

Application Report

90W Single stage PFC-flyback using L6562A for LED driver

Introduction:

In these years, power LEDs for lighting is quite hot application. For the reasons: their life of LED is significantly longer at 100,000 to 15,000 full-power hours (11+ years) to half brightness, the cost of power LEDs is rapidly coming down, and it's easy to find different sources from the market recently.

We are always using the words to talk about LED lighting: high efficiency (light out per watt in), long life... but if we look back to the power supply solution for LED lighting, it's hard to find the benefit of the long life. The E-caps using in the switching mode power supply solution are limiting the total solution's lifetime. And for several tens watt application, it's hard to find suitable solution to meet the regulator requirement: Power Factor or Harmonic Current requirement, but with low costing also.

In this file, introduces the solution without E-cap, using traditional TM PFC controller L6562A to control the flyback topology, combining the functions of PFC(Power Factor correction) and flyback topology (AC-DC converter), to meet the requirements: Long lifetime to match the LED Lighting's feature, PF or Harmonic Current for regulator, and also low costing for commerce. In this application, there are big advantages as talked above, but also a little drawback maybe somebody don't like: double line frequency ripple voltage on output, and also cause the same frequency ripple current on LEDs. It's possible to decrease the value of ripple voltage by adding e-caps at output side as adaptors, but it's impossible to get the same small ripple voltage as adaptors do.

Main characteristics and brief circuit description

The main characteristics of the design are listed below:

- Wide range input voltage (90Vac/60Hz ~ 264Vac/50Hz);
- Vout is set at 35V max, and able to low to 24Vdc with CV loading;
- Iout is set at 5A maximum current limitation;
- EN61000-3-2 is implemented;
- Capable of FCC Class B conducted EMI;
- Isolated output, "safe" voltage;

Brief circuit description:

In this application, I'm using L6562A at Primary side for PFC - PWM control, and TSM1014 at secondary side for CC/CV control.

At primary side:

L6562A as a TM PFC control, I add FOT (fixed off-time) technical here, to change the TM mode to CCM mode control. The five components: D3, C10, C11, R15, R16 implement this change function. Using this FOT technical, we can limited the peak current at primary side for several tens power application and the peak voltage stress with primary MOSFET at starting up stage. A voltage regulator combines with C6, C7, R6, ZD1 and Q2, to supply L6562A a safety VCC voltage. To meet the requirement of different output voltage to cover the tolerance of LED forward voltage drop, the voltage supplies from aux. winding is always a little higher than the max. value of IC VCC pin at normal output conditions, so this regulator is added here. Resistor R7 is added to give a preliminary

voltage on Pin1 to start up the IC. The value of Resistor R7, R9, R12 should be calculated to insure the voltage on Pin2 can be high to 6V and low to 0V, when the voltage on R11 is changing.

The practical value of R14, C9 on Multi pin of IC L6562A and the current sensing resistor R19A,B,C,D, are using to maximize the PF value, minimize the THD and harmonic current.

At secondary side:

Transformer secondary winding is split to two equal parts, the VCC of TSM1014 is regulated from the half point of the secondary winding, to drop to VCC value to the permitted range of this CC/CV controller. The capacitance of filter C-cap on Vref pin should not carefully select to avoid any oscillation of the reference voltage, the recommended value in this board is 10nF.

All the caps value are tried to minimized and replace by ceramic type, thanks to Murata for their advantage cap's technical.

And also for the transformer, thanks to TDK for low core loss materials.

