130 W dimmable constant current LED driver using ICL5102 in PFC and LLC topology

About this document

Scope and purpose

This document presents details of the ICL5102 reference design and product feature set. It describes all the necessary steps to get the board and related environment up and running. It also provides all the necessary information needed for familiarity with this comprehensive solution.

The ICL5102 is a mixed-signal Power Factor Correction (PFC) and resonant controller for dimmable and non-dimmable LED light applications using LLC/LCC topology, for highest efficiency levels exceeding 92 percent at 230 V AC_in and at full load. An outstanding integrated digital PFC stage with an adjustable Total Harmonic Distortion (THD) compensation enables THD less than 10 at 25 percent load/230 V AC_in. In an ultra-wide line input voltage range from V AC_in = 90 V up to 305 V a Power Factor (PF) above 90 percent at greater than 50 percent load is achieved. The ICL5102 LLC constant current board is designed to evaluate the performance and flexibility of the ICL5102 and demonstrates its performance, especially in a wide ambient temperature range from T_A = -40°C to T_A = 55°C at P_OUTnom = 130 W and 230 V AC_in.

Intended audience

This document is intended for anyone using the ICL5102 reference design, either for their own application tests or to use it as a reference for a new ICL5102-based development.
130 W dimmable constant current LED driver
using ICL5102 in PFC and LLC topology

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130 W dimmable constant current LED driver
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Order code/ board connection/ operation set-up

1 Order code/ board connection/ operation set-up

1.1 Order code

REF-ICL5102-U130W-CC/ SA number: SA001715492/ SP number: SP001667160

1.2 Connection diagram

Figure 1 Top view of LED driver connection

1.3 Line input voltage

Connect an AC source at the MAINS INPUT as shown, from 90 V AC up to 305 V AC.

1.4 Constant current output

- Option 1 ➔ Dimming. When using an LED module, ensure the LED voltage at minimum dimming level ($V_{\text{Dim}} = 1.0$ V) is not less than $V_{\text{DimUV}} = 38$ V.
- Option 2 ➔ Connect an LED in a voltage range of 38 V DC up to 76 V DC with a nominal current of minimum 1.75 A to the output stage from Load OUT: GND and Load OUT: “+”.
- Option 3 ➔ Connect an electronic load to Load OUT: GND and Load OUT: “+”; in LED or CV mode.

Note: The output current varies from board to board by ± 3 percent (measured over 20 boards).

1.5 1–10 V dimming interface

Connect a DC source at 1–10 V: GND and 1–10 V: “+”. 10 V is equal to the maximum load current $I_{\text{OUTmax}}$. Minimum output current $I_{\text{OUTmin}}$ is reached when the dimming voltage is equal to $V_{\text{Dim}} = 1.0$ V – for details see Chapter 3 Technical specification.
2 Introduction

This Application Note (AN) describes the characteristics and features of a 130 W SMPS LED demonstration board with dimmable constant current output in a voltage range from 76 V down to 38 V. High efficiency, high PF, low THD and a stable output current over the whole output voltage range makes it very suitable for high-quality LED lighting such as street lights, high-bay lighting or office lighting. With the highly integrated ICL5102 (combo controller with Critical Conduction Mode (CrCM)/Discontinuous Conduction Mode (DCM) PFC and half-bridge LLC integrated), the circuit design is considerably simplified, which results in space and Bill of Materials (BOM) cost savings. Furthermore, numerous monitoring and protection features ensure the highest reliability.

Key specification measurements and waveforms are shown in this AN.

Figure 2 PFC and LLC dimmable constant current reference board
3 Technical specifications

This reference design consists of a CrCM/DCM PFC and a half-bridge LLC, with dimmable constant current output from 38 V (minimum dimming voltage at $V_{\text{DIM}} = 1$ V) up to 76 V LED forward voltage. The demo board is designed for 1–10 V dimming and a non-dimming constant current operation over the whole output voltage range.

The PFC stage of this reference design is controlled by the PFC block of the ICL5102. The PFC stage has an integrated digital PFC control loop. The improved adjustable (via resistor) THD compensation is designed especially for light-load condition at 25 percent load for THD less than 10 percent at 230 V. It operates in CrCM to achieve a good PF and very low THD over a wide load range. When the load decreases to the minimum level, the IC controls the PFC to operate in DCM. The PFC BUS voltage will be sensed highly accurately ($\pm 1.6$ percent) so there is no need for a compensation network. For PFC protection, an open-loop, BUS Over Voltage (OV) and Under Voltage (UV) and surge will be also detected.

