LEDSet

AN-EVAL-ICLS6021J-LED-Demoboard

60W LED Bulb Retrofit Replacement for E27 Socket

LED Demoboard Description

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Revision History	
Page or Item	**Subjects (major changes since previous revision)**
Version 1.0, May 2011	
	First version

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Intention

The new LEDSet high line LED driver ICLSx series was developed for crossover from high performance, including a PFC stage, to cost down with a substantially reduced BOM for mass production – see **Figure 1**.

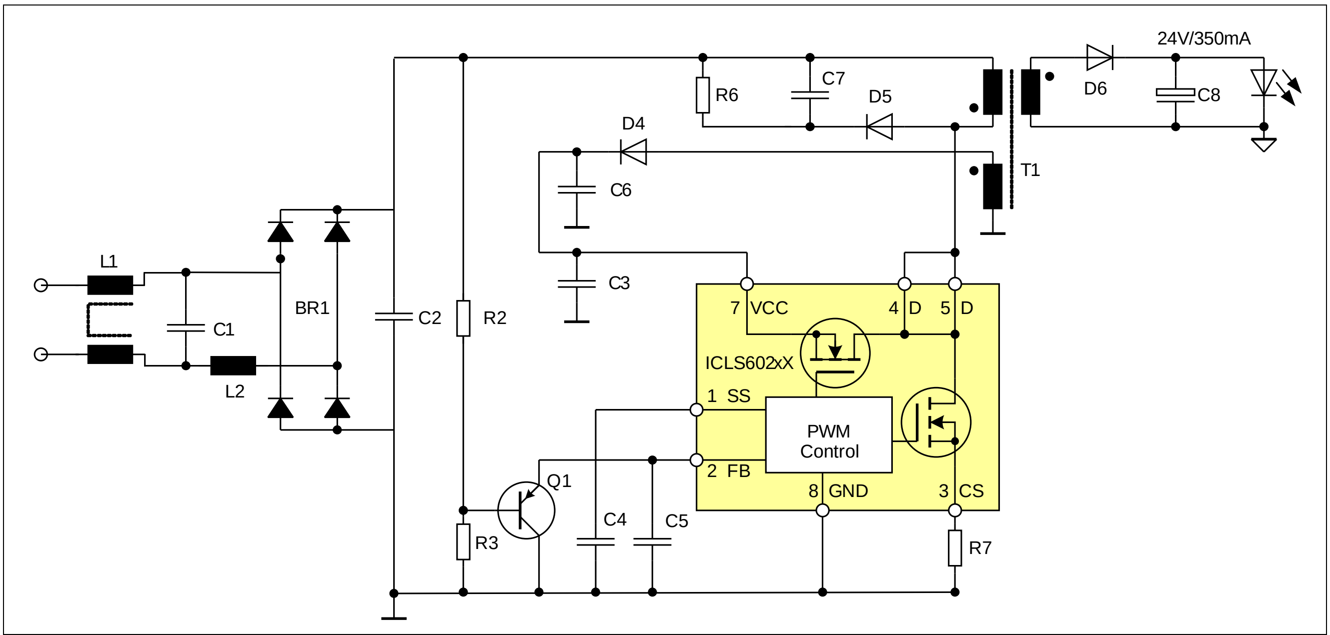


Figure 1 Schematic E27 60W Bulb Replacement Primary-Controlled for Mass Production

This document describes in three stages:

1. the whole network and functionalities
2. the network for the DESIGN-IN phase
3. the design optimization for MASS PRODUCTION

The final LED board design for Mass Production meets all requirements of a dimmer-safe 60W E27 retrofit bulb design regarding:

- Efficiency up to 87 % (functional transformer design)
- Small Form Factor
- High Power Factor > 98 %
- Pass THD according to EN61000-3-2
- Pass EMI according to EN55015
- Low Line Regulation Ripple

Versus the crossover to:

- Cost Down

The technical challenge of this LED demo board design is to fit into a bulb retrofit E27 socket. The LED system IC "LEDSet" makes this challenge possible. The LEDSet system IC series combines a power control IC with integrated protection features and a high avalanche rugged MOSFET – CoolMOS in 650 V or 800 V – within one package.

For E27 bulb socket designs, the device is available in PG-DIP-8-6 and PG-DIP-7 packages; for GU10 spot light socket design as a SMD device in a PG-DSO-16/12 package.

Description

The LED demo board design combines a conventional low cost single stage PFC and flyback converter topology. This type of design is particularly suitable for retrofit lighting applications in E27 sockets, here especially for 60 W bulb replacement.

The LEDSet system driver IC **ICLS6021J** is a current-controlled pulse width modulator together with the smallest CoolMOS power switch on board. Special efforts have been made to compensate temperature dependency in order to achieve a very high accuracy of switching frequency. Short output and floating load protection are implemented by controlling the feedback voltage. Depending on the error case, the IC works in **Auto Restart (ARM)** or **Floating Load Protection (FLPM)** mode. For constant power, Infineon Technologies patented functionality is integrated.

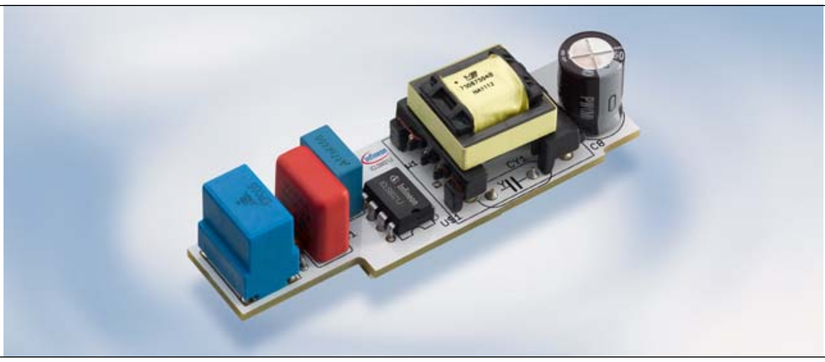


Figure 2 LED Demoboard Top

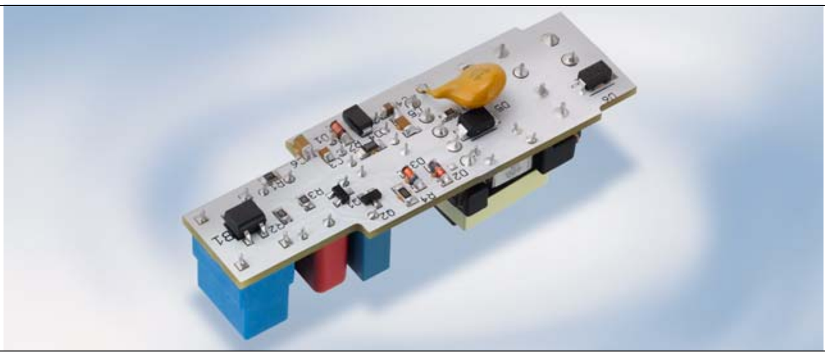


Figure 3 LED Demoboard Bottom

Other LED replacements are also the focus of the LEDSet high line LED drivers – e.g., GU10 for spot light applications or for higher power rating bulb retrofits in E27 sockets.

Cross Reference List LED Designs versus LEDSet

Select the right LEDSet for your dedicated bulb or spot replacement.

Table 1 Cross Reference Selection Table

Replacement Matrix for LED Bulb and LED Spot

Bulb E27 Sockel Power 10 lm/W (+10%)	LED Bulb E27 Sockel Power 70 lm/W	IC / R_{dson} (Power) 230 V_{acin}	 90 V_{acin}	Spot GU10 Sockel Power 20 lm/W (+10%)	LED Spot GU10 Sockel Power 70 lm/W	IC / R_{dson} (Power) 230 V_{ac}	 90 V_{ac}
100 W +	15 W +	ICLS6023J 1.7	ICLS6023J 1.7	not available	not available		
100 W	15 W	ICLS6022J 4.7	ICLS6023J 1.7	not available	not available		
80 W	12 W	ICLS6021J 6.45	ICLS8023Z 2.2	not available	not available		
60 W	9 W	ICLS6021J 6.45	ICLS6022J 4,7	50 W	15 W	ICLS6022G 4.7	ICLS8082G 2.2
40 W	6 W	ICLS6021J 6.45	ICLS6021J 6.45	20 W	6 W	ICLS6022G 4.7	ICLS6022G 4.7
20 W	3 W	ICLS6021J 6.45	ICLS6021J 6.45	10 W	3 W	ICLS6022G 4.7	ICLS6022G 4.7

ICLSx LEDSet Series

Overview of existing products, drain source voltage rating of the power mos CoolMOS inside, fixed operating frequency, drain source on-resistance of the CoolMOS inside, nominal power rating and packaging.

