A New Off-line LED Lighting Driver Solution with multi-transformer LLC Control

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A New Off-line LED Lighting Driver Solution with multi-transformer LLC Control

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ABSTRACT

With TI multi-transformer LLC controller UCC25710, the application note introduces a new off line LED lighting driver solution. Compared to conventional high wattage (>100W) LED lighting driver with AC/DC plus multiple constant current DC/DC converter stage, the new topology can have higher efficiency and lower system cost. A 100W LED lighting driver reference design PMP4302A using this multi-transformer LLC control is developed, which has 4 LED strings with 500mA current and 15 LEDs in series for each string. The experimental results show the new topology is very suitable for general LED lighting application for both outdoor and commercial application with PWM or analog dimming. Meanwhile, the architecture can also be used as LED backlight TV power with high efficiency and ultra-slim form factor.

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1 Introduction

Nowadays, LED technology has emerged as a promising lighting technology to replace the energy-inefficient incandescent lamps and mercury-based fluorescent lamps. Among general LED lighting applications, high wattage (>100W) off-line LED lighting shows the great energy saving and long lifespan compared with conventional lamps, such as high pressure sodium lamps and CFL lamps. The target markets for high wattage professional LED lighting are for outdoor LED street lights and other commercial LED lights.

To make the same brightness for each LED, constant current driving should be implemented for the driven system. Normally, for power rating more than 65W, LED matrix will consist of several LED strings in parallel. And, each string should be controlled by constant current source and each string current should be same to insure the uniform system brightness. In addition, the power system should also make the input current with the same phase and shape of input AC line. Thus, PFC circuit is needed to reduce the current harmonics.

Besides the above mentioned, the efficiency and reliability are very critical for the high wattage LED lighting. High efficiency is not only the basic requirement for energy saving, but also for the power system itself. Because the thermal design is always a big issue for LED lighting systems thus leads to the high ambient temperature for the power, high efficiency LED driver will help the system reliability and thermal performance.

The application note presents a new multi-transformer LLC converter for high wattage LED lighting driver solution. By using the proposed topology, high efficiency and high reliability can be achieved with magnetizing balance to drive multiple LED strings. A 100W reference design PMP4302A is built to verify the overall performance with PWM dimming interface.

2 Proposed Topology

2.1 Traditional topology for high wattage off-line LED lighting driver

Figure 1 shows a typical high wattage off line LED lighting driver topology. In this structure, PFC stage shapes the input current to sinusoidal wave. Boost topology is the best candidate for this stage due to its continuous input current properly and easy configuration. Thus for the wide range input voltage of 85V~264Vac, the output of PFC stage will be higher than the peak input voltage. 380VDC to 400VDC bus is normally selected. Because the PFC output voltage is too high and it is non-isolated, a DC/DC stage with transformer isolation is needed. Normally half bridge LLC resonant converter is used because of its high efficiency and good EMI performance. The DC/DC stage generates the intermediate bus voltage to drive the LED strings. The output voltage level for this stage is based on the number of LEDs and the next constant-current control stage; normally it is below 60Vdc with standard safety voltage. Each LED string will have an individual constant current regulator to regulate the LED current. For most popular high brightness (HB) LED, the current specification range is from 350mA to 750mA.

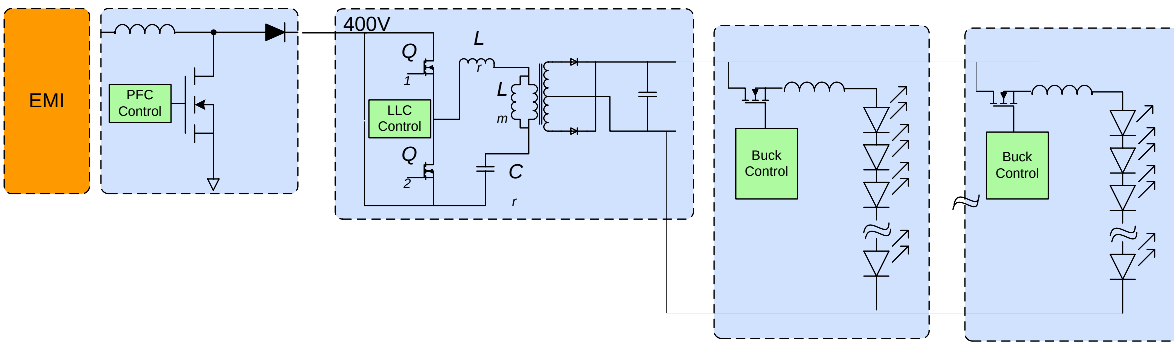


Figure 1. Traditional high wattage off-line LED lighting driver's topology

Even thought traditional high wattage off-line LED lighting driver can achieve good performance, there are some drawbacks:

1. Efficiency. The traditional structure is three stages topology, which includes PFC, isolated PWM and non-isolated DC/DC. The most optimized efficiencies for each stage are 97% for PFC stage, 96% for isolated PWM stage, and 95% for DC/DC stage. So total maximum efficiency it can achieve is about 88%. Of course, there are some methods to improve the efficiency further, such as synchronous rectifier control for both isolated PWM and DC/DC stages, but it is not cost effectively.

2. Cost. From the above figure 1, there are multiple DC/DC stages on each LED strings, which will lead to high cost on this stage with multiple controller, inductors and capacitors.

3. Reliability. Because there are many external components on the traditional LED lighting topology, which will highly influence the performance.

4. EMI. Because multiple switching LED drivers will generate additional high frequency switching noise on the DC/DC stages, and hence affect the measurement results of both conducted and radiated EMI in the LED lighting. More EMI design effort, for example RC snubber network at switch node, EMI filter at output stage or synchronizing the multiple DC/DC controllers, is then required in order to comply with the EMI standard.

