PMP6010

PMP6010 Test Results

Literature Number:SLUU925

TEXAS INSTRUMENTS	Lighting Power Products Longmont Design Center Montu Doshi & Matt Reynolds December 15, 2011 Rev 1.0

UCC28810 & LM3466 Isolated 120VAC 60W LED Three String LED Driver Reference Design

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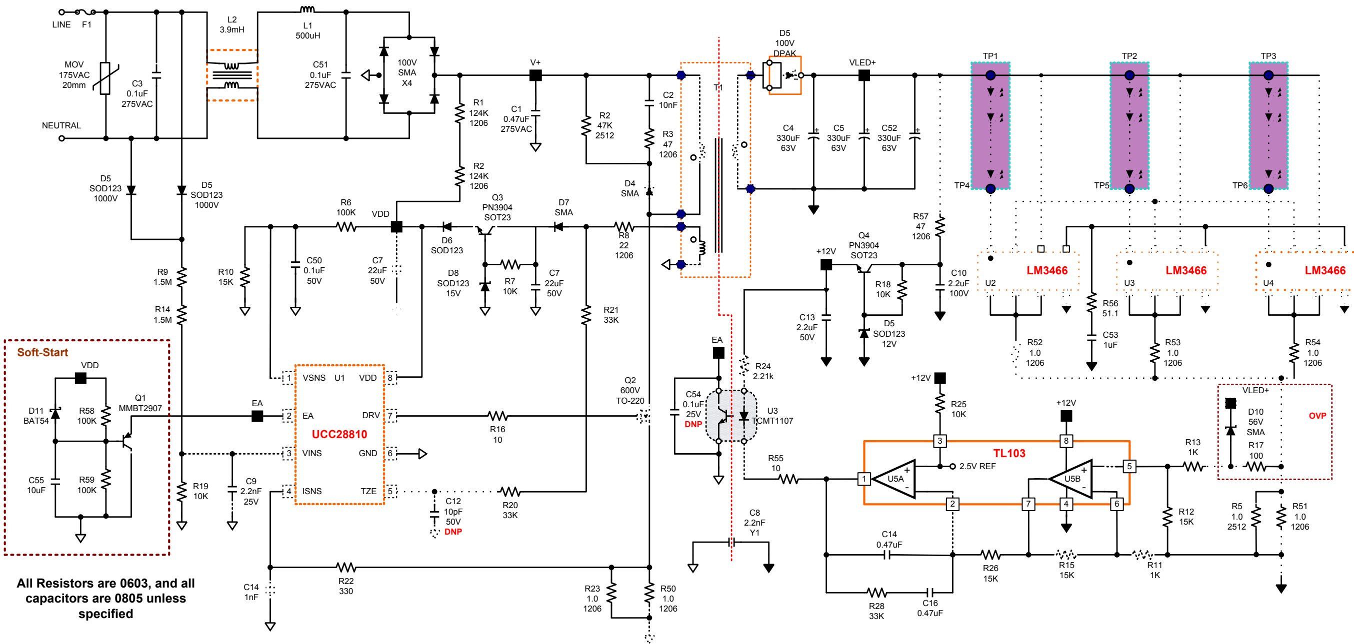
1 60W REV-001 DESIGN PCB

2 TARGET ELECTRICAL SPECIFICATION

- V_{IN} → 90VAC – 132VAC
- V_O → 40V – 50V
- P_O → 60W
- I_O → 1.25A
- Efficiency → 85%

3 PROPOSED SOLUTION/SCHEMATIC



All Resistors are 0603, and all capacitors are 0805 unless specified

4 TRANSFORMER DESIGN

4.1 Design Parameters

- $V_{AC\text{-}MIN}$ = 90 V_{AC}
- $V_{AC\text{-}MAX}$ = 132 V_{AC}
- P_{OUT} = 60 W
- V_{OUT} ≈ 47V
- $V_{DC\text{-}MIN}$ = $\sqrt{2} \times 90V_{AC}$ = 127V
- $V_{DC\text{-}MAX}$ = $\sqrt{2} \times 132V_{AC}$ = 186V
- $V_{O\text{-}MAX}$ ≈ 50V
- P_{IN} = $\frac{P_{OUT}}{\eta}$ (85%) = 70W
- $I_{IN\text{-}AVE}$ = $\frac{P_{OUT}}{\eta \times V_{DC\text{-}MIN}}$ = 550mA
- $f_{SW\text{-}MIN}$ = 120kHz