Figure 1: Schematic

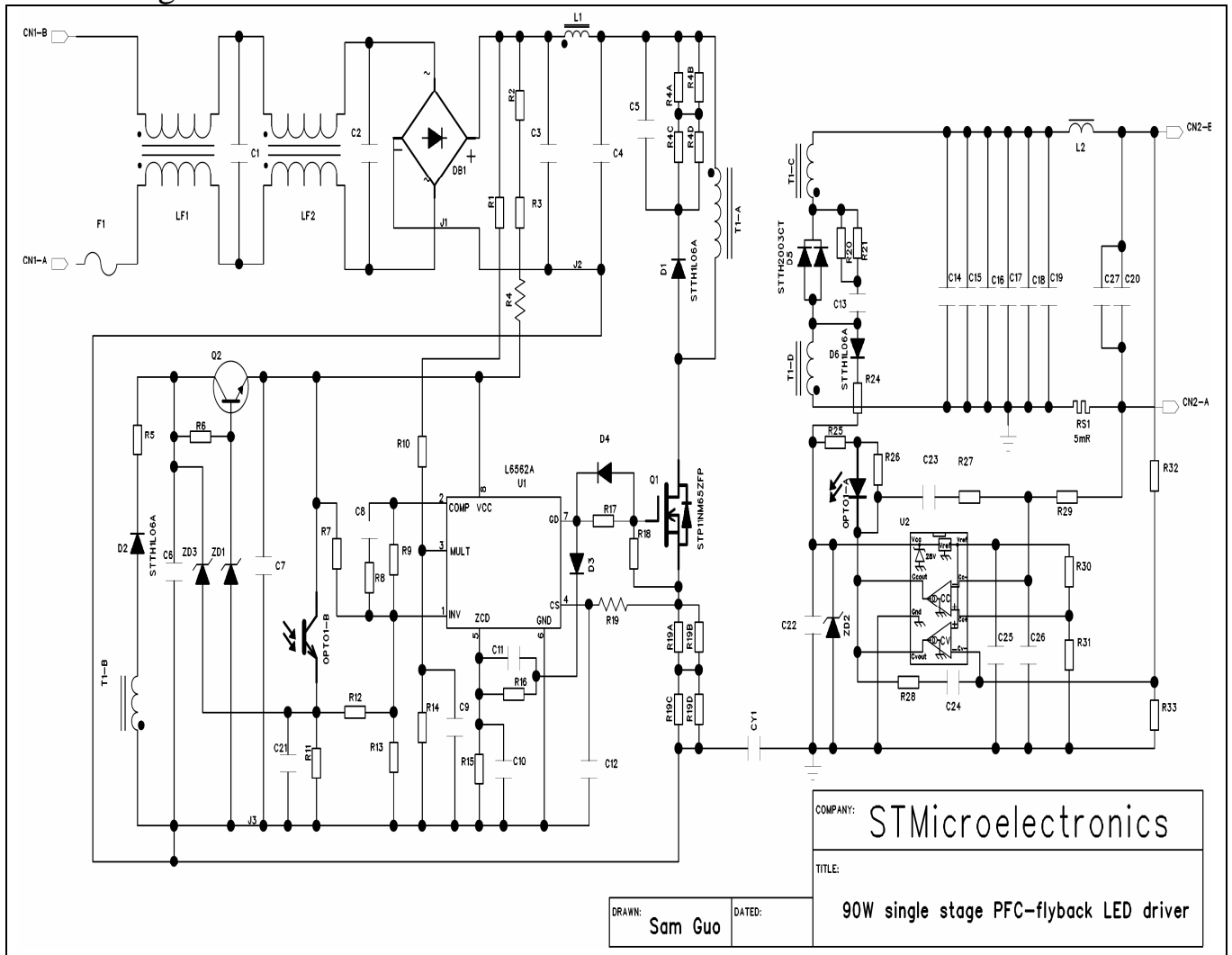


Table 1: Bill of Materials-1

<i>Des.</i>	<i>Part Type/ Part Value</i>	<i>Description</i>	<i>Supplier</i>	<i>CASE STYLE /PACKAGE</i>
C1	100nF	X2 - SAFETY CAP.		6X18mm P=15mm
C2	100nF	X2 - SAFETY CAP.		6X18mm P=15mm
C3	1.0uF	450V - MATEL FILM CAPACITOR		6X16mm P=15mm
C4	1.0uF	450V - MATEL FILM CAPACITOR		6X16mm P=15mm
C5	4.7nF	630V CERCAP - GRM31BR72J472KW01L	MURATA	1206
C6	4.7uF	50V CERCAP - GRM31CR71H475KA12L	MURATA	1206
C7	47uF	16V CERCAP - GRM32ER61C476KE15L	MURATA	1210
C8	1uF	16V CERCAP - GRM39X5R105K16D52K	MURATA	0603
C9	1nF	16V CERCAP - GERNERAL PURPOSE	MURATA	0603
C10	N68	16V CERCAP - NPO	MURATA	0603
C11	N39	16V CERCAP - NPO	MURATA	0603
C12	N33	25V CERCAP - GERNERAL PURPOSE	MURATA	0603
C13	2.2nF	630V CERCAP - GRM31BR72J222KW01L	MURATA	1206
C14	4.7uF	50V CERCAP - GRM31CR71H475KA12L	MURATA	1206
C15	4.7uF	50V CERCAP - GRM31CR71H475KA12L	MURATA	1206
C16	4.7uF	50V CERCAP - GRM31CR71H475KA12L	MURATA	1206
C17	4.7uF	50V CERCAP - GRM31CR71H475KA12L	MURATA	1206
C18	4.7uF	50V CERCAP - GRM31CR71H475KA12L	MURATA	1206
C19	4.7uF	50V CERCAP - GRM31CR71H475KA12L	MURATA	1206
C20	4.7uF	50V CERCAP - GRM31CR71H475KA12L	MURATA	1206
C21	100nF	16V CERCAP - GERNERAL PURPOSE	MURATA	0603
C22	2.2uF	50V CERCAP - GRM31CR71H225KA12L	MURATA	1206
C23	0.47uF	50V CERCAP - GERNERAL PURPOSE	MURATA	0805
C24	0.47uF	50V CERCAP - GERNERAL PURPOSE	MURATA	0805
C25	10nF	50V CERCAP - GERNERAL PURPOSE	MURATA	0603
C26	10nF	50V CERCAP - GERNERAL PURPOSE	MURATA	0603
C27	4.7uF	50V CERCAP - GRM31CR71H475KA12L	MURATA	1206
C28				
C29				
C30				
CN1	AC INLET	2PINAC GERNERAL PROPOSE WITH SAFETY		PTH
CN2	INLET	2PINAC GERNERAL PROPOSE WITH SAFETY		PTH
CY1	2N2	Y1 - SAEFETY CAP. DE1E3KX222M	MURATA	PTH
DB1	D4KB60	4A/600V GERNERAL PURPOSE BRIDGE RECTIFIER		
D1	STTH1L06A	1A/600V ULTRAFAST HIGH VOLTAGE RECTIFIER	ST	SMA
D2	STTH1L06A	1A/600V ULTRAFAST HIGH VOLTAGE RECTIFIER	ST	SMA
D3	LL4148	FAST SWITCHING DIODE		MINIMELF SOD-80
D4	LL4148	FAST SWITCHING DIODE		MINIMELF SOD-80
D5	STTH2003CFP	20A/300V HIGHT FREQUENCY SECONDARY RECTIFIER	ST	TO-220FPAB
D6	STTH1L06A	1A/600V ULTRAFAST HIGH VOLTAGE RECTIFIER	ST	SMA
F1	FUSE - 3.15A	FUSE T3.15A/250V - TIME DELAY		PTH
L1	CHOKE-L	15uH T6.3, OD15.5, ID8.5 1.0MM WIRE		PTH
L2	Jump	Jump wire: D=1.0mm		PTH
LF1	COM-CHOKE	2mH T7.2, OD14, ID7 0.6MM WIRE		T14-7-7
LF2	COM-CHOKE	14mH T8.6, OD16, ID9 0.6MM WIRE		T16-9-9

