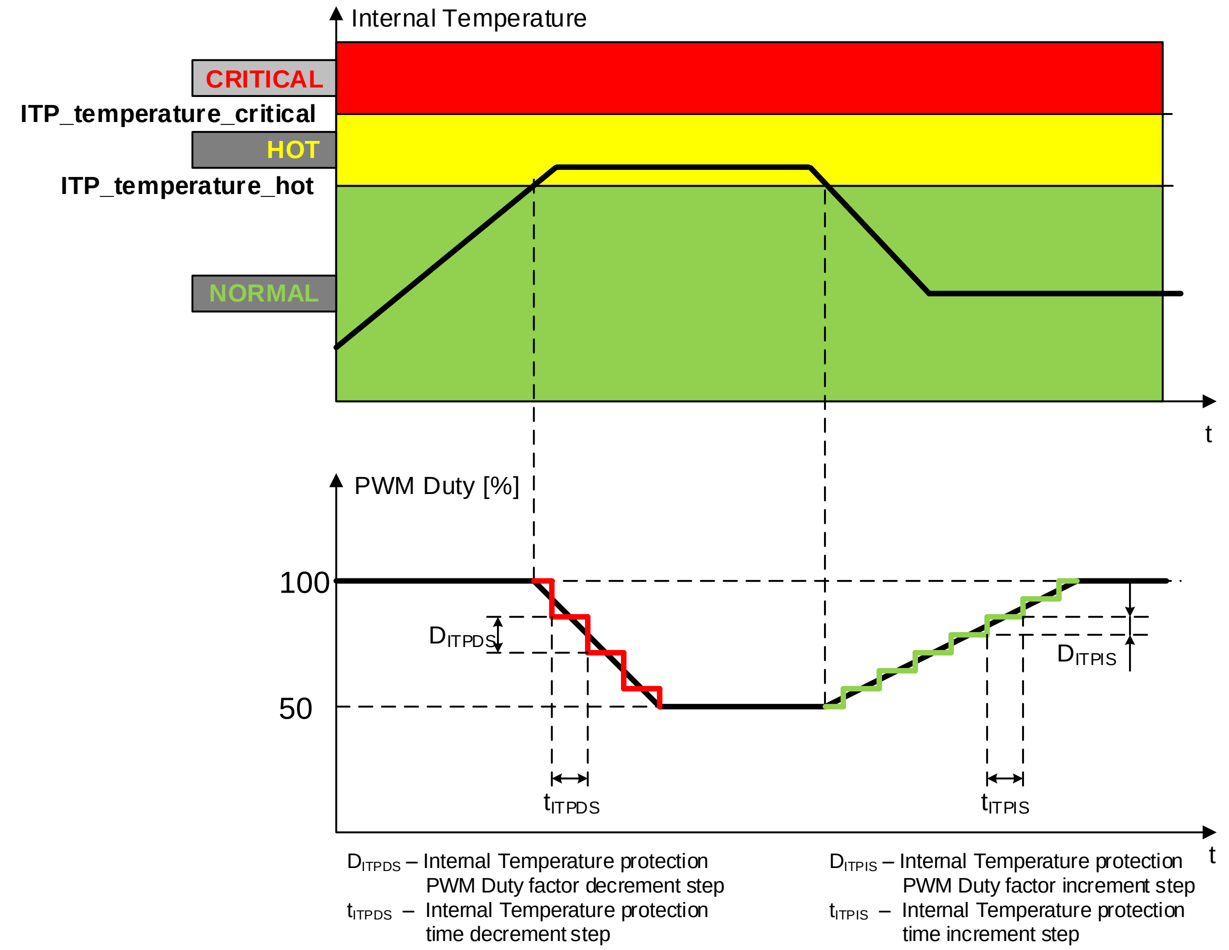
Parameter	ETP_PWM_inc_time_step
Description	External temperature protection time step for increasing current (change of internal PWM duty, see **Figure 18**).
Unit	s
Example Value	10
Min	1
Max	100
Input Type	Enter the desired value.
Input Details	Resolution is 1 s. Should be higher than the sensor time constant (response time). It also depends on project requirements. Usually paired with the parameter ETP_PWM_dec_time_step (see **Table 36**).