2.2 New topology for high wattage off-line LED lighting driver

To address those issues for typical topology, the application note introduces a new topology using TI multi-transformer LLC controller UCC25710. Figure 2 shows a block diagram for this new topology, which includes only two stages with PFC and multi-transformer LLC converter. After PFC stage, there is an isolated half bridge multi-string LLC converter, which makes the primary windings of transformers electrically connected in series. Based on the theory of magnetic balance, since the current of primary windings are the same with series, the output current for each isolated transformer will have the same current to drive each LED string. And each transformer can drive two LED strings.

The multi-transformer LLC controller (UCC25710 in this design) is located on the secondary side, and it senses the sum of LED strings' current and regulates the sinusoid wave ac current that flows through primary windings by using current loop feedback, which makes constant current output on each LED string.

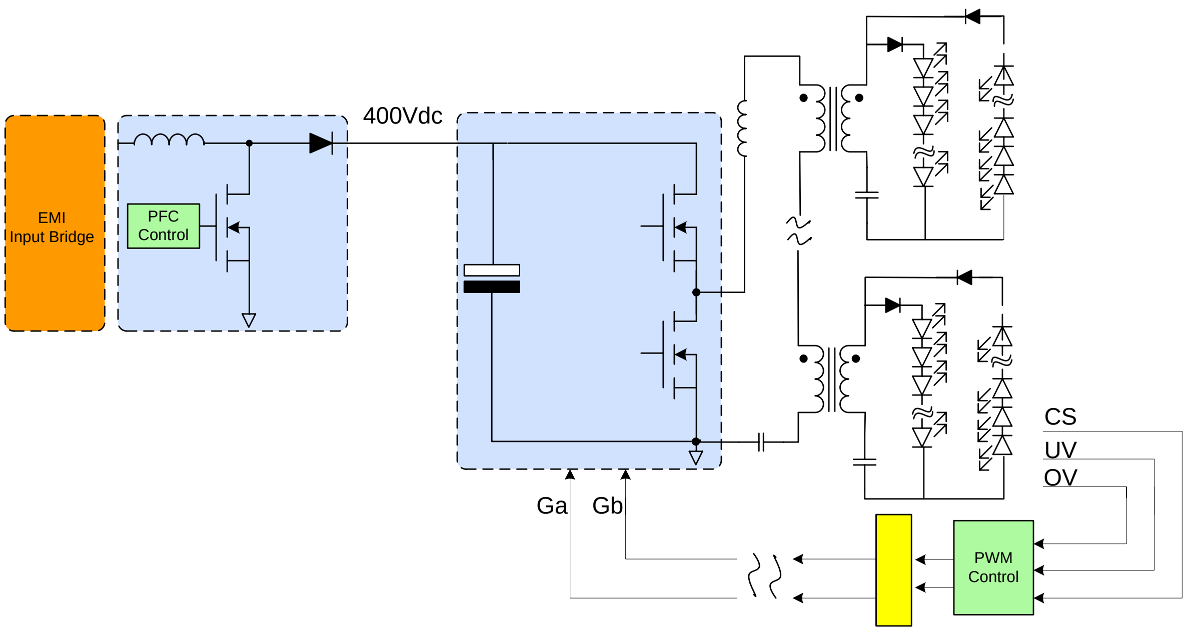


Figure 2. Proposed new high wattage off-line LED lighting driver

The new topology has some key features compared with traditional LED lighting driver topology:

1. High Efficiency. Because it only has two stages with PFC plus multi-transformer LLC, the estimated total efficiency will be higher than 91%. The efficiency will be highly determined by the LLC converter design.

2. Low cost. Compared with conventional topology of high wattage LED lighting, the new topology only includes two stages and fewer controllers, which is cost effectively.

3. High system reliability. As we known, reliability of the LED lighting is determined by thermal management of LEDs and electrical drive, fault detection and protection of the system, as well as electrical component counts. Because of few component' counts on this new topology and good efficiency, the reliability will get greatly improvement.

4. Good EMI performance. Because there are no multiple DC/DC stages on the output, it will help for EMI performance. Meanwhile, LLC converter is operating with ZVS operation that can help reduce noise during switching.

5. Dimming compatible. Because the LLC controller is located on secondary side, the total current of each string is summarized to feedback as current feedback loop, which can be used as PWM dimming or analog dimming.

Unlike the traditional LED lighting topology, the new LED lighting topology will help to reduce components counts to improve efficiency, and help to reduce board size.

3 New Multi-transformer LLC controller

The UCC25710 is based on the LLC resonant half bridge topology. The controller feedback loop is configured to regulate the total current of all LED strings typically with a current sense resistor. As shown in figure 3, the total current for LED strings is sensed by R3 to CS pin and a current loop error amplifier is designed to maintain the steady state operating voltage point of the current amplifier during dimming operation, and the output of current amplifier Icomp will set the control voltage to the VCO (Voltage Controlled Oscillator) with programmable minimum and maximum frequency, which will configure to a close current feedback loop for a LLC topology with LED lighting strings. The optimum Icomp capacitor C1 is determined based on desired LED current and primary current response during dimming.

There are three factors that can control the VCO for LLC control. Firstly, the control voltage to the VCO is set by Icomp (current loop error amplifier output) during LED on-times. Secondly, during start up, the soft start pin SS will control the VCO response until it exceeds Icomp. Thirdly, during dimming the rise and fall rates of the VCO input are controlled by the voltage at the dimming slew rate at capacitor C2, DSR pin, while the pedestal of VCO control level will continue to be controlled by Icomp.

The DSR capacitor C2 and internal 44uA currents control the slew rate of Vvco during dimming off and on transitions. When turn off, DSR is discharged to ground by 44uA current source and when turn on, DSR is discharge to Icomp by 44uA. This will allow potentially audible electro-mechanically induced noise to be minimized.

The LED dimming input ILED-ON control the LED lighting dimming on and off. In addition, the falling, or turn-off, edge of a dimming cycle can be delayed, allowing the current loop to maintain control at low dimming duty-cycles even when the ramp rates have been slowed.