Assume we want a 600V MOSFET

Therefore N_P/N_S maximum would be 5:1. I will choose ~ 3:1

Duty Cycle

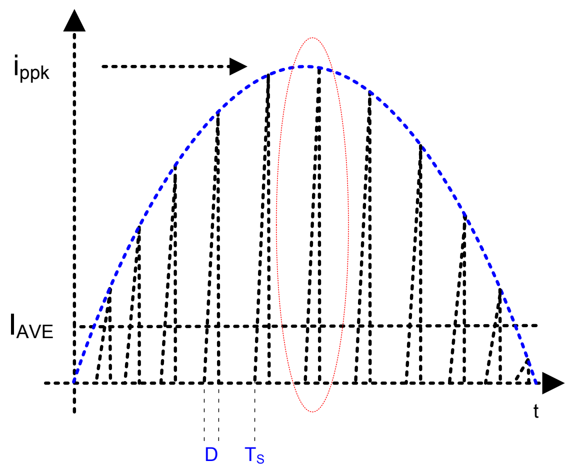
$$D = \frac{\left(V_O \times \frac{N_P}{N_S}\right)}{\left(V_O \times \frac{N_P}{N_S}\right) + \left(V_{IN}\right)}$$

Typical Duty Cycle 0.46

$$D = \frac{\left(V_O \times \frac{N_P}{N_S}\right)}{\left(V_O \times \frac{N_P}{N_S}\right) + \left(V_{IN\text{-}MIN}\right)}$$

D_{MAX} = 0.54

Peak Input Current



$I_{IN\text{-}AVE} = \dfrac{P_{OUT}}{\eta \times V_{DC\text{-}MIN}}$ = 550mA

$$Energy = \frac{1}{2} \times L \times i_{ppk}^2$$

Or, area of the triangle = 1/2 base x height

$i_{PPK} = \dfrac{2 \times I_{AVE}}{D}$ ≈ 2.0A

Therefore $\rightarrow i_{PPK} = \sqrt{\dfrac{P_{IN} \times 2}{f_{SW} \times L}}$

Primary Inductance

$$V = L\frac{di}{dt}$$

$L = \dfrac{V_{IN\text{-}MIN} \times D_{MAX}}{f_{SW-MIN} \times i_{PPK}}$ = 300uH

Choose 200uH – 225uH

Calculating Primary Turns

Maximum operating flux density for most cores is 0.20T

$$B_{MAX} = \frac{L_{PRI} \times i_{PPK}}{N_{PRI} \times A_e}$$

Where A_e equals the specific cores effective area.

PQ26/20 (guess) effective core parameters.

Ae = 119mm²

$$N_P = \frac{L_{PRI} \times i_{PPK}}{B_{MAX} \times A_e}$$

B = Tesla

L = Henrys

$A_e = m^2$

$$N_P = \frac{200 \times 10^{-6}(2.0A)}{(0.20T) \times 51.8 \times 10^{-6} m^2} \approx 39 \text{ turns}$$

Alternatively:

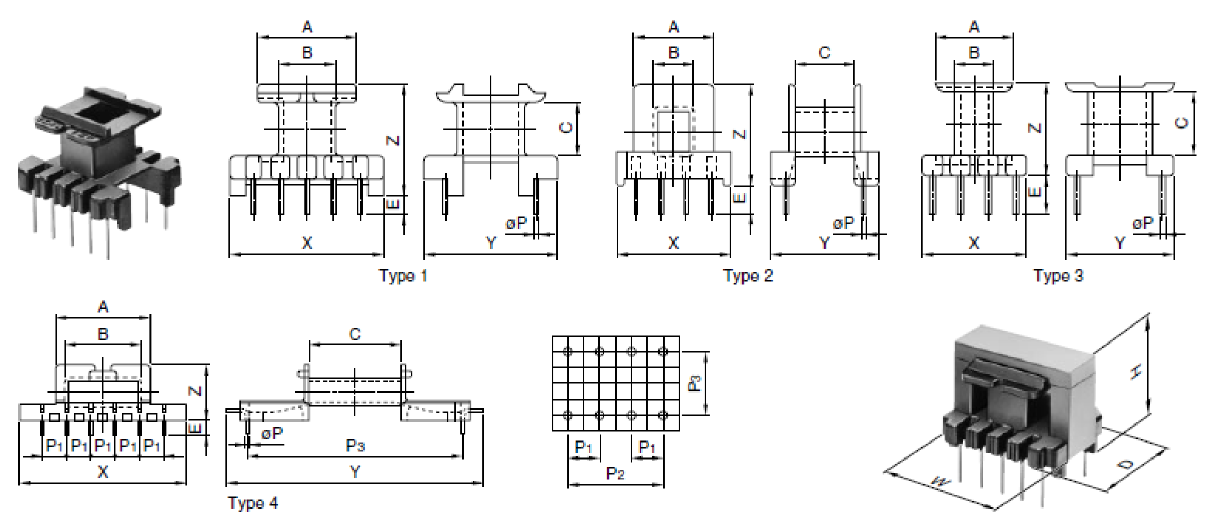
$N_P^2 = \frac{L_{PRI}}{A_L}$ Choose an AL, and calculate primary turns. Graphs similar to the one on the right are quick and simple to use. Define AL (160nH/T^2), and then determine gap. Look for standard A_L numbers when designing your transformer.