Table 2: Bill of Materials-2

Des.	Part Type/ Part Value	Description	Supplier	CASE STYLE /PACKAGE
J1-2	Jump	Jump wire: D=0.8mm		PTH
J3	Jump	Jump wire: D=0.6mm		PTH
J4	0Ω	SMD STANDARD FILM RES - 1/4W - 5% - 250ppm/°C		1206
OPT01	PC817A	OPTOCOUPLER	SHARP	DIP-4 - 10.16MM
Q1	STF11NM65N	12A/650V 0.33Ω N-CHANNEL SECOND GENERATION MOSFET	ST	TO-220FP
Q2	MMBT3904	NPN SMALL SIGNAL BJT MMBT3904LT1		SOT23
R1	1MΩ	SMD STANDARD FILM RES - 1/4W - 1% - 100ppm/°C		1206
R2	330KΩ	SMD STANDARD FILM RES - 1/4W - 1% - 100ppm/°C		1206
R3	330KΩ	SMD STANDARD FILM RES - 1/4W - 1% - 100ppm/°C		1206
R4	330KΩ	AXIAL STAND. M-FILM RES. - 0.166W - 1%		PTH
R4A	47KΩ	SMD STANDARD FILM RES - 1/4W - 5% - 250ppm/°C		1206
R4B	47KΩ	SMD STANDARD FILM RES - 1/4W - 5% - 250ppm/°C		1206
R4C	47KΩ	SMD STANDARD FILM RES - 1/4W - 5% - 250ppm/°C		1206
R4D	47KΩ	SMD STANDARD FILM RES - 1/4W - 5% - 250ppm/°C		1206
R5	4.7Ω	SMD STANDARD FILM RES - 0.1W - 5% - 250ppm/°C		0805
R6	2.2KΩ	SMD STANDARD FILM RES - 0.1W - 5% - 250ppm/°C		0805
R7	680KΩ	SMD STANDARD FILM RES - 0.1W - 5% - 250ppm/°C		0603
R8	10KΩ	SMD STANDARD FILM RES - 0.1W - 5% - 250ppm/°C		0603
R9	100KΩ	SMD STANDARD FILM RES - 0.1W - 5% - 250ppm/°C		0603
R10	1MΩ	SMD STANDARD FILM RES - 1/4W - 1% - 100ppm/°C		1206
R11	1.0KΩ	SMD STANDARD FILM RES - 0.1W - 5% - 250ppm/°C		0603
R12	39KΩ	SMD STANDARD FILM RES - 0.1W - 5% - 250ppm/°C		0603
R13				
R14	10KΩ	SMD STANDARD FILM RES - 0.1W - 1% - 100ppm/°C		0603
R15	7.5KΩ	SMD STANDARD FILM RES - 0.1W - 1% - 100ppm/°C		0603
R16	3.9KΩ	SMD STANDARD FILM RES - 0.1W - 1% - 100ppm/°C		0603
R17	4.7Ω	SMD STANDARD FILM RES - 0.1W - 5% - 250ppm/°C		0805
R18	20KΩ	SMD STANDARD FILM RES - 0.1W - 5% - 250ppm/°C		0603
R19	1KΩ	AXIAL STAND. M-FILM RES. - 0.166W - 5%		PTH
R19A	0.18Ω	SMD STANDARD FILM RES - 1/4W - 5% - 250ppm/°C		1206
R19B	0.18Ω	SMD STANDARD FILM RES - 1/4W - 5% - 250ppm/°C		1206
R19C	0.18Ω	SMD STANDARD FILM RES - 1/4W - 5% - 250ppm/°C		1206
R19D	0.18Ω	SMD STANDARD FILM RES - 1/4W - 5% - 250ppm/°C		1206
R20	24Ω	SMD STANDARD FILM RES - 1/4W - 5% - 250ppm/°C		1206
R21	24Ω	SMD STANDARD FILM RES - 1/4W - 5% - 250ppm/°C		1206
R24	10Ω	SMD STANDARD FILM RES - 0.1W - 5% - 250ppm/°C		0805
R25	1.5KΩ	SMD STANDARD FILM RES - 0.1W - 1% - 100ppm/°C		0805
R26				
R27	1KΩ	SMD STANDARD FILM RES - 0.1W - 5% - 250ppm/°C		0603
R28	4.7KΩ	SMD STANDARD FILM RES - 0.1W - 5% - 250ppm/°C		0603
R29	1KΩ	SMD STANDARD FILM RES - 0.1W - 5% - 250ppm/°C		0603
R30	100KΩ	SMD STANDARD FILM RES - 0.1W - 1% - 100ppm/°C		0603
R31	2.2KΩ	SMD STANDARD FILM RES - 0.1W - 1% - 100ppm/°C		0603
R32	27KΩ	SMD STANDARD FILM RES - 0.1W - 1% - 100ppm/°C		0603
R33	1KΩ	SMD STANDARD FILM RES - 0.1W - 1% - 100ppm/°C		0603
RS1	5mΩ	Resistor wire D=1.0mm		PTH