In summary, the device of UCC25710 includes all of the functions necessary to implement a total LED backlight driver including GM current loop error amplifier, VCO, reference regulator, soft start, dimming duty cycle compensation and protection for OV, UV, current limit, and thermal shut down. There are additional features to minimize audible noise during dimming and provide fast LED current rise and fall times.

In addition to multi-transform LLC topology, UCC25710 is also a good LLC controller for high-volt single LED string output application with dimming interface and minimal audible noise features.

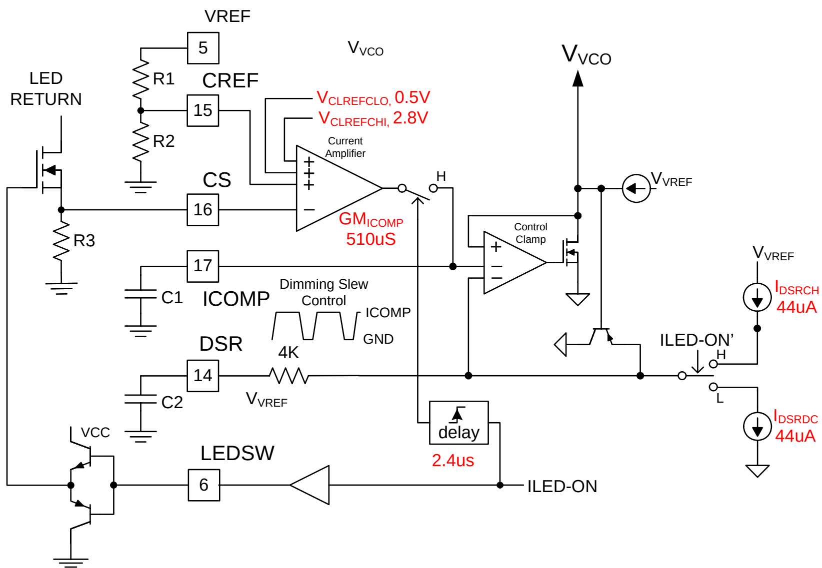


Figure 3. Simplified block diagram for multi-string LLC control UCC25710

4 LLC Multi-transformer design

The innovation of multi-transformer to match current simply uses the magnetic balance theory. As shown in figure 4, the primary windings of multiple transformers are connected in series, in ideal case, the same primary side currents result in the same secondary side current if the transformer turns ratio is the same.

$$\begin{cases} I_{p1} = I_{p2} \\ I_{s1} = I_{s2} = n \times I_{p1} \end{cases} \quad (1)$$

The transformer is not an ideal component; it also includes magnetizing inductor, due to the existence of magnetizing inductor in the transformer, the secondary side current will be slightly different on the output LED string. Fortunately, the magnetizing current is only a small portion of the primary side current and the current match is not sensitive to the difference of the magnetizing current. In order to achieve perfect current matching, it is recommended to increase the magnetizing inductance L_m for the multi-transformer LLC design.

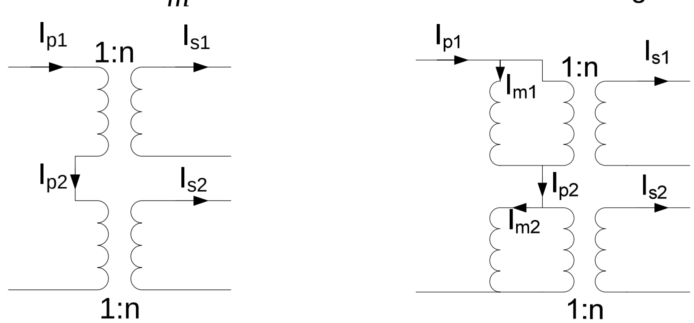


Figure 4. Multi-string transformer structures

To simplify the solution, the topology uses one transformer to drive two LED strings. In the same transformer, when the primary ac sinusoid current is flowing positively, the secondary current is conducted with the same coupling direction. On the other hand, when the primary sinusoid wave ac current is flowing reversely, the other current loop on the secondary side is conducted during switching cycle, as shown in figure 5. The DC blocking capacitor on the output guarantees the positive current and negative current are the same during each switching cycle.

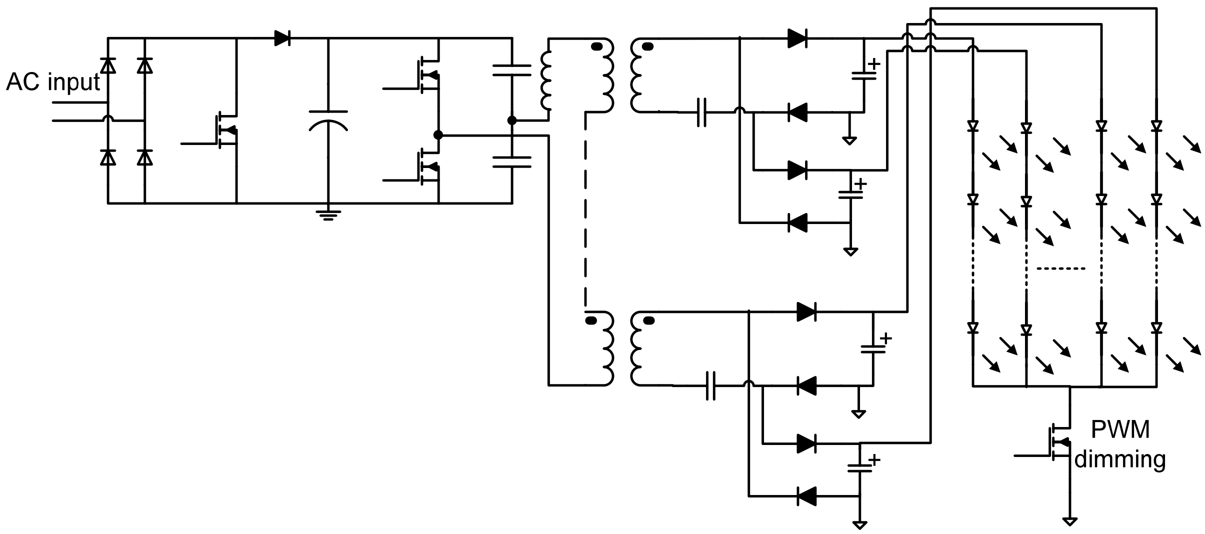


Figure 5. Simplified architecture for multi-string LLC topology with boost PFC

The design of multi-transformer LLC transformer is similar to conventional LLC converter design. To use conventional LLC converter design process, the multiple transformers and reflected loads can be combined into one equivalent transformer load. Once resonant inductor L_S and magnetizing inductor L_m are determined based on a single transformer; simply divide by the number of transformers for each transformer specification target. When operation frequency is equal to the series resonant frequency, input and output voltage for this multi-string LLC converter can be expressed as:

$$V_{LED} = \frac{V_{DCBUS}}{2 \times n \times N_T} \quad (2)$$

Where, n is the primary to secondary turns ratio; V_{DCBUS} is the input voltage of the LLC converter, typically it is the output of the PFC boost converter; V_{LED} is the voltage of LED string and N_T is the number of transformer. In the practical design of 100W two string LLC converter, Input voltage is set at 340 V to 410 V from PFC with norminal point 400 V; The output is equal to 50V / 1 A with two transformer in series. So the equivalent turn ratio is $n' = n \times N_T = 4$.

Meanwhile, the operating frequency is set at around 120 KHz, which is a little higher than resonant frequency to achieve good current matching.

MOSFET turn-off current should be able to discharge junction caps during dead-time (500ns); the following equation should be met to get ZVS operation.

$$L_m \le \frac{T \cdot t_{dead}}{16 \cdot C_{eq}} \quad (3)$$

In the design, it uses a simplified method applied to any resonant topology based on the assumption that input-to-output power transfer is due to the fundamental Fourier Series components of currents and voltages, which is the commonly know as FHA (First Harmonic Approximation).

In the below figure 6, the input of the equivalent network is a square waveform with 50% duty cycle, and the output is also a square waveform with 50% duty cycle, of which amplitudes are $Vin/2$ and nV_o respectively.

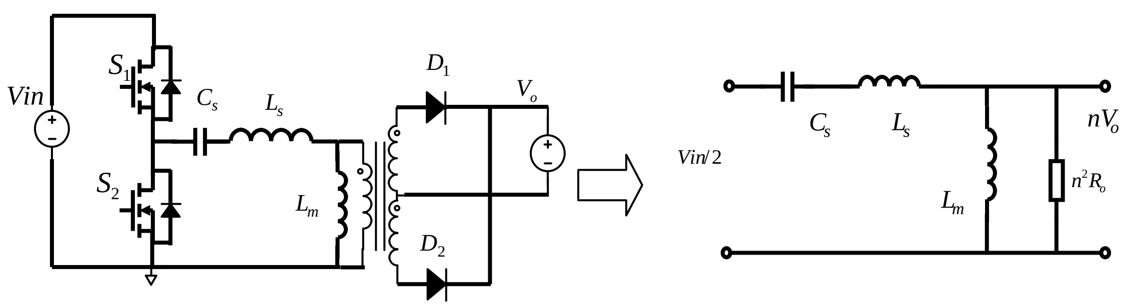


Figure 6. Simplified equivalent network for LLC topology

Considering the fundamental harmonious element of input and output, the DC gain of output to input can be expressed as following equation:

$$\frac{nV_o}{V_{in}/2} = \left| \frac{\dfrac{j\omega L_m n^2 R_o}{j\omega L_m + n^2 R_o}}{\dfrac{1}{j\omega C_s} + j\omega L_m + \dfrac{j\omega L_m n^2 R_o}{j\omega L_m + n^2 R_o}} \right|$$

$$\frac{nV_o}{V_{in}/2} = \frac{1}{\sqrt{\left(\dfrac{1}{\omega^2 L_m C_s}\right)^2 \left(\dfrac{\omega^2}{\omega_m^2} - 1\right)^2 + \left(\dfrac{1}{\omega C_s n^2 R_o}\right)^2 \left(1 - \dfrac{\omega^2}{\omega_s^2}\right)^2}} \quad (4)$$

Where, ω_S is the resonant angle frequency of L_S and C_S in series:

$$\omega_s = \frac{1}{\sqrt{L_s C_s}} \quad (5)$$

ω_m is the resonant angle frequency if C_s, L_s and L_m in series

$$\omega_m = \frac{1}{\sqrt{(L_m + L_s)C_s}} \quad (6)$$

The variables in equation (4) can be replaced by three normalized variables

f_n is the normalized frequency by series resonant frequency of L_s and C_s.

$$f_n = \frac{\omega}{\omega_s} \quad (7)$$

Q is the load resistance normalized by impedance of resonant inductance at series resonant frequency.

$$Q = \frac{n^2 \cdot R_o}{\omega_s L_s} \quad (8)$$

h is the factor for magnetizing inductance normalized by resonant inductance.

$$h = \frac{L_m}{L_s} \quad (9)$$

Using the equivalent circuit, a normalized DC gain equation is deduced as follows:

$$M(f_n, h, Q) = \frac{nV_o}{V_{in}/2} = \frac{1}{\sqrt{(1 + \frac{1}{h} - \frac{1}{f_n^2 \cdot h})^2 + Q^2 \cdot (\frac{1}{f_n} - f_n)^2}} \quad (10)$$

