43 W PFC-SSR flyback demo board with ICL88xx

Flyback IC for lighting applications

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Scope and purpose

Two-stage topologies are growing in popularity because of the convenient scalability of power on the primary side as well as the features on the secondary side. High light quality, very low dimming levels, and more complex systems with sensors and MCUs require a stable output voltage enabled by constant voltage (CV) secondary-side regulated (SSR) topology. More stringent standards for flicker and total harmonic distortion (THD) as well as harmonics are also points in favor of SSR topology. The controller used in SSR configuration is suitable for on/off LED drivers and is the best solution for minimum dimming levels down to 0.1 percent and dim-to-off.

Intended audience

Engineers interested in using ICL88xx as SSR high power factor (PF) flyback with CV output.

Table of contents

1 Introduction

SSR is the best-fit topology for on/off LED drivers and drivers with minimum dimming down to dim-to-off. The main difference between SSR and primary-side regulation (PSR) topology is based on the fact that in the PSR system the main channel secondary-side output voltage is measured indirectly on the primary auxiliary supply winding. This means the coupling between the main secondary and auxiliary windings does affect the regulation accuracy. In contrast, the SSR system directly measures the output, which makes the transformer design easier and less complicated. For the best THD and PF performance the crossover frequency of the feedback loop should be in the range of 5 to 20 Hz. If the crossover frequency is too low, the feedback reaction would be very slow, making it unsuitable for dynamic load changes such as sudden load loss. At the same time, a lower crossover frequency improves THD. It's a compromise between feedback reaction and iTHD. But, if a faster load-jump-dependent loop is required, a fast path can be easily added to the existing feedback loop.

For the secondary-side overvoltage protection (OVP) it is necessary to say that it has a 10 percent tolerance over the production and temperature range; this fact must be considered during the design of the driver. If the overvoltage level is too close to the normal operation voltage, it may lead to accidental triggering of the protection during fast load changes, especially at high input voltages. Here the feedback loop is too slow to react to a sudden load loss, and it can't control the output voltage within the very tight limit anymore. The converter will therefore move to hiccup oscillation. The OVP level must have a proper margin. If it's mandatory to improve regulation accuracy, there are a few options:

- To use a dynamic feedback or dynamic bleeder, which is active only when the voltage reaches a certain point. This adds some complexity and increases cost.
- To increase the size of the output capacitor.

If only dimming to 5 to 10 percent is required and a larger output voltage tolerance (3 to 5 percent) is acceptable then it might be possible to go for a PSR design, where the system costs are lower compared with the SSR solution. The ICL88xx family can be used with all the features in the SSR system as well as the PSR topology. More information about the PSR solution can be found in the **Engineering Report of the PSR reference design**.

As a default setup, the reference design board is assembled with a start-up circuit based on a depletion mode MOSFET BSS126i on a very small adapter board. After the first start, the IC is then supplied from the auxiliary winding and the start-up circuit is disabled. This setup offers the lowest standby losses. If low standby consumption is not necessary as an option, the start-up circut can be changed to a resistive start-up. Here only the resistor R35 in the main schematic (**Figure 2**) with 0 Ω and a protective Zener diode with 22 V needs to be added while the daughterboard gets removed.

This reference design is provided with two regulation circuits. Both circuits are designed as plug and play solutions, but at least one has to be connected to the main board.

The two boards shall show the trade-off between cost; here the TL431 board offers the cheaper solution, and standby performance, while the op-amp board shows an overall 30 mW better performance.

ICL8800 is a family member, which is cost-optimized and can be perfectly used for on/off drivers and dimming down to 5 percent, as shown in **Figure 29**.

ICL8810 is a family member with the burst mode (BM) feature. This helps to control the output voltage quite accurately down to a very low output power level and dim-to-off operation. After the limit of ICL8800 shown in **Figure 28**, the IC moves gradually to BM, as shown in section 7.3, and finally to the standby mode shown in **Figure 36**.

ICL8820 is a family member with a BM and jitter feature. In addition to the BM, this IC offers a jitter function during DC operation. This helps to pass the EMI requirements for DC operation, required for the emergency lighting system. This behavior is shown in sections 7.4 and 11.2.

2 Specifications

Input and output specifications of the ICL88xx PFC-SSR flyback demo board are shown in the table below.

Table 1 Design specifications

Specification	Symbol	Value	Unit
Maximum AC input voltage	V AC	90 to 305	V_{rms}
Normal operational AC input voltage	$V\ AC_{max}$	100 to 277	V_{rms}
Normal operational AC input frequency	F_{line}	47 ~ 63	Hz
Secondary-side regulated CV output set-point	$V_{out,setpoint}$	54	V
Steady-state output load current	I_{out}	0 ~ 800	mA
Steady-state full-load output power	$P_{out,full}$	43.2	W
Minimum efficiency at $P_{out,full}$	$\eta_{min,at,P,out,full}$	91	%
Target minimum switching frequency at $P_{out,full}$	$f_{sw,min,at,P,out,full}$	52	kHz
Minimum load for ICL8800		10 percent at 277 V AC/ 5 percent at 230 V AC/1.5 percent at 120 V AC	
Standard compliance			
Harmonics	–	EN 61000-3-2 class C	–
EMI	–	EN55015	–
Board dimensions			
Size	L x B	Main board: 171 x 27	mm
Size	L x B	PlugIN-TL: 36.5 x 27	mm