Table 3: Bill of Materials-3

<i>Des.</i>	<i>Part Type/ Part Value</i>	<i>Description</i>	<i>Supplier</i>	<i>CASE STYLE /PACKAGE</i>
T1	TRANSFORMER	PQ3220-PC47/PC95 TDK		DWG
U1	L6562A	TRANSITION-MODE PFC CONTROLLER	ST	SO-8
U2	TSM1014	LOW CONSUMPTION VOLTAGE AND CURRENT CONT	ST	SO-8
ZD1	15V/0.5W	ZENER DIODE		MINIMELF SOD-80
ZD2	22V/0.5W	ZENER DIODE		MINIMELF SOD-80
ZD3				

Electrical Testing Results:

Efficiency

The unit's efficiency is tested at different input voltage and different output loading on CV mode. Because the output voltage and current are combined with a large AC component, the output power is no longer able to simply calculate by the average or RMS value of Voltage and Current time each other. Below results are basing on the electrical loading constant voltage mode (CV), to simplify the testing structure, if compare to the actual characteristics using LEDs, the waveforms and performances are very similar.

Table 4:

Testing conditions: CV loading 33V

Vin	Iin (mA)	Pin (W)	PF	Vo (V) rms	Po (W)	Eff. (%)
90Vac/60Hz	1028.1	91.56	0.99	33.24	74.36	81.21
100Vac/60Hz	949.4	93.84	0.99	33.26	78.09	83.22
115Vac/60Hz	856.0	96.50	0.98	33.27	81.68	84.64
120Vac/60Hz	813.9	96.00	0.98	33.27	81.92	85.33
220Vac/50Hz	503.6	103.32	0.92	33.30	90.94	88.02
230Vac/50Hz	485.8	103.15	0.92	33.30	91.00	88.22
240Vac/50Hz	467.7	102.51	0.91	33.30	90.24	88.03
264Vac/50Hz	439.4	102.91	0.88	33.30	90.25	87.70

Testing conditions: CV loading 30V

Vin	Iin (mA)	Pin (W)	PF	Vo (V) rms	Po (W)	Eff. (%)
90Vac/60Hz	1086.6	96.92	0.99	30.28	78.69	81.19
100Vac/60Hz	1124.8	111.38	0.99	30.33	92.05	82.64
115Vac/60Hz	965.1	109.40	0.98	30.33	92.73	84.76
120Vac/60Hz	923.3	109.11	0.99	30.33	92.79	85.04
220Vac/50Hz	488.6	100.16	0.92	30.32	87.73	87.59
230Vac/50Hz	471.5	99.91	0.92	30.32	87.48	87.56
240Vac/50Hz	456.0	99.63	0.91	30.32	87.30	87.62
264Vac/50Hz	426.5	99.34	0.88	30.32	86.92	87.50

Table 5:

Testing conditions: CV loading 27V

Vin	Iin (mA)	Pin (W)	PF	Vo (V) rms	Po (W)	Eff. (%)
90Vac/60Hz	1064.6	94.83	0.99	27.31	77.49	81.71
100Vac/60Hz	947.6	93.63	0.99	27.31	78.30	83.63
115Vac/60Hz	826.2	93.49	0.98	27.31	79.58	85.12
120Vac/60Hz	793.3	93.51	0.98	27.32	79.84	85.38
220Vac/50Hz	445.0	89.59	0.92	27.31	78.22	87.31
230Vac/50Hz	430.0	89.40	0.90	27.31	77.94	87.18
240Vac/50Hz	417.3	89.39	0.89	27.31	78.04	87.30
264Vac/50Hz	392.8	89.31	0.86	27.31	77.91	87.24

No load input power

Vin	Pin (mW)	Vo (V)
90Vac/60Hz	708	34.94
100Vac/60Hz	872	34.94
115Vac/60Hz	917	34.94
230Vac/50Hz	771	34.96
240Vac/50Hz	781	34.96
264Vac/50Hz	846	34.96

Harmonic Current

This unit is also designed to follow the requirement per. EN6100-3-2 class C (lighting).