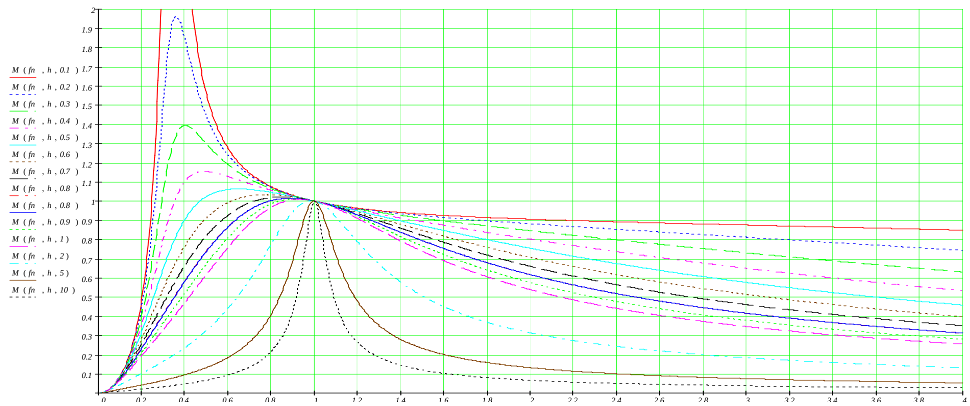


Figure 7. DC gain curve for LLC topology

DC gain curve is changed with different Q, M is the normalized DC gain which is a function of h, f_n and Q. And the h, f_n and Q are also normalized variables which are related to the parameters of actual parameter such as L_s, L_m and C_s and turn rations of transformer.

In a real design, the value of Q is a trade-off between conduction loss, switching loss and start up current. Having curves and considering actual devices, selection of Q and h for parameter selection become possible. Here, it can assume $Q = 0.2$ and $h = 8$ firstly for this design. So it can calculate L_s, L_m and C_s as below:

$$L_s = \frac{4 \cdot n'^2 \cdot R_o \cdot Q}{\pi^3 \cdot f_s} \quad (6)$$

Here R_o is output equivalent resistor with $R_o = \dfrac{\dfrac{V_{o1}}{I_{o1}} \cdot \dfrac{V_{o2}}{I_{o2}}}{\dfrac{V_{o1}}{I_{o1}} + \dfrac{V_{o2}}{I_{o2}}} = 25$.

The resonant inductance is selected as $L_{s=100uH}$.

$$C_s = \frac{\pi}{16 \cdot f_s \cdot n'^2 \cdot R_o \cdot Q} \quad (7)$$

The equivalent resonant capacitor is selected as $C_s = 24nF$.

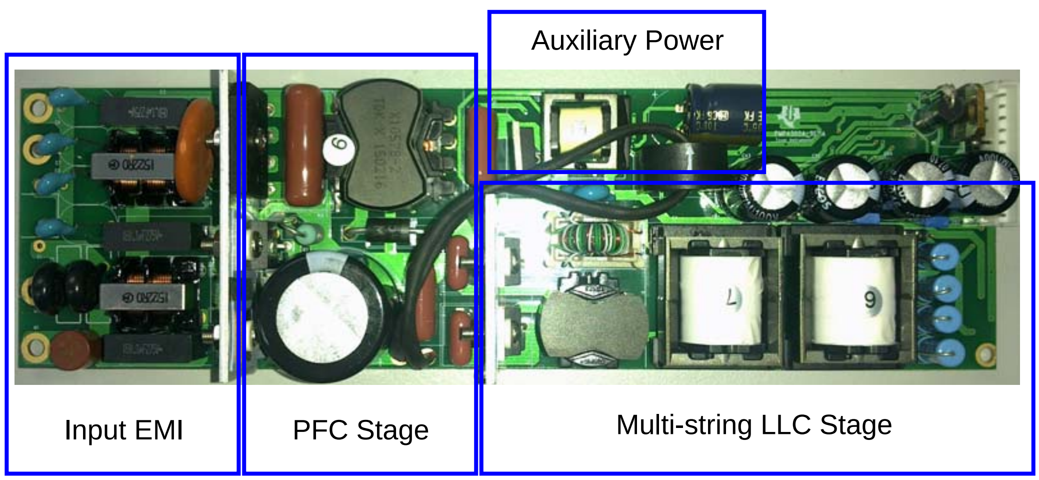
$$L_m = \frac{4 \cdot n'^2 \cdot R_o \cdot h \cdot Q}{\pi^3 \cdot f_s} \quad (8)$$

The equivalent magnetizing inductance of transformer is selected as $L_m = 820uH$. Because multi-string transformer used two transformers in series, the inductance for each transformer is 410uH. Based on AP method for magnetic component, PQ2625 or equivalent cores with same Ae are chosen, then the turns for primary and secondary can be calculated accordingly. Here, we select $N_p = 30$ and $N_s = 17$.

5 100W off-line LED lighting driver design

Based on UCC28810 (TM PFC), UCC27510 (multi- transformer LLC controller) and UCC28610 (auxiliary green mode Flyback controller), a 100W reference design PMP4302A is developed with 4 output strings and 15 LEDs per string. The dimensions for this demonstration board is 245mm(L)x18mm(W)x11mm(H), which is very suitable for high wattage general LED lighting form factor. The figure 8 shows the PMP4302A reference design board photo including input EMI filter, TM PFC stage, auxiliary power supply stage and multi-string LLC stage. Table 1 gives the electrical specification for this reference design.

5.1 Design Specification



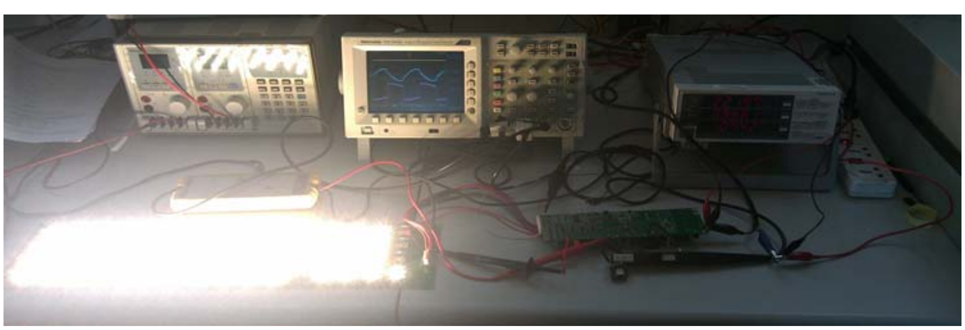


Figure 8. Demo board for PMP4302A reference design

Table 1. Electrical Design Specification

Specification Items	Min	Typical	Max
Input AC Voltage	90Vac	220Vac	264Vac
Output Voltage Tolerance		54Vdc	60Vdc
Number of LED strings		4	
Output current per string	485mA	500mA	515mA
Output current tolerance per string			+-3%
PWM dimming range	1%		100%
Power Factor (90Vac~264Vac)	0.95	0.98	0.99
Efficiency @ 100% dimming	88%	91.5%	
Turn-on Delay			200ms
Output String Open Loop		Yes	
Output String Over-voltage	60Vdc w/ latched off		
Output String Under-voltage			40Vdc w/ latched off
Output String Short		Yes	
Maximum Input Current @ 90Vac 100% dimming light		1.3A	
Primary over current			2A