$$N_P = \sqrt{\frac{L_{PRI}}{A_L}} = 35\text{turns} \rightarrow Al = 160nH/T^2$$

$$N_P = \sqrt{\frac{L_{PRI}}{A_L}} = 45\text{turns} \rightarrow Al = 100nH/T^2$$

4.2 Core/Bobbin Selection

EE AND EI BOBBINS



Part No.	Type	Dimensions in mm / inches							
		A	B	C	E	X	Y	Z	t
BE22-118CPFR	1	12.5 .492	7.9 .311	8.45 .332	6.0 .236	22.0 .866	17.0 .669	17.3 .681	0.85 .033
BE22/19/6-118CPFR	1	15.2 .598	7.9 .311	8.45 .332	6.0 .236	22.0 .866	17.0 .669	17.3 .681	0.85 .033
BE25-118CPFR	1	18.1 .713	9.1 .358	9.8 .386	6.0 .236	25.0 .984	18.0 .709	19.3 .760	0.90 .035
BE28-1110CPLFR	1	18.1 .713	9.9 .390	9.6 .378	7.0 .276	28.0 1.102	25.0 .984	20.6 .811	0.90 .035
BE30-1110CPFR	1	19.2 .756	13.1 .516	13.7 .539	7.0 .276	30.0 1.181	25.0 .984	24.65 .970	0.85 .033
BE30-1112CPFR	1	19.4 .764	13.1 .516	13.7 .539	7.0 .276	30.0 1.181	25.0 .984	24.65 .970	0.70 .028
BE33-1112CPLFR	1	23.1 .909	12.4 .488	16.6 .654	7.0 .276	33.0 1.299	28.0 1.102	28.6 1.126	0.90 .035
BE35-1112CPLFR	1	24.0 .945	12.7 .500	15.7 .618	7.0 .276	35.0 1.378	25.0 .984	28.7 1.130	0.90 .035
BE40-1112CPFR	1	26.5 1.043	14.0 .551	17.3 .681	7.0 .276	36.0 1.417	30.0 1.181	30.5 1.201	0.80 .031
BE40-1112CPNFR	1	26.5 1.043	14.0 .551	17.3 .681	7.0 .276	36.0 1.417	30.0 1.181	30.5 1.201	0.80 .031

Part No.	Dimensions in mm						Parameter		Wt	Accessory item
	øP (mm)	P_1 (mm)	P_2 (mm)	P_3 (mm)	Terminal pins	W D H (mm)	Aw (mm²)	ℓw (mm)	(g)	
BE22-118CPFR	0.8	5.0	15.0	12.5	8	22.3 17.1 20.1	20.0	38.6	2.3	—
BE22/19/6-118CPFR	0.8	5.0	15.0	12.5	8	22.4 17.1 19.1	31.5	42.8	2.7	—
BE25-118CPFR	0.8	5.0	15.0	12.5	8	25.8 18.1 20.5	42.5	49.4	3.5	—
BE28-1110CPLFR	0.8	5.0	20.0	17.5	10	28.5 25.1 22.7	39.4	59.1	5.0	—
BE30-1110CPFR	0.8	5.0	20.0	20.0	10	30.4 25.1 28.6	44.5	61.0	4.9	FE-30-F FE-30-G
BE30-1112CPFR	0.8	5.0	25.0	20.0	12	30.4 25.1 28.6	43.2	58.0	6.2	
BE33-1112CPLFR	0.8	5.0	25.0	22.5	12	33.5 28.1 31.2	88.8	72.3	6.8	—
BE35-1112CPLFR	0.8	5.0	25.0	20.0	12	35.5 25.1 30.9	88.7	68.5	7.7	—

Part No.	Effective parameter				Electrical characteristics			Wt	Bobbin item
	C1 (mm^{-1})	Ae (mm^2)	ℓe (mm)	Ve (mm^3)	AL-value (nH/N^2) Without air gap	AL-value (nH/N^2) With air gap	Core loss (W) max. 100kHz, 200mT, 100°C	(g)	
PC40EE20/20/5-Z	1.38	31.0	43.0	1340	1400±25%	100±7% 160±10%	0.51	7.5	—
PC40EF20-Z	1.34	33.5	44.9	1500	1570±25%	100±7% 160±10%	0.69	7.4	—
PC40EE22-Z	0.970	41.0	39.6	1620	2180±25%	125±7% 250±10%	0.61	8.8	BE22-1110CPFR BE22-118CPFR BE-22-5116
PC40EE25/19-Z	1.22	40.0	48.7	1950	2000±25%	100±7% 200±10%	0.86	9.1	—
PC40EF25-Z	1.11	51.8	57.8	2990	2000±25%	100±7% 160±10%	1.40	15	—
PC40EE25.4-Z	1.21	40.3	48.7	1963	2000±25%	125±7% 250±10%	0.90	10	—
PC40EE30-Z	0.529	109.0	57.7	6290	4690±25%	200±5% 400±7%	2.90	32	BE30-1110CPFR BE30-1112CPFR BE-30-5112
PC40EE30/30/7-Z	1.12	59.7	66.9	4000	2100±25%	160±5% 250±7%	1.51	22	—

4.3 Wire selection and transformer build

W_B - Bobbin width is equal to dimension 12mm from the above illustration.