3 Connections

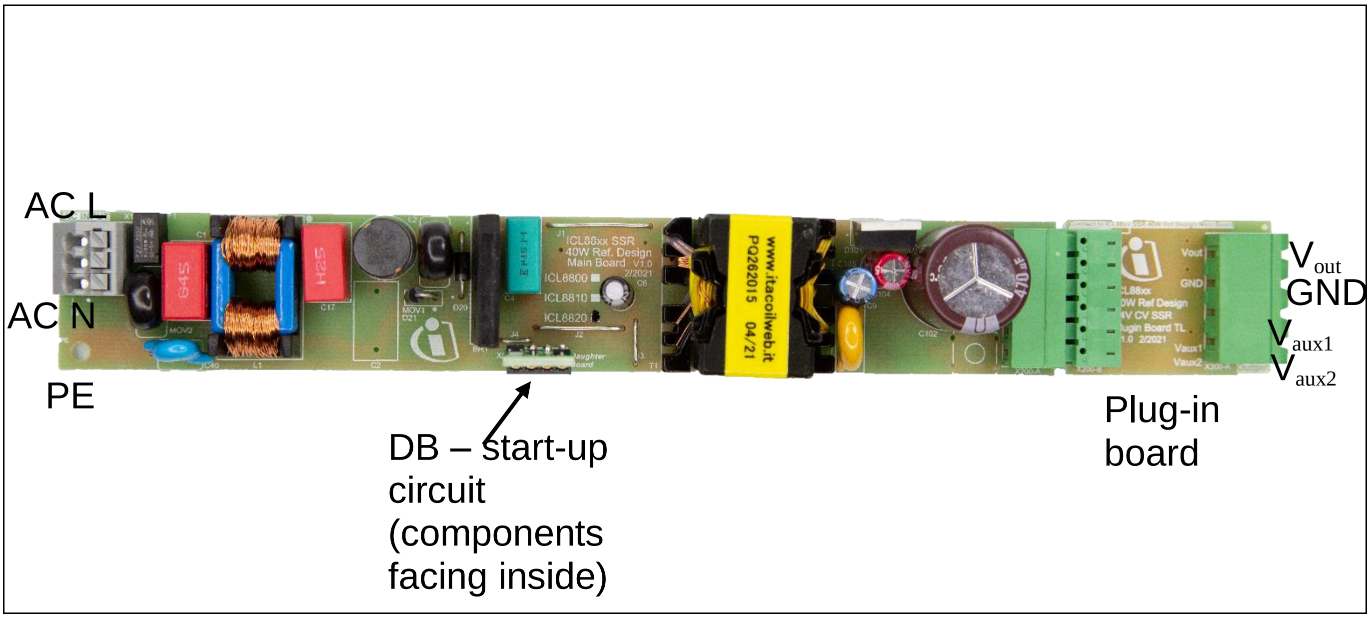


Figure 1 Top side with connections

4 Schematics

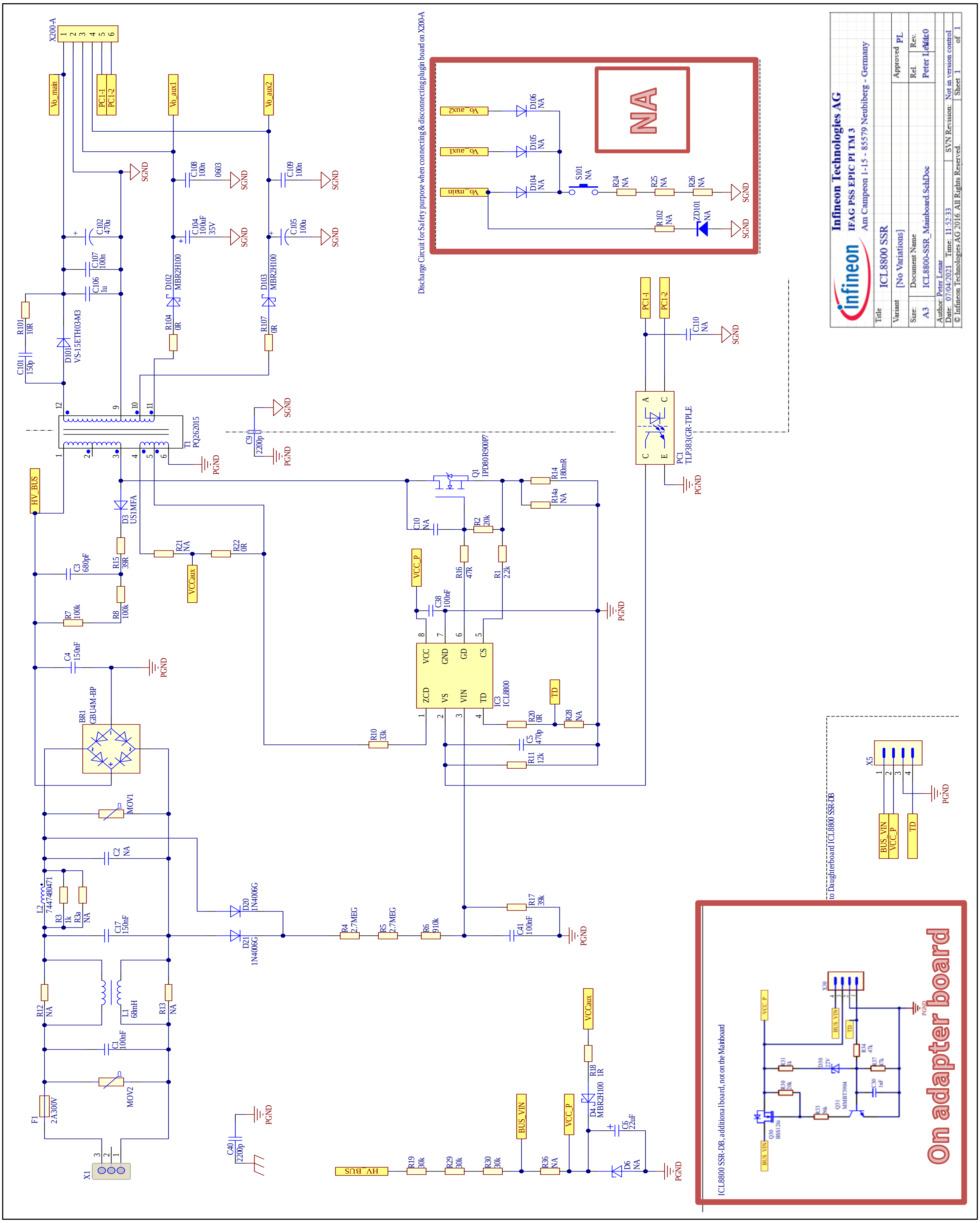


Figure 2 Schematic of the ICL88xx PFC-SSR flyback demo board

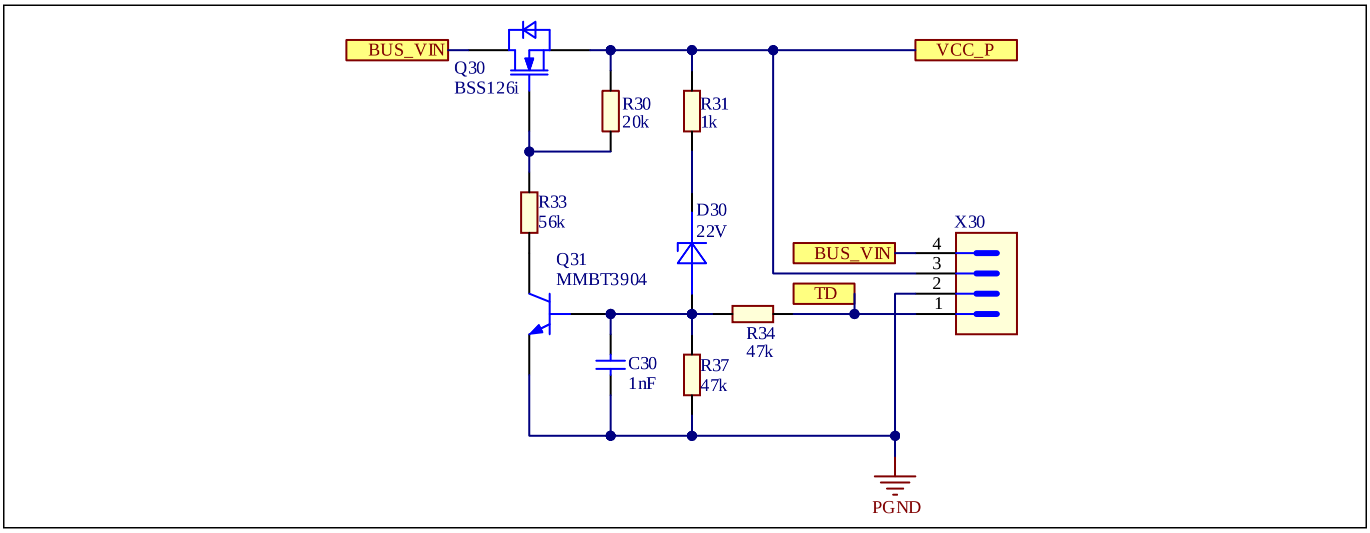


Figure 3 Schematic of the daughterboard with start-up circuit

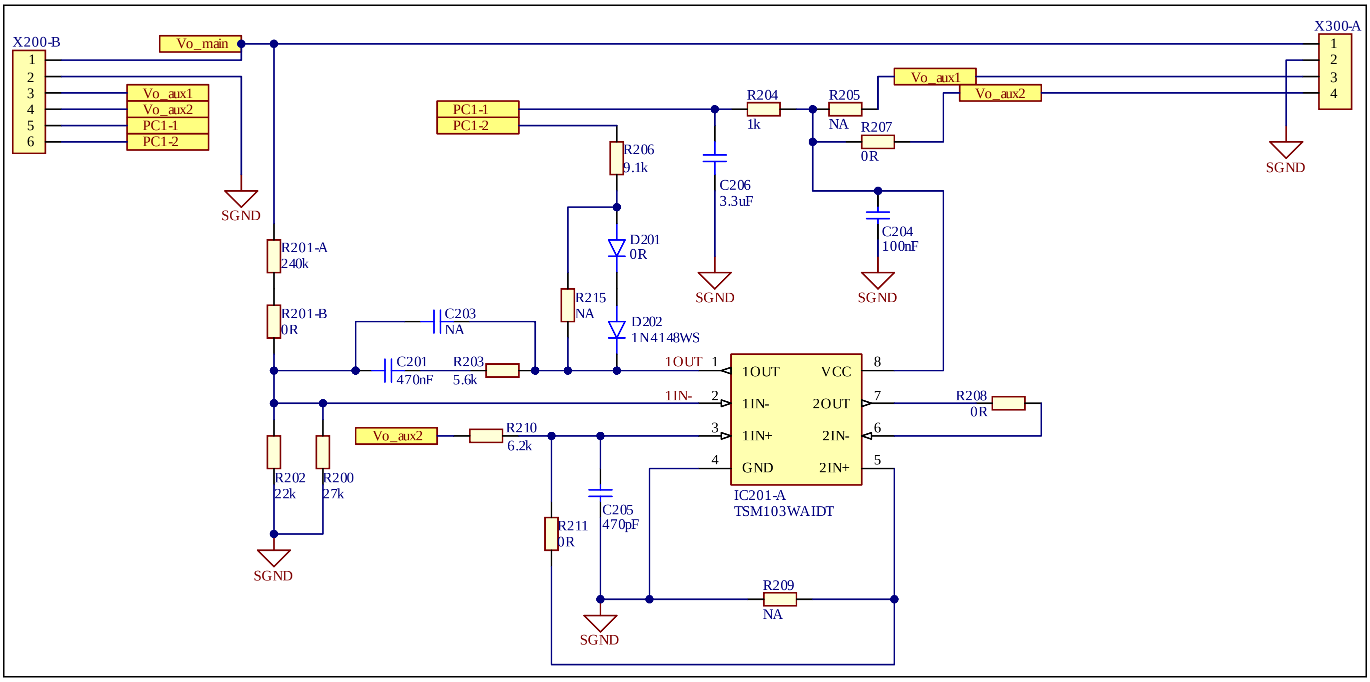


Figure 4 Schematic of the op-amp plug-in board with the feedback loop

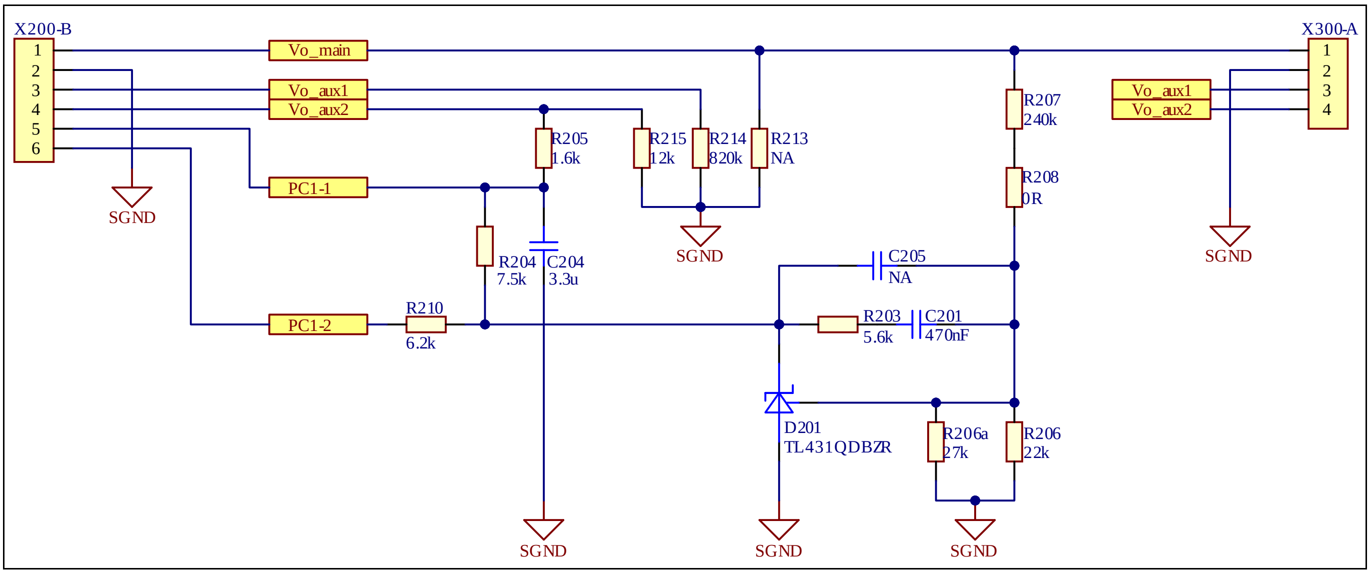


Figure 5 **Schematic of the TL431 plug-in board with the feedback loop**

5 Layouts

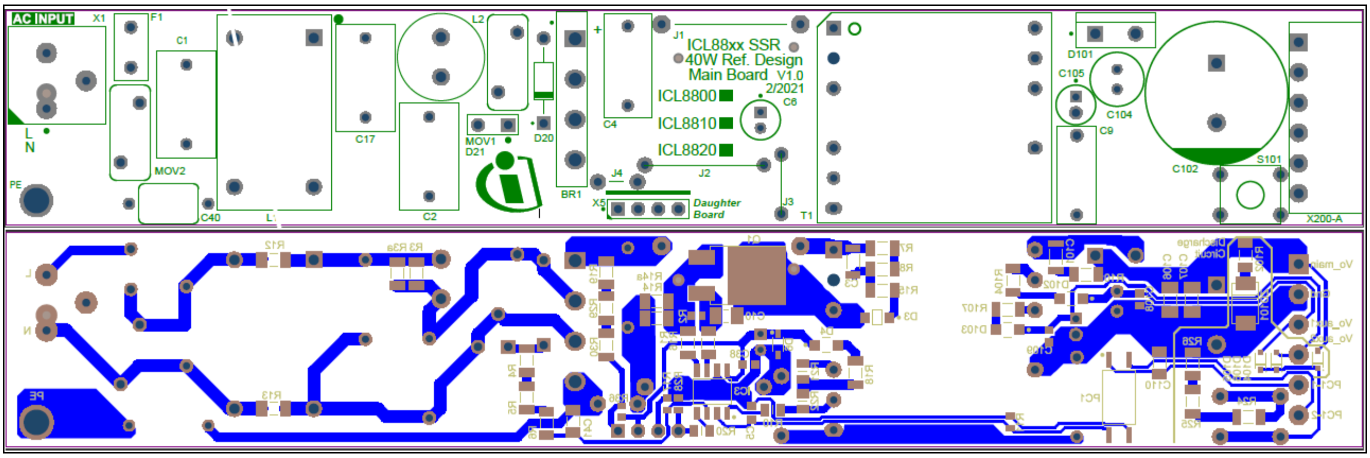


Figure 6 Layout of the top and bottom side of the main power board

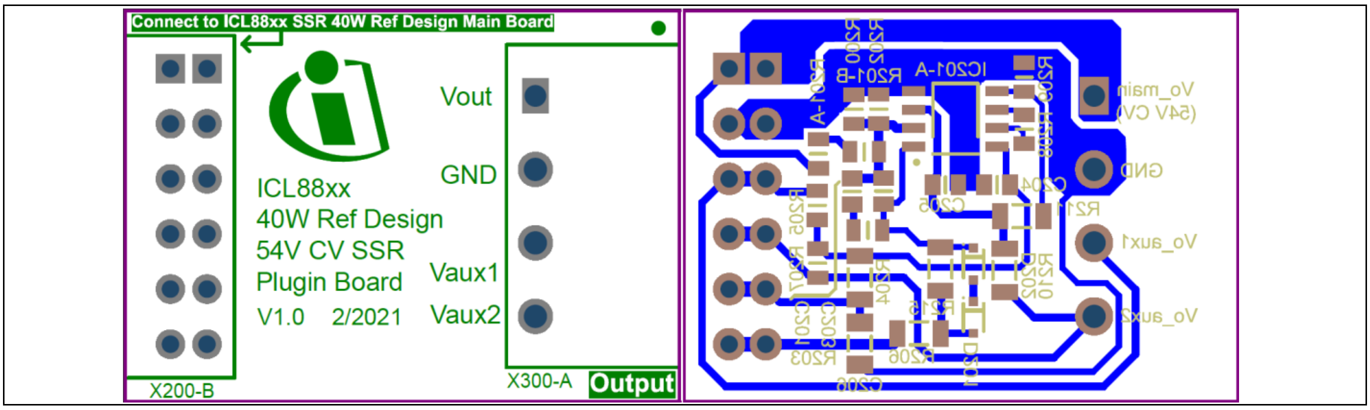


Figure 7 Layout of the op-amp regulation plug-in board

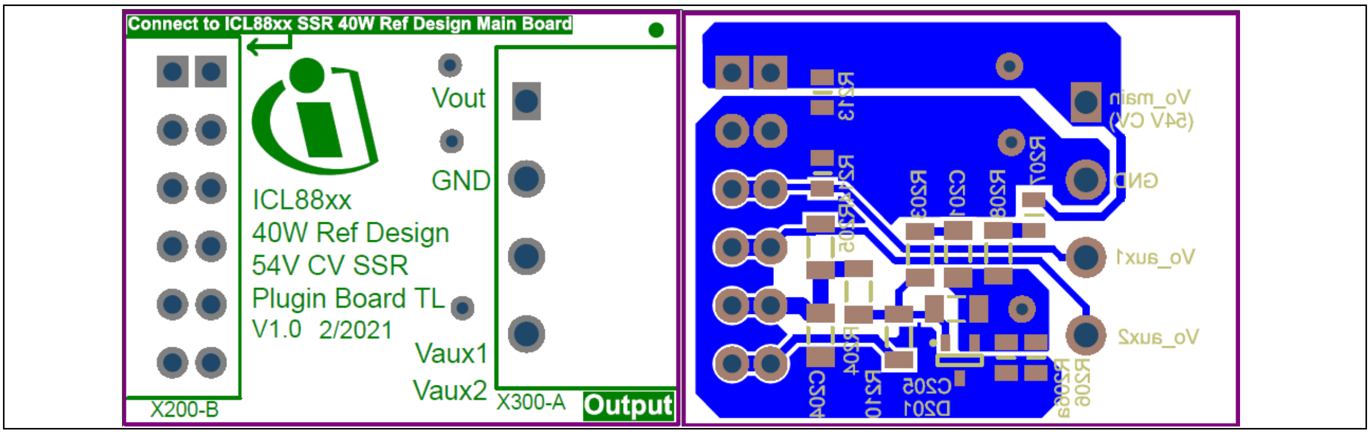


Figure 8 Layout of the TL431 regulation plug-in board

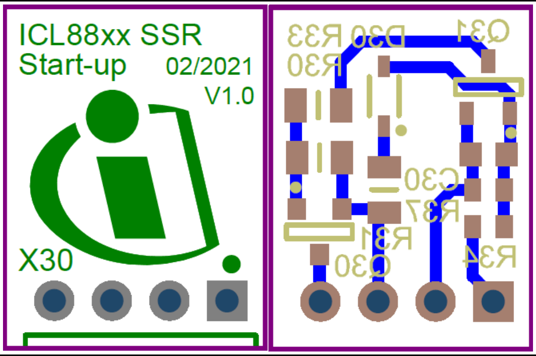


Figure 9 Layout of the start-up board

6 Board combinations

Based on the markings on the top side of the board, a different IC out of the ICL88xx family is assembled. The ICs and the boards can be changed without any additional measures. Based on the selected IC, different features are built in.

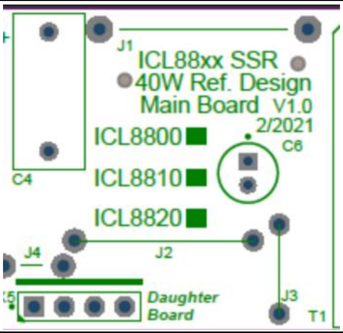


Figure 10 The soldered-in IC is marked on the powerboard's top side

6.1 Start-up options

As described earlier, the board offers two options for start-up. The resistive circuit is cheap but has constant losses, which are dependent on the input voltage. It is perfect for on/off drivers and dimmable drivers without standby requirements.

The active start-up circuit can provide faster charging of the V_{CC} capacitor. The biggest advantage is the controllable resistive path. In that way the losses are only present during start-up, and if the V_{CC} gets too low. This option is most suitable where standby losses matter.

If testing without the start-up board, the start-up resistors have to be increased to around 200 kΩ, and R36 has to be added, and D6 with 22 V has to be added. This start-up board has to be unplugged.

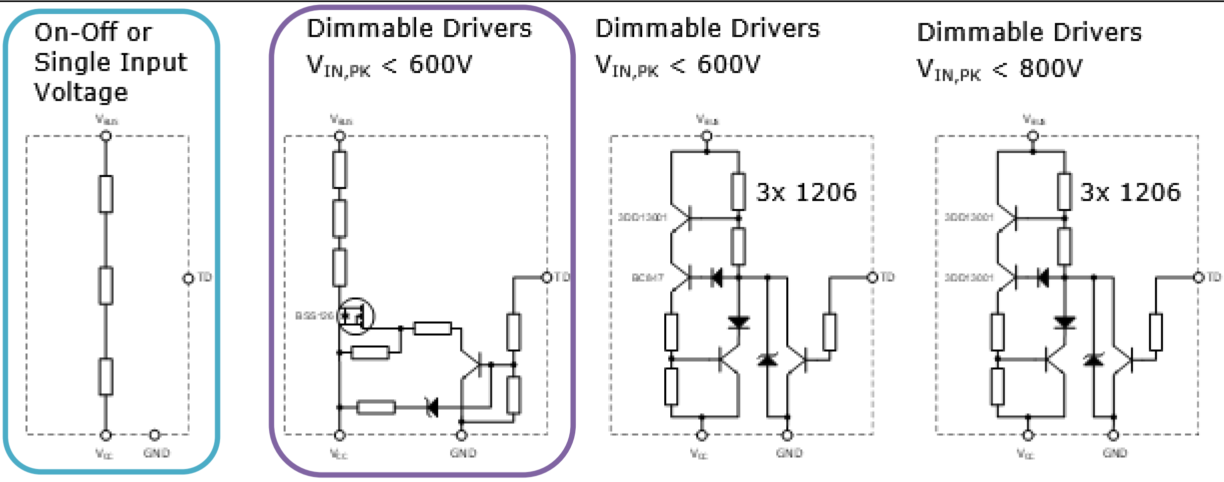


Figure 11 A selection of start-up options

6.2 SSR circuit

Here, again, two options are offered. The TL431 is the simpler circuit but has higher losses due to the minimum current for the TL431 in order to stay operational.

The choice is between low-cost higher standby losses, and higher-cost better standby performance.

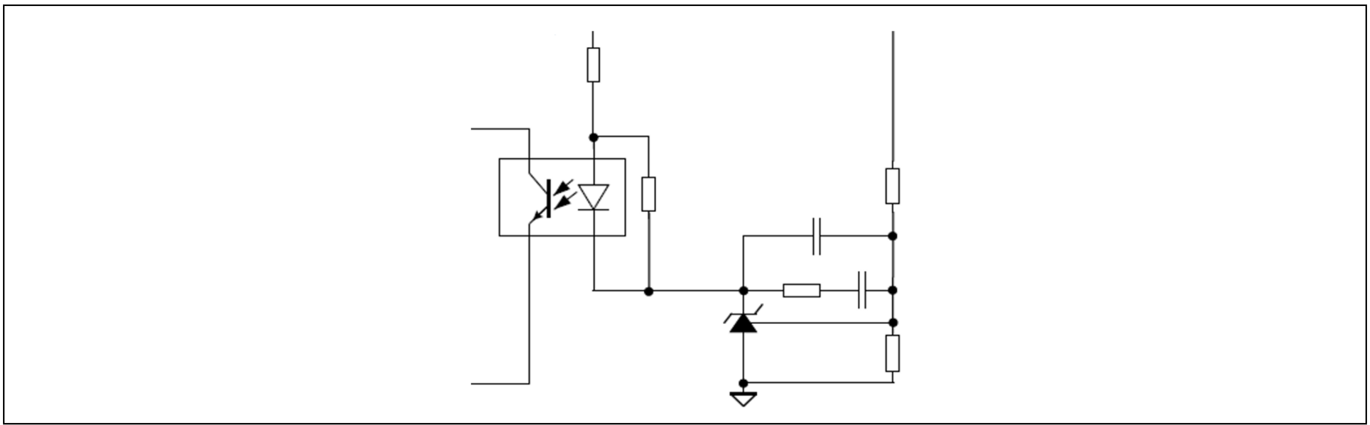


Figure 12 TL431 circuit

On the other hand, the op-amp with integrated voltage reference offers the best standby performance.

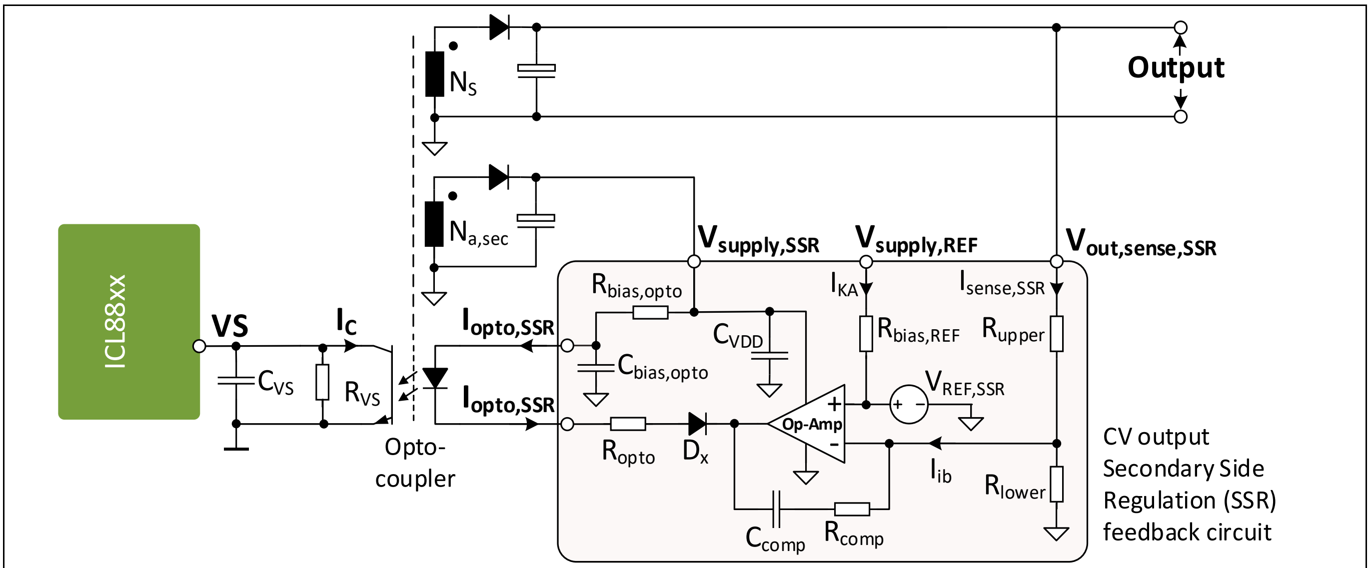


Figure 13 Op-amp circuit

Both circuits have their advantages and downsides, and there is no general answer to which circuit is the best. It always depends on the input and output specifications, the focus on cost or performance, and the availability of components.

For test purposes, both boards can be used as plug and play.

Attention: ***Make sure the ouput capacitor is discharged and the AC mains voltage is turned off before changing the feedback board. To make the process easier, the footprint of a discharge circuit is already added on the main PCB. After assembling it the ouput capacitor can be safely discharged by the push of a button.***