Table 36 External Temperature Protection Time Step for Current Decreasing

Parameter	ETP_PWM_dec_time_step
Description	External temperature protection time step for decreasing current (change of internal PWM duty, see **Figure 18**).
Unit	s
Example Value	10
Min	1
Max	100
Input Type	Enter the desired value.
Input Details	Resolution is 1 s. Should be higher than the sensor time constant (response time). It also depends on project requirements. Usually paired with the parameter ETP_PWM_inc_time_step (see **Table 35**).

Table 37 V_{cc} Voltage Reference Value

Parameter	Vcc_reference
Description	Reference value of V_{cc} voltage for external temperature measurement calibration.
Unit	V
Example Value	15.00
Min	11.00
Max	24.00
Input Type	Enter the desired value.
Input Details	Typical value for the V_{cc} in-design. If ETP_comp_Vcc (see **Table 18**) is enabled, this value is used as a reference for external temperature measurement compensation due to V_{cc} variation.



D_{ITPDS} – Const
t_{ITPDS} – ITP_PWM_dec_time_step
D_{ITPIS} – Const
t_{ITPIS} – ITP_PWM_inc_time_step

Figure 17 Internal Temperature Protection Behavior

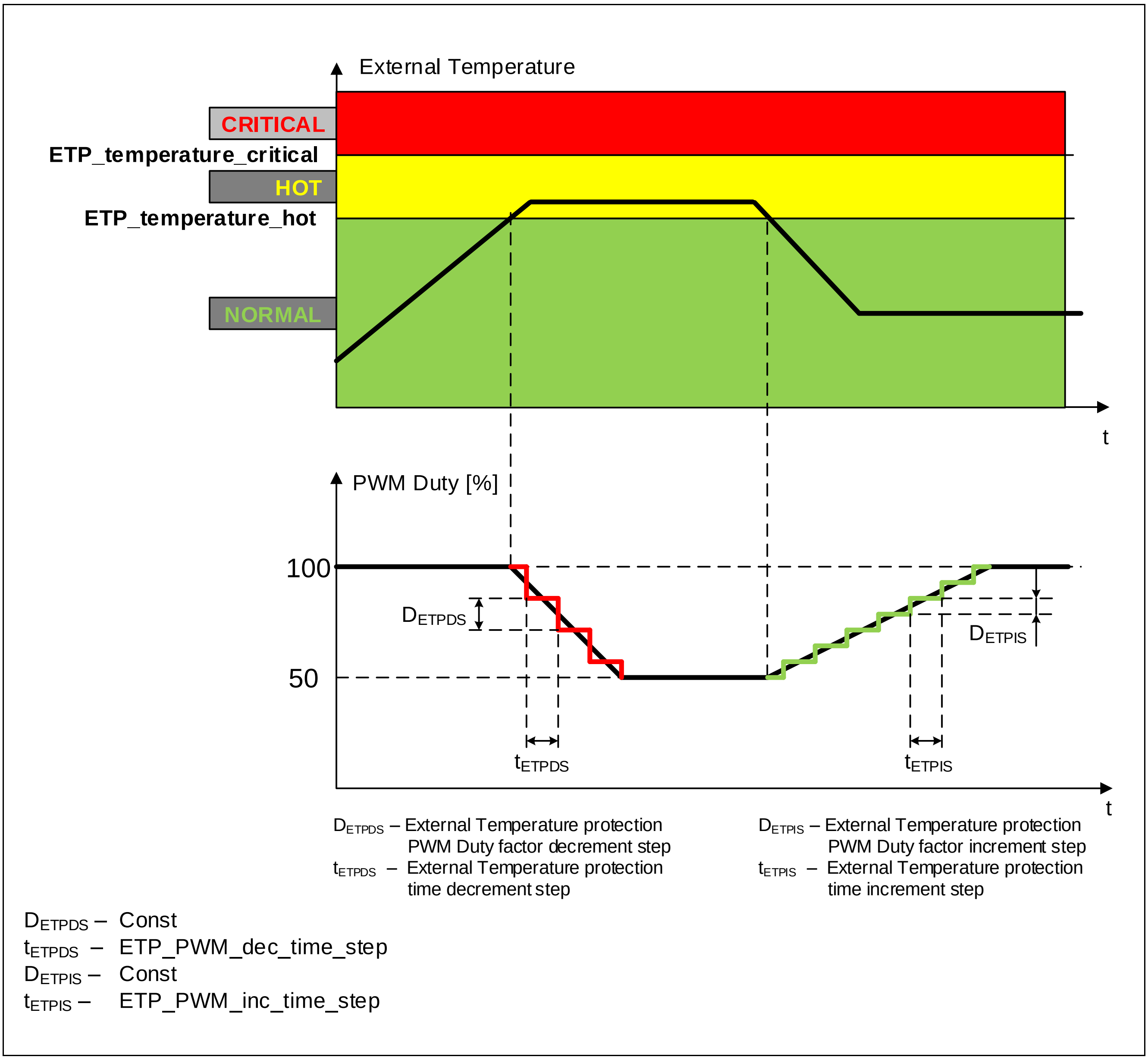


Figure 18 External Temperature Protection Behavior

3.1.4 Startup and Shutdown

There are two parameters that the user can utilize to set time steps for soft-start and soft-shutdown procedures. A more detailed explanation of these parameters can be found in [1].

Table 38 Soft-start Time Step

Parameter	Softstart_time_step
Description	Reference current ramp increment time intervals – t_{CSUS} (see Figure 16).
Unit	ms
Example Value	1
Min	0
Max	6553
Input Type	Enter the desired value.
Input Details	Used to adjust the load rate change. Abrupt or high rate load changes could cause instability in the input voltage provided from the first stage.

Table 39 Soft-shutdown Time Step

Parameter	Softshutdown_time_step
Description	Reference current ramp decrement time interval - t_{CSDS} (see Figure 16).
Unit	ms
Example Value	2
Min	0
Max	6553
Input Type	Enter the desired value.
Input Details	Used to adjust the load rate change. Abrupt or high rate load changes could cause instability in the input voltage provided from the first stage.