Table 2 LEDSet Product Overview

Summary Fixed Frequency Products

Nr.	LED SET Naming	V_{DS} [V]	f_{RUN} [kHz]	R_{RDSON} [Ohm]	NOMINAL Power 230_{VACIN} ± 15%	 90_{VACIN} - 270_{VACIN}	Package
1	ICLS6021J	650	67	6.45	12	5	DIP-8
2	ICLS6022J	650	67	4.70	17	9	DIP-8
3	ICLS6022G	650	67	4.70	17	9	PG-DSO-12
4	ICLS6023J	650	67	1.70	26	15	DIP-8
5	ICLS8023Z	800	65	2.26	24	12	DIP-7

Technical Specifications of the ICLS6021J Demoboard

Table 3 LED ICLS6021J Demoboard Specification

Technical Specifications Demoboard ICLS6021J

Input Voltage Range [1]	207 ... 254V_{ACIN}
Nominal Input Voltage	Typical @ 230V_{ACIN}
Input Frequency	50, 60 Hz
Fixed Switching Frequency	67kHz
Output Voltage	24V
Output Current	350mA
Output Power typically	8.5 W
Line Regulation (207 ...254V) I_{LED}	< 5%
Efficiency	Typical > 84% up to 87% [2]
Power Factor	98% PLUS
THD Harmonics according 61000-3-2	PASS
EMI according EN55015 for Lamps	PASS
Transformer Safety Class	Reinforced
Dimmer Save[3]	YES
Ambient Temperature	80°C

[1] Also available as PAPER design in US DOMESTIC range
[2] Using Transformer Class FUNCTIONAL
[3] NO Dimming Performance Supported only Safe against malfunction

Design Description

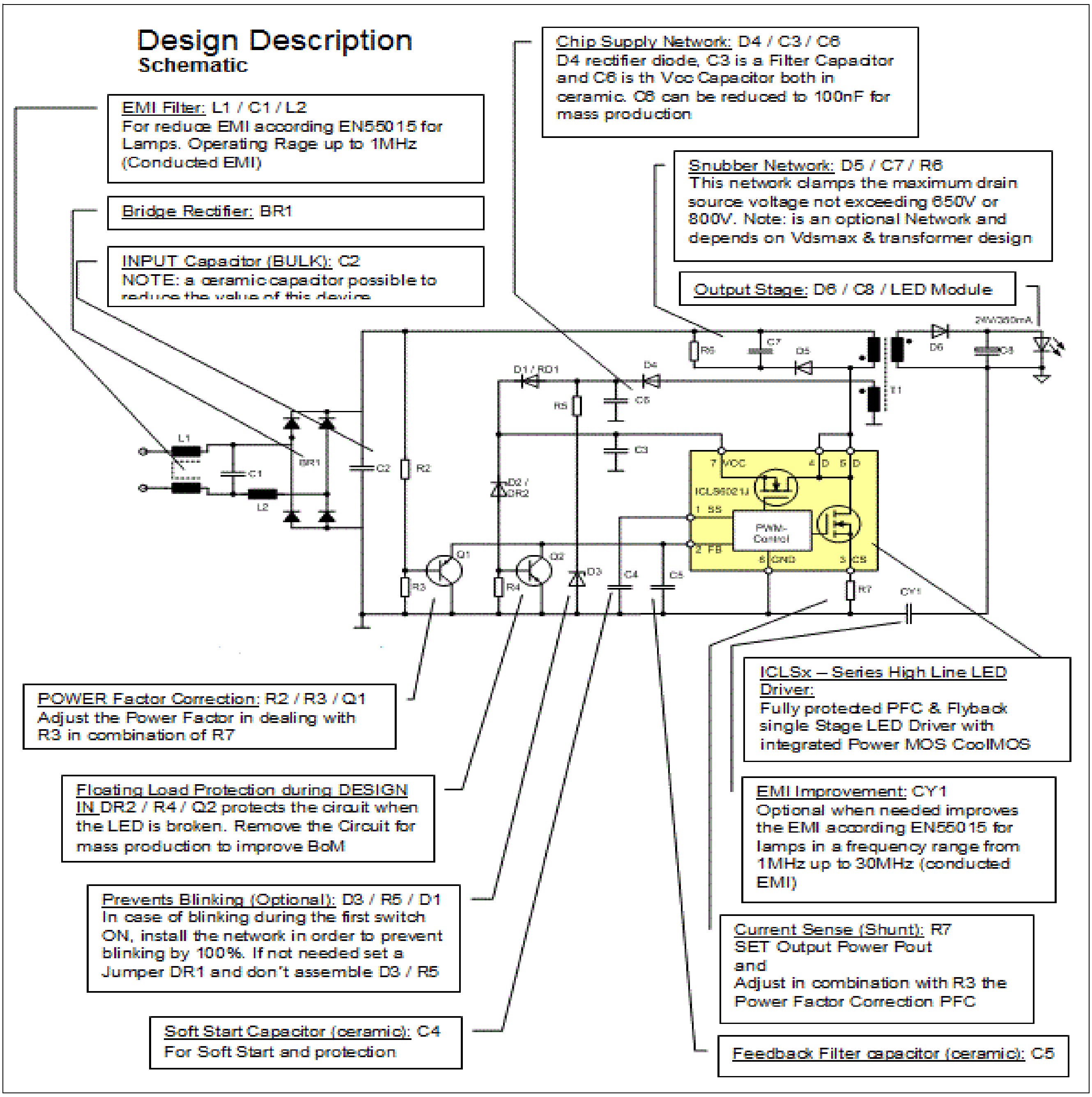


Figure 4 **General Schematic**

Overall BOM

Table 4 Overall BOM

PFC Flyback singlestage LED Driver Board
230Vacin / BOM for ICLS6021J
24V / 350mA / 8.4Win / 230VAC

Component	Value	Package
IC1	ICLS6021J	DIP8
Q1	BC807 (PNP)	SOT23
Q2	BC817 (NPN) **optional**	SOT23
BR1	VISHAY B6S-E3/80	SMD
D1 / RD1	LL4148 / 0 Ohm **optional**	Minimelf / 1206
D2 / RD2	Z-24V / 43k **optional**	Minimelf / 1206
D3	Z-4V3 **optional**	Minimelf
D4	BYG-22D	SMA
D5	MURS160	SMB
D6	ES1D	SMA
C1	68nF 250VAC MKP-X2	RM10
C2	47nF 400VAC	RM7.5 EPCOS B32520-C6473-K000
C3	100nF/50V	0805
C4	470nF/50V	0805
C5	2.2nF/15V	1206
C6	10µF/35V **optional** 100nF/35V	1206
C7	1nF/400	RM7.5
C8	150µF/35V (ELKO)	RM5
CY1	1nF / 250AC-Y1 **optional**	RM7.5
L1	2X22mH/0.3A	B82720-K2301N042
L2	1mH/130mA	Axial / EPCOS B78108S1105J
T1	3.26mH (AIR Gap=0.2mm)	EF16/8/5
	Wuerth Nr. 760875040	Np2_1/Ns7_6/Naux5_4=158/39/33
R1	0	0805
R2	1M	0805
R3	18k	0805
R4	1k **optional**	1206
R5	10k **optional**	0805
R6	130k	RM7.5 / axial
R7	3R0	1206 / 1%
W1	Wire	Diameter: 0.5mm
		Changing Date: 110516 / KLING

Description of the Single Stage for PFC and Flyback Operation

Startup

From the high line voltage, the chip supplies itself via the integrated startup cell. During this phase, the startup cell charges the Vcc cap C6 with a constant current of 1 mA up to 18.0 Vcctyp. The IC current consumption is about 300 µA during this phase. After reaching Vccontyp = 18.0 V the startup cell is shut off to save energy and increase efficiency during normal operation.

Soft start

The soft start controls the input current, the duration of the soft start phase via the external C4 capacitor and also defines the response time in the case of an error. During startup, the soft start pin controls the primary current. When the soft start ends (the feedback signal is lower than the soft start signal), the feedback takes over control of the primary current.

Operation mode

During operation, the VCC pin is supplied via a separate transformer winding with associated rectification didode D4 and buffering C6. C3 is a filter capacitor in order to prevent glitches for a proper working Vcc stage. The IC current is about 3 mA with active gates.

Snubber network

R6, C7 and D5 dissipate the energy of the leakage inductance and clamp the drain source voltage below the maximum drain source voltage of Vdsmax = 650 V @ 110 °C.

Primary current limitation

The CoolMOS source current is sensed with an external shunt resistor R7. When the voltage at R7 exceeds the internal current limit threshold, the gate driver shuts off immediately.

Output voltage

Power is coupled out on the secondary side via a fast-acting diode D6 with low forward voltage. The capacitor C8 performs energy buffering.

The storage capacitor C8 should have the lowest possible internal resistance (low ESR) in order to minimize the output voltage ripple caused by the triangular current characteristic.

Note: If using resistive load, reduce the soft start capacitor to 220 nF / 35 V.

Power Factor Correction

Output voltage is controlled for constant power and defined by the LED module used: LEDON 24 V 350 mA.

The feedback signal regulates the power factor via the network R2, R3 and Q1 in combination with R7. The feedback pin is internally connected to the current sensing, which regulates the waveform of the input current as a mirror of the feedback signal.

Protection modes for short output and floating load

Together with the soft start capacitor C4, the feedback also senses errors in order to protect the bulb against destruction. In the case of a short output, the IC falls into the Auto Restart Mode (ARM). If an open load event occurs, the IC falls into the Floating Load Protection (FLP) Mode.

Note: For FLP, the network DR2, R4 and Q2 has to be assembled (optional).

EMI network

For conducted EMI issues, L1, C1 and L2 filter at a frequency up to 1 MHz, CY1 filters from 1 MHz up to 30 MHz.