7 Performance

7.1 Performance with op-amp

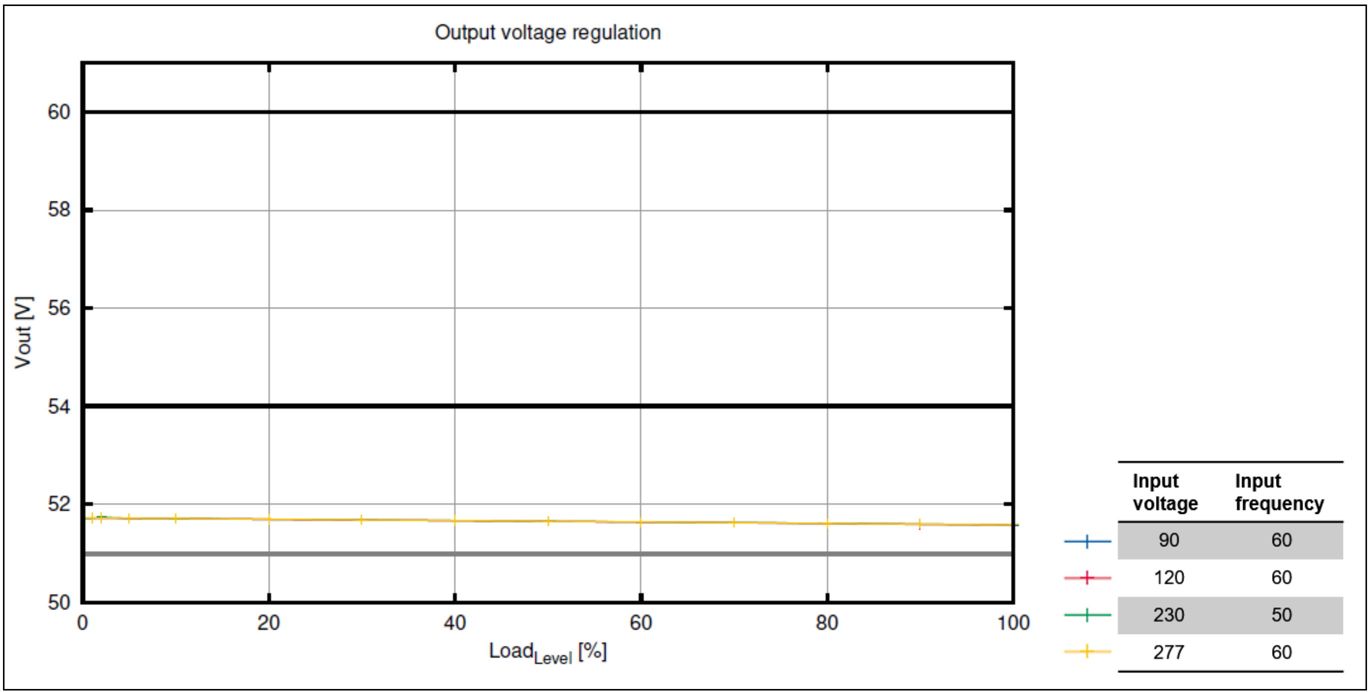


Figure 14 V_{out} regulation

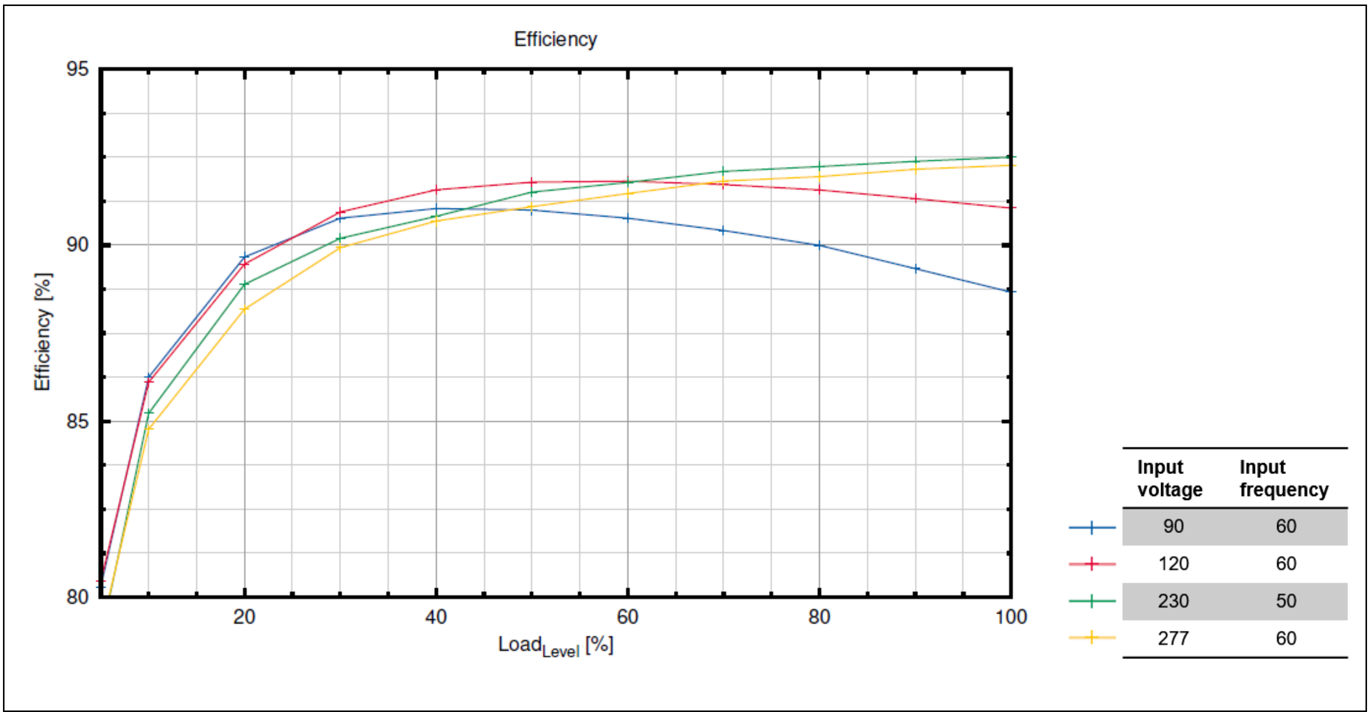


Figure 15 Efficiency

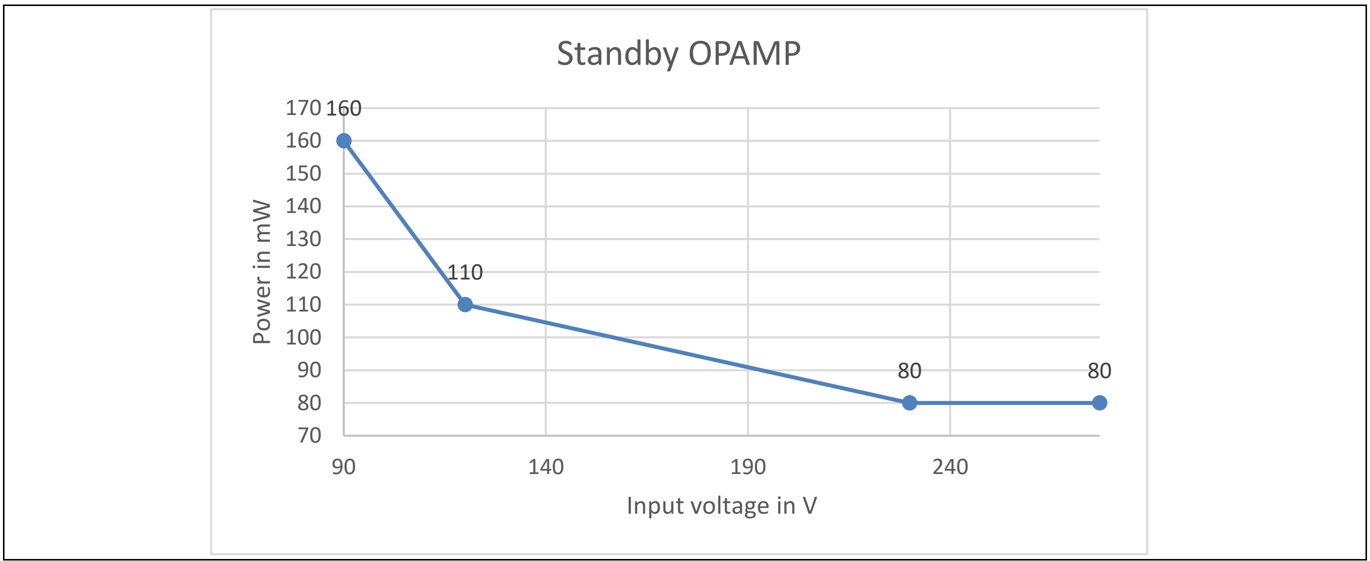


Figure 16 No-load input power

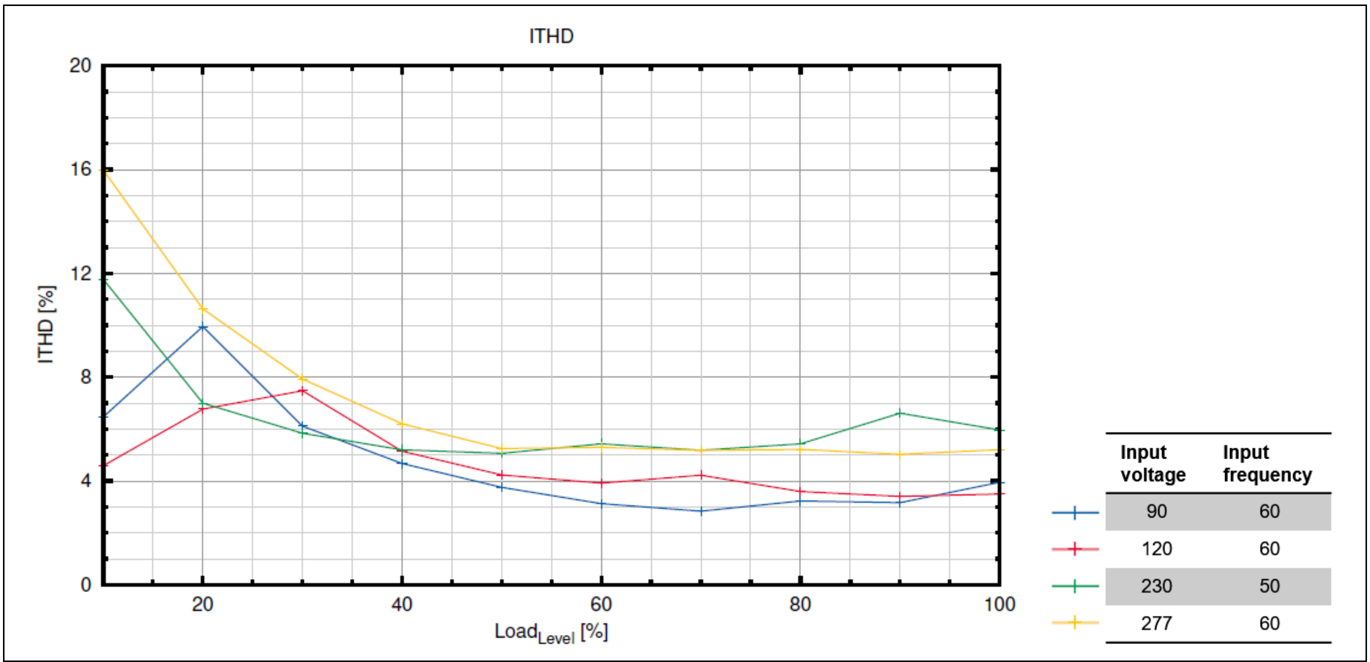


Figure 17 THD measurement

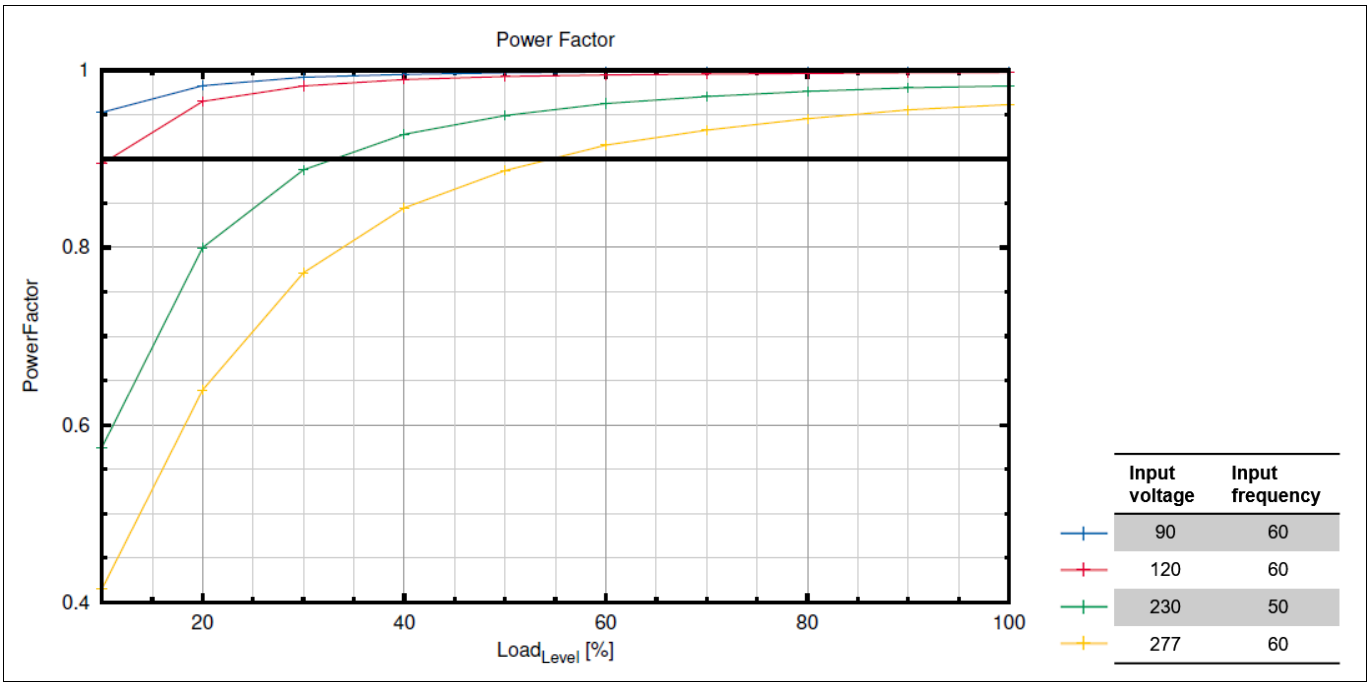


Figure 18 **PF measurement**

7.2 Performance with TL431

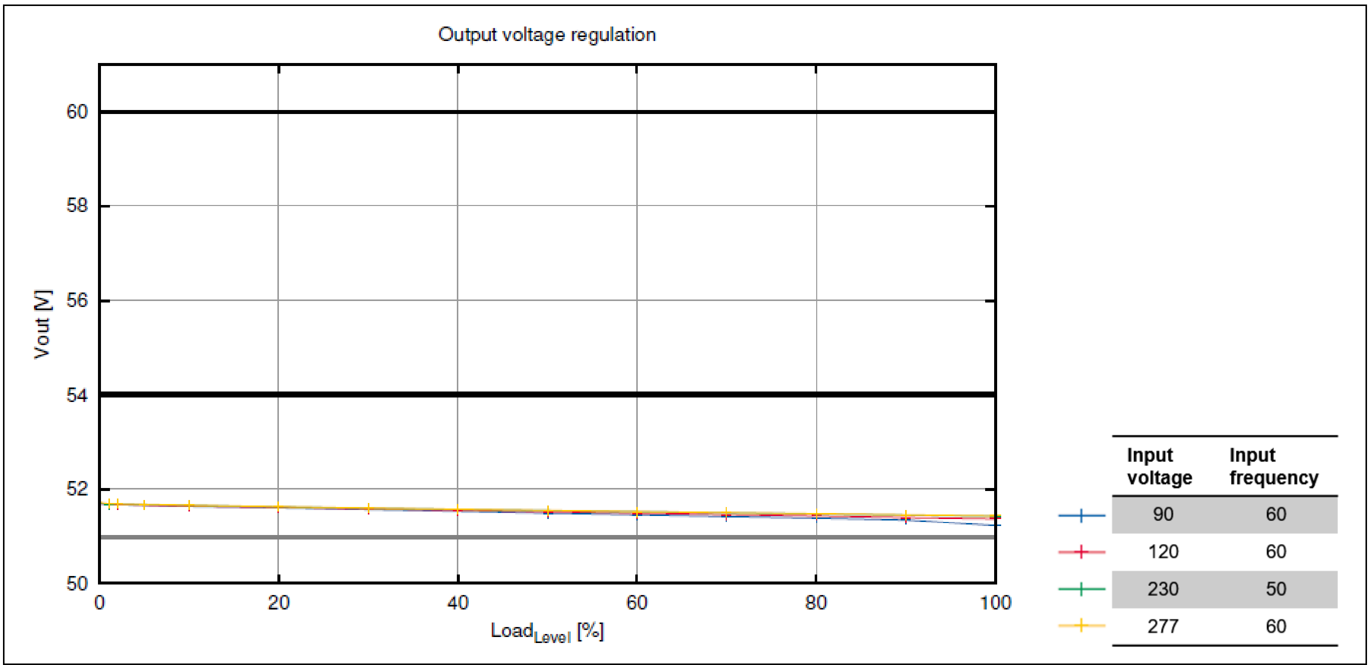


Figure 19 **V_{out} regulation**

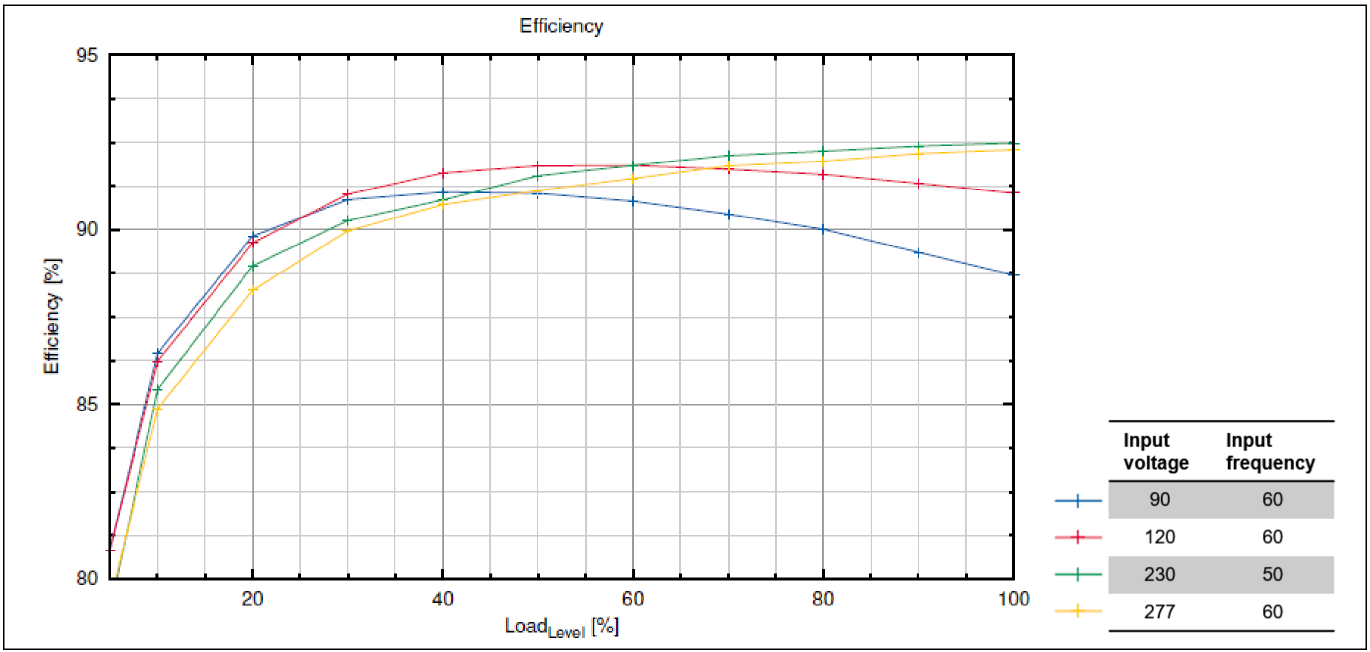


Figure 20 **Efficiency**

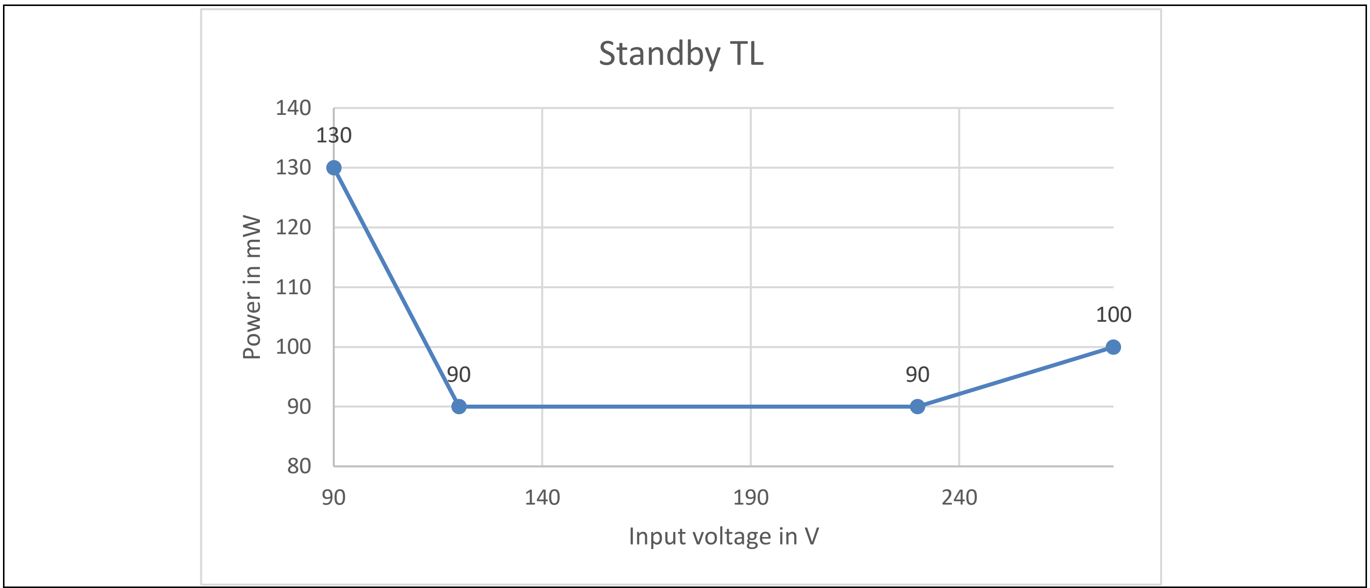


Figure 21 **No-load input power with a very low current optocoupler optimized for efficiency**

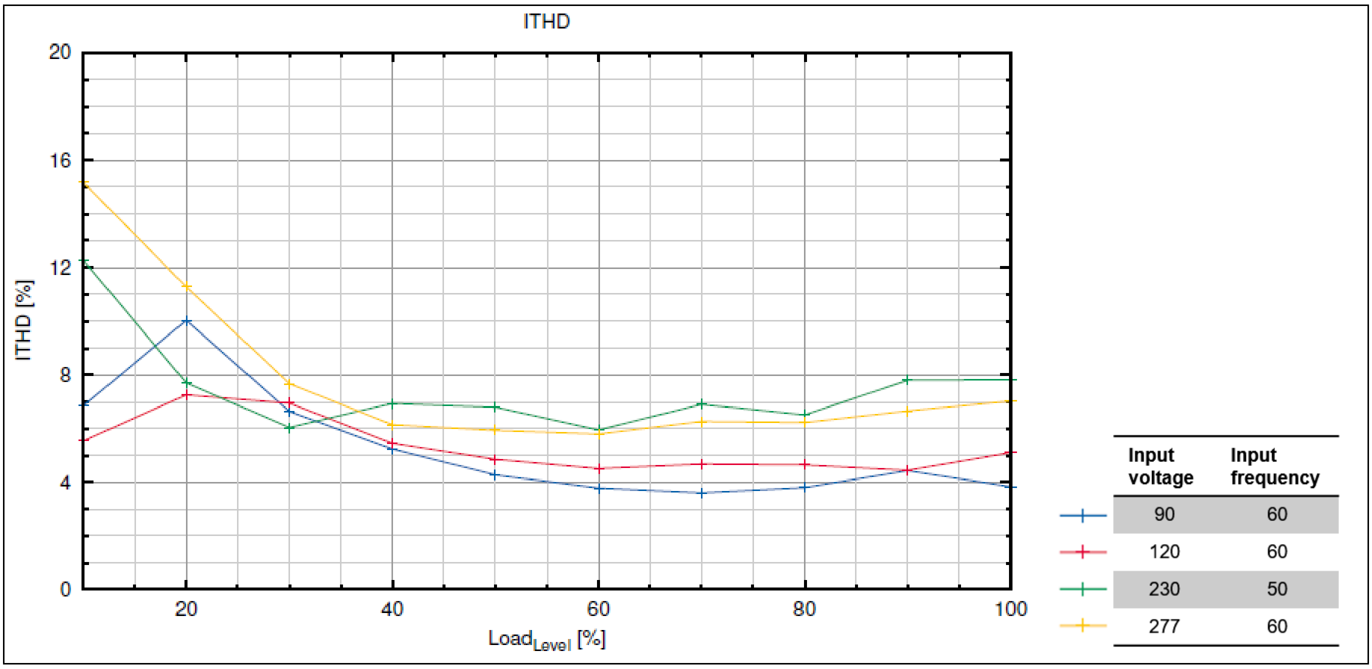


Figure 22 THD measurement

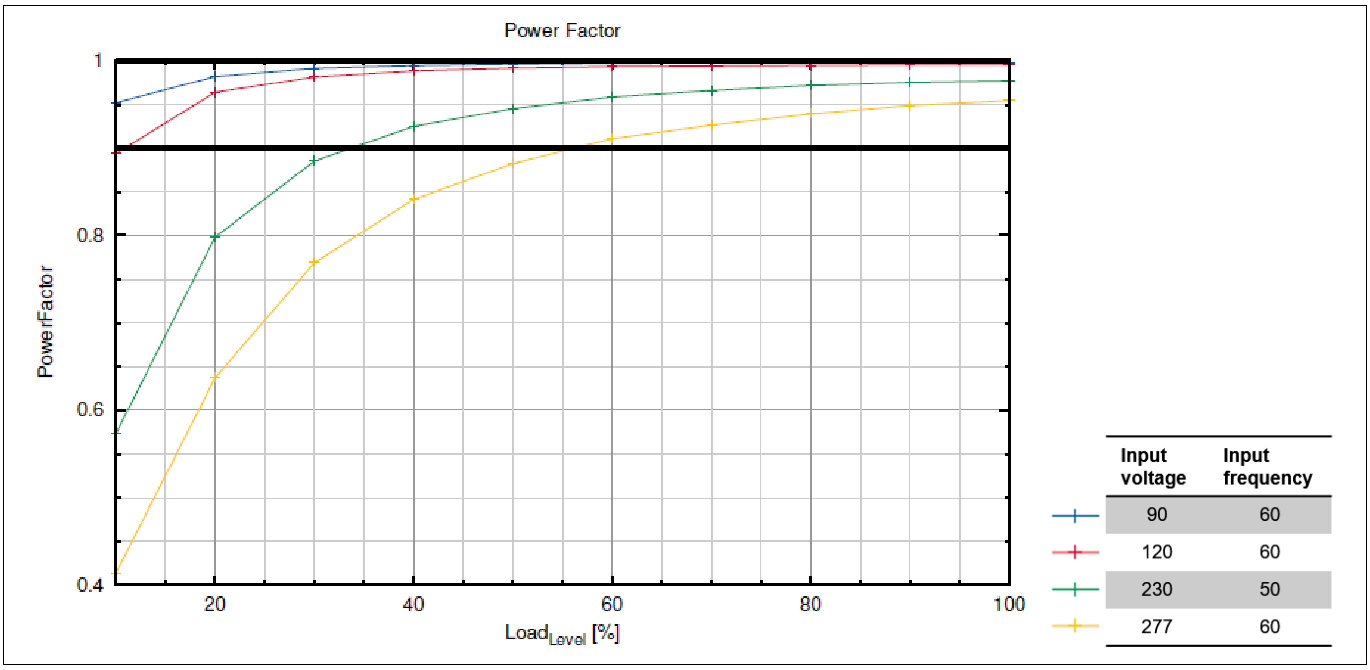


Figure 23 PF measurement

8 Key waveforms

8.1 Start-up

This part shows the start-up behavior of the driver at various input voltages and loads.

The V_{CC} pull-up resistors and V_{CC} capacitor are selected such that the start-up time in the worst case is less than 200 ms.

In order to save energy and make the design-in easier, the gate voltage is reduced during start-up.