The half-bridge LLC stage has a fixed duty cycle of $D = 0.5$ with a self-adapting dead-time from 250 ns to 750 ns. ICL5102 provides an extended operation frequency range up to a typical 330 kHz in order to provide a wide dimming range and support LCC topologies. The three-state self-adapting soft-start starts with HF and has a capacitive mode regulation implemented. The following protection functions are implemented: output short-circuit protection, LLC Over Current Protection (OCP), capacitive mode regulation, Over Temperature Protection (OTP), output Over Voltage Protection (OVP) and Brown Out (BO) detection. Active Burst Mode (ABM) provides standby power below 300 mW (board level) and can be disabled.

Features

- Input voltage range: 90–305 V AC
- Input voltage frequency: 47–63 Hz
- Regulated nominal output current: $I_{\text{OUTnom.min}} = 1.75 \ A_{\text{MIN}}$ in an output voltage range from 38 V DC up to 76 V DC
- $I_{\text{OUTmin}} = 74–76$ mA (5 percent of $I_{\text{OUTnom.min}}$ at $V_{\text{DIM}} = 1.0$ V)
- Output current ripple at $V_{\text{OUT}} = 76$ V/1.75 A: $I_{\text{OUTRipplemax}} = 110$ mA$_{\text{P-P}}$ (± 3 percent)
- Dimming using an analog 1–10 V interface
- STB less than 300 mW
- Time to light: $tT2L \sim 350$ ms at 90 V AC/$V_{\text{DIM}} = 1.0$ V
- Efficiency at nominal load: ~ 92.0 percent at 230 V AC
- PF: greater than 90 percent at 50 percent load (230 V AC$_{in}$)
- Input current THD: less than 10 percent at 25 percent load (230 V AC$_{in}$)
- Low-temperature start-up at $-40$°C $T_A$
- OTP at 95 °C/auto-restart at 85°C
- Output OVP at $V_{\text{OUT}} = 90$ V DC
- BO/Brown In (BI) detection: at 71 V AC$_{in}$/BI at 79 V AC$_{in}$
- Harmonics: according to EN 61000-3-2 Class C
- EMI: according to EN 55015
- Safety : according to EN 61347-2-13
- Board dimensions: 178 mm (L) × 52 mm (B) × 32 mm
4 Schematic

Figure 3  Schematic
Key measurements using LED load

5.1 Operating area

The output current of the reference design is tested under $I_{OUT_{nom}} = 1.75$ A at 230 V AC in a voltage range between 76 V$_{OUT}$ and 38 V$_{OUT}$. Within this area the driver is working in constant current operation as shown in Figure 4.

![U-I Characteristic @ 230VACIN](image)

**Figure 4** Constant current operating area
5.2 Dimming performance

The chart below shows the output current versus the 1–10 V dimming voltage tested at 230 V AC input voltage.

Note: Do not exceed the maximum dimming level of $V_{\text{Dim}}$ to make it greater than 10 V (OC) or (shut ON) below $V_{\text{Dim}}$ – less than 1.0 V – which is not specified.

![Dimming Characteristic @ 230VACIN](chart)

**Figure 5 Dimming characteristics**

**Note:** When using an LED module:

- While dimming, the forward voltage of the LED drops from its nominal value e.g. $V_{\text{fLED}} = 76$ V down to its lowest dimming level $V_{\text{Dim}} = 59$ V at $V_{\text{Dim}} = 1.0$ V
- The lowest specified dimming voltage at $V_{\text{Dim}} = 1.0$ V is $V_{\text{Dim1V}} = 38$ V

**Note:** The LED driver is designed to start up without flashing at the lowest dimming level of $V_{\text{Dim}} = 1.0$ V.
5.3 Efficiency

The charts below show the overall system efficiency (PFC + LLC) of the reference design measured at line input to the output stage at 76 $V_{\text{OUT}}$ and 38 $V_{\text{OUT}}$ respectively.

![Efficiency Chart](image-url)

**Figure 6** Efficiency at $V_{\text{ACIN}} = 230$ V $\text{AC}_{\text{IN}}$
130 W dimmable constant current LED driver using ICL5102 in PFC and LLC topology

Key measurements using LED load

5.4 Power factor vs $P_{\text{OUT}}$

The smart internal digital PFC stage results in a PF higher than 90 percent at 50 percent load, which is achieved at $V_{\text{IN}} = 230 \text{ V AC}$. 