3.1.5 Output Current Set

This part of the design parameters box is used to set reference current and reference resistor values, and to arrange reference currents in groups. Available parameters are described in the following tables.

Table 40 Reference Current Values

Parameter	I_ref_xx, where xx is in a range from 01 to 16.
Description	These parameters are reference current values.
Unit	mA
Example Value	Values used as examples in this document are given in the Table 41.
Min	Typically ¼ of max.
Max	Typically 80% of the current range – (Current_sense_OCP1 / R_current_sense).
Input Type	Enter the desired values.
Input Details	Care should be taken to ensure that the highest current plus half of the ripple should not exceed the current range.

Reference current parameter values presented as examples in this document are given in the following table (**Table 41**).

Table 41 Example Values of Reference Currents

Reference Current	Example Value
I_ref_01	800
I_ref_02	750
I_ref_03	700
I_ref_04	650
I_ref_05	600
I_ref_06	550
I_ref_07	500
I_ref_08	450
I_ref_09	400
I_ref_10	350
I_ref_11	300
I_ref_12	250
I_ref_13	0
I_ref_14	0
I_ref_15	0
I_ref_16	0

Table 42 Current Ripple Percentage

Parameter	Curr_ripple_perc
Description	Current ripple percentage that is used during the startup sequence or when the frequency ripple controller is turned off.
Unit	%
Example Value	30.00
Min	1
Max	100
Input Type	Enter the desired value.
Input Details	I_ripple = I_ref_xx · Curr_ripple_perc / 100

Table 43 Reference Current Table Arrangement

Parameter	Ref_current_xx, where xx is in a range from 01 to 16.
Description	All available reference currents should be arranged in four groups and assigned to these parameters.
Unit	mA
Example Value	One example of current arrangement is given in **Table 44**.
Min	0
Max	-
Input Type	Select desired current from the drop-down menu. Currents that will be available from the drop-down menu are defined in **Table 41**.
Input Details	It is not mandatory, but it is nonetheless recommended that the table be filled in descending order.