W_M - Equals the margin tape required width.

O_D – Outside diameter of the wire used.

As an example, if we have 18mm of bobbin width, and we want to add 4mm of tape on each side, then we have 10mm of width.

I want to split the primary into two windings (series connected), 52T total (13 X 2 X 2) across bobbin.

$$O_{D\text{-}MAX} = \frac{W_B - 2W_M}{\text{Turns}}$$

- 22-gauge wire has an O_D of 0.6438mm diameter
- 24-gauge wire has an O_D of 0.511mm diameter
- 28-gauge wire has an O_D of 0.321mm diameter

One could use triple insulated wire on the secondary; therefore no margin tape is required.

- **Primary wire gauge= 20Ga**
- **Secondary (triple insulated) wire gauge= 20Ga**
- **Auxiliary wire gauge= 24Ga**

Gauge to diameter and vice versa conversion

http://www.66pacific.com/calculators/wire_calc.aspx

Triple insulated wire

http://www.furukawa.co.jp/makisen/eng/product/texe_series.htm

We need to guarantee that the primary inductance keeps us in DCM.

4.4 Transfomer Design #1

V_{IN} = 90V_{AC} – 132V_{AC}

V_O = 40V ~ 50V

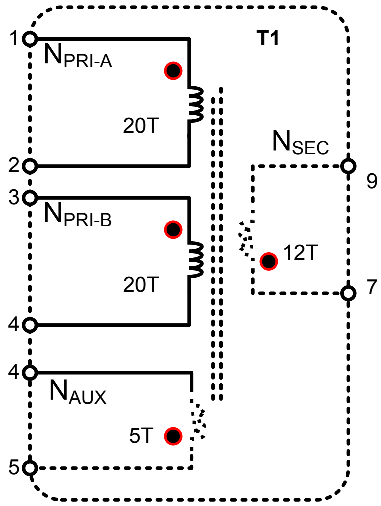
I_{PRI-PK} = 2.0A

P_{OUT} = 60W (max)

Core/bobbin = EF25 vertical type

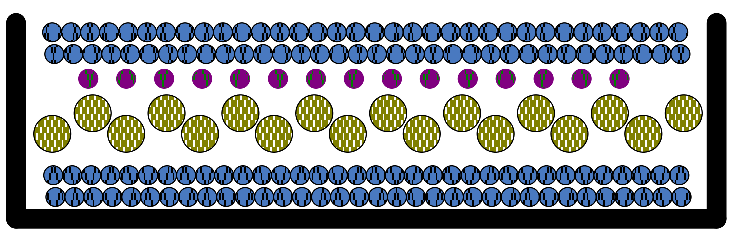
- Mag Inc R material
- Ferroxcube 3F3 material
- Epcos N87 material

A_l = 160nH/turns^2



- V_{OUT} = 45V
- V_{AUX} = 18V
- NPR:NSEC = ~ 4:1
- N_{PRI} = 40T - N_{SEC} = 12T - N_{AUX} = 5T

Primary (Aux Winding): $V_{AUX} = \left(\frac{V_{OUT}}{N_{SEC}}\right) \times P_2$