![Power Factor @ 230VACIN](image)

**Figure 7** PF at 230 V AC$_{\text{IN}}$
5.5 THD vs P_{OUT}

Due to the smart THD adjustment via a resistor at the Zero Crossing Detection (ZCD) pin of the ICL5102, a THD below 10 percent at 25 percent load is achieved at $V_{IN} = 230$ V AC.

![Graph showing THD at 230 V AC_{IN}](image)

**Figure 8** THD at 230 V AC_{IN}
5.6 Standby power/ABM

In order to decrease the standby power to a minimum, the ICL5102 has an integrated ABM. The outstanding performance of the integrated burst mode differentiates between four exit cases by using only one pin:

- Exit 1: Load jump during burst sleep (pause)
- Exit 2: Load jump during burst pulse (train)
- Exit 3: Burst pulse train time-out due to high static load
- Exit 4: Burst duty cycle in case of dimming to a certain level, which can be set

During ABM, capacitive load detection and a power limitation are active in order to prevent any malfunction. ABM can be disabled to achieve flicker-free light output.

![ABM: Entry](image1)

![ABM: Pulse train/sleep/PFC activity](image2)

**Figure 9** ABM

**Figure 10** Standby mode

- **Standby = 270 mW** at VAC$_{IN}$ = 90 V/V$_{DIM}$ = 0 V
- **Standby = 300 mW** at VAC$_{IN}$ = 300 V/V$_{DIM}$ = 0 V
5.7 BO detection

The voltage at BO pin 12 must be above $V_{\text{BO}} = 1.4 \, \text{V}$ during monitoring (initial start-up) to enable a BI. If the voltage at this pin drops below $V_{\text{BO}} = 1.2 \, \text{V}$ for longer than 50 ms during operation, a BO is detected and the controller powers down and auto-restarts the internal system. Use a double rectifier and high ohmic resistors for the voltage divider.

5.7.1 BO distortion explanation

The BO detection function of the ICL5102 is based on a DC voltage on pin 12 (BO) that represents the average value of the rectified mains voltage, see Figure 11.

The level at the BO pin becomes incorrect when the half-bridge is not running, at start-up or in RUN mode when a protection shuts off e.g. BO. In both cases, the input diode bridge is not conducting. This causes a Common Mode (CM) voltage from mains to power GND, see the red arrow in Figure 11. It results in a shifting up of the average value of the RMS rectified voltage, see “Common mode distortion” in Figure 11. Note: The peak value stays the same. In order to compensate for this effect place a film capacitor $C_{\text{BO},1}$ from $R_{\text{BO},1}$ (as shown in Figure 11) to power GND.

![Figure 11: Impact of conducting vs non-conducting (distortion)](image-url)
### 5.7.2 BO distortion measurements

The figures below show the rectified mains during start-up on the left-hand side, and RUN mode on the right-hand side.

<table>
<thead>
<tr>
<th>Start-up:</th>
<th>RUN Mode:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change from CM voltage (BR not conducting) supply OFF, into DM voltage (BR conducting) supply ON</td>
<td>Change from DM voltage (BR conducting) into CM voltage (BR not conducting)</td>
</tr>
</tbody>
</table>

![Figure 12 BO distortion measurements](https://arrow.com)
5.8 OTP

The OTP detects the temperature via an external NTC sensor. Figure 13 shows the operation of the OTP. If the voltage $V_{OTP1}$ is less than 703 mV during start-up, the controller prevents a power-up. If the voltage at pin 11 drops below $V_{OTP2} = 625$ mV during RUN or burst mode, the IC powers down and auto-restarts when it rises above $V_{OTP1} = 703$ mV. Delay in both cases is 620 µs, and the typical current sourced by this pin is $I_{OTP} = 100$ µA. In order to disable OTP connect a 20 k resistor from pin 11 to GND.

![Over Temperature Detection](image)

**Figure 13** OTP

*Note: If OTP is disabled, do not set a capacitor parallel to the 20 k resistor to GND. This would lead to a malfunction during ABM. For OTP use an NTC and a capacitor less than 47 nF from pin 11 to GND, as shown in Figure 14.*
5.8.1 Board hot spot

The board was tested around the temperature hub at the corner cases. The ambient temperature was $T_a = 25^\circ C$, $I_{out} = 1.75$ and a mains voltage at 230 V. Figure 15 shows the thermal behavior of the evaluation board with a hot spot.