Table 44 Example of Reference Currents Arrangement

Reference Current	Example Value
Ref_current_01	800
Ref_current_02	750
Ref_current_03	700
Ref_current_04	700
Ref_current_05	650
Ref_current_06	600
Ref_current_07	550
Ref_current_08	550
Ref_current_09	500
Ref_current_10	450
Ref_current_11	400
Ref_current_12	400
Ref_current_13	350
Ref_current_14	300
Ref_current_15	250
Ref_current_16	250

Table 45 Reference Resistors

Parameter	R_iset_xx, where xx is in a range from 01 to 16.
Description	Reference current set resistor values.
Unit	kΩ
Example Value	One example of reference resistor values is given in **Table 46**.
Min	R_ref_sc / ((1 - R_iset_tolerance / 100) · (V_ref_rc_charge / V_adc_th - 1))
Max	-
Input Type	Enter the desired values.
Input Details	It is mandatory that the table be arranged in ascending order. If any of the currents is not used, it is recommended that the corresponding reference resistor be set to a value 10 times higher than the highest resistor value (e.g. 1000.00 kΩ). For more information, please refer to Section **2.2.6**.

Table 46 Example of Reference Resistors Values

Reference Resistor	Example Value
R_iset_01	2.15
R_iset_02	10.00
R_iset_03	15.00
R_iset_04	21.50
R_iset_05	33.20
R_iset_06	43.20
R_iset_07	53.60
R_iset_08	63.40
R_iset_09	71.50
R_iset_10	82.50
R_iset_11	90.90
R_iset_12	100.00
R_iset_13	1000.00
R_iset_14	1000.00
R_iset_15	1000.00
R_iset_16	1000.00

3.2 Testing

After complete setting of the available parameters, it is necessary to test the application with a new configuration csv file whose parameters will be loaded to RAM. After successful testing in RAM, the parameters can be burned into the device's internal memory. It is possible to burn a complete parameter set as well as patching only dedicated parameters from their original setting. Details about the handling can be found in the .dp vision User Manual (see **[3]**).

4 Use Cases

The purpose of this section is to provide a step-by-step guide for users to create custom ILD2111 DC/DC buck applications. The ILD2111 evaluation system can be used as a reference (see [2]) and serves as a good starting point.

4.1 Changing Output Current

A possible use case is that output currents need to be changed. For example, if a new requirement is that the average output current is in the range from 200 mA to 600 mA with steps of 100 mA, several parameters and hardware components should be changed in order to achieve the desired behavior. Let us assume that other main system requirements from **Table 2** have not been changed.

The following hardware components should be changed:

- Inductor (see Section **2.2.2**) – Since the average output current requirement is changed, the current ripple will be changed accordingly (see equation **(5)**). According to equation **(4)**, the inductor value should be recalculated. Additionally, the inductor peak current should be adjusted according to equation **(7)**.
- Freewheeling diode (see Section **2.2.3**) – The average forward diode current depends on the average output current (see equation **(8)**). Since the maximum average output current is reduced, the average diode forward current could also be reduced. Because of this, a new diode with a lower average forward current could be selected. This change is not mandatory and the same diode could be used – like for the example in this document.
- MOSFET (see Section **2.2.4**) – The maximum continuous drain current depends on the maximum possible output current. The maximum average output current, and consequently the ripple, were reduced and because of that a MOSFET with lower maximum continuous drain current could be selected (see equation **(11)**). This change is not mandatory and the same MOSFET could be used – like for the example in this document.
- Current sense resistor (see Section **2.2.5**) – The current sense resistor value directly depends on the maximum output current and its value needs to be adjusted according to equation **(13)**. The current sense range should be left unchanged.
- Reference current set resistors (see Section **2.2.6**) – In this example, only five different average output currents are used and consequently only five different R_iset resistors will be used. The same capacitors C_ref, C_filt and resistor R_ref_sc could be used – like for the example in this document. More information on how these resistors values are determined can be found in Section **2.2.6**.
- Input capacitors (see Section **2.3.1**) – Both ceramic and bulk capacitance values could be reduced if they are used (input capacitors are optional). According to equation **(26)**, the minimum required ceramic capacitance depends on the maximum average output current and its value could be reduced. Bulk capacitance depends on the maximum output transient current (see equations **(28)** and **(29)**), which is in this case reduced. This will result in a reduction of the minimum bulk capacitance. This change is not mandatory and the same ceramic and bulk capacitors could be used – like for the example in this document.

The following parameters should be changed in the configuration file using the .dp vision tool:

- Hardware configuration – Only the parameter R_current_sense (see **Table 10**) should be changed to the value of the current sense resistor, which will be recalculated.
- Output current set – All reference current values I_ref_xx (see **Table 40**) should be changed according to the new requirement. Additionally, reference resistors values R_iset_xx (see **Table 45**) and reference current arrangement table parameters Ref_current_xx (see **Table 43**) should be changed. New values of these parameters are presented in the following tables and figures.

Table 47 New Values of Reference Currents

Reference Current	Example Value
I_ref_01	600
I_ref_02	500
I_ref_03	400
I_ref_04	300
I_ref_05	200
I_ref_06	0
I_ref_07	0
I_ref_08	0
I_ref_09	0
I_ref_10	0
I_ref_11	0
I_ref_12	0
I_ref_13	0
I_ref_14	0
I_ref_15	0
I_ref_16	0

Table 48 Possible Reference Currents Arrangement

Reference Current	Example Value
Ref_current_01	600
Ref_current_02	600
Ref_current_03	500
Ref_current_04	500
Ref_current_05	400
Ref_current_06	400
Ref_current_07	400
Ref_current_08	400
Ref_current_09	300
Ref_current_10	300
Ref_current_11	300
Ref_current_12	300
Ref_current_13	200
Ref_current_14	200
Ref_current_15	200
Ref_current_16	200

Table 49 New Reference Resistor Values

Reference Resistor	Example Value
R_iset_01	10.00
R_iset_02	21.50
R_iset_03	43.20
R_iset_04	63.40
R_iset_05	100.00
R_iset_06	1000.00
R_iset_07	1000.00
R_iset_08	1000.00
R_iset_09	1000.00
R_iset_10	1000.00
R_iset_11	1000.00
R_iset_12	1000.00
R_iset_13	1000.00
R_iset_14	1000.00
R_iset_15	1000.00
R_iset_16	1000.00

Output current set		
I_ref_01	600	mA
I_ref_02	500	mA
I_ref_03	400	mA
I_ref_04	300	mA
I_ref_05	200	mA
I_ref_06	0	mA
I_ref_07	0	mA
I_ref_08	0	mA
I_ref_09	0	mA
I_ref_10	0	mA
I_ref_11	0	mA
I_ref_12	0	mA
I_ref_13	0	mA
I_ref_14	0	mA
I_ref_15	0	mA
I_ref_16	0	mA
Curr_ripple_perc	30.00	%
Ref_current_01	600	mA
Ref_current_02	600	mA
Ref_current_03	500	mA
Ref_current_04	500	mA
Ref_current_05	400	mA
Ref_current_06	400	mA
Ref_current_07	400	mA
Ref_current_08	400	mA
Ref_current_09	300	mA
Ref_current_10	300	mA
Ref_current_11	300	mA
Ref_current_12	300	mA
Ref_current_13	200	mA
Ref_current_14	200	mA
Ref_current_15	200	mA
Ref_current_16	200	mA