Table 6:

Vin=115Vac/60Hz	Pin:	95.7 W	Iin:	0.844 A
Vin=230Vac/50Hz	Pin:	100.24 W	Iin:	0.4743 A
	PF:	0.987		
	PF:	0.908		

Set CV loading = 30V					
Limits for class C equipment (light >25W)					
Harmonic order	Maximum permissible har		Testing Result		Pass/Fail
	%		%		
	115Vac/60Hz	230Vac/50Hz	115Vac/60Hz	230Vac/50Hz	
2	2	2	0.03	0.07	
3	29.61	27.24	8.73	17.32	
5	10	10	0.79	5.39	
7	7	7	0.20	3.37	
9	5	5	0.42	2.82	
11 ≤ n ≤ 39	3	3			
11	3	3	0.63	2.35	
13	3	3	0.60	2.22	
15	3	3	0.48	2.07	
17	3	3	0.34	1.82	
19	3	3	0.33	1.58	
21	3	3	0.26	1.53	
23	3	3	0.31	1.41	
25	3	3	0.45	1.27	
27	3	3	0.51	1.14	
29	3	3	0.34	0.96	
31	3	3	0.22	0.86	
33	3	3	0.04	0.82	
35	3	3	0.16	0.86	
37	3	3	0.30	0.80	
39	3	3	0.35	0.72	
Result					Pass

(=30*PF)

Waveforms and Protection

Normal operating waveforms:

In below section, will try to add some waveform to show the unit's performance when it works in steady states.