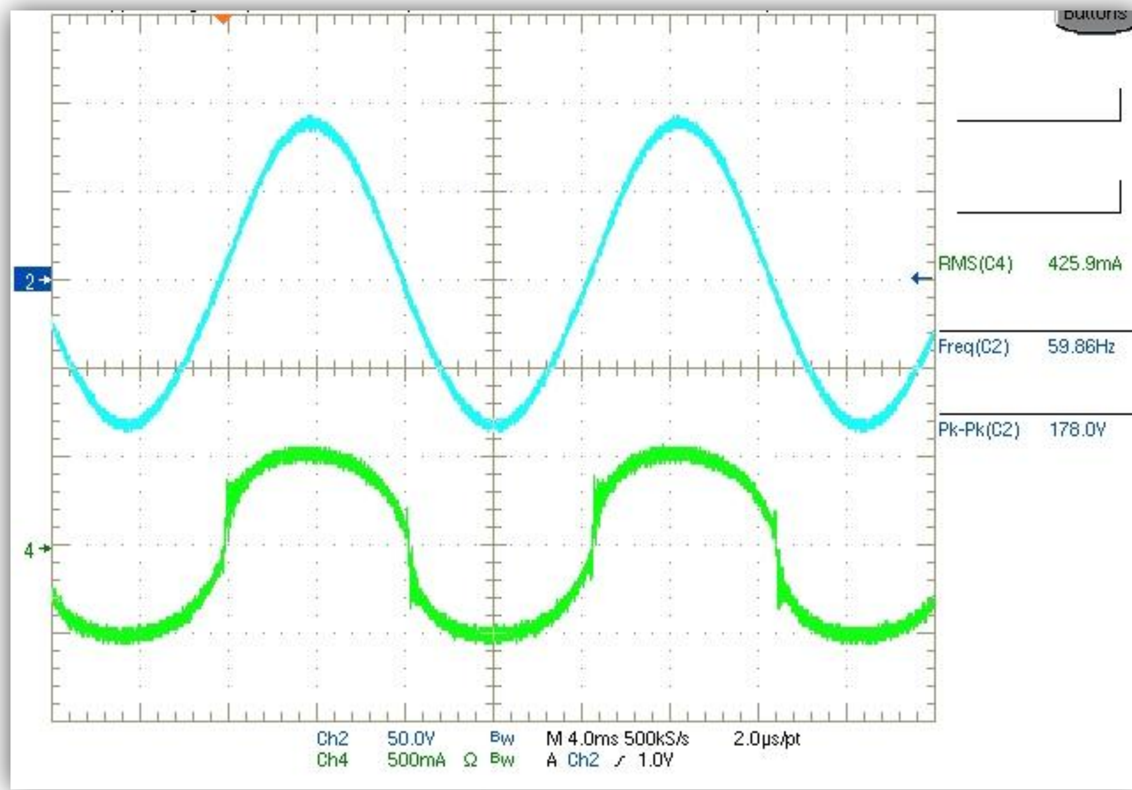
4.5 60W Driver Performance

Input Voltage	Input Power	Power Factor	Output Voltage	Output Current	Output Power	Efficiency
115VAC	67W	0.980	47V	1.25A	58W	86.5%