Figure 19 New Reference Currents and Possible Arrangement

R_iset_01	10.00	kOhm
R_iset_02	21.50	kOhm
R_iset_03	43.20	kOhm
R_iset_04	63.40	kOhm
R_iset_05	100.00	kOhm
R_iset_06	1000.00	kOhm
R_iset_07	1000.00	kOhm
R_iset_08	1000.00	kOhm
R_iset_09	1000.00	kOhm
R_iset_10	1000.00	kOhm
R_iset_11	1000.00	kOhm
R_iset_12	1000.00	kOhm
R_iset_13	1000.00	kOhm
R_iset_14	1000.00	kOhm
R_iset_15	1000.00	kOhm
R_iset_16	1000.00	kOhm

Figure 20 New Reference Resistor Values

4.2 Changing External Temperature Thresholds and V_{cc} Voltage

For this use case, the external temperature thresholds and V_{cc} voltage need to be changed. For example, new requirements are that the external temperature hot threshold is 70°C, the external temperature critical threshold is 80°C and the V_{cc} voltage is changed to 20 V. In order to achieve the desired behavior, hardware components and parameters should be changed. Let us assume that the other main system requirements from **Table 2** have not been changed.

The following hardware components should be recalculated and changed:

- External temperature sensor pull-up resistor R_TS_pull_up (see Section **2.3.3**) – A new pull-up resistor value should be calculated using equations **(35)** and **(36)**.
- External PWM dimming pull-up resistor (see Section **2.3.4**) – The value of this resistor depends on the V_{cc} voltage and its new value should be calculated using equation **(38)**.

The following parameters should be changed in the configuration file using the .dp vision tool:

- Hardware configuration – Only parameter R_TS_pull_up (see **Table 11**) should be changed to the new recalculated value.
- Temperature guard – The parameters ETP_temperature_hot (see **Table 31**), ETP_temperature_critical (see **Table 32**) and Vcc_referent (see **Table 37**) should be changed to the new values. Voltage levels for representing ETP_temperature_hot and ETP_temperature_critical should be recalculated using equation **(35)**. New values of these parameters are presented in **Figure 21**.

Temperature guard		
ITP_temperature_hot	120	degreeC
ITP_temperature_critical	123	degreeC
ETP_temperature_hot	1.18	V
ETP_temperature_critical	1.26	V
ITP_PWM_inc_time_step	10	s
ITP_PWM_dec_time_step	10	s
ETP_PWM_inc_time_step	10	s
ETP_PWM_dec_time_step	10	s
Vcc_referent	20.00	V

Figure 21 New External Temperature Protection Parameters Setup

4.3 Change Startup Parameters

For this use case, the startup parameter Softstart_time_step (see **Table 38**) should be changed in order to increase or decrease the output current rising time during startup. For example, the requirement is that the value of this parameter should be increased to 5 ms. Let us assume that the other main system requirements from **Table 2** have not been changed.

For this use case, only the Softstart_time_step parameter needs to be changed and its value should be directly set to 5 ms. Changing the value of this parameter using the .dp vision tool is presented in **Figure 22**.

Startup & shutdown		
Softstart_time_step	5	ms
Softshutdown_time_step	2	ms

Figure 22 Changing Softstart_time_step Parameter

5 References

[1] ILD2111 Data Sheet
[2] ILD2111 Evaluation System Application Note
[3] .dp Vision User Manual

Revision History

Major changes since the last revision

Page or Reference	Description of change
Revision 1.0 (2015-03-31)	
Page **7**	Value of symbol $V_{IN\_MAX\_MEAS}$ in **Table 2** updated
Page **8**	Complete chapter **2.2.1** updated
Page **18**	Complete chapter **2.3.1** updated
Page **40**	Chapter **3.1.4** updated (maximum values)

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