Board Layout TOP

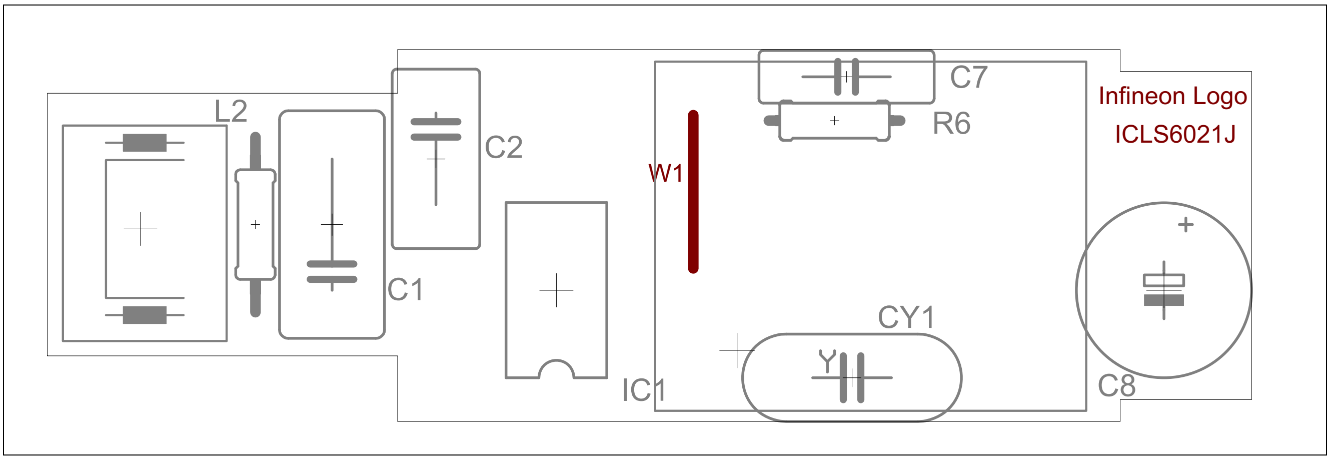


Figure 5 Board Layout TOP

Board Layout BOTTOM

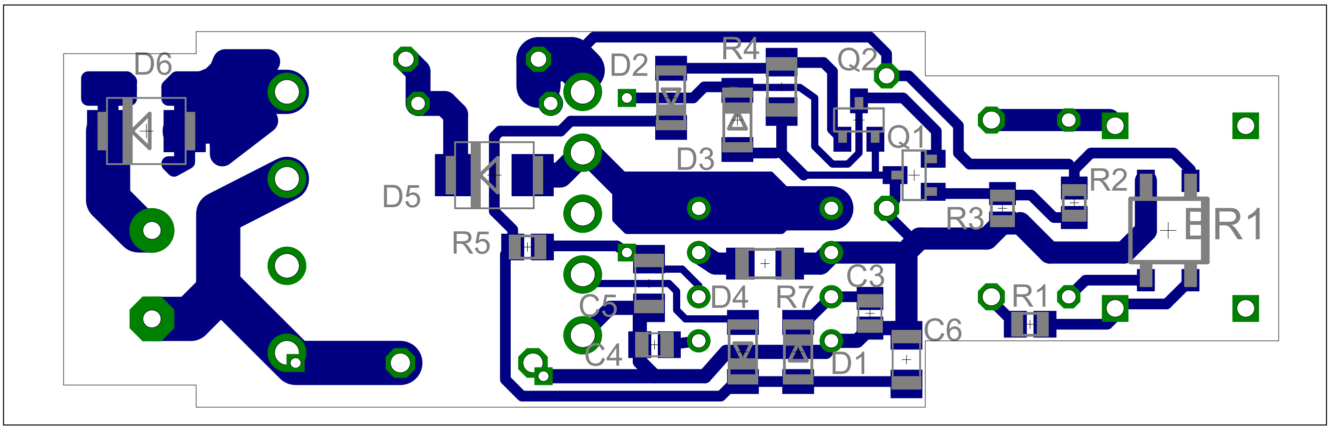
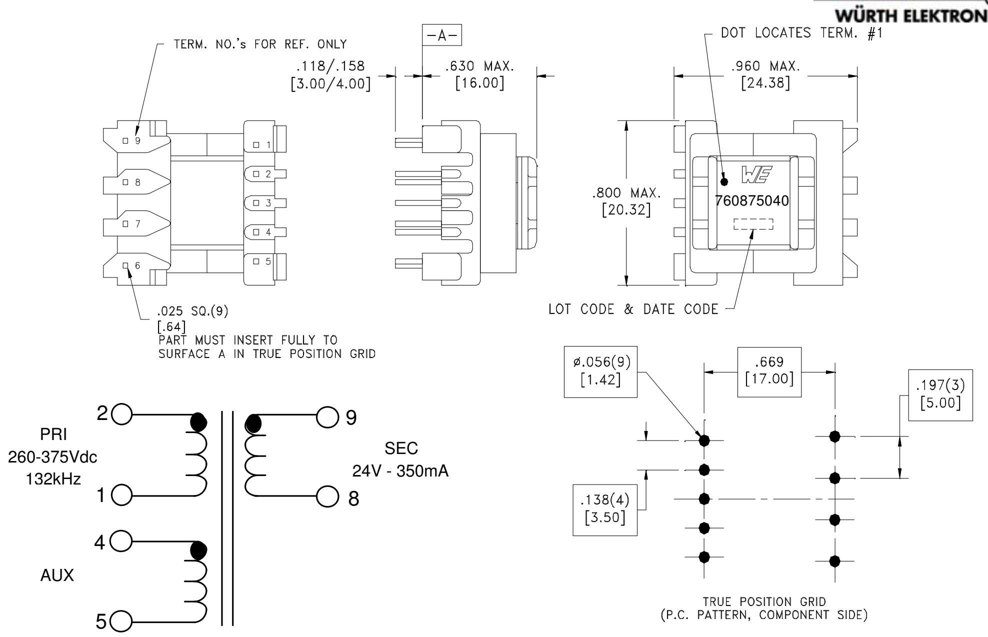


Figure 6 Board Layout BOTTOM

Transformer Construction

CUSTOMER TERMINAL	RoHS	LEAD(Pb)–FREE
Sn96%, Ag4%	Yes	Yes

WÜRTH ELEKTRONIK



ELECTRICAL SPECIFICATIONS @ 25°C unless otherwise noted:

D.C. RESISTANCE (@20°C):	2-1 , 4.70 Ohms ±10%.
	9-8 , 0.60 Ohms ±10%.
	4-5 , 1.32 Ohms ±10%.
DIELECTRIC RATING:	4500VAC, 1 minute tested by applying 4500VAC for 1 second between pins 2-9 (2+4).
	500VAC, 1 minute tested by applying 625VAC for 1 second between pins 1-5.
INDUCTANCE:	3.26 mH ±10%, 10KHz, 100mVAC, 0mADC, 2-1, Ls.
SATURATION CURRENT:	330mA saturating current that causes 20% rolloff from initial inductance.
LEAKAGE INDUCTANCE:	61µH typ., 100µH max., 100KHz, 100mVAC, 2-1(4+5, 8+9), Ls.
TURNS RATIO:	(2-1):(9-8), (4.051):(1.00), ±1%.
	(2-1):(4-5), (4.787):(1.00), ±1%.

Designed to comply with the following requirements as defined by IEC61558-2-17:
- Reinforced insulation for a primary circuit at a working voltage of 400VDC.

OPERATING TEMPERATURE RANGE: -40°C to 125°C including temp. rise.

Wire insulation & RoHS status not affected by wire color. Wire insulation color may vary depending on availability.

T_0_5280

WE-Midcom, Inc. Watertown, SD USA Toll Free: 800-643-2661 Fax: 605-886-4486	Unless otherwise specified, tolerances are as follows: Angles: ±1° Fractions: ±1/64 Decimals:±.005(.127mm)	WE-Midcom, Inc.	
	Drawing Title Transformer	Drawing Number 760875040	Rev. 00
This drawing is dual dimensioned. Dimensions is brackets are in millimeters	Revisions: See Sheet 1	Scale ----	Sheet 2 of 5
	Engineer:ANC		03/02/2011

Figure 7 Transformer Specification Flyback Transformer Reinforced

Design Optimization

DESIGN-IN Phase

Schematic for Design-IN Phase

During the Design-IN phase, the designer should install the overvoltage protection circuitry R2 / R3 and Q1 in order to protect the design against floating (missing) loads.

Note: For mass production, remove this network (as LED is connected). In the case of floating (missing) loads, the IC dies internally via Vcc over voltage Vccmax = 27 V.

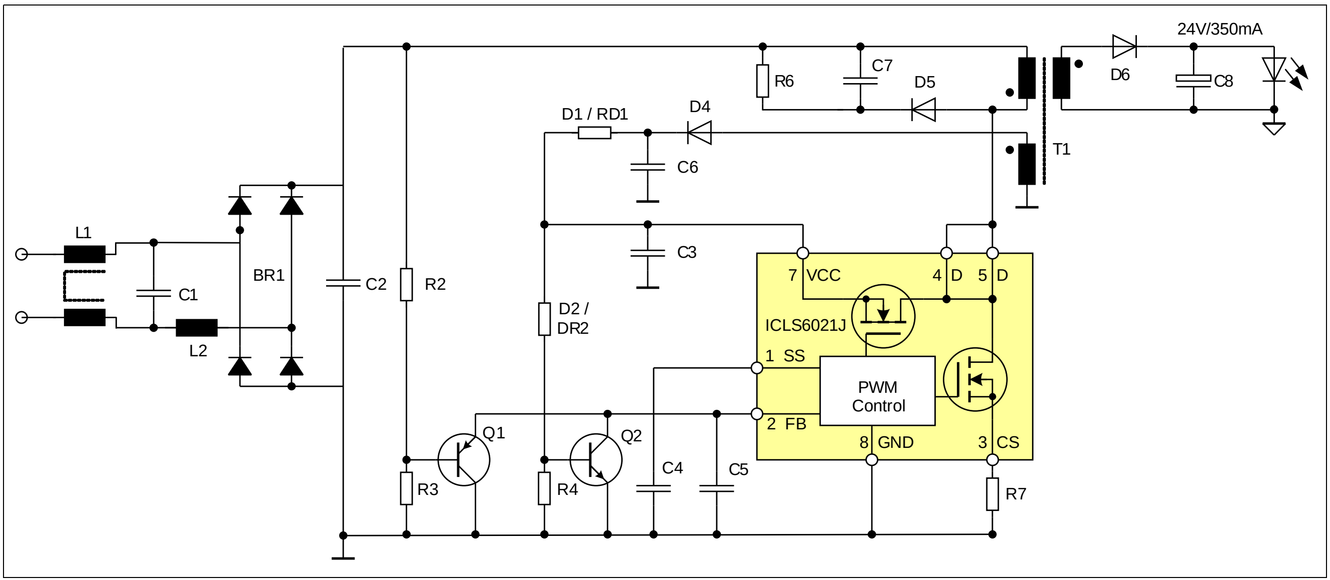


Figure 8 Schematic Design IN

BOM Design-IN Phase

Table 5 BOM for Design-IN

PFC Flyback singlestage LED Driver Board
230Vacin / BOM for ICLS6021J
24V / 350mA / 8.4Win / 230VAC