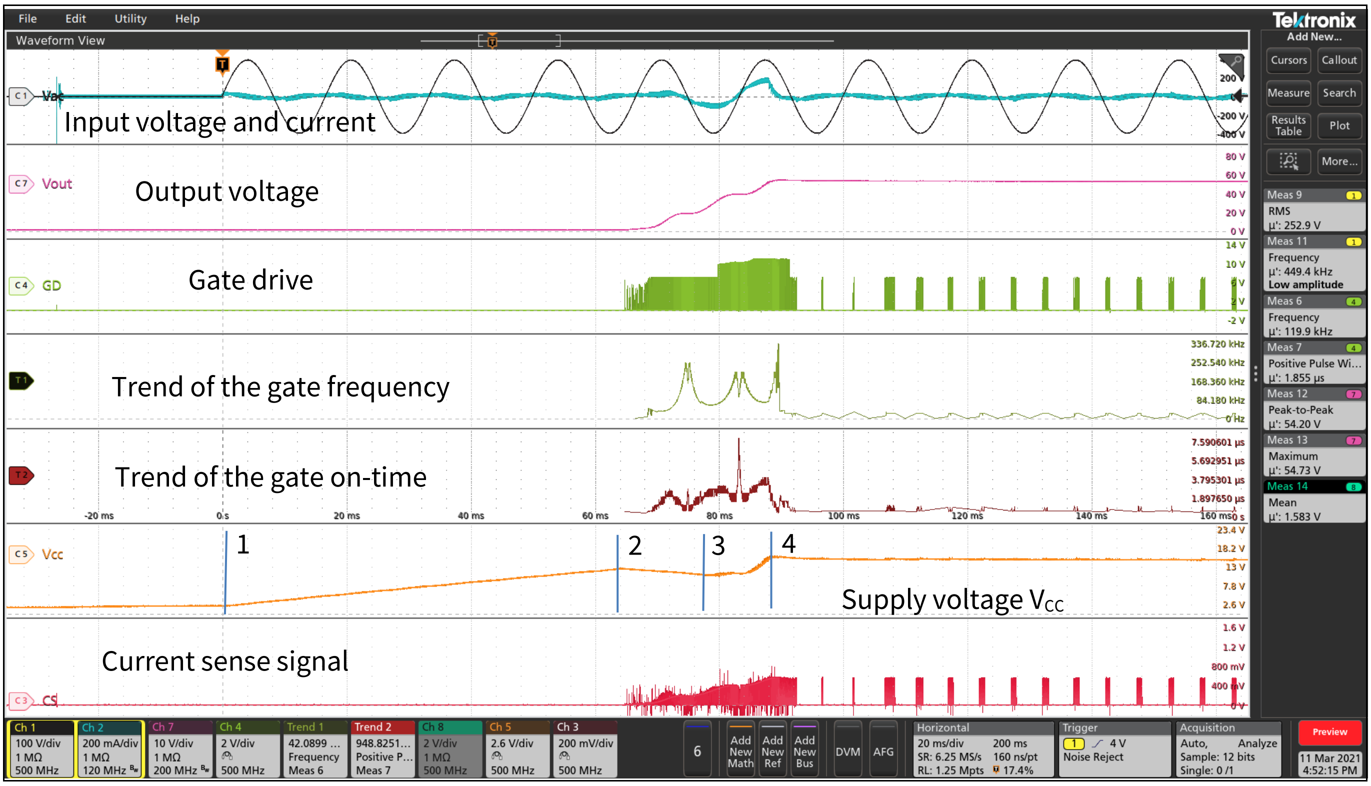


Figure 24 Start-up at 277 V at no load

Table 2 Self-supply during start-up referring to Figure 24

Section	Explanation
1	Start of the AC input voltage and start of the V_{CC} capacitor charging
2	Start of the IC, supply only from the V_{CC} capacitor
3	Auxiliary winding delivering power to the V_{CC} capacitor
4	Normal operation with self-supply

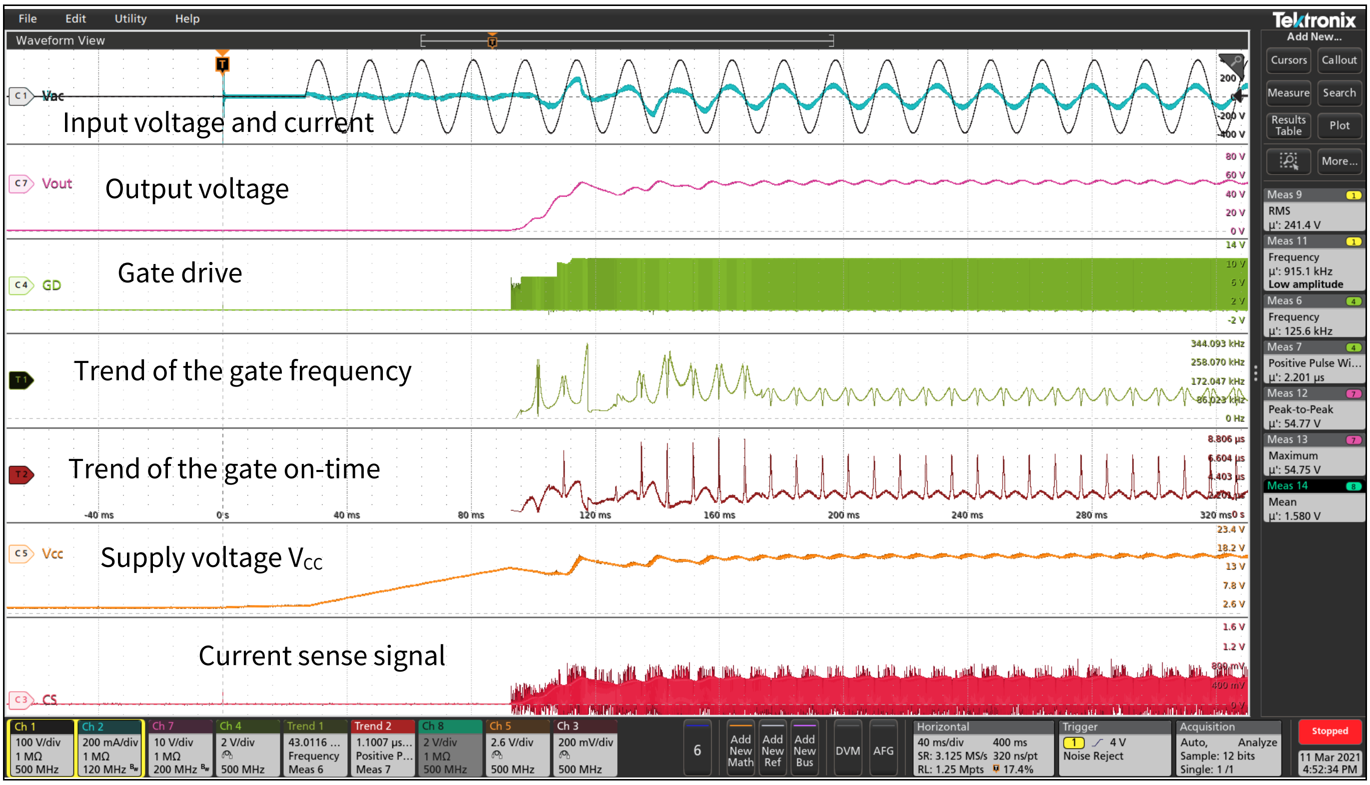


Figure 25 Start-up at 277 V at full load

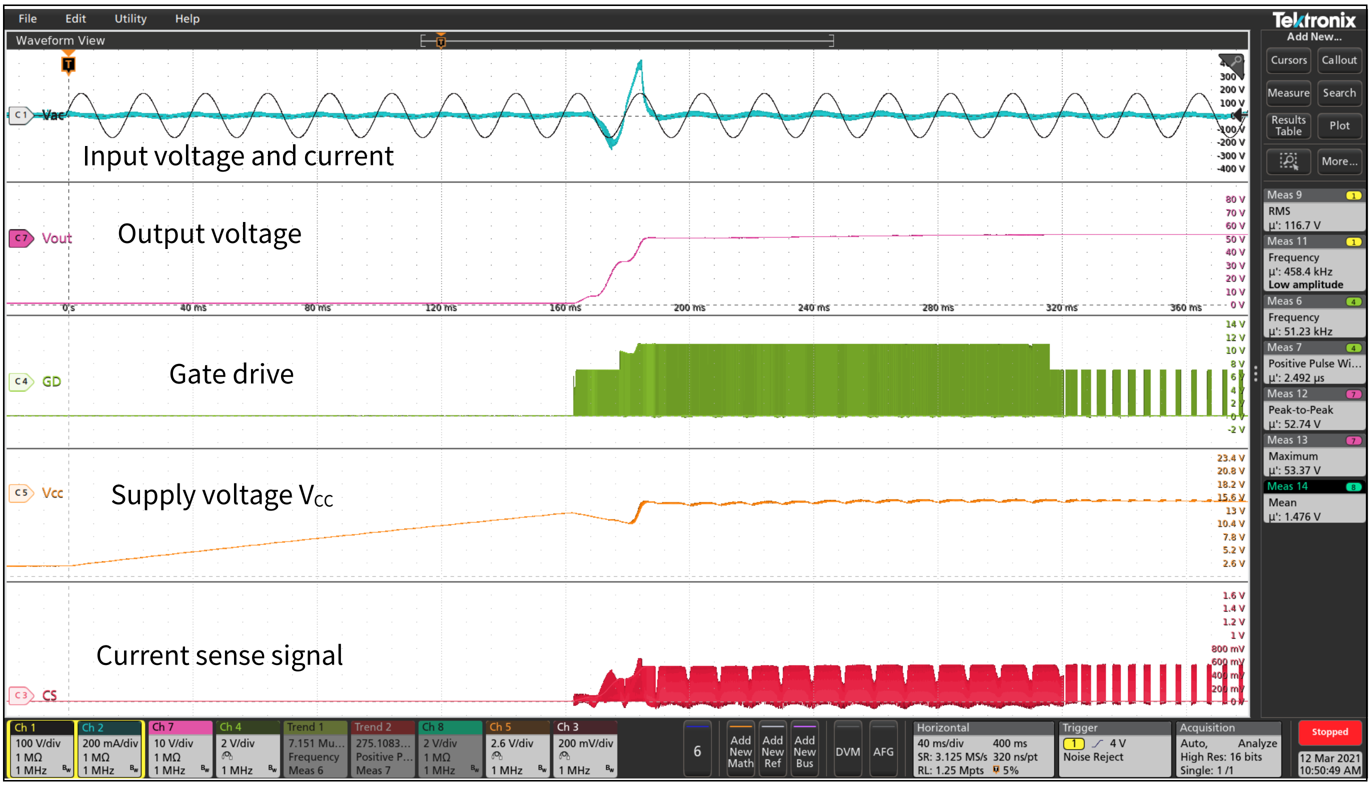


Figure 26 Start-up at 120 V at no load

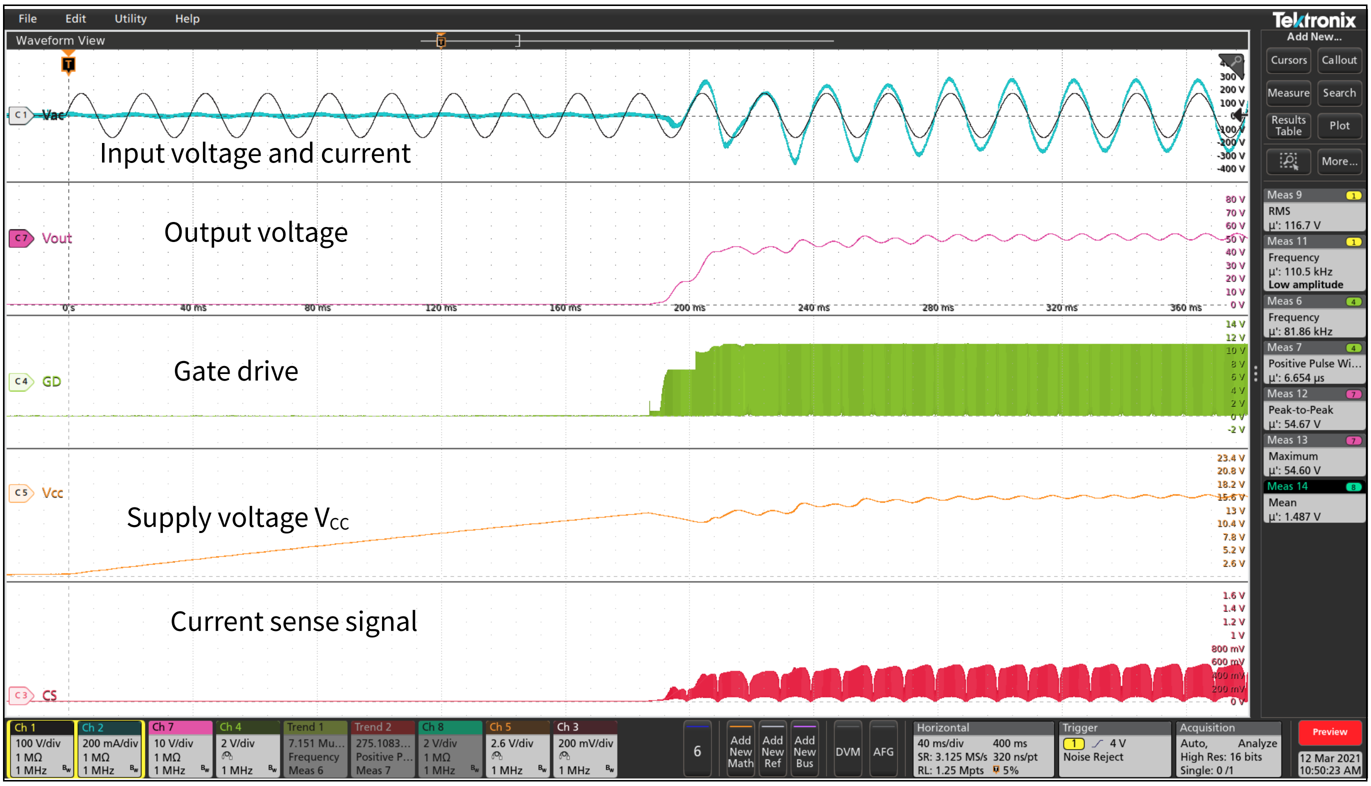


Figure 27 Start-up at 120 V at full load

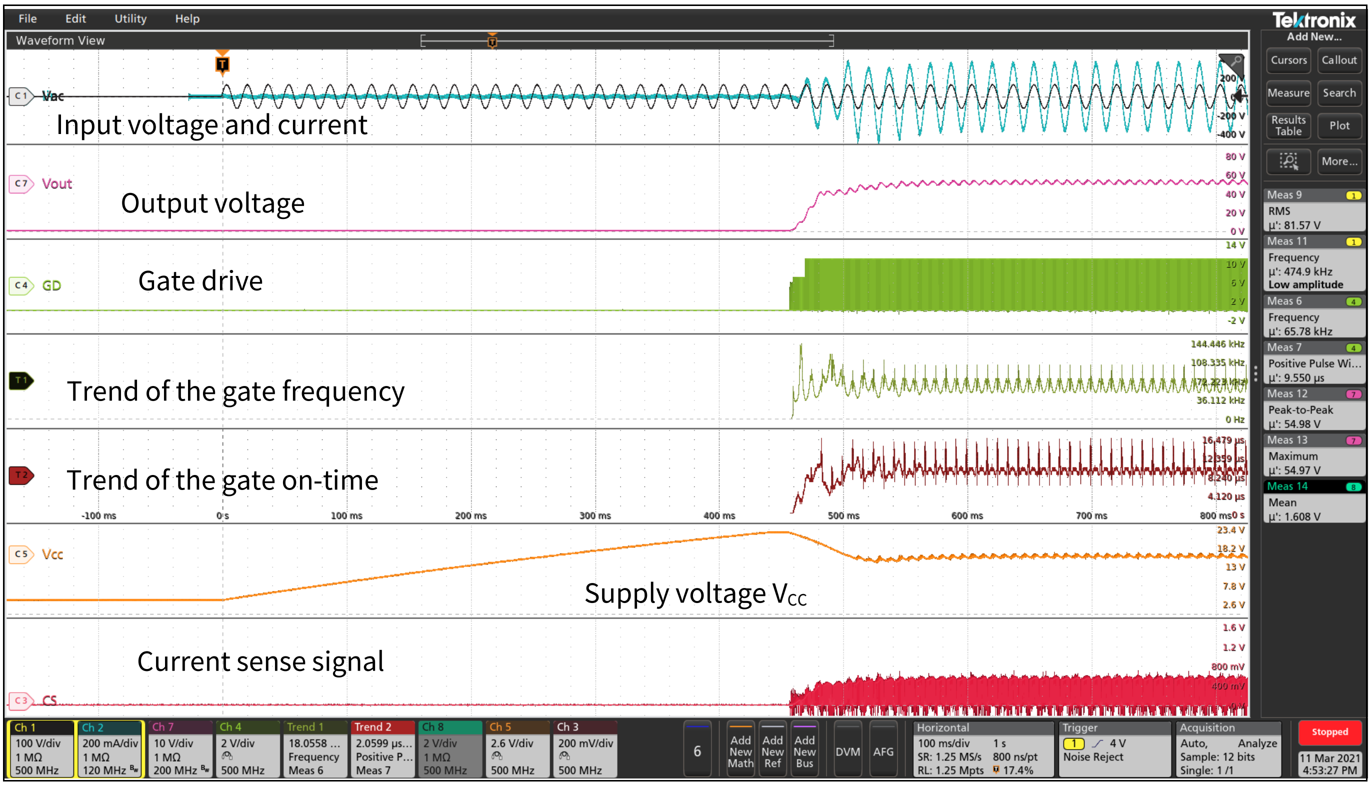


Figure 28 Start-up at 90 V at full load, delay due to V_{in} pin averaging

Because the input voltage is internally averaged, it may result in delayed start-ups close to the brown-in voltage.

8.2 Steady-state

This chapter shows the switching waveforms in steady-state operation.

Because the ICL8800 has no BM and the minimum on-time is limited, the output voltage will rise to the output OVP if the lowest power limit is reached.

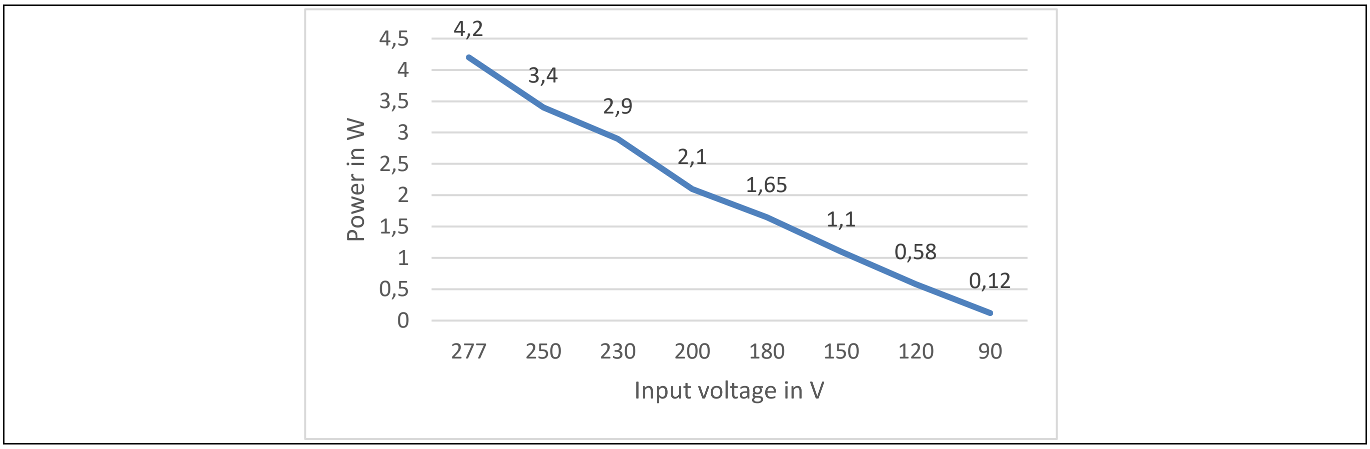


Figure 29 Lower power limit of the ICL8800 in this design due to missing BM

Figure 30 230 V first valley operation (V_{out} ripple pk-pk 5.3 V)

Figure 31 230 V third valley operation (V_{out} ripple pk-pk 3.7 V)

Figure 32 230 V ninth valley operation (V_{out} ripple pk-pk 2.5 V)

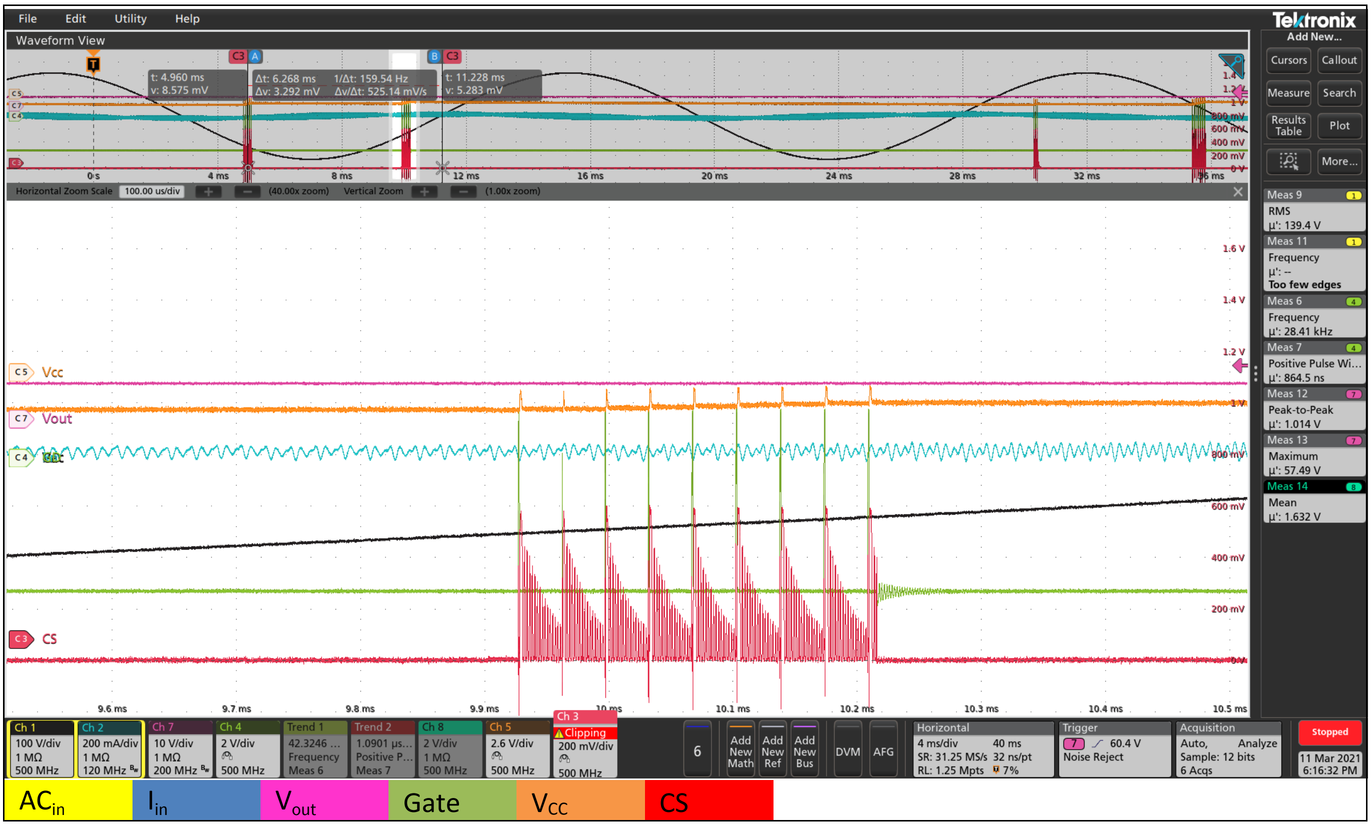


Figure 33 230 V burst mode operation ICL8810 and ICL8820 only (V_{out} ripple pk-pk 1.01 V)

8.3 Burst mode (only ICL8810 and ICL8820)

The oscilloscope screenshots in this chapter offer an insight into the very smooth and nearly ripple-free BM operation of the ICL8810 and ICL8820.