Vin=115Vac/60Hz, Loading CV=33V

Vin=230Vac/50Hz Loading CV=33V

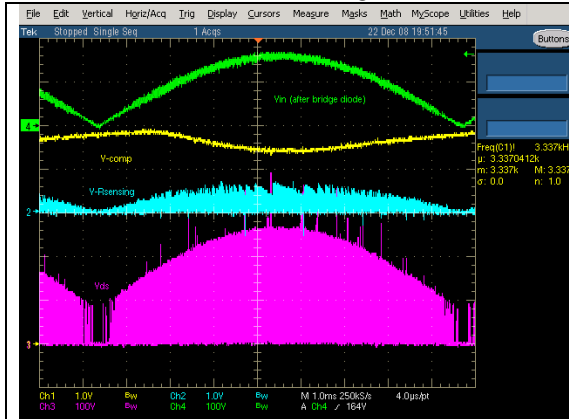


Figure 2

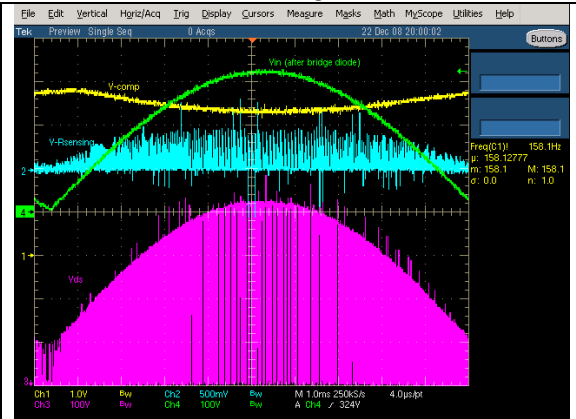


Figure 3

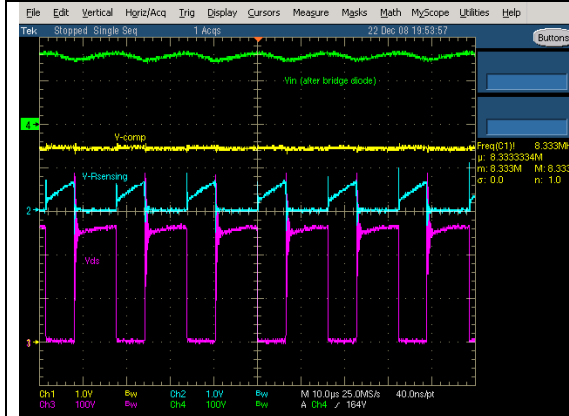


Figure 4

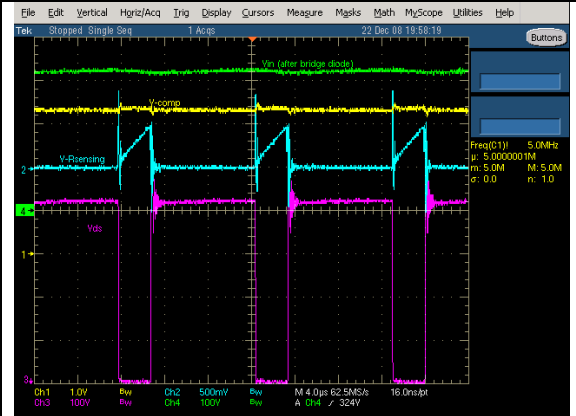


Figure 5

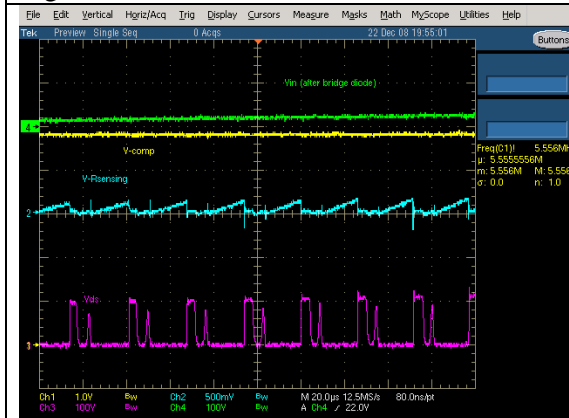


Figure 6

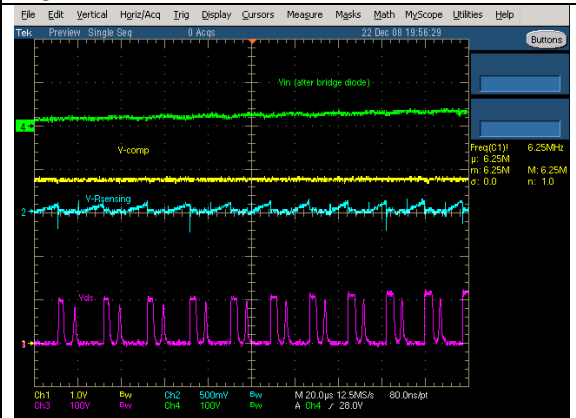


Figure 7

Above record the waveforms at primary side at nominal conditions. Figure 4,5 record the extension waveform of figure 2,3 when input voltage at the top of the sine waveform. And figure 6,7 record the extension waveform of figure 2,3 when input voltage at the bottom of the sine waveform.

From these waveforms we can find: the unit works in the mode of “fix-off-time”, means the turn off time of the MOSFET does not change when the input is waving. And the switching frequency doesn’t change so much when the input voltage change from low to high.

The waveform in figure 2 and 3, look like some click, but it causes by the display of the oscilloscope and the actual waveform is smooth.