Component	Value	Package
IC1	ICLS6021J	DIP8
Q1	BC807 (PNP)	SOT23
Q2	BC817 (NPN)	SOT23
BR1	VISHAY B6S-E3/80	SMD
D1 / RD1	0	1206 Jumper
D2 / RD2	43k	1206
D3	n.a.	1206
D4	BYG-22D	SMA
D5	MURS160	SMB
D6	ES1D	SMA
C1	68nF 250VAC MKP-X2	RM10
C2	47nF 400VAC	RM7.5 EPCOS B32520-C6473-K000
C3	100nF/50V	0805
C4	470nF/50V	0805
C5	2.2nF/15V	1206
C6	10µF/35V	1206
C7	1nF/400	RM7.5
C8	150µF/35V (ELKO)	RM5
CY1	n.a.	RM7.5
L1	2X22mH/0.3A	B82720-K2301N042
L2	1mH/130mA	Axial / EPCOS B78108S1105J
T1	3.26mH (AIR Gap=0.2mm)	EF16/8/5
	Wuerth Nr. 760875040	Np2_1/Ns7_6/Naux5_4=158/39/33
R1	0	0805
R2	1M	0805
R3	18k	0805
R4	1k	1206
R5	n.a.	0805
R6	130k	RM7.5 / axial
R7	3R0	1206 / 1%
W1	Wire	Diameter: 0.5mm
		Changing Date: 110509 / KLING

Mass Production

Schematic for Mass Production

The only case which leads to destruction of the IC is a floating load. In this case the IC destroys itself via Vcc overvoltage exeeding Vccmax = 27 V. From this point of view, there is no need for protection against floating loads if the LED is broken – the bulb is damaged anyway. All other protections are still activated.

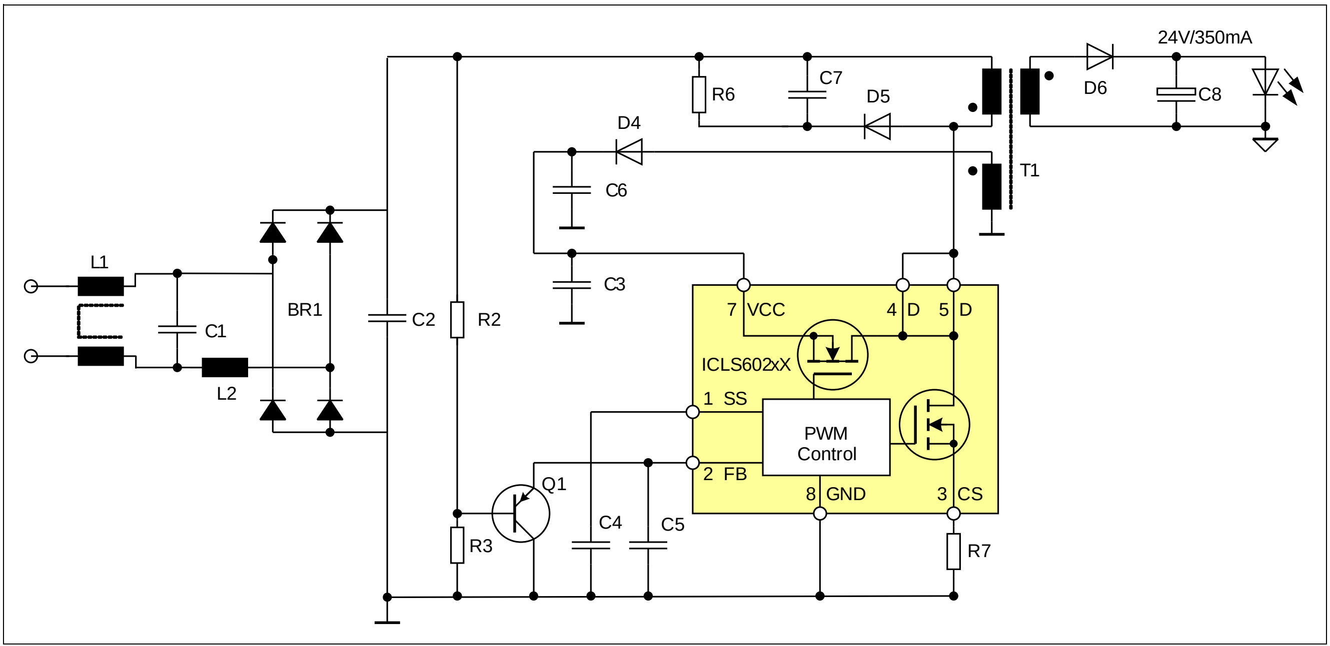


Figure 9 Schematic Mass Production

BOM Mass Production

Table 6 BOM Mass Production

PFC Flyback singlestage LED Driver Board 230Vacin / BOM for ICLS6021J 24V / 350mA / 8.4Win / 230VAC		
Component	Value	Package
IC1	ICLS6021J	DIP8
Q1	BC807 (PNP)	SOT23
BR1	VISHAY B6S-E3/80	SMD
D4	BYG-22D	SMA
D5	MURS160	SMB
D6	ES1D	SMA
C1	68nF 250VAC MKP-X2	RM10
C2	47nF 400VAC	RM7.5 EPCOS B32520-C6473-K000
C3	100nF/50V	0805
C4	470nF/50V	0805
C5	2.2nF/15V	1206
C6	100nF/35V	1206
C7	1nF/400	RM7.5
C8	150µF/35V (ELKO)	RM5
L1	2X22mH/0.3A	B82720-K2301N042
L2	1mH/130mA	Axial / EPCOS B78108S1105J
T1	3.26mH (AIR Gap=0.2mm)	EF16/8/5
	Wuerth Nr. 760875040	Np2_1/Ns7_6/Naux5_4=158/39/33
R2	1M	0805
R3	18k	0805
R6	130k	RM7.5 / axial
R7	3R0	1206 / 1%
W1	Wire	Diameter: 0.5mm
		Changing Date: 110509 / KLING

Performance, Adjustments and Fine Tuning

Efficiency

Figure 10 shows the impact of the transformer designs: Functional / Reinforced and Mass Production.

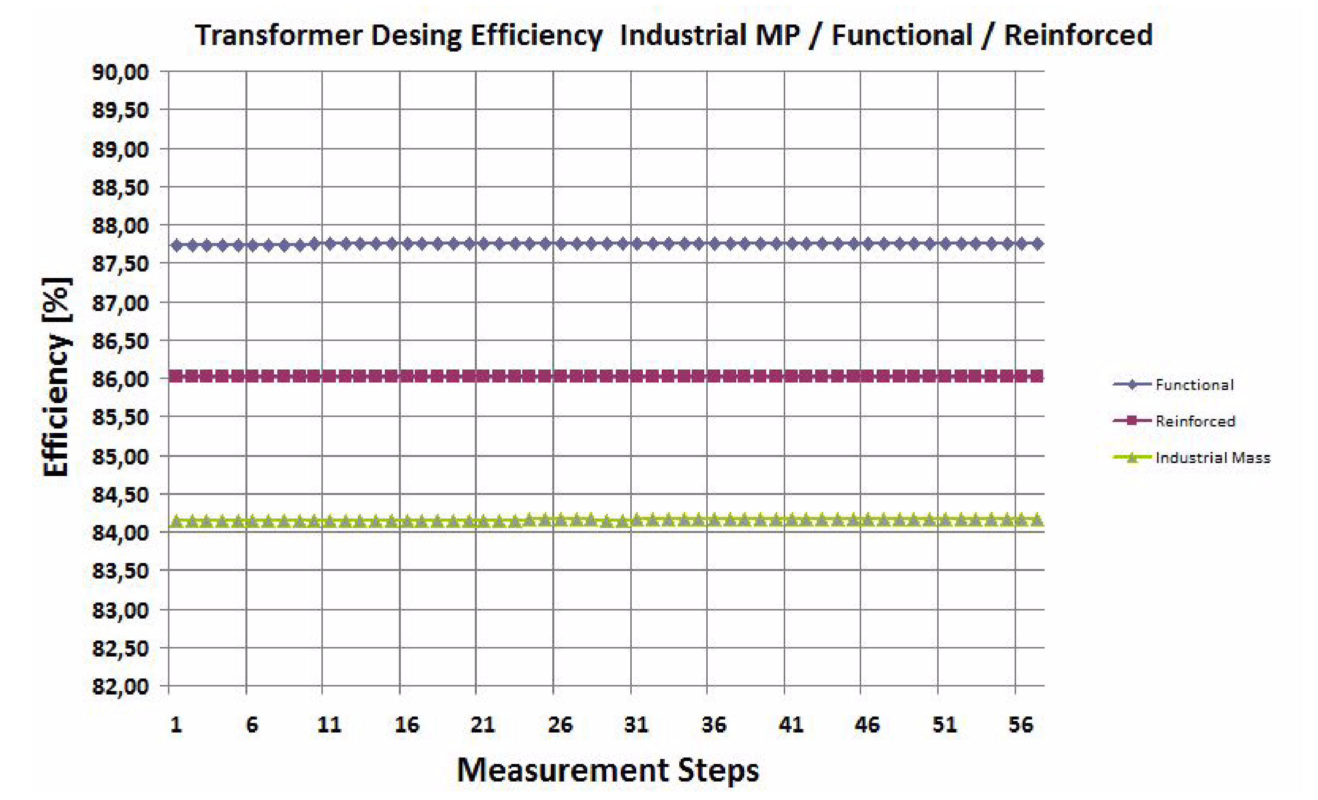


Figure 10 Efficiency versus Transformer Design

Adjusting the Line Regulation

Use the following table in order to adjust the line regulation (output current versus AC line input voltage) to your requirements. For the result of each configuration, see **Figure 11**.