In order to save energy and make the design-in easier, the gate voltage is reduced in BM. Furthermore, the BM has a very smooth entry and exit. This gradual change of modes is shown in the images below.

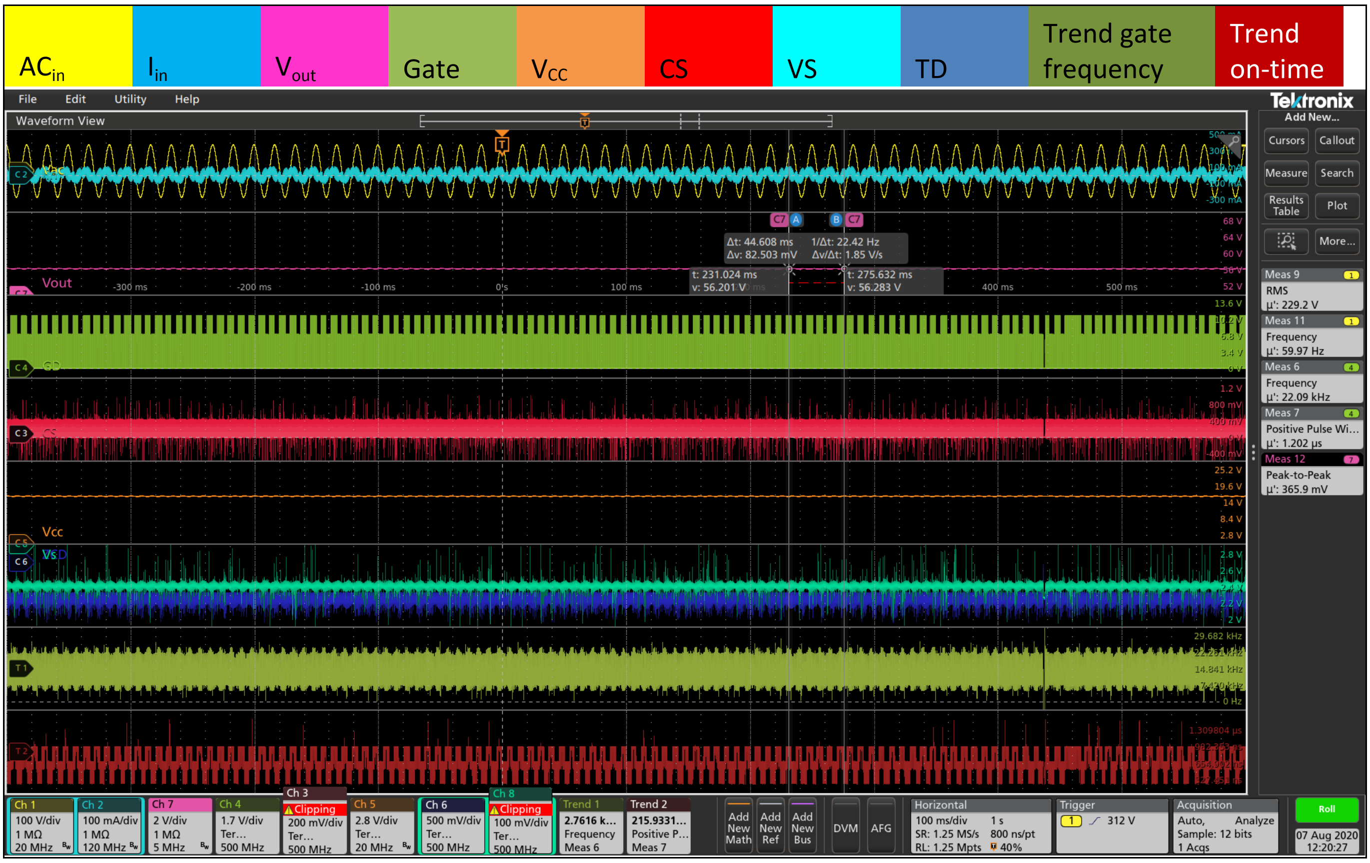


Figure 34 **Operating point between BM and normal operation, smooth BM entry (365.9 mV pk-pk at V_{out})**

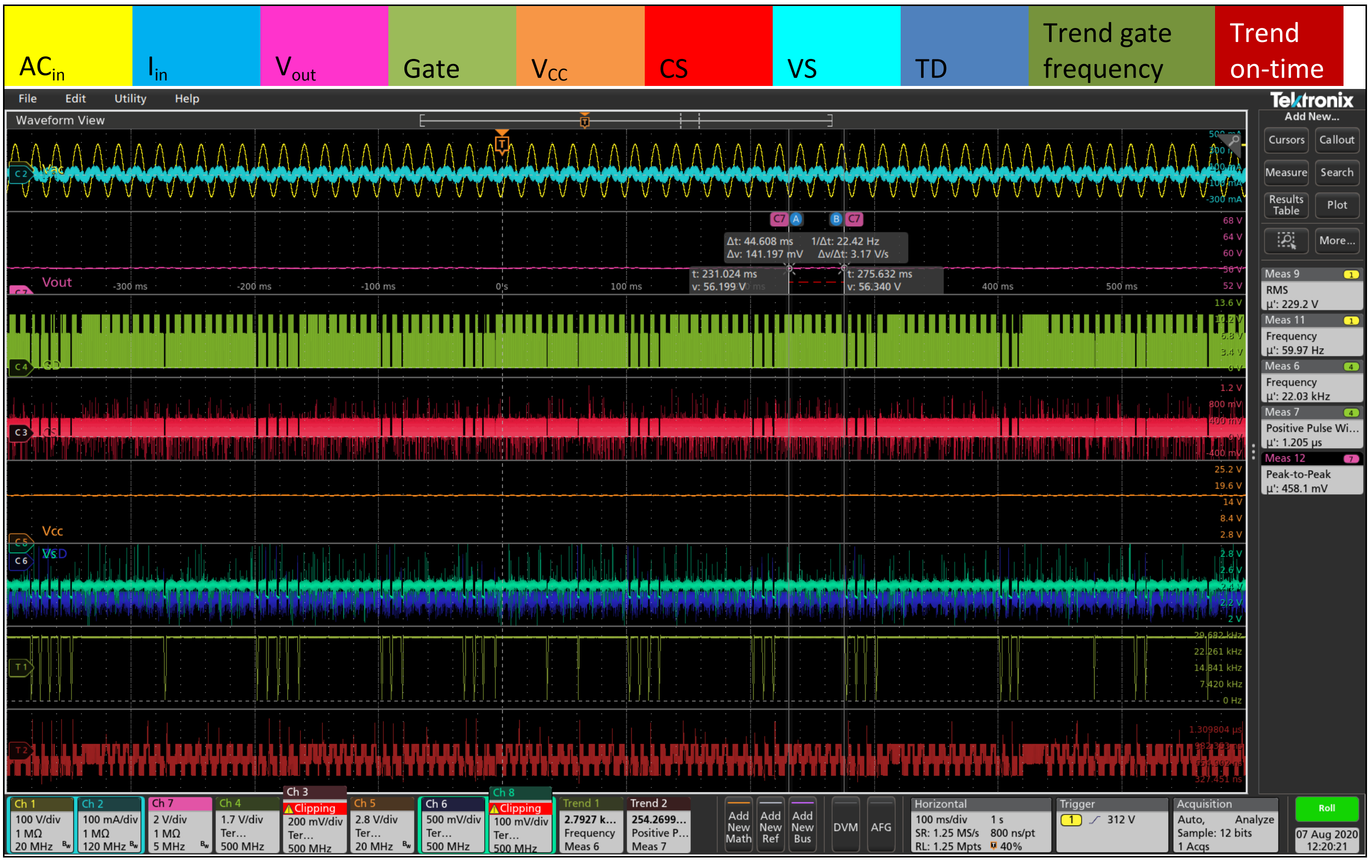


Figure 35 Operating point with partial IC sleep (458 mV pk-pk at V_{out})

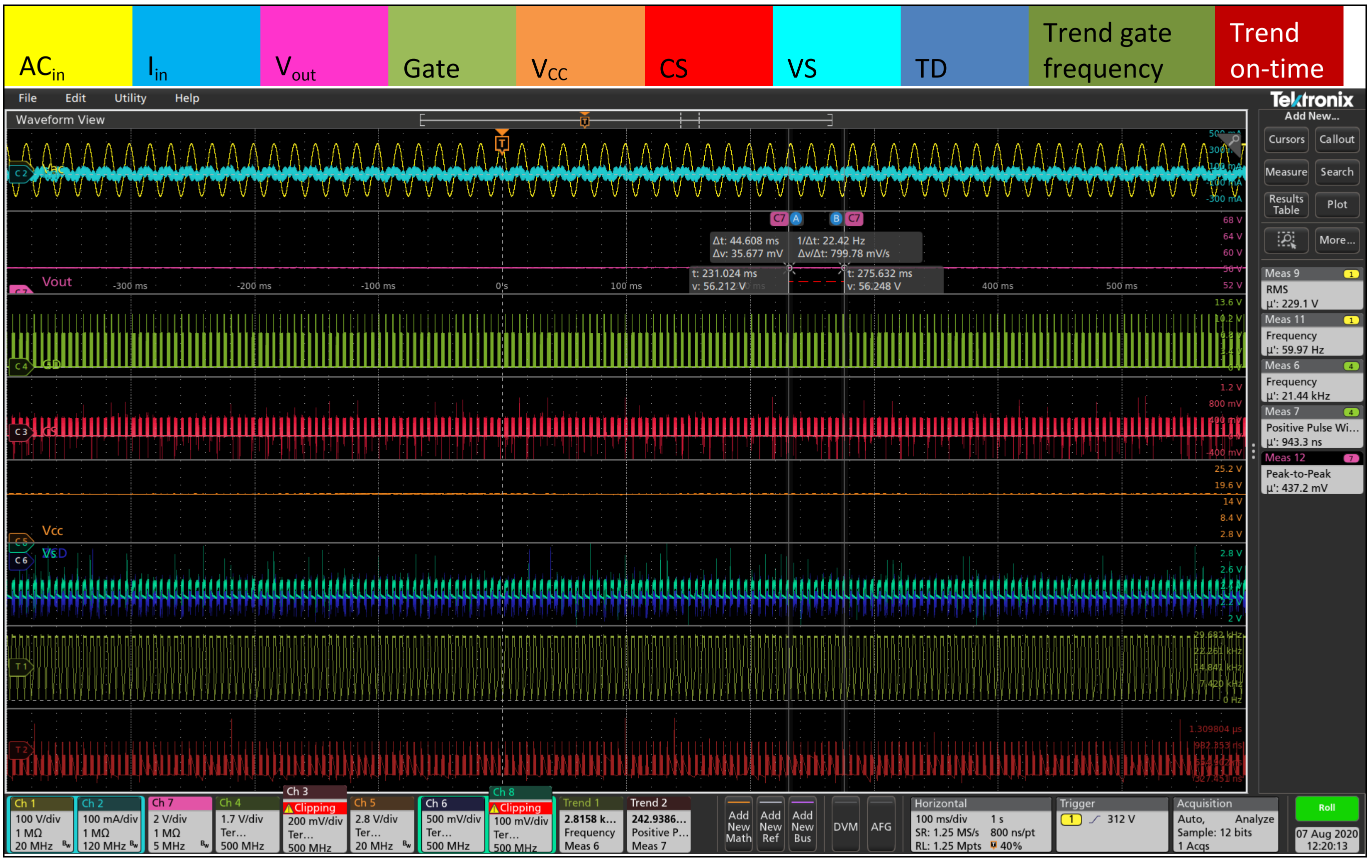


Figure 36 Operating point fully in BM (437 mV pk-pk at V_{out})

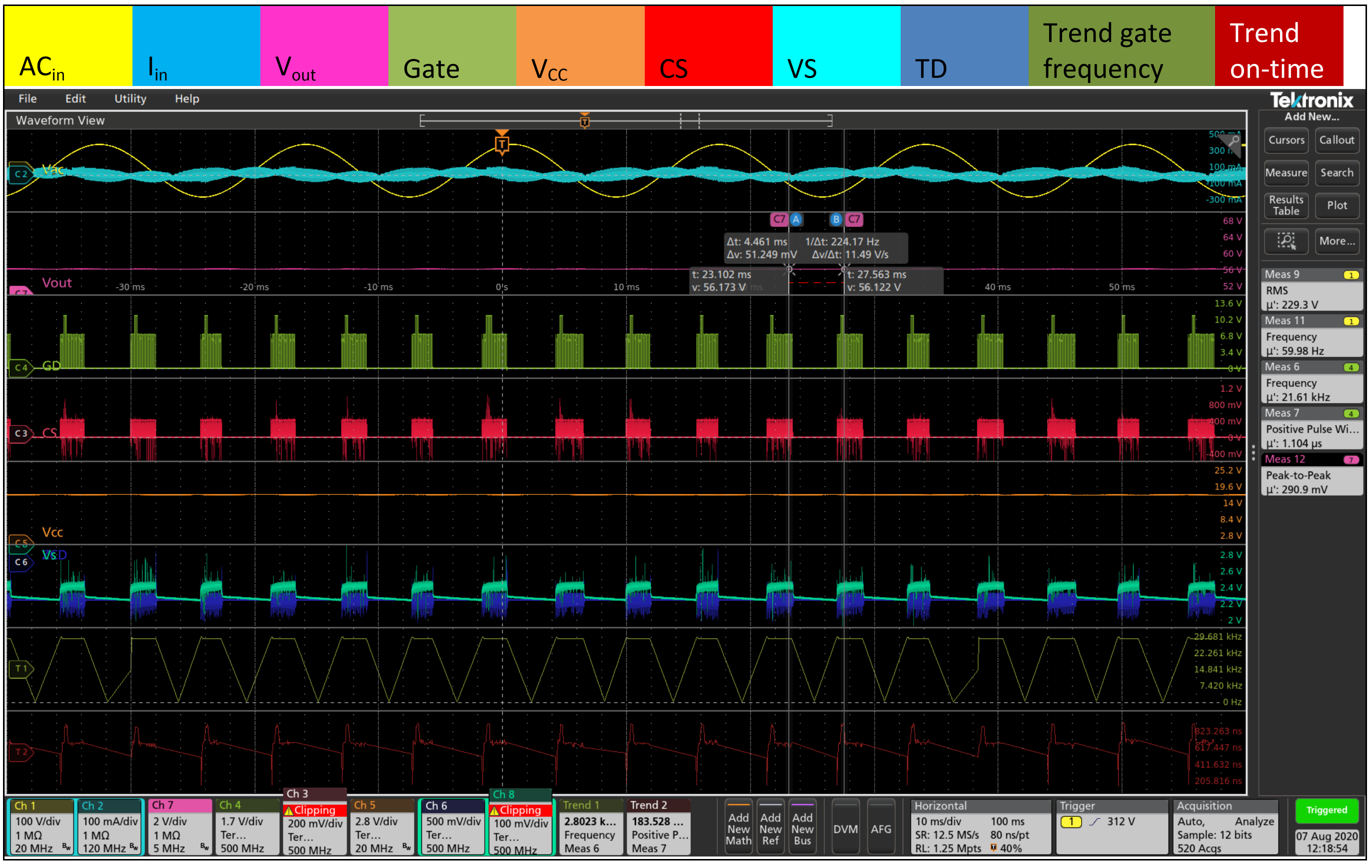


Figure 37 Operating point in BM

8.4 V_{CC} maintainance mode

Because this IC only generates pulses when the feedback requires it, after a load drop the OVP might be triggered. In this case it will be a long time until the next pulses are generated (this is highly dependent on the system and the size of the V_{CC} capacitor). In BM during the IC sleep the VS pin voltage is zero. To check the power demand the VS pin gets pulled up after the wake-up of the IC. If no pulse is needed, the IC falls back to sleep again. This will happen every 200 Hz.

If the V_{CC} voltage gets too low there are mechanisms to keep the IC operational:

- In addition to the BM wake-up according to the control loop, a higher-priority V_{CC} wake-up threshold may trigger a burst start if V_{CC} drops as low as $V_{VCCwake}$. The controller continues with the burst until V_{CC} increases up to $V_{VCCburst}$ again (this behavior can be seen in **Figure 38**).
- In parallel, the TD pin lowers its voltage to allow an external start-up circuit to charge the V_{CC} capacitor until $V_{VCCburst}$ is reached.

This BM control allows tight output regulation and reduces the standby power, because no unnecessary pulses are generated. In addition, it allows the use of a small V_{CC} capacitor.

This V_{CC} maintainance mode is designed to have minimal inpact on the output voltage. Furthermore, the coupling and the fact that in this case the auxiliary winding has the highest power demand should help with minimizing the impact on the output voltage. This behavior can also help to keep microcontroller functional, and it is shown in **Figure 38**.

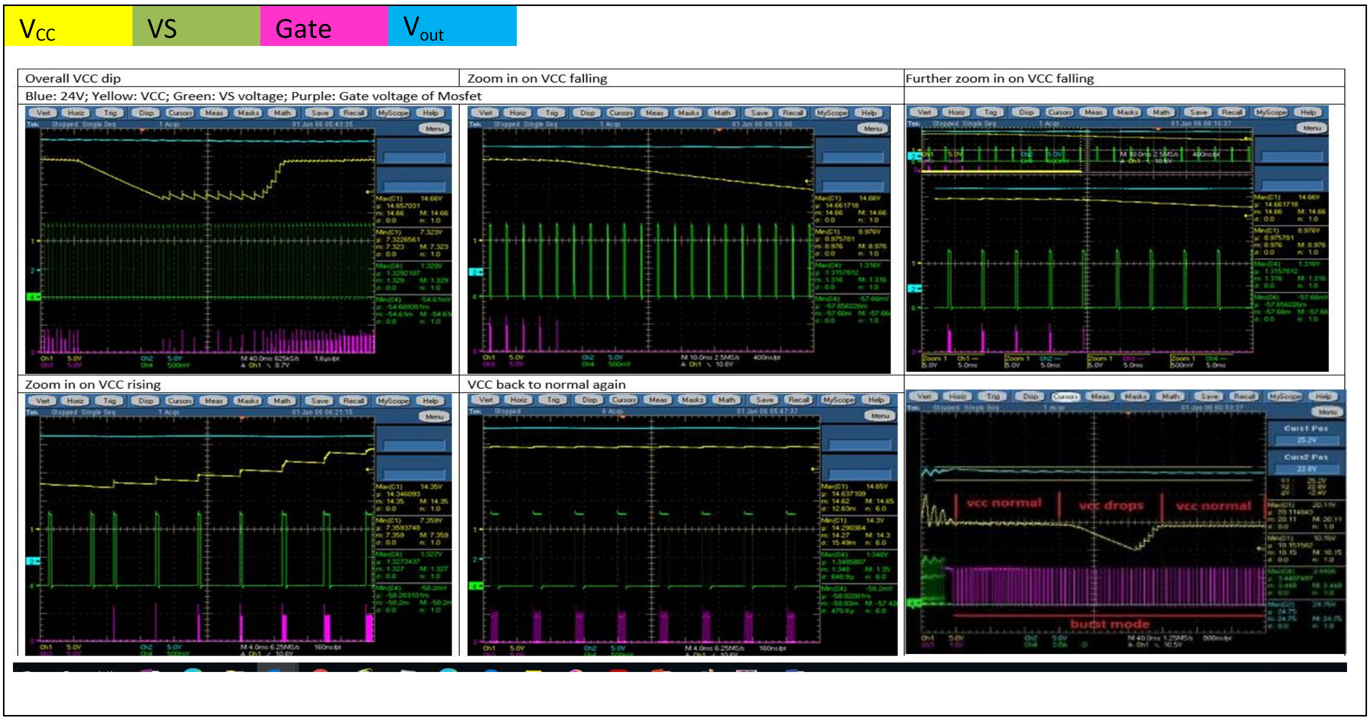


Figure 38 V_{CC} **maintainance mode if** V_{CC} **drops too low, with minimum impact on output; VS signal shows wake-ups and gate-only pulses if necessary**

8.5 DC jitter (only ICL8820)

The VIN pin automatically detects the AC and DC voltage. If it detects DC, the jitter is added to the ouput of the pulse-width modulation (PWM) generator.

This function eases the design of the emergency lighting driver, as no additional circuit is needed. This feature helps to pass the required EMI standard. The fast restart time of 200 ms also qualifies this IC for designs where a fast restart after the change to DC is required.

Pulling down the VIN pin lets the IC restart even faster. Here the restart conditions are checked every 25 ms. Please refer to the chapter EMI to see the effect of the jitter on the measured spectrum.