Vin=115Vac/60Hz, Loading CV=33V

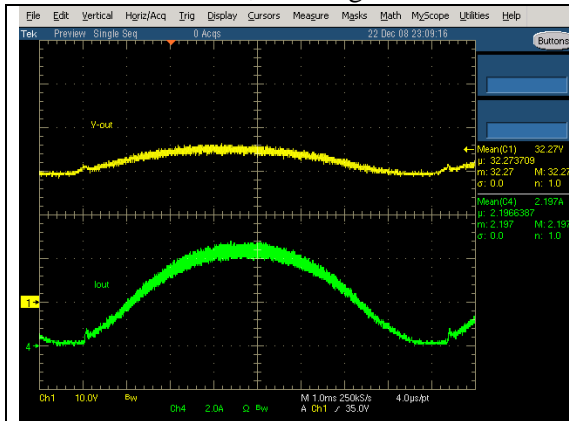


Figure 8

Vin=230Vac/50Hz Loading CV=33V

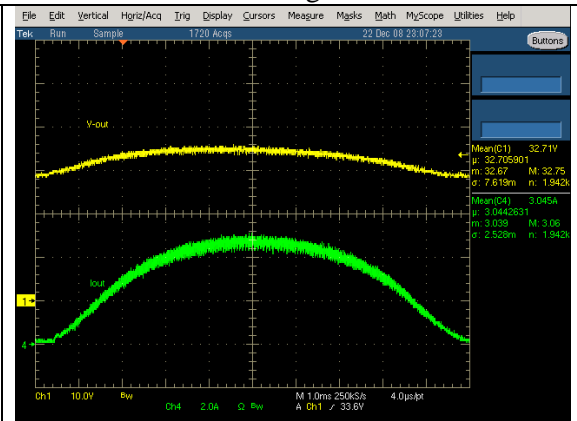


Figure 9

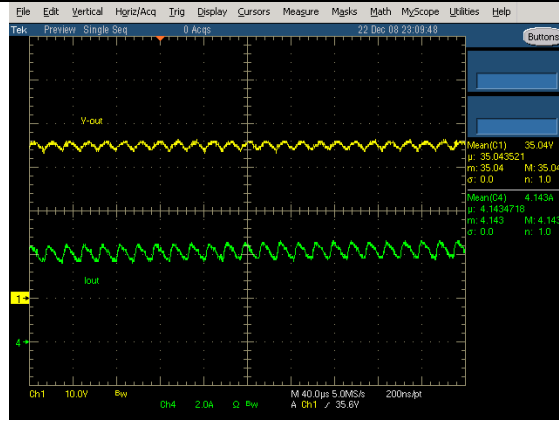


Figure 10

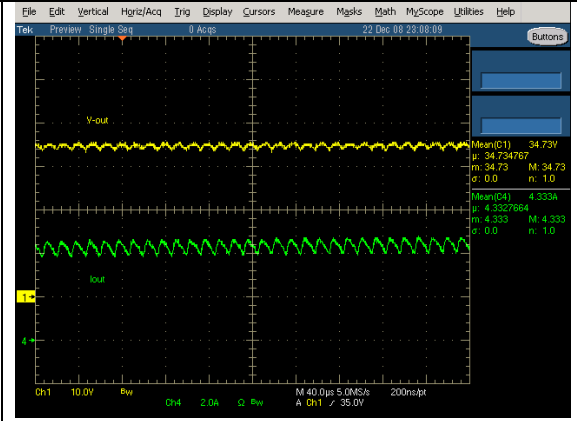


Figure 11

From above, shows the waveforms of output current and output voltage.

Because small value of ceramic capacitors (total is $8 \times 4.7\mu\text{F}$ for 90W output) is used at the secondary output section, we can find large low frequency and high frequency ripple voltage and ripple current. It’s possible to decrease these ripple by increasing the capacitance of caps if you like. The high frequency can be very small (like peak to peak smaller than 1% of nominal (average value) output voltage), but for the line frequency ripple, same as the words at the beginning of this document, it’s almost impossible to do a large improvement.

Starting-up waveforms:

In below, will show the waveforms at the unit's starting-up stage.