Table 7 Configuration Chart for Line Regulation

Configuration Table

Configuration	R3	R7
1	9.0 kΩ	2.0 Ω
2	11.0 kΩ	2.4 Ω
3	13.0 kΩ	2.7 Ω
4	15.0 kΩ	2.7 Ω
5	16.0 kΩ	3.0 Ω
6	18.0 kΩ	3.0 Ω
7	20.0 kΩ	3.0 Ω
8	22.0 kΩ	3.0 Ω
9	24.0 kΩ	3.0 Ω
10	27.0 kΩ	3.0 Ω
11	30.0 kΩ	3.0 Ω

Choose your configuration by using the result of **Figure 11**.

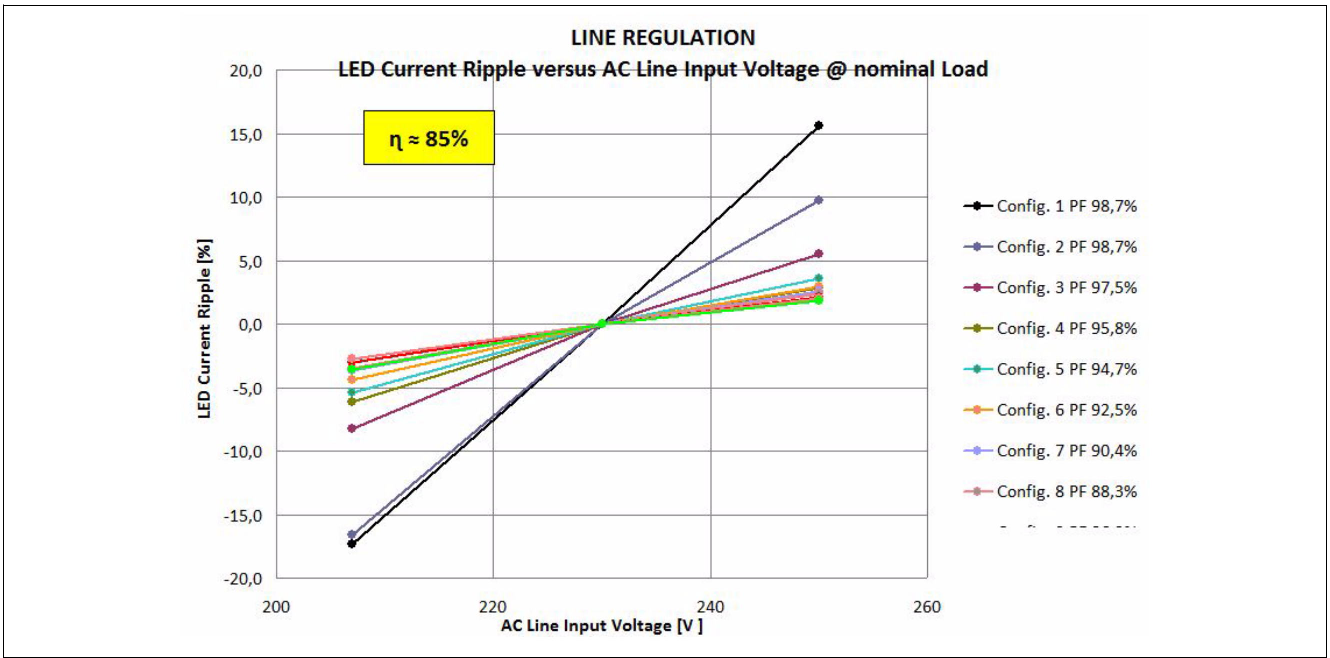


Figure 11 Result of the Configuration

The Y-axis shows the relative deviation of the LED output current versus the AC line INPUT voltage (X-axis). The ffficiency is independent of the configuration.

Adjusting the Power Factor Correction

Use the following configuration table in order to adjust the power factor to your requirements. The result of the configuration is shown below.

Table 8 Configuration Chart for Power Factor Correction

Configuration Table

Configuration	R3	R7
1	9.0 kΩ	2.0 Ω
2	11.0 kΩ	2.4 Ω
3	13.0 kΩ	2.7 Ω
4	15.0 kΩ	2.7 Ω
5	16.0 kΩ	3.0 Ω
6	18.0 kΩ	3.0 Ω
7	20.0 kΩ	3.0 Ω
8	22.0 kΩ	3.0 Ω
9	24.0 kΩ	3.0 Ω
10	27.0 kΩ	3.0 Ω
11	30.0 kΩ	3.0 Ω

Choose your configuration by using the result of **Figure 12**.

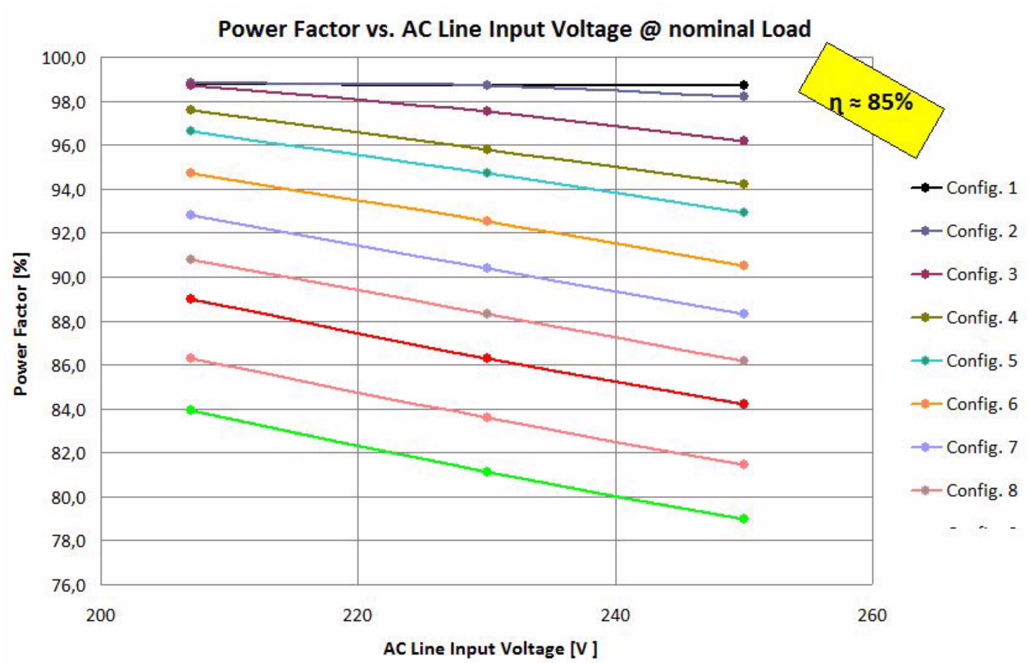


Figure 12 Power Factor versus AC Line Input Voltage

The Y-axis shows the relative deviation of the power factor versus the AC line INPUT voltage (X-axis). The efficiency is independent of the configuration.