Scope Shots

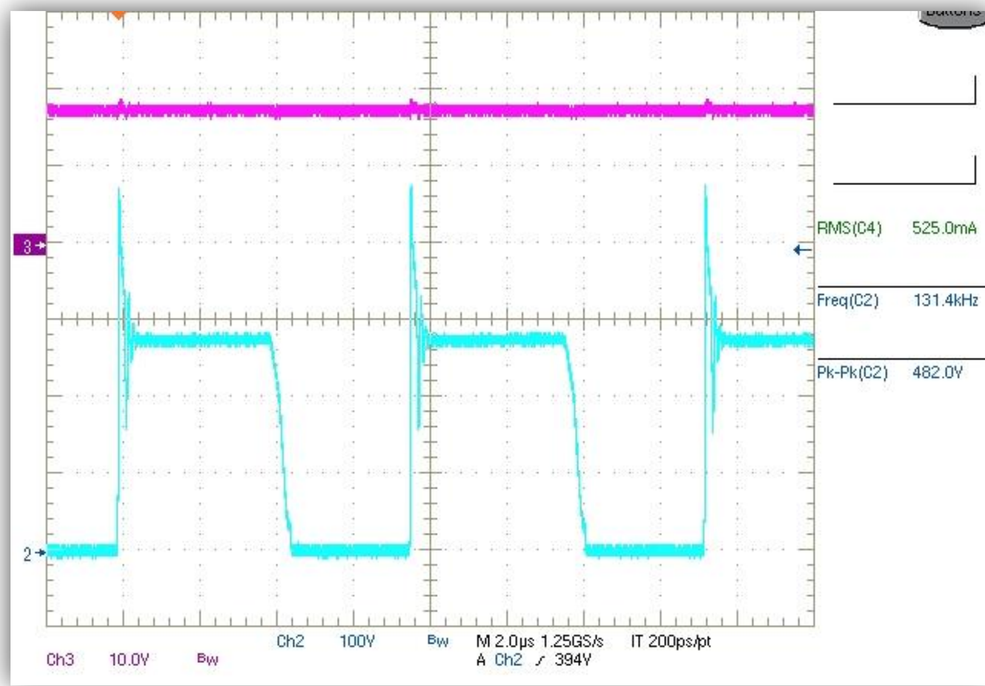
AC Line Voltage and Current

P_{OUT} = 45W

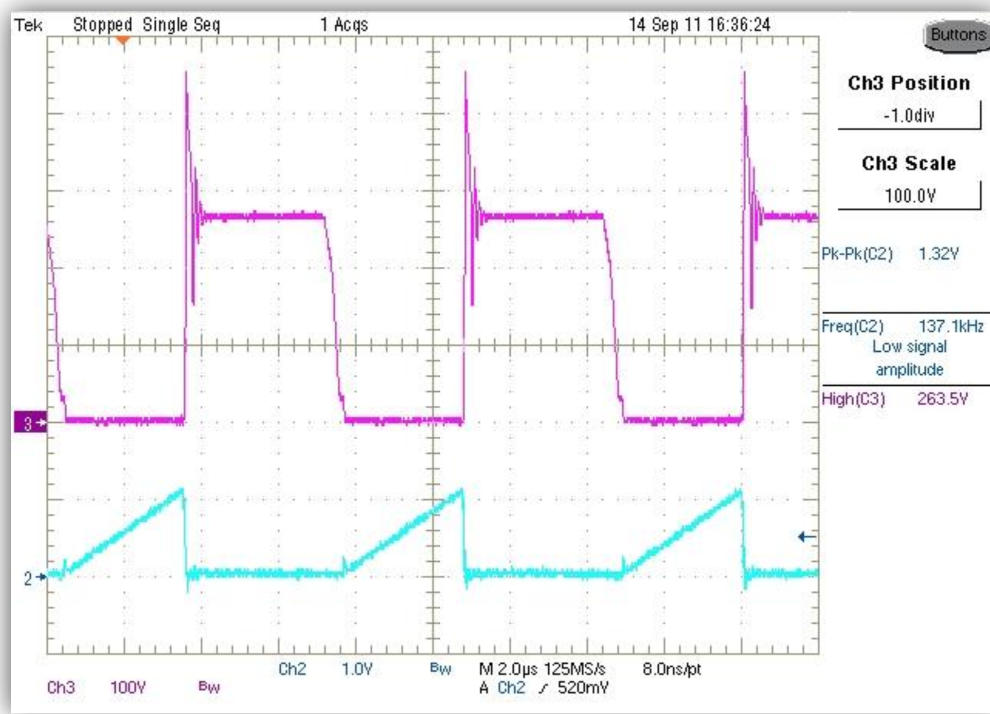


Primary Waveforms

V_{DS} (blue), Primary V_{CC} (pink)

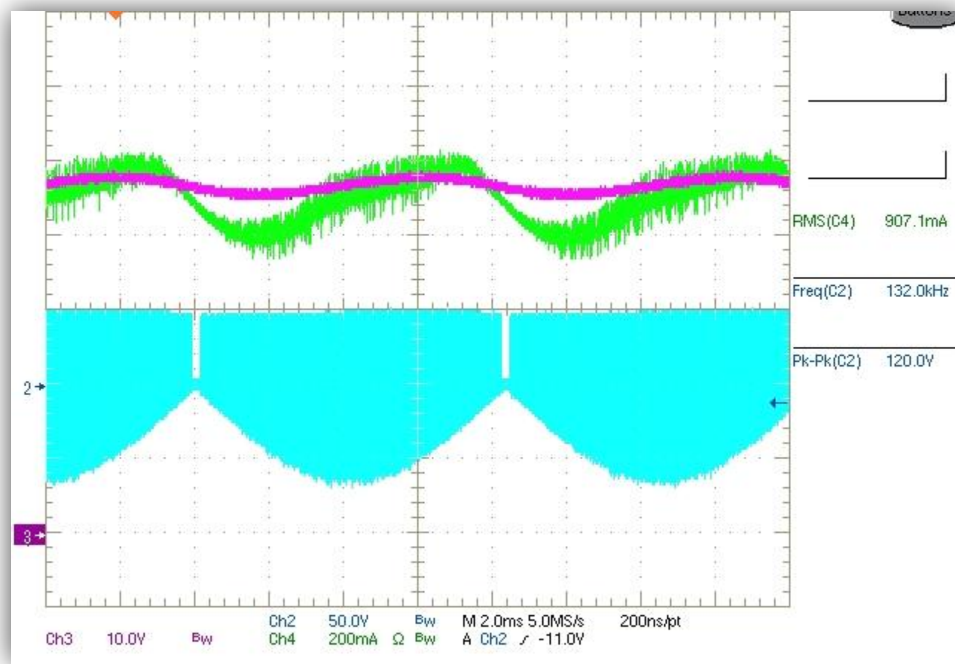


V_{DS} (pink), I_{DS} (blue)