5.2 Schematics

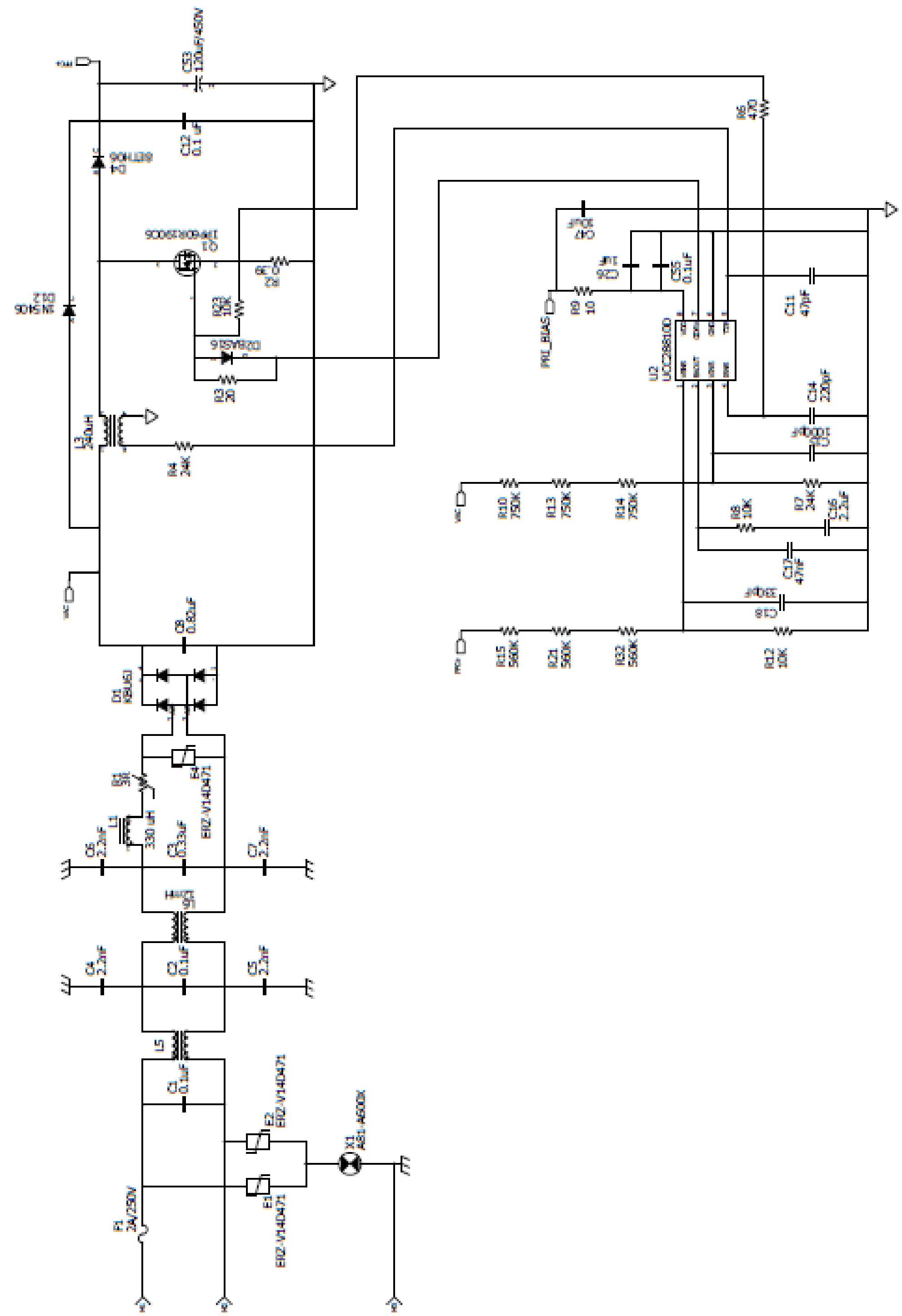


Figure 9. PFC stage schematics for PMP4302A

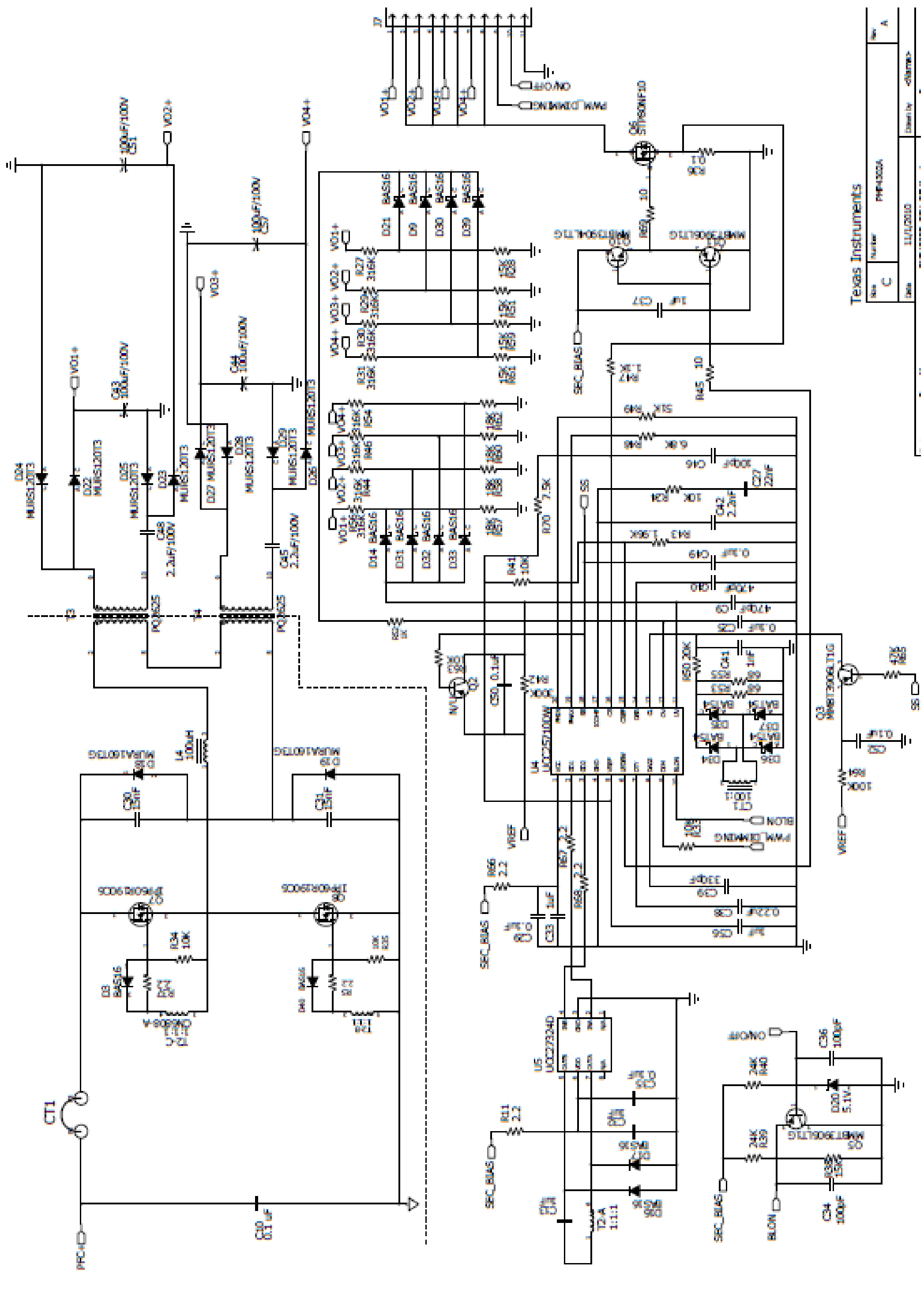


Figure 10. Multi-string LLC stage schematics of PMP4302A

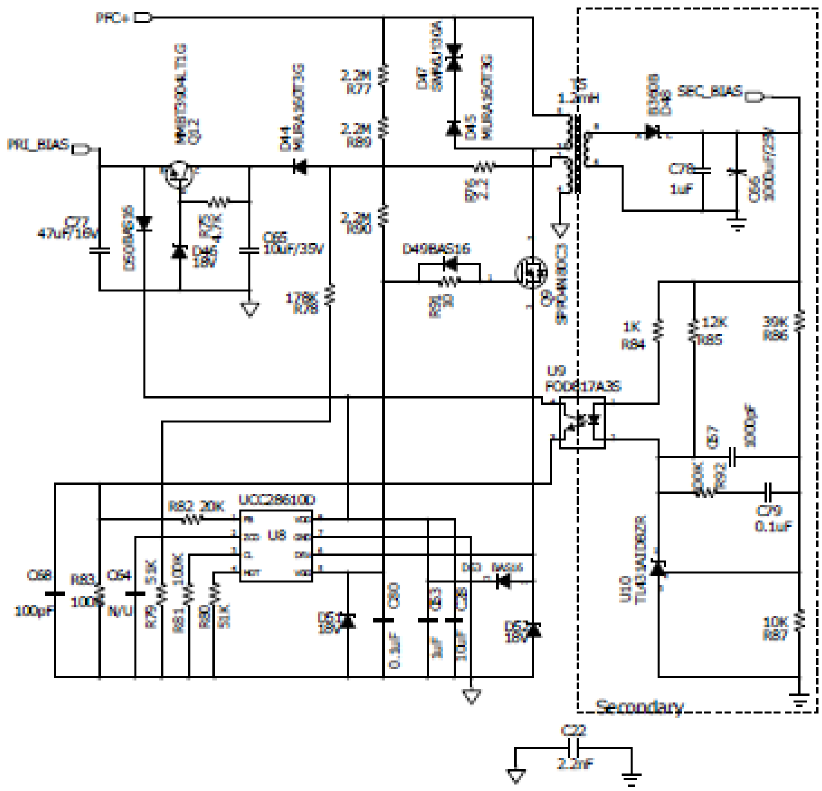


Figure 11. Auxiliary Flyback stage schematics of PMP4302A

5.3 Output Current Matching

Because of transformer’s magnetic balance with primary winding in series, the multi-transformer LLC converter can have good current matching performance. There are two considerations to improve current matching performance between the strings:

1. It is recommended to set operating frequency above resonance at nominal input voltage range of the LLC converter in order to improve LED current matching and transient response during dimming. This will make the output current operating with CCM, and it will have much small difference current between each string.

2. In real transformer, the magnetizing current of the transformer has influence of output current matching, smaller magnetizing current will have good current matching performance. It is important to set the equivalent magnetizing inductance of the transformer as high as possible to minimize the magnetizing current.

Table 2 gives the output current on each LED string with input voltage from 90Vac to 264Vac at 100% dimming. Table 3 also shows the output current with PWM dimming duty cycle from 5% to 100% at 90Vac, 230Vac and 264Vac input. The output current matching tolerance is less than +-3% according to the below data.