EMC

In order to improve the EMC see chapter

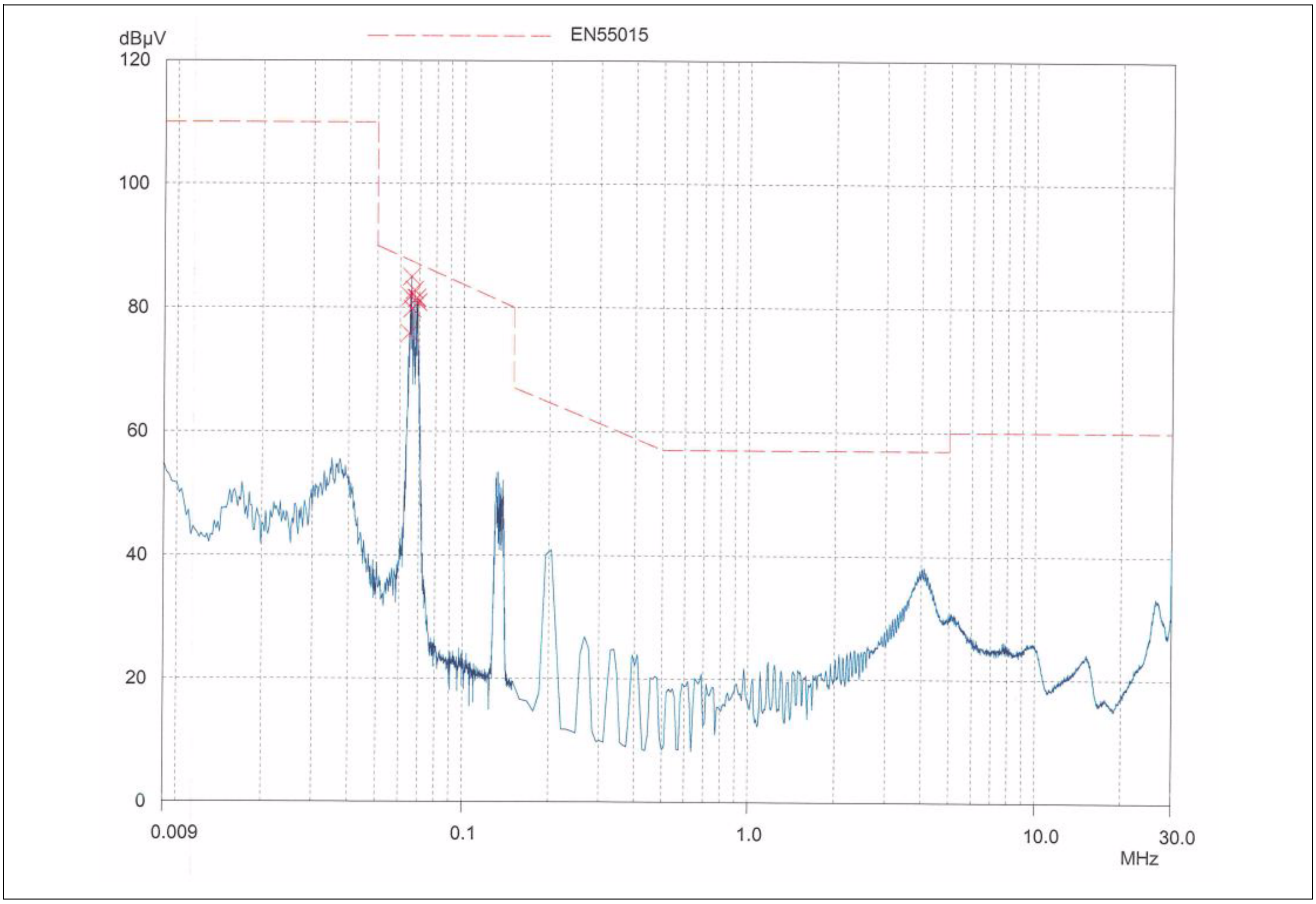


Figure 13 Conducted Emission EN55015 for Lighting

Summary of Main Performance Parameter

NOTE: The values depend on the set configuration, there is crosstalk between line regulation and Power Factor Correction.

Table 9 Overall Summary of the Main Performance Parameter

	Request World Wide	IFX ICLS6021J Demoboard
Power Factor	> 0.8	Up to 98%
THD according EN61000-3-2		PASS
η	> 80%	> 85%
EMI according EN55015		PASS
Line Regulation ILED	30%	< 5%