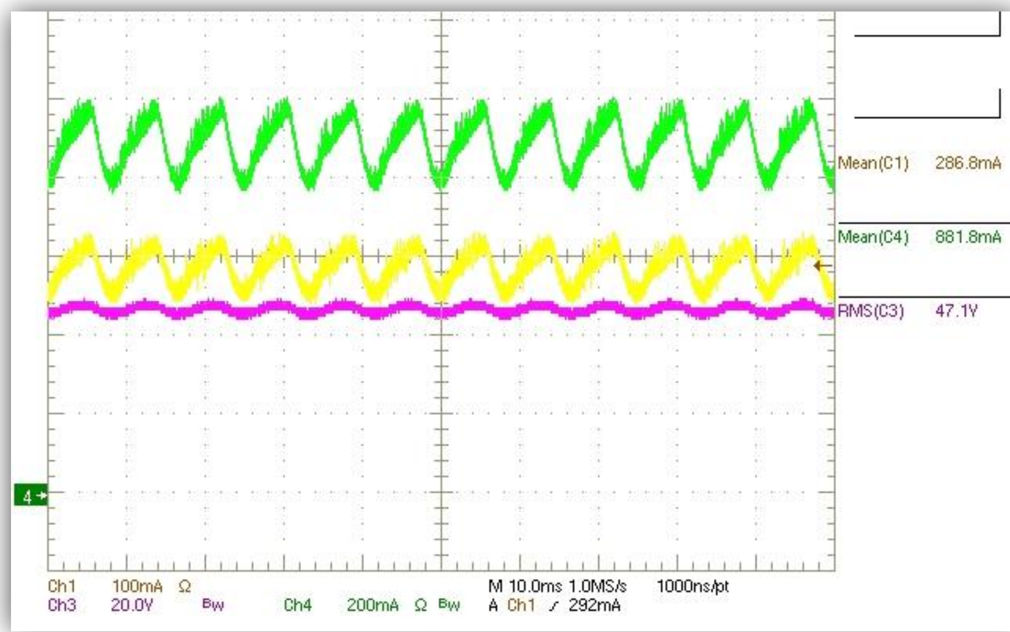


Secondary Waveforms

Diode voltage anode (blue), Total output current (green), Output voltage (pink) - P_{OUT} = 45W

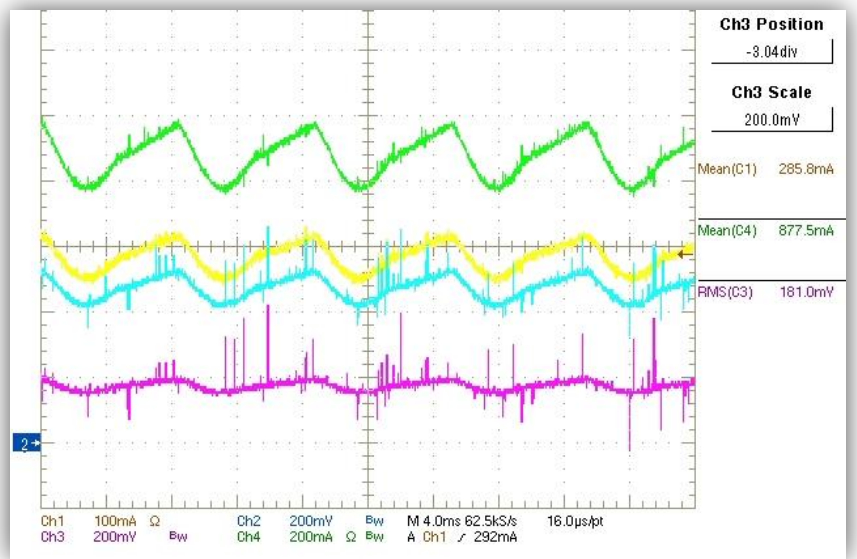


Output voltage (pink), Total output current (green), Single LM3446 current output (yellow) - P_{OUT} = 45W