$V_{in}=90V_{ac}/60Hz$, Loading $CV=33V$

$V_{in}=264V_{ac}/50Hz$ Loading $CV=33V$

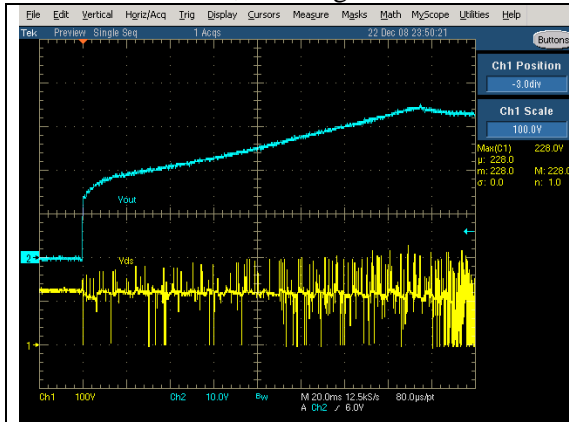


Figure 12

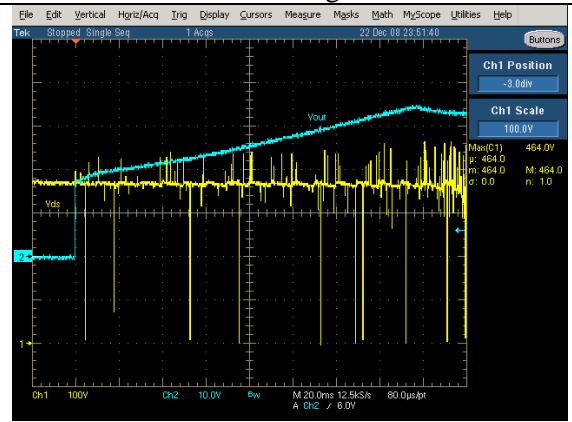


Figure 13

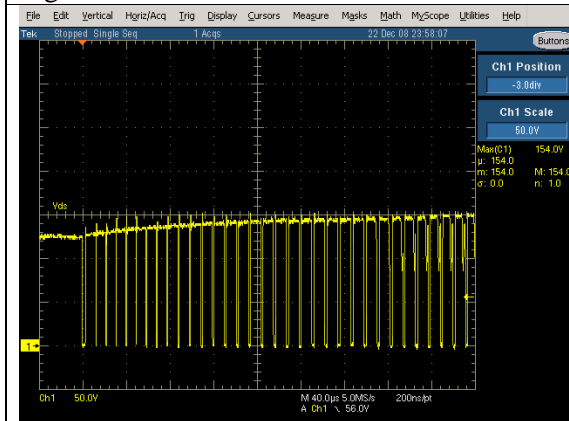


Figure 14

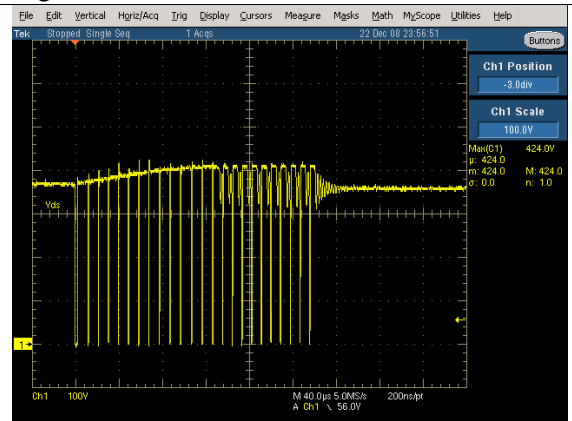


Figure 15

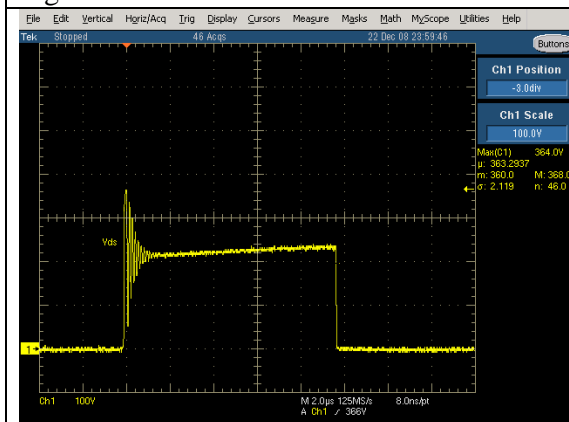


Figure 16

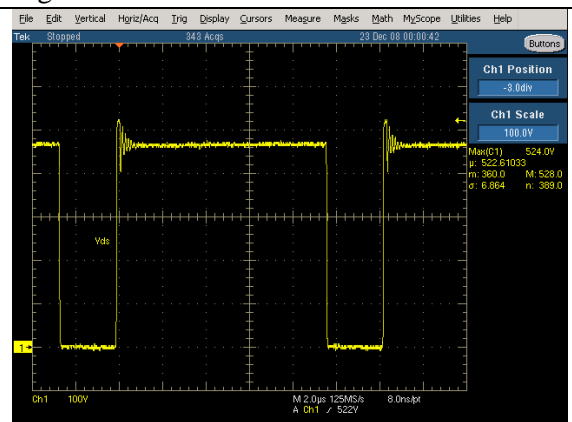


Figure 17

Figure 12,13 are long time starting-up stage waveforms, Ch1 is V_{ds} voltage waveform of primary switching power MOSFET, Ch2 is output voltage. Figure 14,15 are the V_{ds} voltage waveform of the same FET which trigger at the instantaneous starting switch second. Figure 16, 17 are the waveforms at normal operating condition.

From these waveforms, we can find the switching power MOSFET has enough margin of voltage stress at starting-up stage. Actually the voltage stress at starting-up stage is smaller than the value at normal operating condition.

Protection:

The unit has implemented output short circuit protection. And output over voltage protect by primary sensing from aux winding.

For short circuit protection, the transformer is been specially handled. The primary aux. winding for V_{cc} supply is been put between secondary windings. This structure is used to minimize the effect of the leakage inductance of the aux. winding.

$V_{in}=90V_{ac}/60Hz$, Loading $CV=33V$ before short $V_{in}=264V_{ac}/50Hz$ Loading $CV=33V$ before short

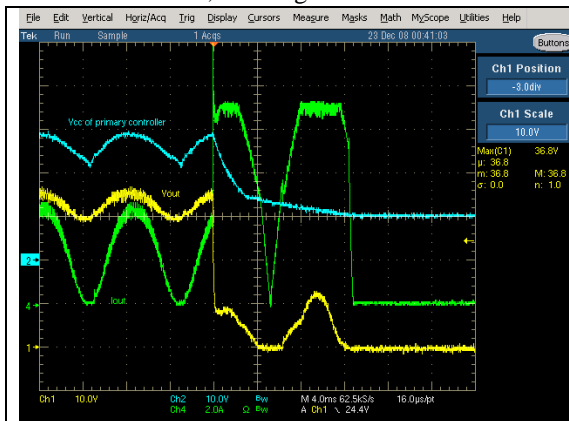


Figure 18

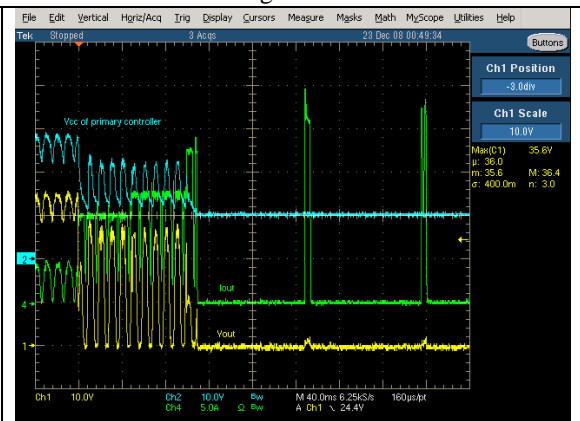


Figure 19

References:

- [1]. AN1895 APPLICATION NOTE EVAL6562-375W, 375W FOT-CONTROLLED PFC, STMicroelectronics
- [2]. AN1792 APPLICATION NOTE DESIGN OF FIXED-OFF-TIME-CONTROLLED PFC PRE-REGULATORS WITH THE L6562, BY CLAUDIO ADRAGNA
- [3]. AN1059 APPLICATION NOTES DESIGN EQUATIONS OF HIGH-POWER-FACTOR FLYBACK CONVERTERS BASED ON THE L6561, BY CLAUDIO ADRAGNA

Appendix 1:

Transformer Specification