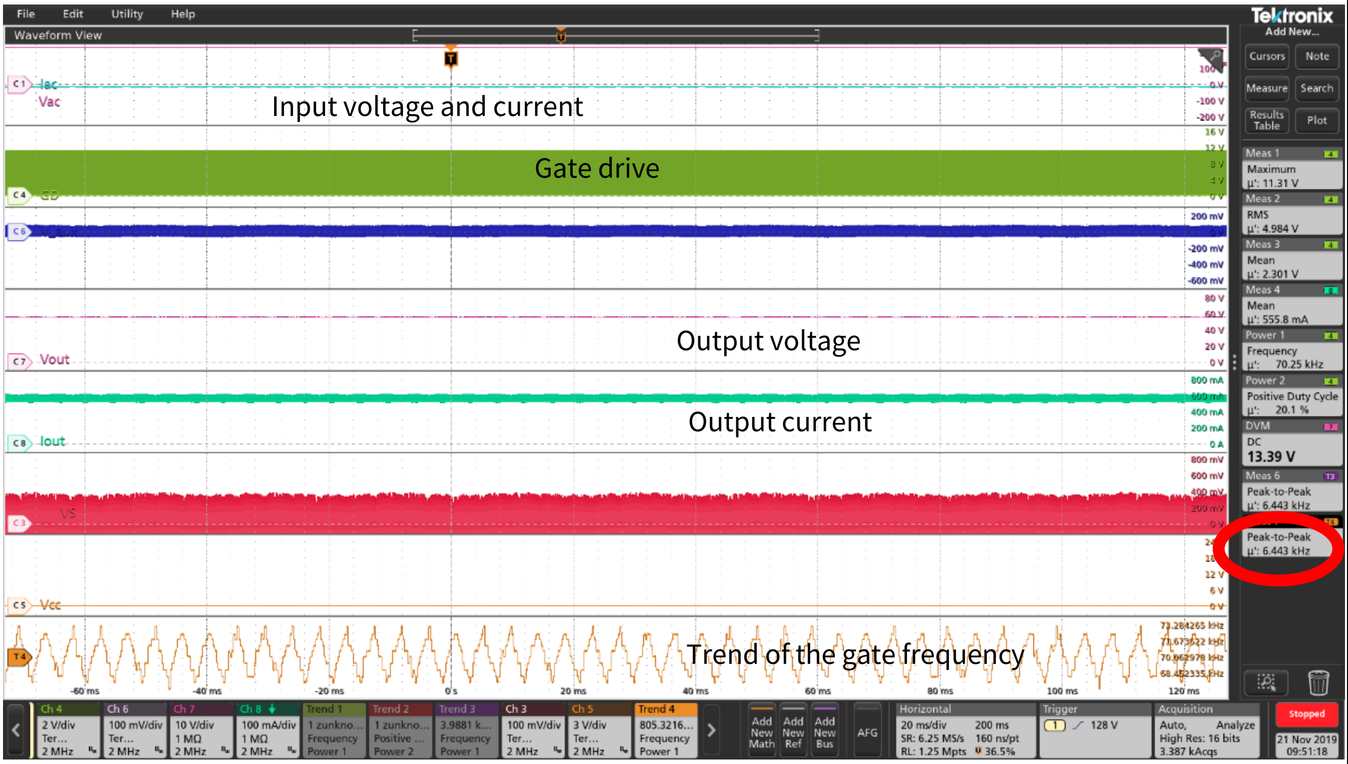


Figure 39 ICL8820 DC jitter at 30 W, amplitude: 6.443 kHz

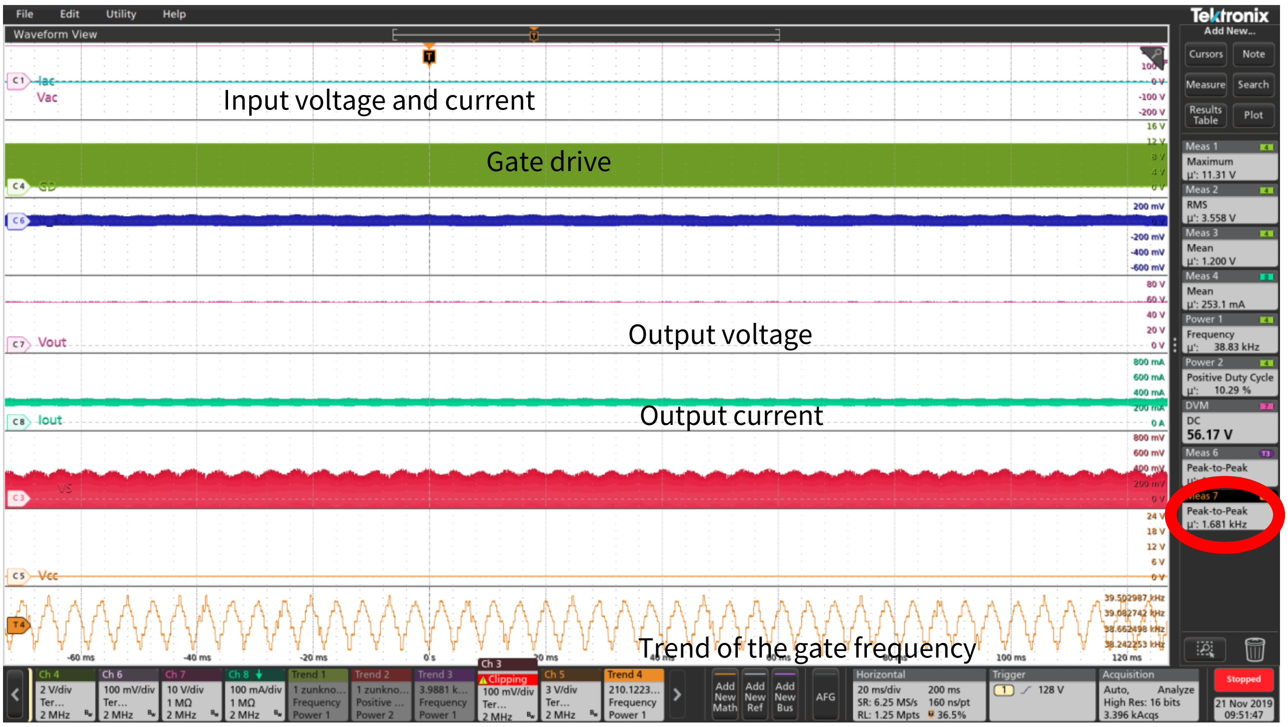


Figure 40 ICL8820 DC jitter at 13 W, amplitude: 1.681 kHz

8.6 Secondary-side output OVP

The secondary-side OVP is very accurate compared with other products. The IC senses the current flowing into the ZCD pin. This current is internally multiplied with a fixed factor. The resulting current is injected into the CS pin during the off-time of the MOSFET.

This multifunctional use of the OCP offers an 8 percent IC accuracy over the whole temperature range and production variations.

Offering an accurate and cycle-by-cycle-based fast OVP can save cost and eases the design of SELV LED drivers.

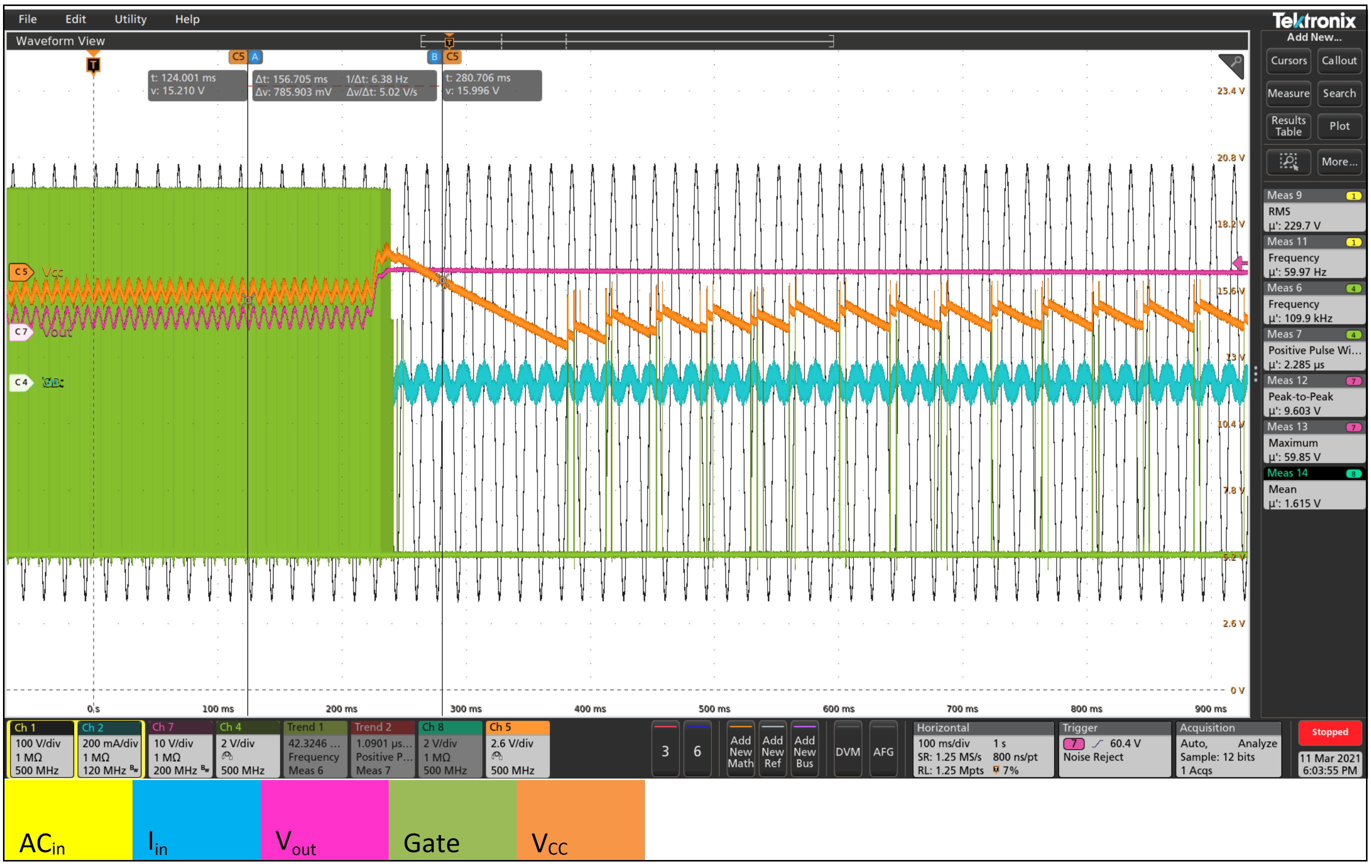


Figure 41 Secondary-side OVP at 59.85 V after sudden output open condition following BM entry

9 Thermal images

Table 3 Thermally measured components

SP1	CMC
SP2	Diode bridge
SP3	MOSFET
SP4	Transformer
SP5	Output diode

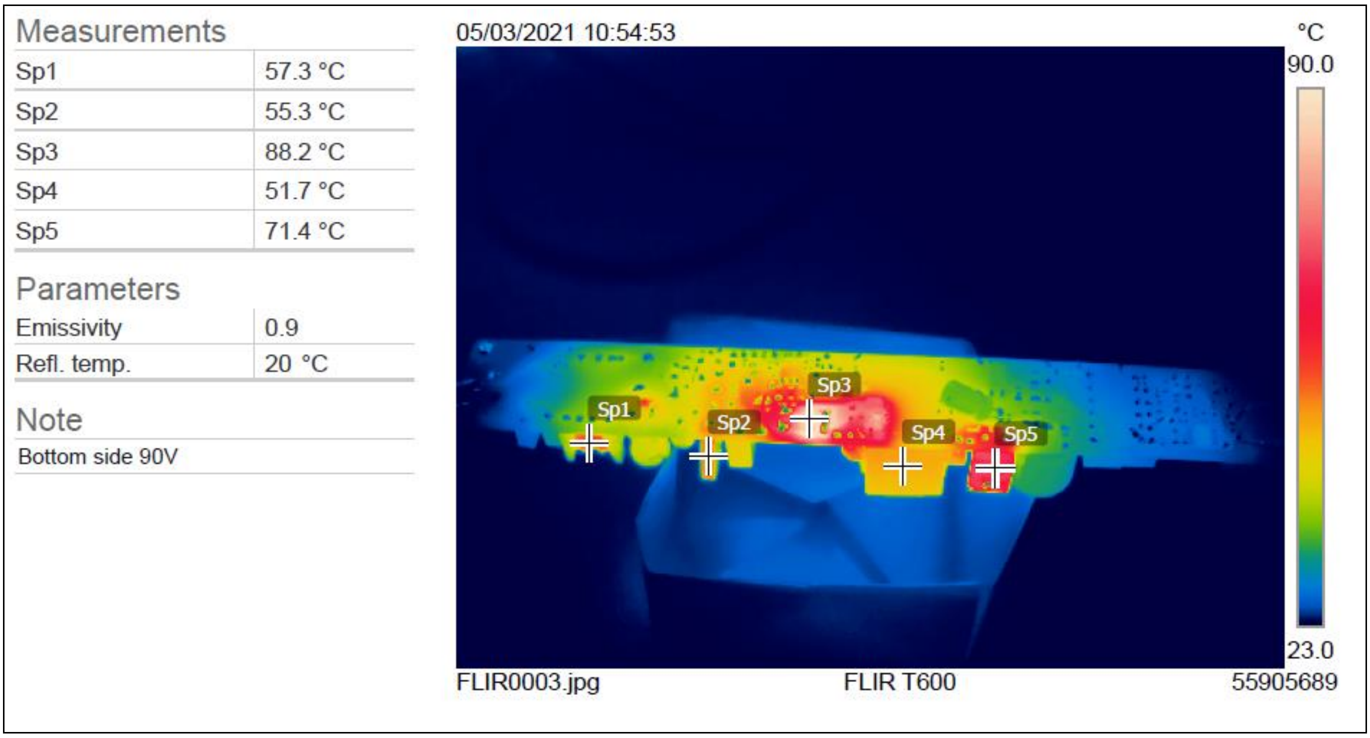


Figure 42 Thermal image – bottom side 90 V

Measurements	
Sp1	66.4 °C
Sp2	57.4 °C
Sp3	84.2 °C
Sp4	56.2 °C
Sp5	74.4 °C

Parameters	
Emissivity	0.9
Refl. temp.	20 °C

Note

Top side 90V

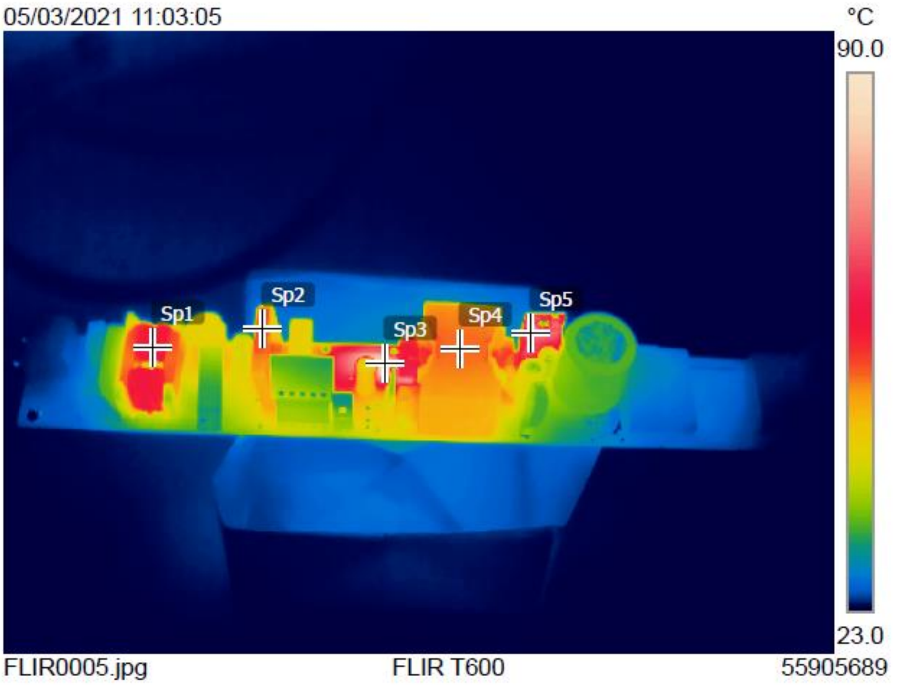


Figure 43 Thermal image – top side 90 V

Measurements	
Sp1	27.8 °C
Sp2	38.2 °C
Sp3	71.3 °C
Sp4	48.9 °C
Sp5	70.5 °C

Parameters	
Emissivity	0.9
Refl. temp.	20 °C

Note

Bottom side 300V

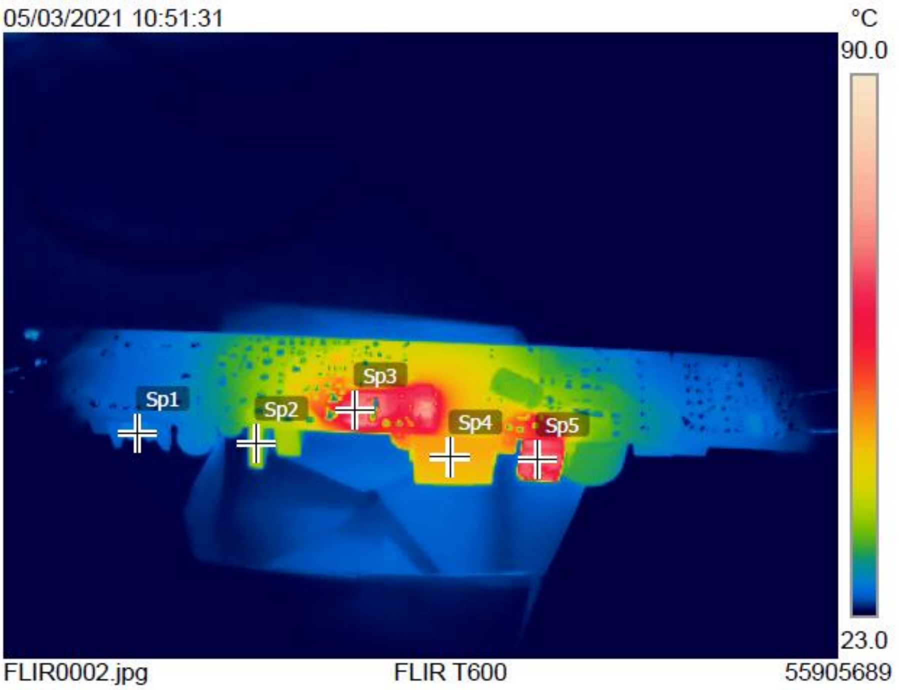


Figure 44 Thermal image – bottom side 300 V

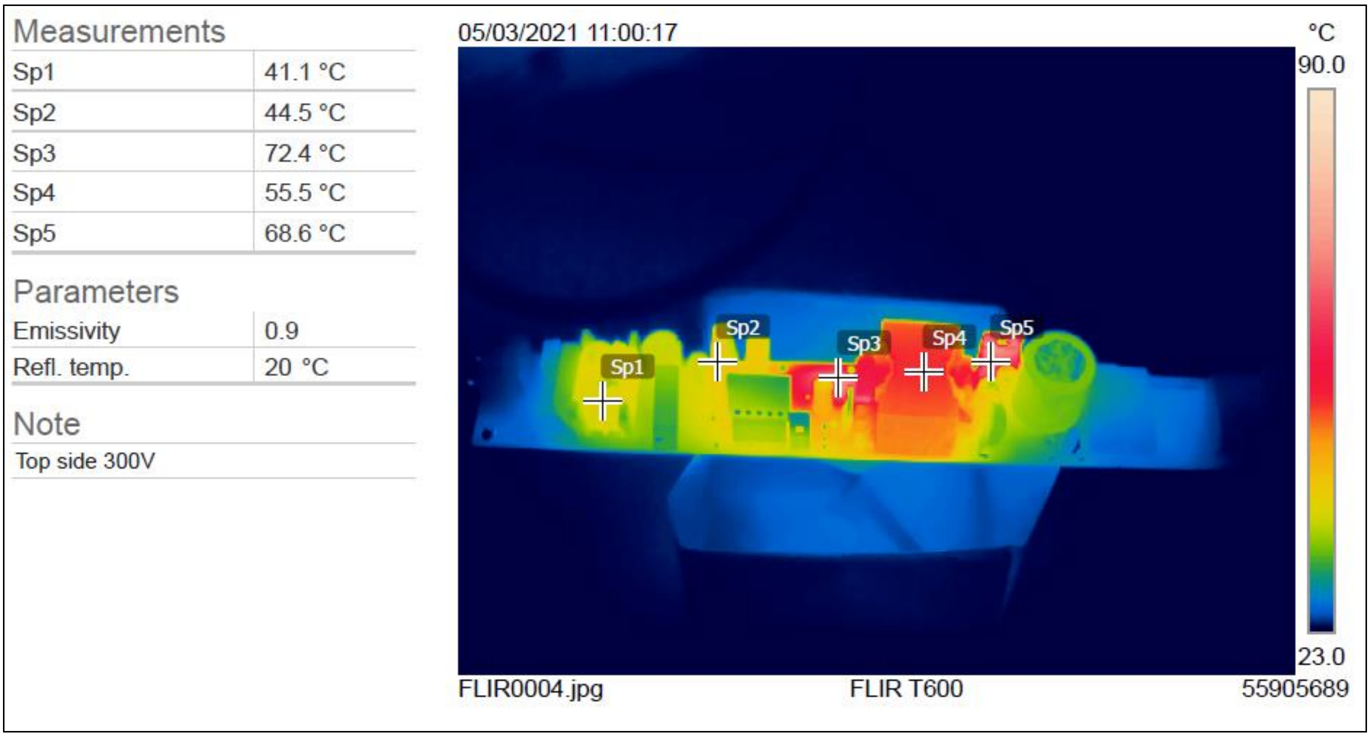


Figure 45 **Thermal image – top side 300 V**

10 Set-up and measurement remarks

- AC source: Chroma 61502
- Load: Chroma 63105A in CC mode with V_{on} threshold of 25 V
- Power-up of the board must be done with the adapter boards plugged in
- If testing without the start-up board, the start-up resistors have to be changed – R36 has to be added, D6 with 22 V has to be added
- Because the feedback loops are optimized to deliver a good THD and PF, the crossover frequency of the loop is very low. This compromises the load-jump behavior and favors soft-dimming behavior. For dynamic load changes an additional D-path in the feedback loop is required. This can usually consist of a resistor and a capacitor in parallel to the upper voltage divider resistor. But non-linear feedback with diodes instead of a resistor is also possible. A circuit example is shown in **Figure 46**.
- The fast-reacting second OVP and the slow feedback loop may cause unwanted behavior, where the system is stuck in repetitive restarts. Here the output voltage rises very fast to the OVP level (half-charged output capacitor, fast AC restart, etc.) and triggers the protection while the feedback loop had no time to react. This can occur for multiple reasons, such as a too-small output capacitor or when the output voltage set-point is too close to the OVP level. Solutions include increasing the output capacitor, increasing the threshold for the OVP, lowering the set-point or changing the behavior of the load.