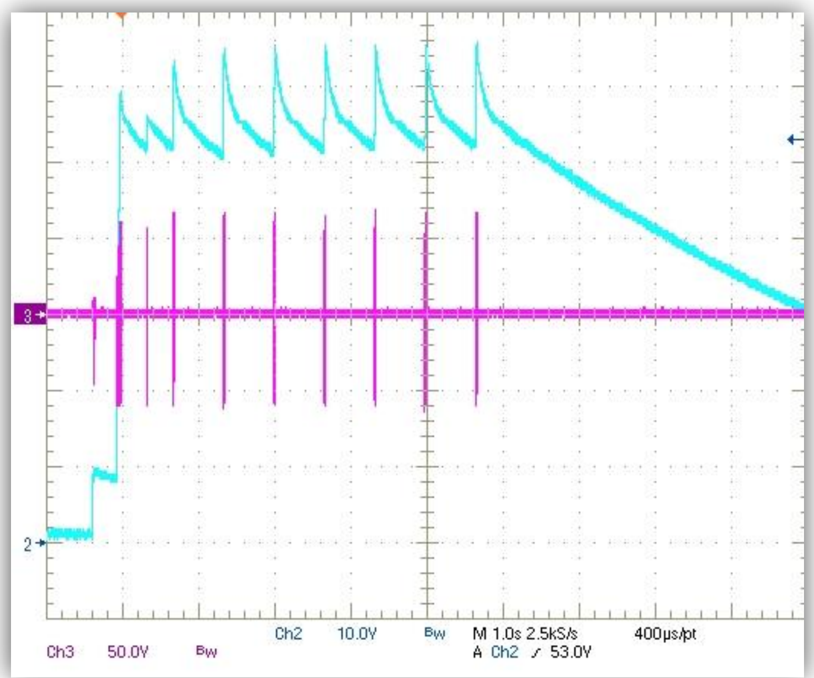
Output Current Sense waveforms

CH1 (yellow) output current of single LM3466, CH4 (green) total current, CH2 (blue) single channel sense voltage, CH3 (pink) total output current sense - P_{OUT} = 45W



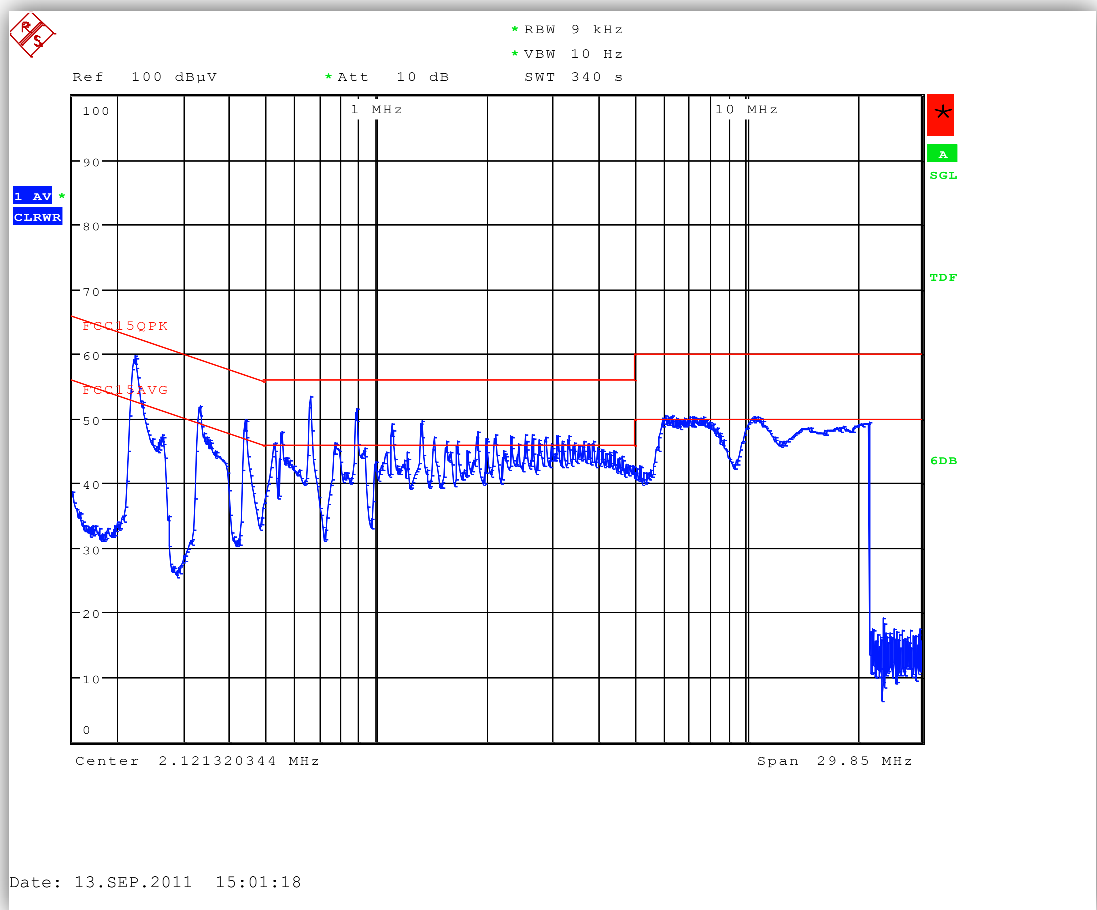
Fault Condition Waveforms

Start up into open load, and shutdown - Blue Trace (CH@) is output voltage, Pink trace (CH3) anode of secondary diode (no damage to LED driver)



EMI

Rev-001


RBW 9 kHz
VBW 10 Hz
Ref 100 dBµV
Att 10 dB
SWT 340 s
1 MHz
10 MHz
100
90
80
70
60
50
40
30
20
10
0
1 AV
CLRWR
FCC15QPK
FCC15AVG
A
SGL
TDF
6DB
Center 2.121320344 MHz
Span 29.85 MHz
Date: 13.SEP.2011 15:01:18

5 REVISION HISTORY

Date	Author	Revision	Description
Dec 18, 2011	Matt Reynolds	1.0	- Initial report.