Typical Curves

A: Normal Run Mode Condition

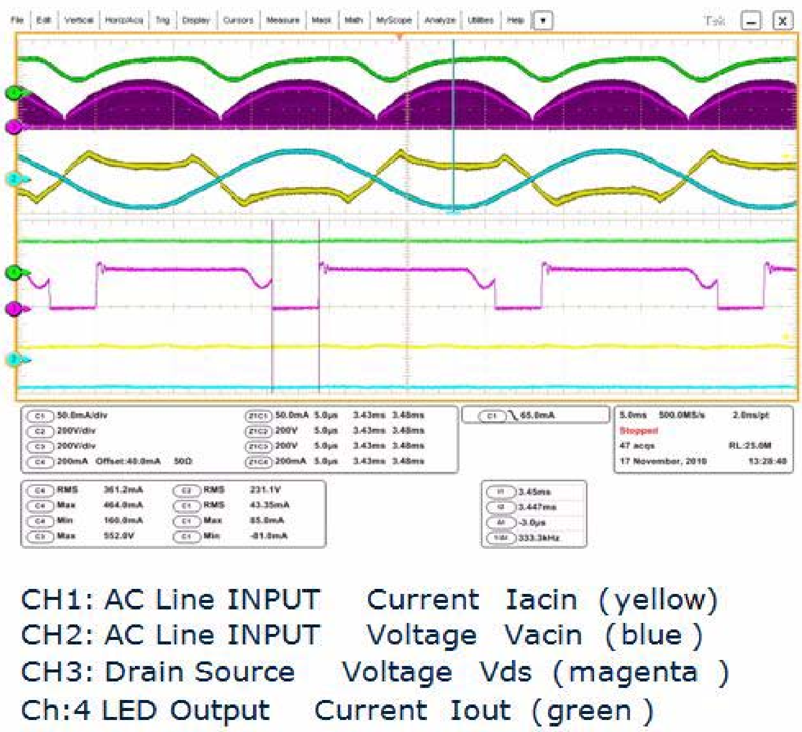


Figure 14 Typical Curves 1

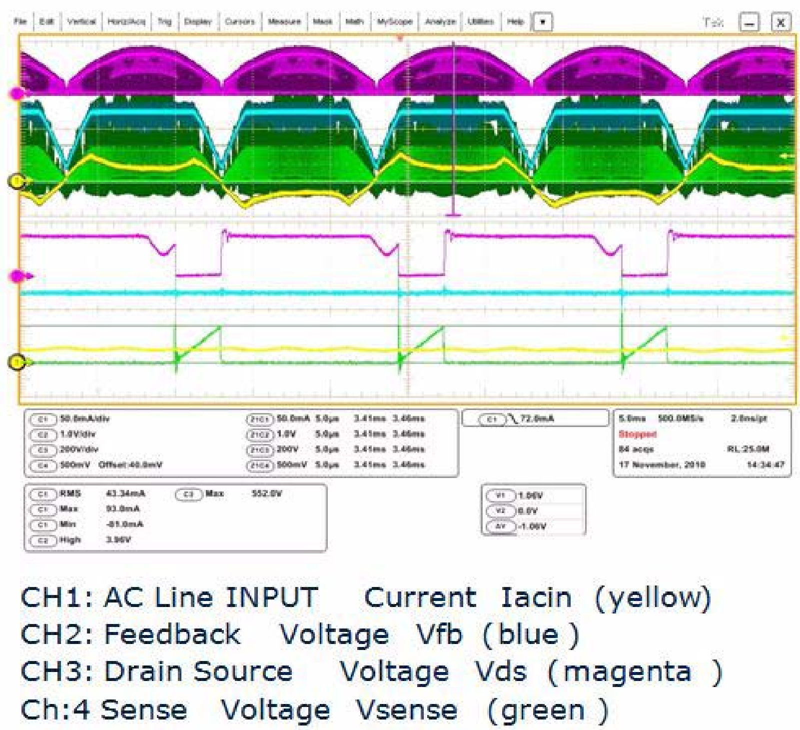


Figure 15 Typical Curves 2

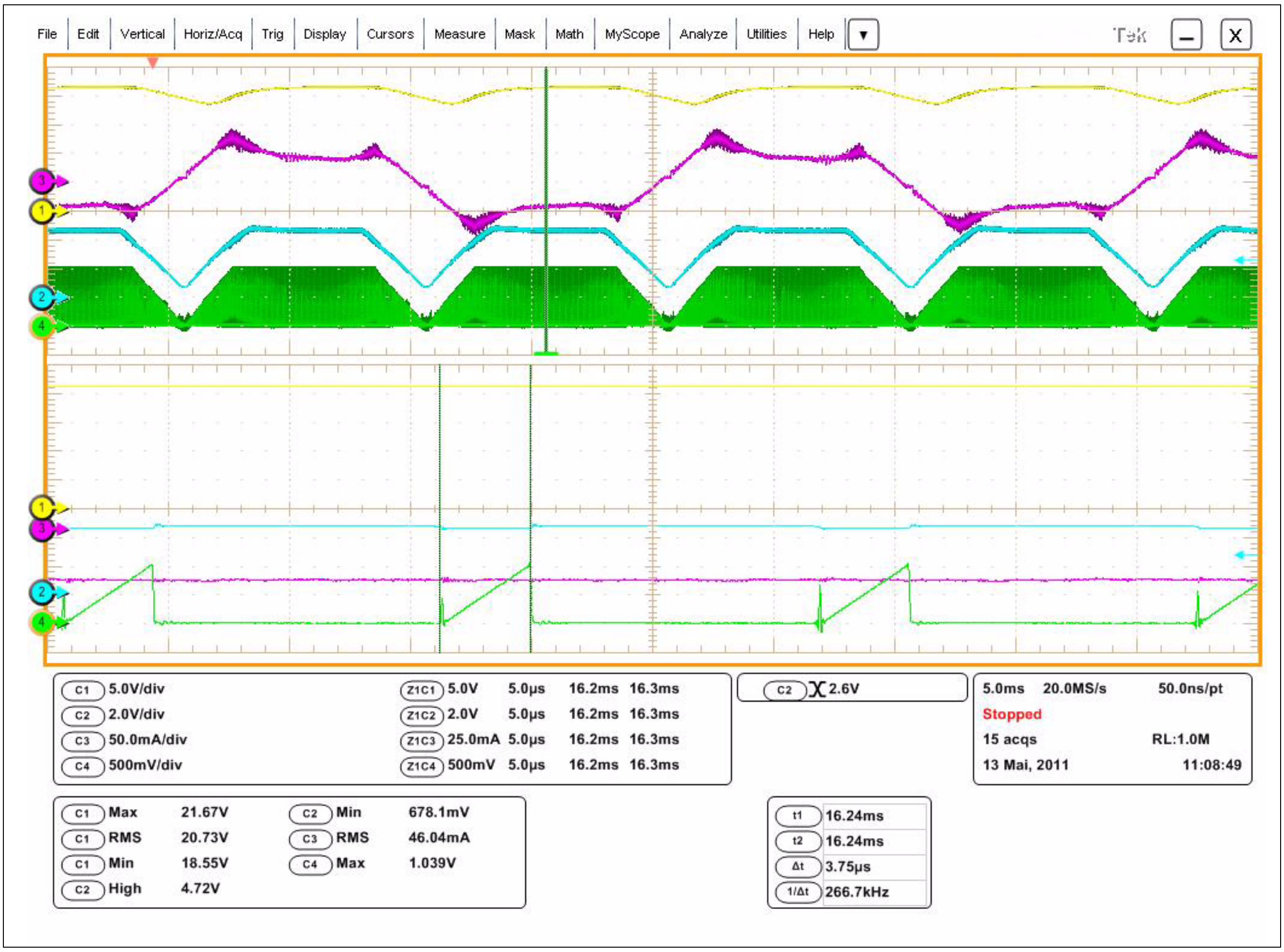


Figure 16 Typical Curves 3

B: Startup and Protected Error Events

Startup

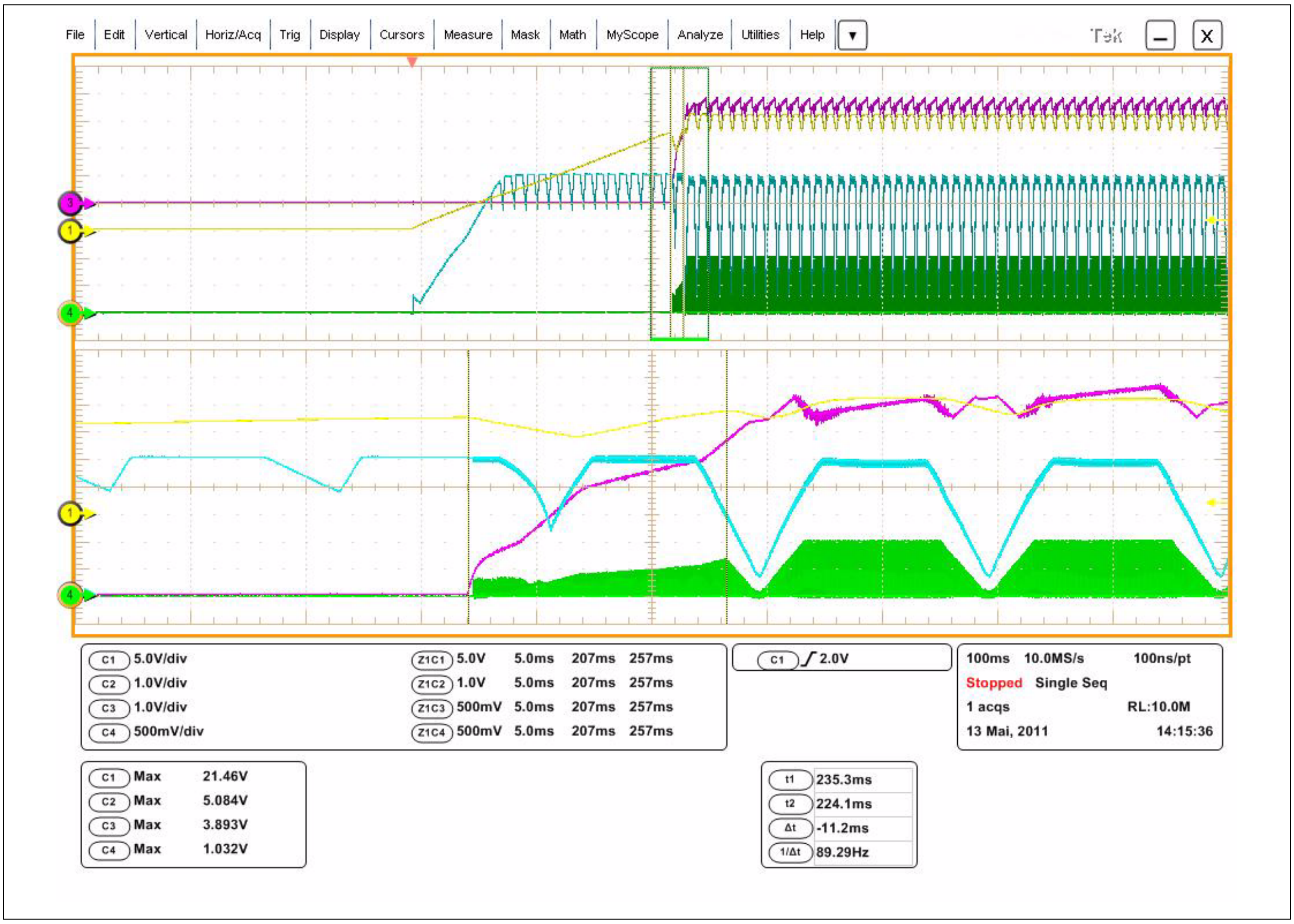


Figure 17 Startup Normal Condition

Description

When supplied with line voltage, the self-depletion cell of IC charges C3 and C6 with approx. 1 mA, causing VCC at pin 7 to ramp up. When passing the level of 18 V, self-depletion is switched off and the Soft Start procedure is started. The CoolMOS current during the Soft Start phase is limited (compared to the normal operating mode), rising with voltage at pin 1 until leaving current control to the PWM section at 3.1 V and more.

VCC drops during Soft Start (C3/C6 discharged by the IC supply current of approx. 3 mA) until the transformer auxiliary winding delivers sufficient supply voltage.

The voltage at the feedback pin 2 is controlled by rectified line voltage (voltage divider R2/R3 and Q1) and chip-internal pull-up resistor. During periods near zero crossing of line voltage feedback is kept low, leading to small output current pulses, which results in a good power factor.

During current control of the PWM section (normal operating mode) the Soft Start voltage controls jitter of the switching frequency, leading to improved EMI performance.

Startup with Floating Load Protection (FLP)

Figure 18 Startup with Floating Load into Floating Load Protection Mode

Description

Startup of circuit as usual, but a missing load leads to rising output voltage and auxiliary voltage.

Reaching the VCC threshold of 24.5 V (voltage divider RD2/R4 and Q2) leads to a reduction in the feedback voltage and hence to reduced output current pulses to keep the output voltage below the maximum rating of components. When the feedback level falls below 1.35 V, the Soft Start voltage begins to rise up to a threshold of 4 V (depends on the C4 value) and the IC is switched into the FLP mode.

Startup with Short OUT Auto Restart Mode (ARM)

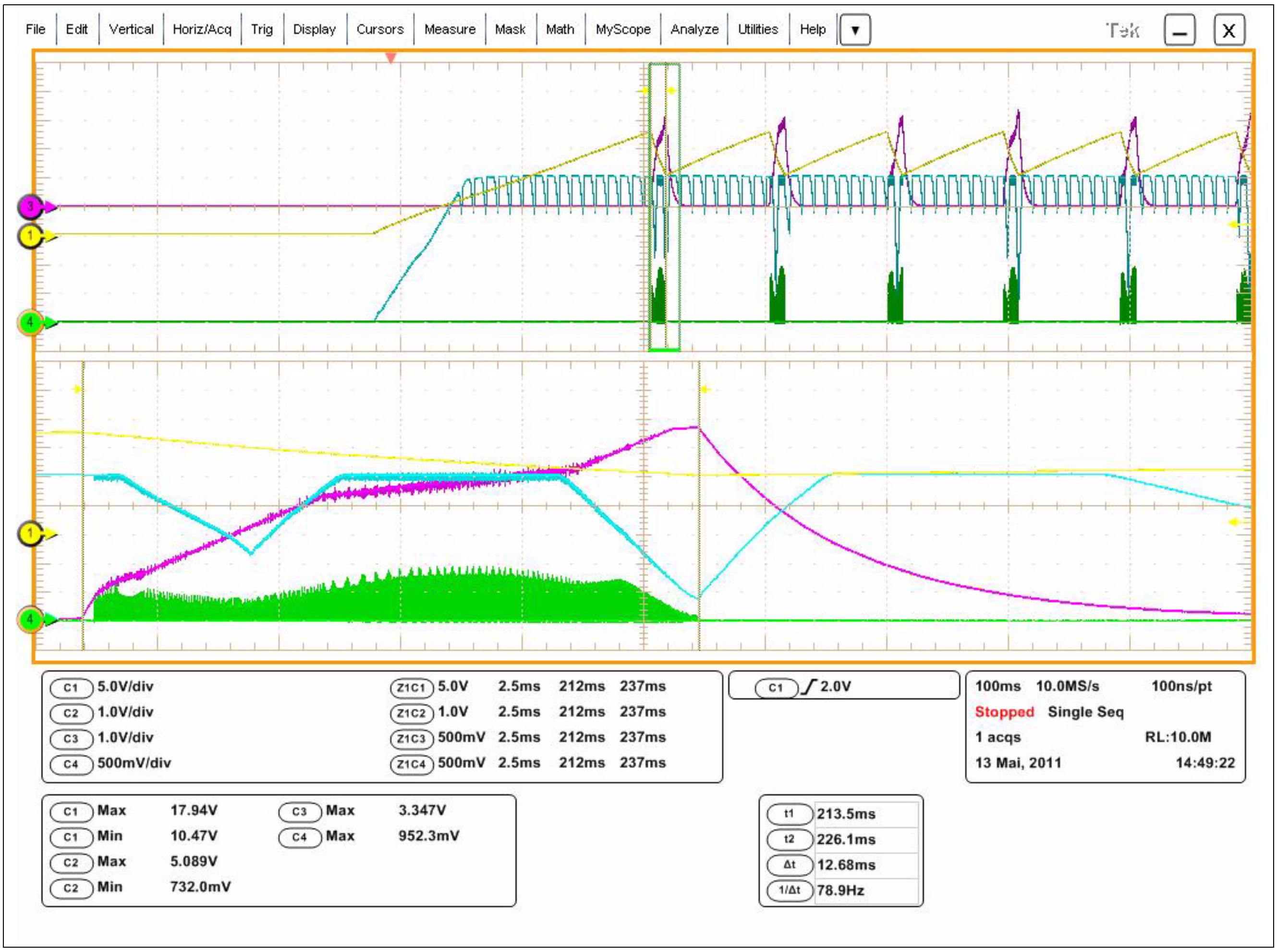


Figure 19 Startup with Short Output into Auto Restart Mode

Description

Startup of circuit as usual, but shortened output causes the auxiliary voltage not to rise. After VCC capacitors (C3/C6) are discharged below a level of the undervoltage logout (10.3 V), the CoolMOS stops switching and starts Auto Restart mode (charging C3/C6 through the internal depletion cell up to 18 V).

This procedure repeats an unlimited number of times to prevent the circuit from overheating.