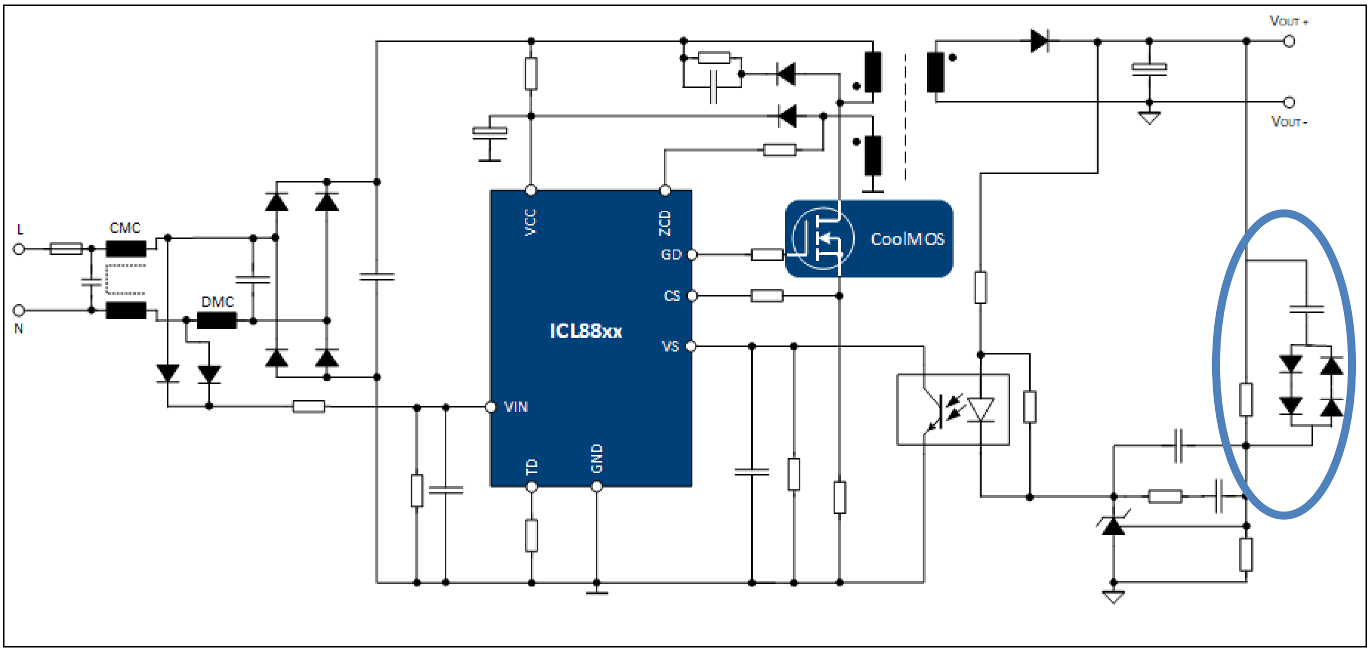


Figure 46 Non-linear feedback circuit for highly dynamic loads without compromising THD and steady-state performance

11 Harmonics

Because the ICL88xx family are primarily designed for lighting, they can easily pass the harmonic standard.

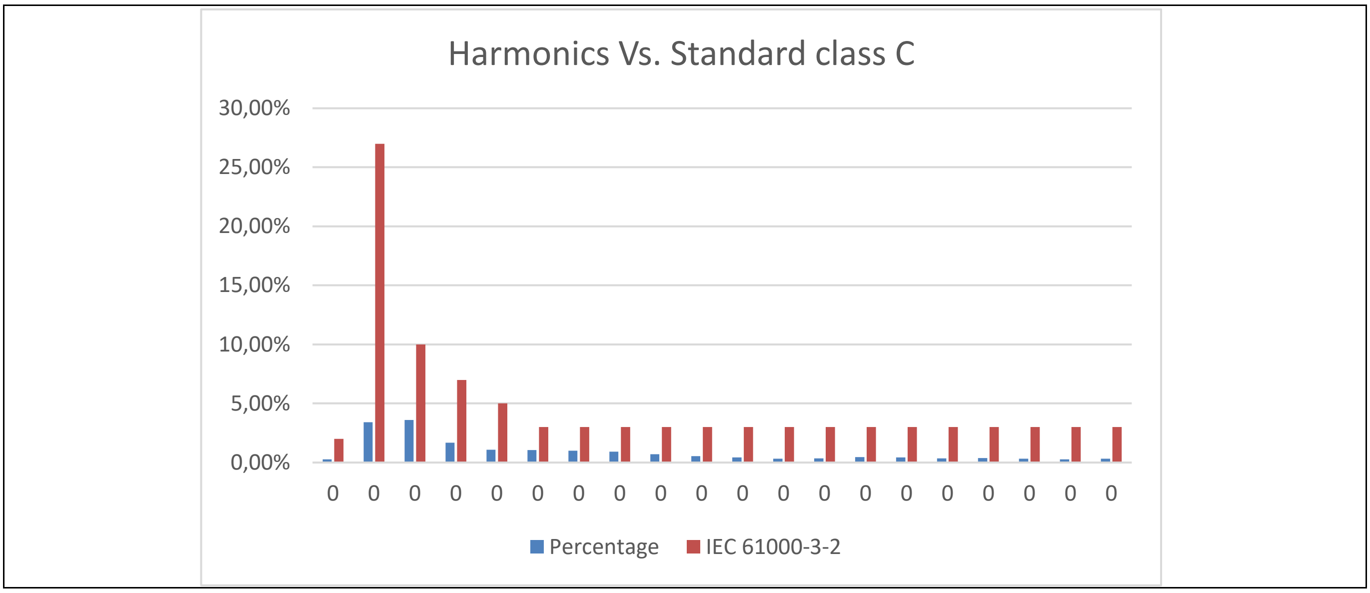


Figure 47 Harmonics measurement at 277 V full load

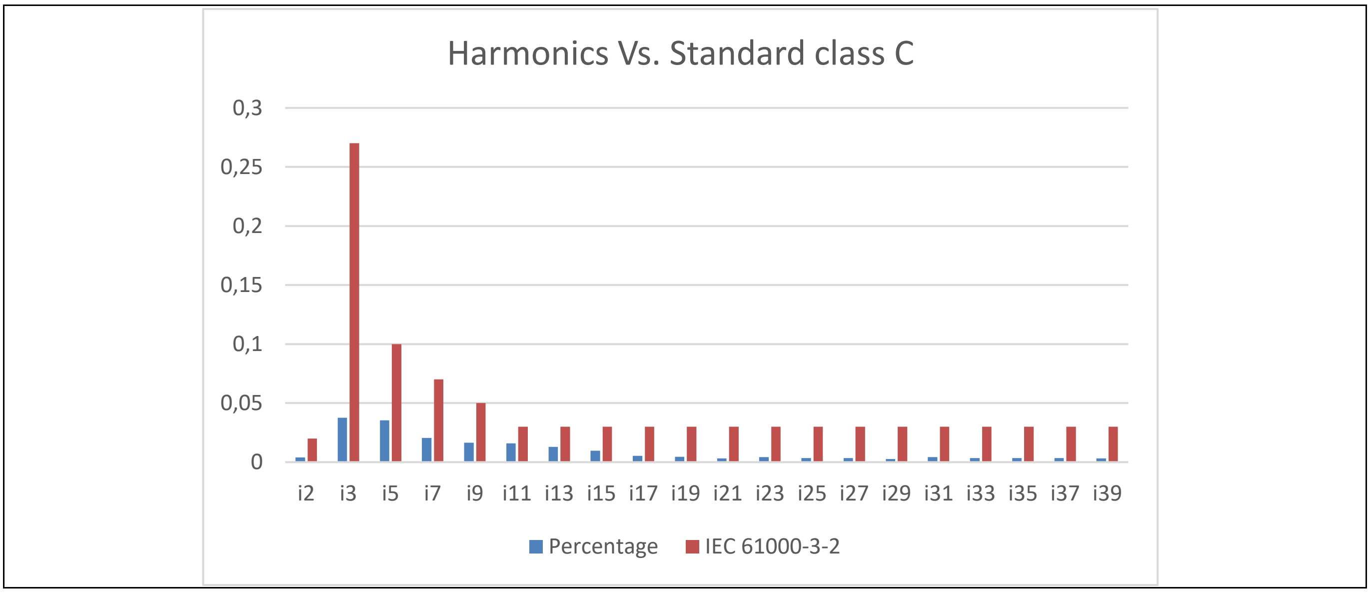


Figure 48 Harmonics measurement at 230 V full load

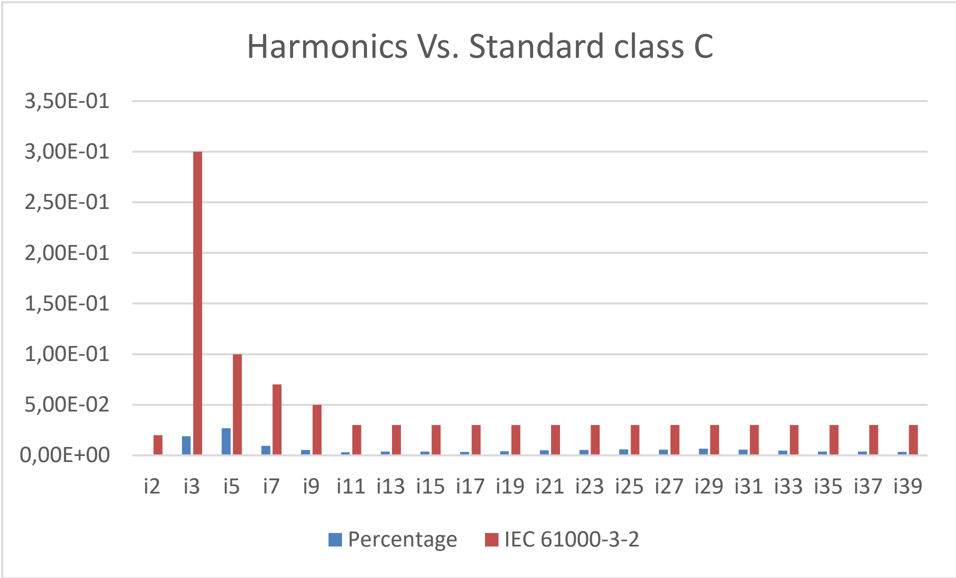


Figure 49 Harmonics measurement at 120 V full load

12 EMI measurements

12.1 AC input

The SSR reference board can easily pass the EMI standard for AC operation.

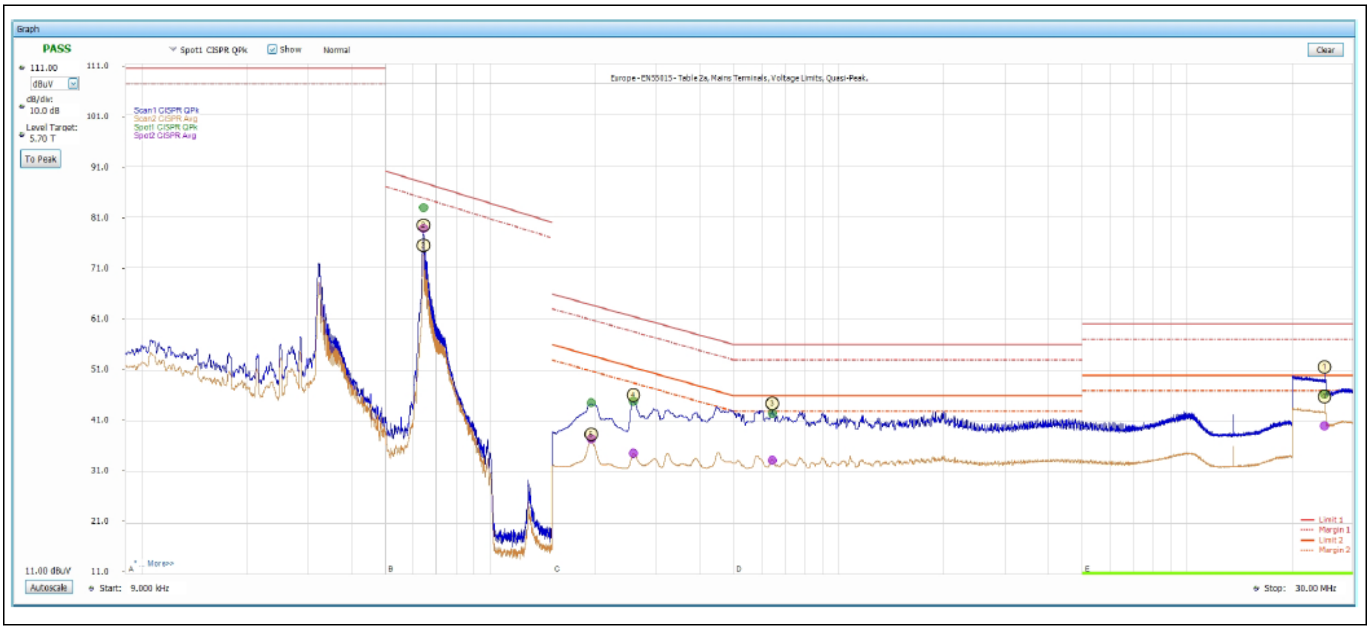


Figure 50 120 V L

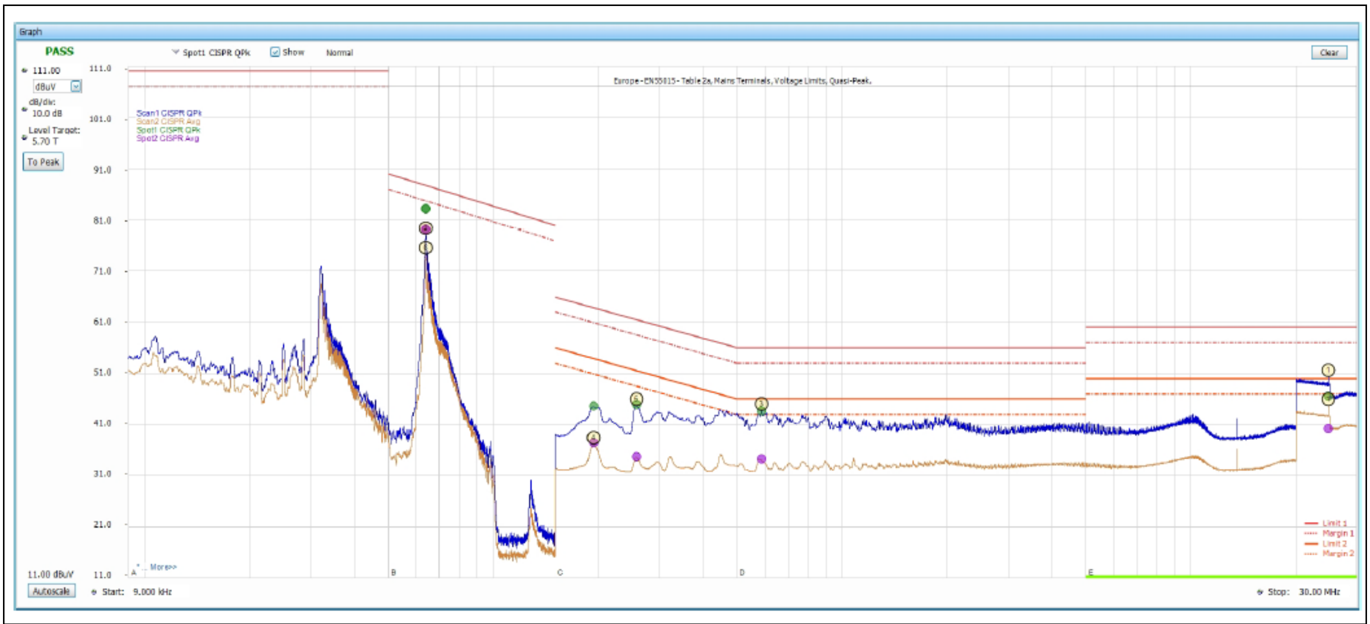


Figure 51 120 V N

12.2 DC input (ICL8820 only)

The EMI measurements for DC input are given below.

With regard to DC operation, only the ICL8820 can pass the DC test due to the implemented jitter.

The sudden jump at 30 MHz is due to measurement system error and can also be seen with no device connected.

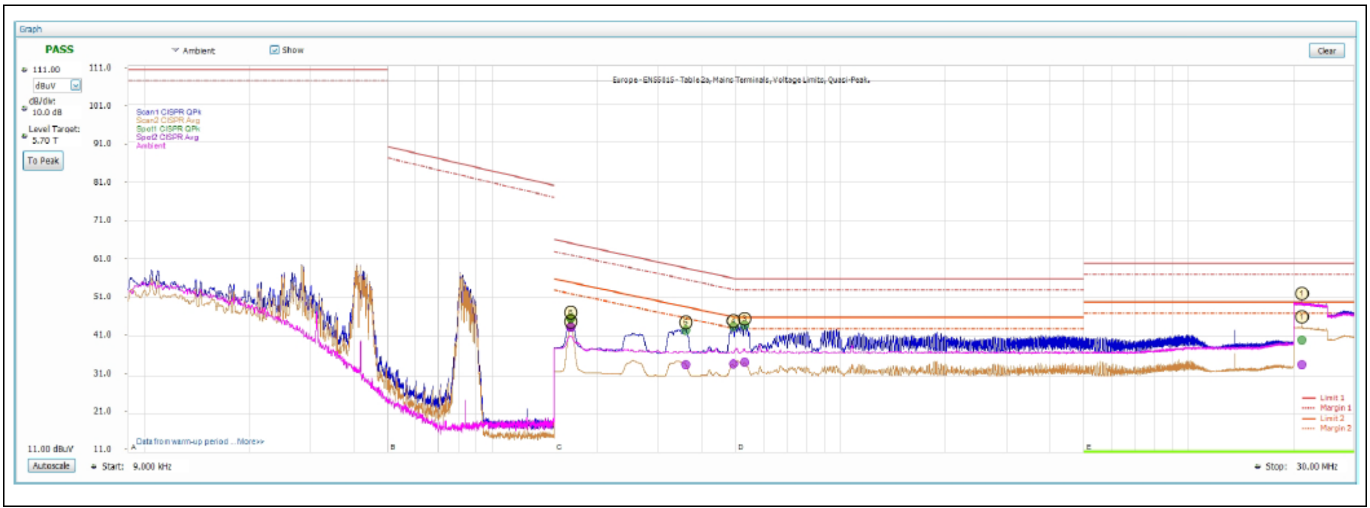


Figure 52 120 V DC

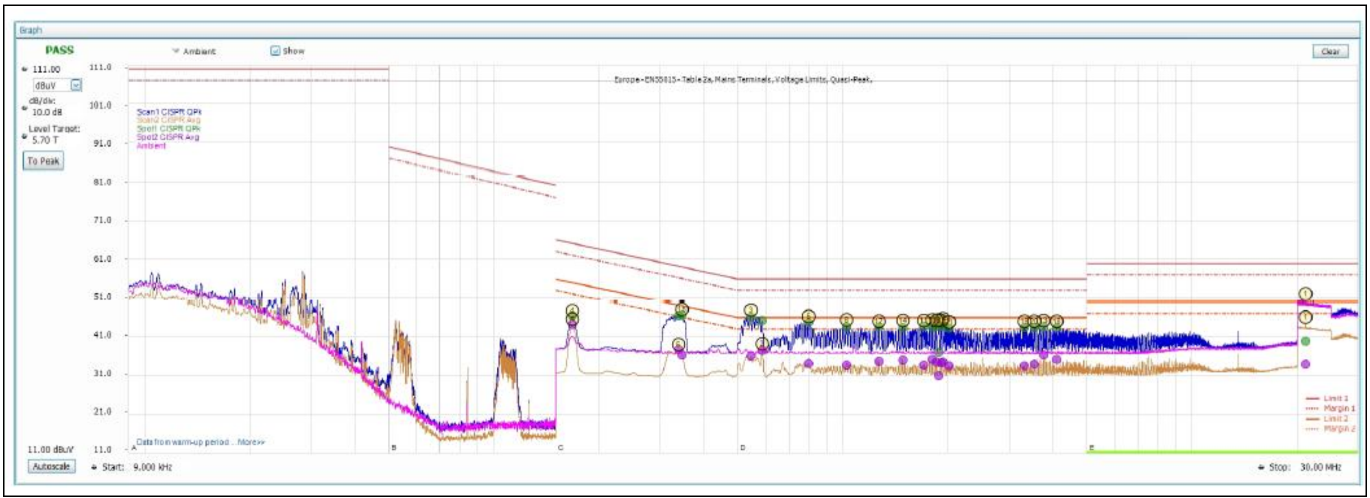


Figure 53 160 V DC

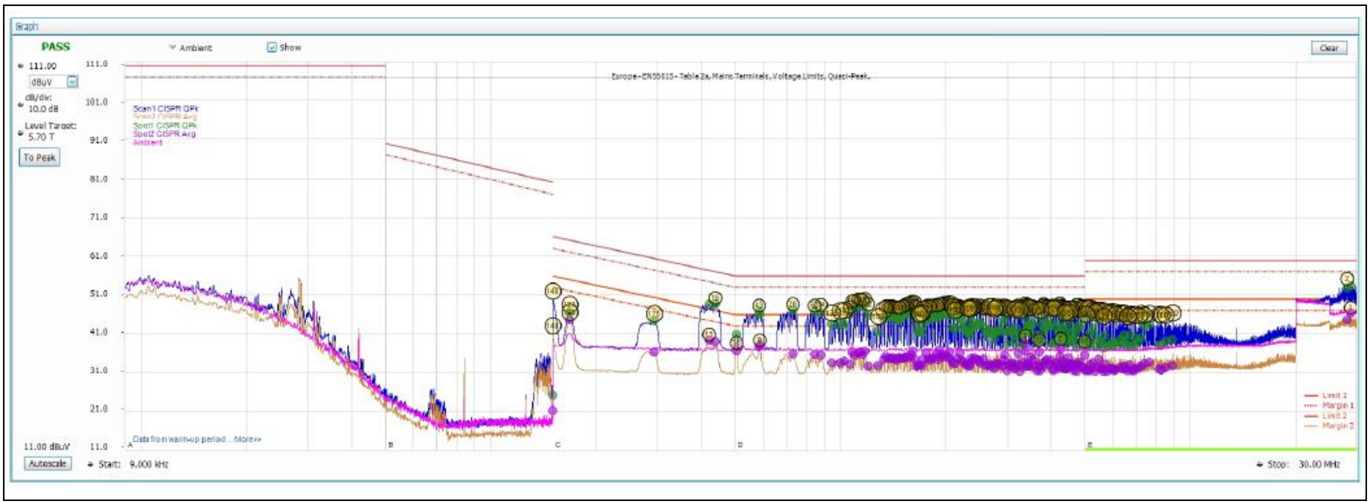
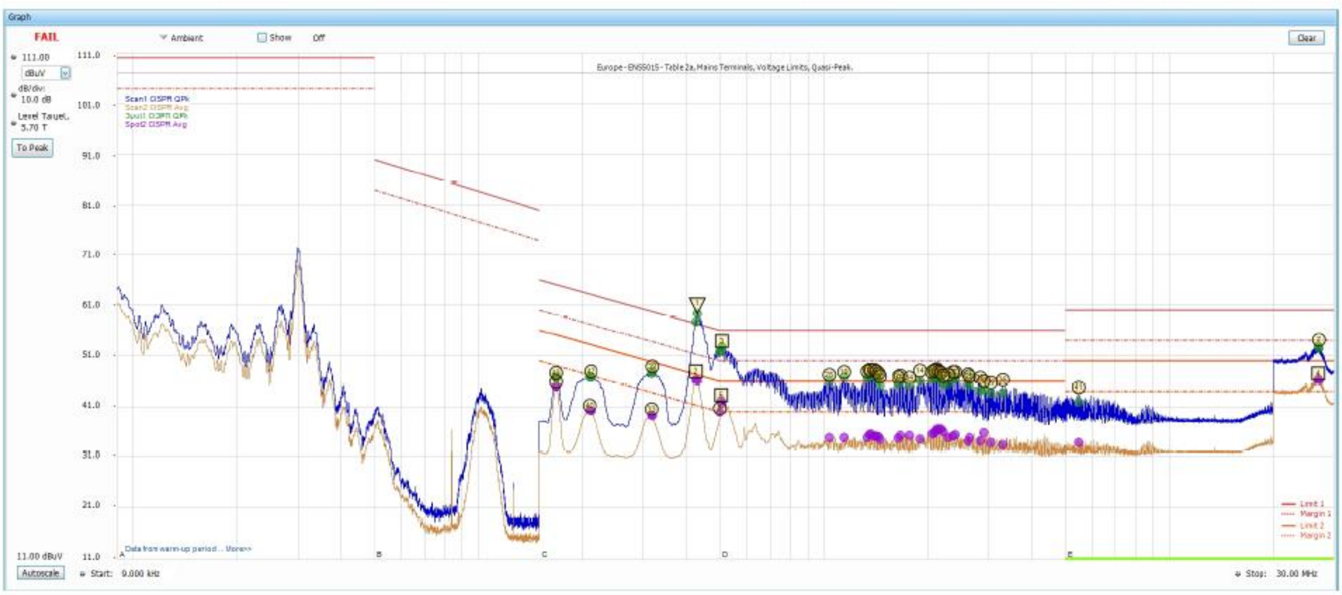