Figure 15 Hot spot on board
5.9 Surge protection

Description of SURGE protection

In case of a surge event, the voltage at the BUS capacitors C5 and C8 increases, and the driver stages of the ICL5102 are shut off when $V_{bus}$ is greater than 115 percent for longer than 50 ms. After the surge, the controller restarts automatically when $V_{bus}$ drops below 109 percent of the rated voltage. This feature allows for driving 500 V MOSFETs at the half-bridge stage when adequate EMI and DC-link networking is present.

5.10 Harmonics according to IEC EN 61000-3-2

![Harmonics graph](image)

**Figure 16** Harmonics according to EN 61000-3-2 Class C
130 W dimmable constant current LED driver using ICL5102 in PFC and LLC topology

Key measurements using LED load

5.11 EMI measurement

5.11.1 Filter design

In Figure 17 you can see the line input filter, which is optimized for EMI according to EN 55015 and meets the harmonics according to EN 61000-3-2 Class C.

![Line input filter](image)

Figure 17 Line input filter

5.11.2 Conducted EMI measurement according to EN 55015

![Conducted EMI measurement](image)

Figure 18 Conducted EMI measurement according to EN 55015
130 W dimmable constant current LED driver using ICL5102 in PFC and LLC topology

Magnetic power specification

6 Magnetic power specification

6.1 CM choke specification L1 and L2

For the line input filter, standard CM choke 2 × 5.0 mH/2.5 A from Würth Elektronic, part number 744 8233 05, is used.

![CM choke specification L1 and L2](image)

Figure 19 CM choke L1 and L2
6.2 DM choke specification L5

For the line input filter, standard DM choke 360 µH/130 Ω/180 µH typ./1000 V from Würth Elektronic, part number 750 3157 55, is used.

**Electrical Specifications @ 25°C unless otherwise noted:**

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<tr>
<th>Parameter</th>
<th>Test Conditions</th>
<th>Value</th>
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<tr>
<td>DC Resistance</td>
<td>1-2</td>
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<tr>
<td>Inductance</td>
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<td>45Vrms, 1.07A, 1x</td>
</tr>
<tr>
<td>Inductance</td>
<td>1-2</td>
<td>450Vrms, 2.5A, 1x</td>
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<tr>
<td>Dielectric</td>
<td>1-cap</td>
<td>1000VAC, 1 second</td>
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![Diagram of DM choke L5](image-url)
6.3 PFC choke specification L6

For the PFC stage, a standard PFC choke with 360 µH inductance from Würth Elektronic, part number 750 343180 Ref. 1, is used.

Figure 21 PFC choke L6
6.4 LLC resonant choke specification L7

As resonant choke for the LLC resonant tank, a choke with 160 µH inductance from Würth Elektronic, part number 750 3428 05 Rev. 4, is used.

![LLC resonant choke](image-url)
6.5 LLC transformer specification TR1

As the main magnet for the LLC topology, a transformer with 1.5 mH inductance from Würth Elektronik, part number 750 3428 86, is used.

![LLC transformer diagram]

**Figure 23** LLC transformer
130 W dimmable constant current LED driver using ICL5102 in PFC and LLC topology

Board layout

7 Board layout

Figure 24 Layout (bottom view)

Figure 25 Assembly print (top view)
### 8 BOM

<table>
<thead>
<tr>
<th>Designator</th>
<th>Type</th>
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**Notes:**
- **ICL5102** used in PFC and LLC topology.
- **130 W dimmable constant current LED driver.**

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**Diagrams and Additional Notes:**

- [Diagram of BOM](https://example.com/diagram)
- [Footnotes and Additional Details](https://example.com/footnotes)
### 130 W dimmable constant current LED driver using ICL5102 in PFC and LLC topology

**BOM**

<table>
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<th>Designator</th>
<th>Type</th>
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<th>Manufacturer/PartNumber</th>
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<td>CRC0805FR-0720K</td>
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130 W dimmable constant current LED driver using ICL5102 in PFC and LLC topology

## Revision history

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<th>Document version</th>
<th>Date of release</th>
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<td>V1.1</td>
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