Startup with Floating Load

Figure 20 Startup with Floating Load into Auto Restart Mode

Description

Startup of circuit as usual.

If feedback is higher than 4.5 V, the Soft Start voltage begins to rise until a threshold of 4 V (depends on the C4 value) is reached, which triggers Auto Restart Mode. The procedure repeats as long as load is missing, ensuring only low supply current under missing load conditions.

RUN Mode: Restart from Floating Load

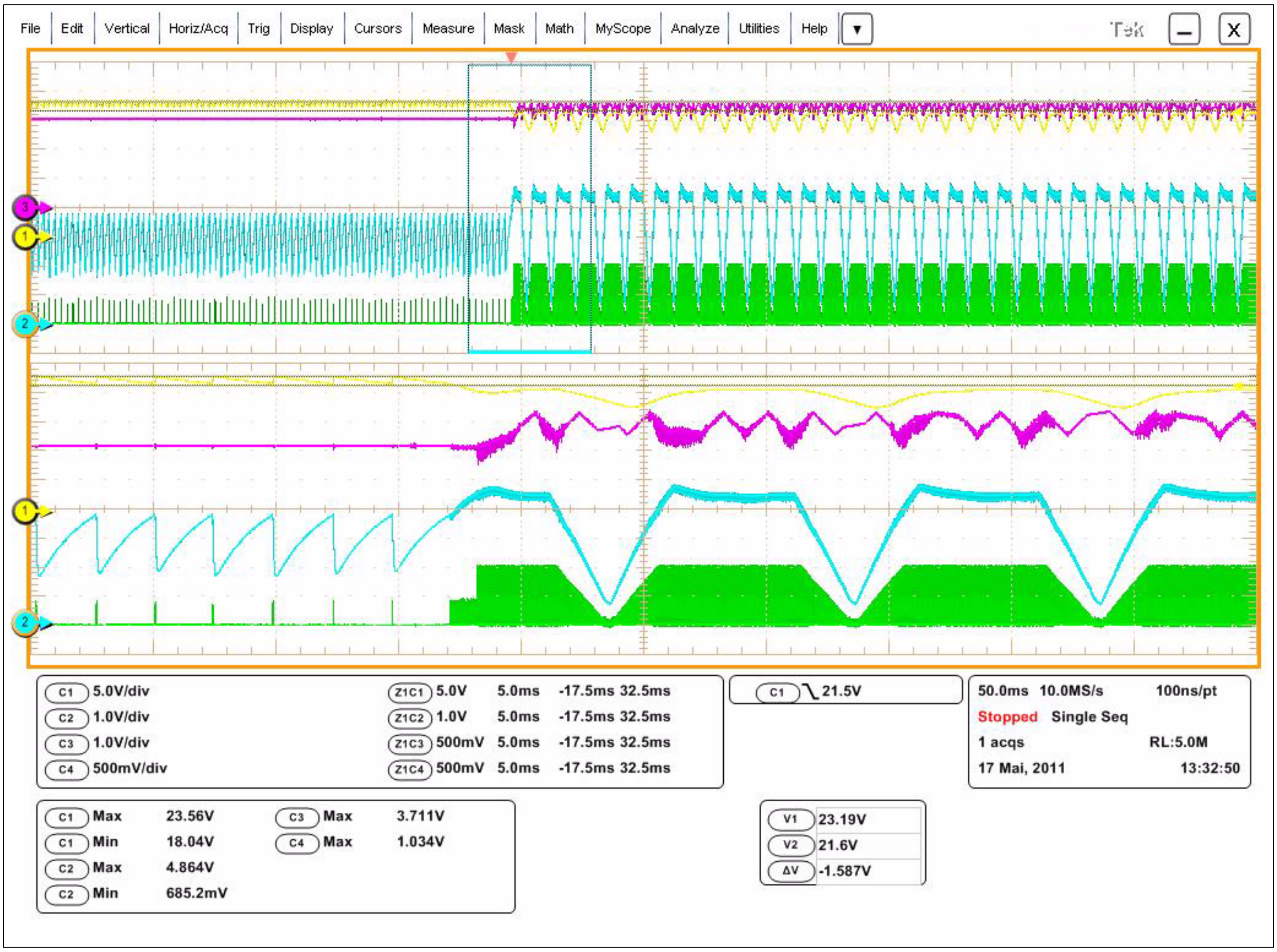


Figure 21 RUN Mode Restart from Floating Load

Description

Precondition: Floating Load Protection (FLP), see description above.

Once a correct load is connected, the circuit resumes normal operation: loaded output leads to lower VCC, releasing the overvoltage protection circuit (RD2, R4, Q2) and feedback exceeding 4.5 V. The FLP mode is exited and the Soft Start voltage begins to rise, alternating between 3.2 V to 3.6 V for frequency jitter control.

RUN Mode Event into Floating Load Protection (FLP)

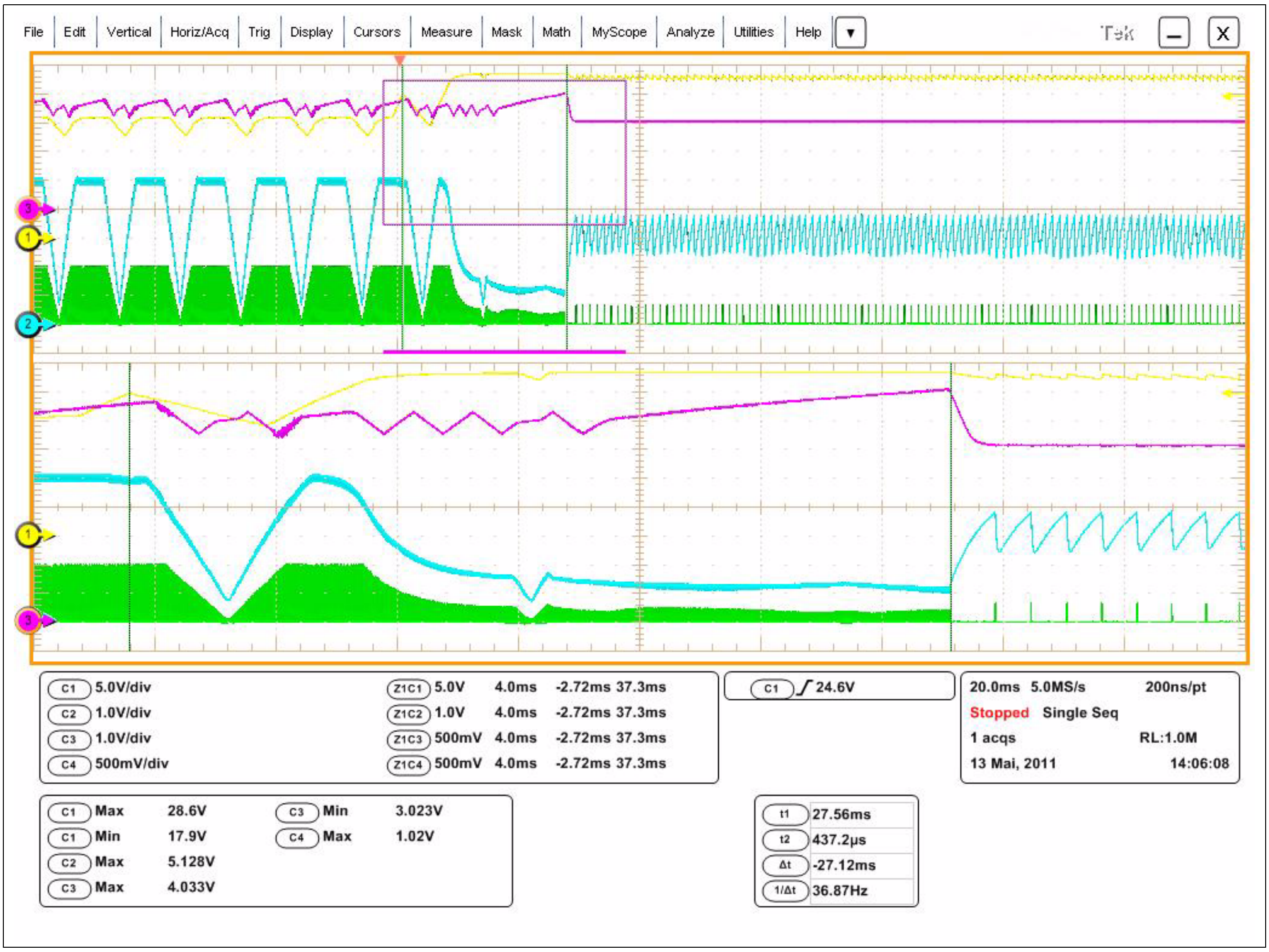


Figure 22 RUN Mode Event of Floating Load

Description

Precondition: Normal operating mode before the load becomes disconnected. Then the following happens: Reaching a VCC threshold of 24.5 V (voltage divider RD2/R4 and Q2) leads to reduction of the feedback voltage and hence reduced output current pulses to keep the output voltage below the maximum rating of components. If feedback falls below 1.35 V, the Soft Start voltage begins to rise up to a threshold of 4 V (the time to do so depends on the C4 value) and the IC is switched into FLP.

RUN Mode Event into Short OUT

Figure 23 RUN Mode Event into Short Output

Description

Precondition: Normal operating mode before shorting output. Then the following happens:
Auxiliary voltage drops, no further charging of VCC capacitors (C3/C6), undervoltage logout at 10.3 V is entered. The CoolMOS stops and Auto Restart mode is entered (charging C3/C6 through the internal depletion cell up to 18 V…). This procedure repeats an unlimited number to prevent the circuit from overheating.

Run Mode Restart from Short OUT

Figure 24 RUN Mode Restart from Short OUT

Description

Precondition: Output was shortened, then proper load connected. The following happens: the next Soft Start phase starts normal mode in the same way as for a normal startup.

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