Figure 54 230 V DC



Enable	Spot #	Range	Freq (Hz)	Scan1 CISPR QPk		Scan2 CISPR Avg		Spot1 CISPR QPk		Spot2 CISPR Avg	
				Ampl	Delta (Limit1)	Ampl	Delta (Limit2)	Ampl	Delta (Limit1)	Ampl	Delta (Limit2)
√	1	C	430.984 kHz	59.38 dBuV	2.14 dBuV	-- dBuV	-- dBuV	59.32 dBuV	2.09 dBuV	46.00 dBuV	-1.23 dBuV
√	2	C	426.128 kHz	-- dBuV	-- dBuV	46.67 dBuV	-0.66 dBuV	57.67 dBuV	0.34 dBuV	46.36 dBuV	-0.97 dBuV
√	3	D	507.312 kHz	52.67 dBuV	-3.33 dBuV	-- dBuV	-- dBuV	52.71 dBuV	-3.29 dBuV	41.70 dBuV	-4.30 dBuV
√	4	E	26.939 MHz	-- dBuV	-- dBuV	46.26 dBuV	-3.74 dBuV	52.86 dBuV	-7.14 dBuV	46.38 dBuV	-3.62 dBuV
√	5	D	504.781 kHz	-- dBuV	-- dBuV	42.08 dBuV	-3.92 dBuV	52.00 dBuV	-4.00 dBuV	42.13 dBuV	-3.87 dBuV
√	6	C	500.000 kHz	-- dBuV	-- dBuV	39.47 dBuV	-6.53 dBuV	51.77 dBuV	-4.23 dBuV	39.87 dBuV	-6.13 dBuV
√	7	E	27.037 MHz	52.92 dBuV	-7.08 dBuV	-- dBuV	-- dBuV	52.50 dBuV	-7.50 dBuV	46.17 dBuV	-3.83 dBuV

Figure 55 Failed test: ICL8800 or ICL8810 without jitter 230 V DC

13 Magnetics

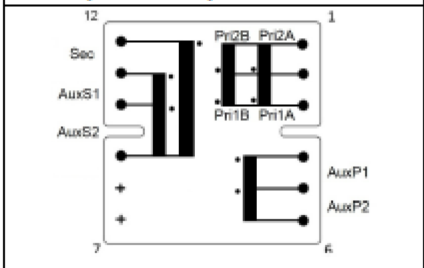
The datasheet of the flyback transformer is shown below.

itacoilweb		DATASHEET	11/07/2019	REV	00
		EDITED	Davide Maida	APPROVED	Dario Radaelli
FINAL P/N	PQ262015	REV 00		SAMPLING CODE	PQ262015-240619A
PRELIMINARY P/N	OP1901015			CUSTOMER P/N	
CUSTOMER	INFINEON TECHNOLOGIES AG (Munich)				

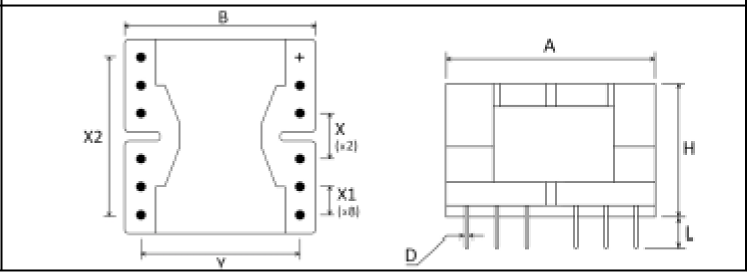
DESCRIPTION	Flyback Transformer PQ2620 low loss core	
TEST/FEATURES		
Inductance Pri1A+Pri2A	544,0 µH ±10,0%	10KHz / 100mV
Leakage Inductance Pri1A+Pri2A	5,0 uH max (short-circuit on Sec+AuxP1+AuxP2+AuxS1+AuxS2)	10KHz / 100mV
Dielectric Strenght	Pri1A+Pri1B+AuxP1+AuxP2+Pri2A+Pri2B / Sec+AuxS1+AuxS2	3,0KVac / 2sec.

WINDINGS		
Pri1A	16ts - 2x0,20 - gr.2 130° (1UEW)	
Pri2A	16ts - 2x0,20 - gr.2 130° (1UEW)	1 Ts PE ad.tape 0,06mm 130° yellow
Sec	10ts - 3x0,35 - TIW 130° EN60950	1 Ts PE ad.tape 0,06mm 130° yellow
AuxP1	1ts - 0,16 - gr.2 130° (1UEW)	
AuxP2	3ts - 0,16 - gr.2 130° (1UEW)	1 Ts PE ad.tape 0,06mm 130° yellow
Pri1B	16ts - 2x0,20 - gr.2 130° (1UEW)	
Pri2B	16ts - 2x0,20 - gr.2 130° (1UEW)	1 Ts PE ad.tape 0,06mm 130° yellow
AuxS1	1ts - 0,20 - TIW 130° EN60950	
AuxS2	2ts - 0,20 - TIW 130° EN60950	2 Ts PE ad.tape 0,06mm 130° yellow

LAYOUT (bottom view)



DRAWING



DIMENSIONS (mm)									
A	28,0 max	B	30,5 max	H	21,8 max	X	7,5 typ	X1	3,8 typ
X2	22,7 typ	Y	25,5 typ	DØ	0,6 typ	L	3,0 min		

COMPONENT	THERMAL CLASS	
Bobbin	150°C (B)	
Copper Wire	155°C (F)	
Tape	130°C (B)	
Tube	200°C (N)	
Varnish	180°C (H)	

NOTES
REACH & RoHS compliant

14 Bill of materials

Table 4 Start-up board

#	Quantity	Designator	Description	Manufacturer	Value
1	1	C30	Capacitor 1 nF/50 V/0603/X7R/5%	Yageo	1 nF
2	1	D30	Diode 22 V/22 V/SOD-323	Nexperia	22 V
3	**1**	**Q30**	**BSS126i/PG-SOT-23-3-5**	**Infineon**	**BSS126i**
4	1	Q31	MMBT3904/SOT-23-3	NXP Semiconductors	MMBT3904
5	1	R30	Resistor 20k/150 V/0805/1%	Vishay	20k
6	1	R31	Resistor 1k/150 V/0805/1%	Vishay	1k
7	1	R33	Resistor 56k/150 V/0805/1%	Vishay	56k
8	2	R34, R37	Resistor 47k/75 V/0603/1%	Vishay	47k
9	1	X30	Connector SSW-104-02-G-S-RA/female/4-pin/2.54 mm/90 degrees	Samtec	SSW-104-02-G-S-RA

Table 5 Op-amp board

#	Quantity	Designator	Description	Manufacturer	Value
1	1	C201	Capacitor 470 nF/50 V/0805/ X7R/10%	Murata	470 nF
2	1	C204	Capacitor 100 nF/50 V/0805/ X7R/10%	Yageo	100 nF
3	1	C205	Capacitor 470pF/50V/0805/C0G/5%	Murata	470 pF
4	1	C206	Capacitor 3.3 µF/25 V/1206/ X7R/10%	Murata	3.3 µF
5	1	D201	0 R/75 V/0603/1%	Yageo/Phycomp	0 R
6	1	D202	1N4148WS/SOD-323	Vishay	1N4148WS
7	1	IC201-A	Op-amp IC with reference voltage/SOIC-8	ST	Op-amp IC with reference voltage
8	1	R200	Resistor 27k/150 V/0805/1%	Vishay	27k
9	1	R201-A	Resistor 240k/150 V/0805/1%	Vishay	240k
10	1	R201-B	Resistor 0 R/150 V/0805/1%	Vishay	0 R
11	1	R202	Resistor 22k/150 V/0805/1%	Vishay	22k

12	1	R203	Resistor 5.6k/150 V/0805/1%	Vishay	5.6k
13	1	R204	Resistor 1k/200 V/1206/1%	Vishay	1k
14	1	R206	Resistor 9.1k/200 V/1206/1%	Vishay	9.1k
15	1	R207	Resistor 0 R/150 V/0805	Vishay	0 R
16	1	R208	Resistor 0 R/150 V/0805	Vishay	0 R
17	1	R210	Resistor 6.2k/200 V/1206/1%	Vishay	6.2k
18	1	R211	Resistor 0 R/200 V/1206	Vishay	0 R
19	1	X200-B	Terminal block/6 pins/3.81 mm pitch/3.81*6 – duplicate – duplicate	Würth	Terminal block/6 pins/3.81 mm pitch
20	1	X300-A	Terminal block/4 pins/5.08 mm pitch/691313510004	Würth	Terminal block/4 pins/5.08 mm pitch
21	0	C203	Capacitor NA/50 V/0805/X7R/10%	Murata	NA
22	0	R205	Resistor NA/150 V/0805/0 R	Vishay	NA
23	0	R209	Resistor NA/150 V/0805/0 R	Vishay	NA
24	0	R215	Resistor NA/200 V/1206/0 R	Vishay	NA

Table 6 TL431 board

#	Quantity	Designator	Description	Manufacturer	Value
1	1	C201	Capacitor 470 nF/50 V/1206/X7R/5%	KEMET	470 nF
2	1	C204	Capacitor 3.3 µ/25 V/1206/X7R/10%	Murata	3.3 µ
3	1	C205	Capacitor 470 pF/50 V/1206/X7R/5%	Samsung Electro-Mechanics	470 pF
4	1	D201	Int TL431QDBZR/SOT-23	Nexperia	TL431QDBZR
5	1	R203	Resistor 5.6k/200 V/1206/1%	Vishay	5.6k
6	1	R204	Resistor 1k/200 V/1206/1%	Vishay	1k
7	1	R205	Resistor 1k/200 V/1206/1%	Vishay	1k
8	1	R206	Resistor 22k/150 V/0805/1%	Vishay	22k
9	1	R206a	Resistor 27k/150 V/0805/1%	Vishay	27k
10	1	R207	Resistor 240k/150 V/0805/1%	Vishay	240k
11	1	R208	Resistor 12k/200 V/1206/1%	Vishay	12k
12	1	R210	Resistor 6.2k/200 V/1206/1%	Vishay	6.2k
13	1	R214	Resistor 820k/150 V/0805/1%	Vishay	820k
14	1	X200-B	Terminal block/6 pins/3.81 mm	Würth	Terminal block/6

			pitch/3.81*6 – duplicate – duplicate		pins/3.81 mm pitch
15	1	X300-A	Terminal block/4 pins/5.08 mm pitch/691313510004	Würth	Terminal block/4 pins/5.08 mm pitch
16	0	R213	Resistor NA/150 V/0805/1%	Vishay	NA

Table 7 Power board

#	Quantity	Designator	Description	Manufacturer	Value
1	1	BR1	Bridge rectifier/4 A/1000 V/SIP345W114P508L2205H2125Q4B	MCC	Bridge rectifier/4 A/1000V
2	1	C1	Capacitor 100 nF/310 V AC/radial/10%	Würth	100 nF
3	1	C3	Capacitor 680 pF/630 V/1206/C0G/5%	Murata	680 pF
4	1	C4	Capacitor 150 nF/630 V/CAP-P10-L13-T6-H12/20%	KEMET	150 nF
5	1	C5	Capacitor 470 p/50 V/0603/X8L/20%	Yageo	470 p
6	1	C6	Capacitor 22 µF/50 V/CAP-P2-D5-H12/20%	Panasonic	22 µF
7	1	C9	2200 p/500 V AC/Disk/Y5U/20%	Vishay	2200 p
8	1	C17	150 nF/310 V AC/L13_W7_H13_P10_CS	Würth	150 nF
9	1	C38	Capacitor 100 nF/50 V/0603/X7R/10%	AVX	100 nF
10	1	C40	2200 p/CAPRR1000W60L750T500H1150B/	Murata	2200 p
11	1	C41	Capacitor 100 nF/50 V/ 1206/X7R/20%	KEMET	100 nF
12	1	C101	Capacitor 150p/630 V/1206/U2J/5%	Murata	150 p
13	1	C102	470 µ/80 V/CAP-P7.5-D18-H20/20%	United Chemi-con	470 µ
14	1	C104	100 µF/35 V/WCAP-ATG5_6.3x11	Würth	100 µF
15	1	C105	100 µ/25 V/CAP-P2-D5-H12/20%	Nichicon	100 µ
16	1	C106	1 µ/100 V/1206/X7R/10%	AVX	1 µ
17	1	C107	100 n/100 V/1206/X7R	AVX	100 n
18	1	C108	100 n/50 V/0603/X7R/10%	Samsung Electro-Mechanics	100 n
19	1	C109	100 n/50 V/0603/X7R/10%	Samsung Electro-Mechanics	100 n
20	1	D3	Diode US1MFA/SOD-23FL	ON Semiconductor	US1MFA

21	1	D4	Diode MBR2H100/SOD-123FL	ON Semiconductor	MBR2H100
22	1	D20	Diode 1N4006G/800V/DO-41	ON Semiconductor	1N4006G
23	1	D21	Diode 1N4006G/800 V/DO-41	ON Semiconductor	1N4006G
24	1	D101	15 A/300 V/TO-220AC	Vishay	15 A/300 V
25	1	D102	Diode MBR2H100/SOD-123FL	ON Semiconductor	MBR2H100
26	1	D103	Diode MBR2H100/SOD-123FL	ON Semiconductor	MBR2H100
27	1	F1	Fuse 300 V/2 A/ FUSRR508W62L835T430H820B/	Bussmann by Eaton	Fuse 300 V/2 A
28	**1**	**IC3**	**ICL88xx/SOIC-8**	**Infineon**	**ICL88xx**
29	1	J1	Connector 17.5 mm pitch jumper 0.8 mm wire/JP-THT-1.00_2.20_17.5_0.80-2P	PRO Power	17.5 mm pitch jumper 0.8 mm wire
30	1	J2	15 mm pitch jumper 0.8 mm wire/JUMP1.0/15 – duplicate	PRO Power	15 mm pitch jumper 0.8 mm wire
31	1	J3	7.5 mm pitch jumper 0.8 mm wire/JUMP1.0/7.5 – duplicate	PRO Power	7.5 mm pitch jumper 0.8 mm wire
32	1	J4	Connector 10 mm pitch jumper 0.8 mm wire/JP-THT-1.00_2.20_10_0.80-2P	PRO Power	10 mm pitch jumper 0.8 mm wire
33	1	L1	Inductor 68 mH/B82732F/30%	Epcos	68 mH
34	1	L2	470 µH/1.15 A/7447480471 (WRU)	Würth	470 µH/1.15 A
35	1	MOV1	Varistor 510 V/radial type/10%	Panasonic	Varistor 510 V
36	1	PC1	TLP383 (GR-TPL,E/TLP383)	Toshiba	TLP383 (GR-TPL,E)
37	**1**	**Q1**	**MOSFET, 0.9 Ω, 800 V, DPAK**	**Infineon**	**MOSFET, 0.9 Ω, 800 V, DPAK**
38	1	R1	Resistor 2.2k/200 V/1206/1%	Vishay	2.2k
39	1	R2	Resistor 20k/75 V/0603/1%	Vishay	20k
40	1	R3	Resistor 1k/200 V/1206/1%	Vishay	1k
41	1	R4	Resistor 2.7 MEG/200 V/1206/1%	Vishay	2.7 MEG
42	1	R5	Resistor 2.7 MEG/200 V/1206/1%	Vishay	2.7 MEG
43	1	R6	Resistor 910k/200 V/1206/1%	Vishay	910k
44	1	R7	Resistor 100k/200 V/1206/1%	Vishay	100k

45	1	R8	Resistor 100k/200 V/1206/1%	Vishay	100k
46	1	R10	Resistor 33k/150 V/0805/1%	Vishay	33k
47	1	R11	Resistor 12k/75 V/0603/1%	Vishay	12k
48	1	R14	Resistor 180 mR/200 V/1206/1%	Vishay	180 mR
49	1	R15	Resistor 39 R/200 V/1206/1%	Vishay	39 R
50	1	R16	Resistor 47 R/200 V/1206/1%	Vishay	47 R
51	1	R17	Resistor 39k/75 V/0603/1%	Vishay	39k
52	1	R18	Resistor 1 R/200 V/1206/1%	Vishay	1 R
53	1	R19	Resistor 30k/200 V/1206/1%	Vishay	30k
54	1	R20	Resistor 0 R/150 V/0805	Vishay	0 R
55	1	R22	Resistor 0 R/150 V/0805	Vishay	0 R
56	1	R29	Resistor 30k/200 V/1206/1%	Vishay	30k
57	1	R30	Resistor 30k/200 V/1206/1%	Vishay	30k
58	1	R101	Resistor 10 R/200 V/1206/1%	Vishay	10 R
59	1	R104	Resistor 0 R/200 V/1206	Vishay	0R
60	1	R107	Resistor 0 R/200 V/1206	Vishay	0 R
61	1	T1	PQ2620 544 µH/PQ2620	Itacoil	PQ2620, 544 µH
62	1	X1	250-203/WAGO_250-203	WAGO	250-203
63	1	X5	Connector 826936-4/CON-M-THT-826936-4	TE Connectivity	826936-4
64	1	X200-A	6-pin pluggable terminal block/3.81*6 – duplicate	Würth	6-pin pluggable terminal block
65	0	C2	NA/310 V AC/L13_W7_H13_P10_CS	Würth	NA
66	0	C10	NA/630 V DC/1206/X7R/10%	TDK	NA
67	0	C110	Capacitor NA/25 V/1206/X7R/10%	Murata	NA
68	0	D6	Diode NA/22 V/SOD-323	Nexperia	NA
69	0	D104	NA/SOD-323	Vishay	NA
70	0	D105	NA/SOD-323	Vishay	NA
71	0	D106	NA/SOD-323	Vishay	NA
72	0	MOV2	Varistor, 510 V/radial type/10%	Panasonic	Varistor, 510 V
73	0	R3a	Resistor NA/200V/1206/1%	Vishay	NA
74	0	R12	NA/200 V/1206/1%	Yageo/Phycomp	NA
75	0	R13	NA/200 V/1206/1%	Yageo/Phycomp	NA

76	0	R14a	Resistor NA/200 V/1206/1%	Vishay	NA
77	0	R21	Resistor NA/150 V/0805/0 R	Vishay	NA
78	0	R24	Resistor NA/200 V/1206/1%	Vishay	NA
79	0	R25	Resistor NA/200 V/1206/1%	Vishay	NA
80	0	R26	Resistor NA/200 V/1206/1%	Vishay	NA
81	0	R28	Resistor NA/75 V/0603/1%	Vishay	NA
82	0	R36	Resistor NA/75 V/0603/0 R	Vishay	NA
83	0	R102	NA/1206		NA
84	0	S101	NA/Çá´¥¿ª¹Ø7.6*5.08 – duplicate	Würth	NA
85	0	ZD101	NA/SMA	Taiwan Semiconductor	NA

Revision history

Document version	Date of release	Description of changes
V 1.0	02-06-2021	First release

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