Table 2. Output current with input voltage

Vin	Io1(A)	Io2(A)	Io3(A)	Io4(A)
90	0.5086	0.5065	0.5064	0.5023
100	0.5083	0.5063	0.5068	0.5025
110	0.5081	0.5062	0.5067	0.5028
130	0.5081	0.5061	0.5077	0.5029
160	0.5079	0.5057	0.5073	0.503
180	0.5077	0.5056	0.5073	0.503
200	0.5076	0.5055	0.5075	0.5032
220	0.5076	0.5054	0.5074	0.5032
230	0.5077	0.5055	0.5076	0.5033
264	0.5078	0.5056	0.5075	0.5031

Table 3. Output current with PWM dimming and input voltage

90Vin								
Dimming	**Io1(mA)**	**Io2(mA)**	**Io3(mA)**	**Io4(mA)**	**Max(mA)**	**Min(mA)**	**Ave(mA)**	**%**
5%	25.1	24.6	25.8	25.7	25.8	24.6	25.3	2.371542
10%	50.4	49.7	51.4	51.4	51.4	49.7	50.725	1.675702
20%	100.9	100.1	102.8	102.5	102.8	100.1	101.575	1.329067
30%	151.4	150.4	154.1	153.8	154.1	150.4	152.425	1.213712
40%	201.9	200.7	205.4	204.9	205.4	200.7	203.225	1.156354
50%	252.5	251	256.3	255.6	256.3	251	253.85	1.043924
60%	302.8	301.5	307.7	307.4	307.7	301.5	304.85	1.016894
70%	353.5	351.8	358.6	357.8	358.6	351.8	355.425	0.956601
80%	403.9	402.2	409.7	408.8	409.7	402.2	406.15	0.923304
90%	454.3	452.2	461.1	460.1	461.1	452.2	456.925	0.973902
99%	499.3	496.7	507.2	506.2	507.2	496.7	502.35	1.045088
100%	503.9	501.4	512.4	511.7	512.4	501.4	507.35	1.084064
230Vin								
Dimming	**Io1(mA)**	**Io2(mA)**	**Io3(mA)**	**Io4(mA)**	**Max(mA)**	**Min(mA)**	**Ave(mA)**	**%**
5%	25.2	24.5	25.9	25.7	25.9	24.5	25.325	2.764067
10%	50.4	49.7	51.5	51.3	51.5	49.7	50.725	1.774273
20%	100.9	100.1	102.7	102.5	102.7	100.1	101.55	1.280158
30%	151.4	150.4	154.1	153.6	154.1	150.4	152.375	1.21411
40%	201.9	200.9	205.1	204.9	205.1	200.9	203.2	1.033465
50%	252.4	251.1	256.4	255.8	256.4	251.1	253.925	1.043615
60%	302.9	301.4	307.7	307	307.7	301.4	304.75	1.033634
70%	353.5	351.8	358.6	357.8	358.6	351.8	355.425	0.956601
80%	403.9	402.2	409.7	408.8	409.7	402.2	406.15	0.923304
90%	454.3	452.2	461.1	460.1	461.1	452.2	456.925	0.973902
99%	499.3	496.7	507.2	506.2	507.2	496.7	502.35	1.045088
100%	503.9	501.4	512.4	511.7	512.4	501.4	507.35	1.084064
264Vin								
Dimming	**Io1(mA)**	**Io2(mA)**	**Io3(mA)**	**Io4(mA)**	**Max(mA)**	**Min(mA)**	**Ave(mA)**	**%**

5%	25.1	24.6	25.8	25.7	25.8	24.6	25.3	2.371542
10%	50.4	49.7	51.4	51.4	51.4	49.7	50.725	1.675702
20%	100.9	100.1	102.8	102.5	102.8	100.1	101.575	1.329067
30%	151.4	150.4	154.1	153.8	154.1	150.4	152.425	1.213712
40%	201.9	200.7	205.4	204.9	205.4	200.7	203.225	1.156354
50%	252.5	251	256.3	255.6	256.3	251	253.85	1.043924
60%	302.8	301.5	307.7	307.4	307.7	301.5	304.85	1.016894
70%	353.5	351.8	358.6	357.8	358.6	351.8	355.425	0.956601
80%	403.9	402.2	409.8	408.6	409.8	402.2	406.125	0.935673
90%	454.3	452.4	461.1	460.3	461.1	452.4	457.025	0.951808
99%	499.4	496.7	507.2	506.2	507.2	496.7	502.375	1.045036
100%	503.9	501.4	512.4	511.7	512.4	501.4	507.35	1.084064

5.4 Efficiency

Efficiency is a key benefit for this solution, and it is also related to the components' selection and transformer design. The below figure is the efficiency curve with PWM dimming, and it shows the highest efficiency is above 91%. For the non-dimming version, it uses only one schottky diode for each string and there is no need for PWM dimming's MOSFET on the output side, which can improve another 1~2% for overall efficiency.

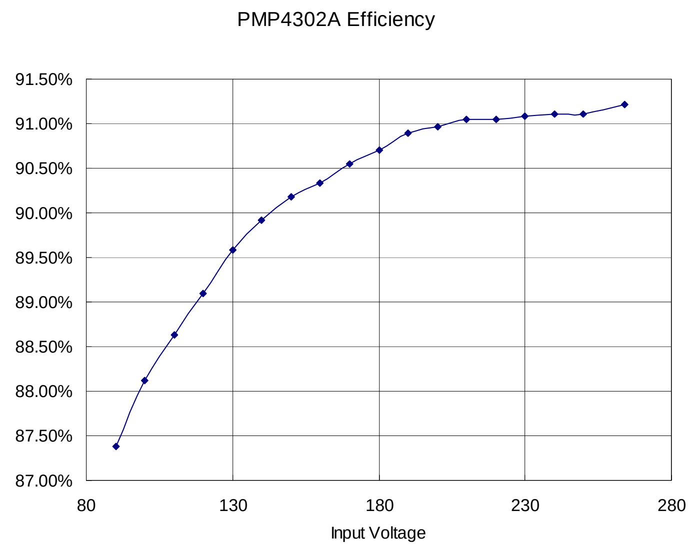
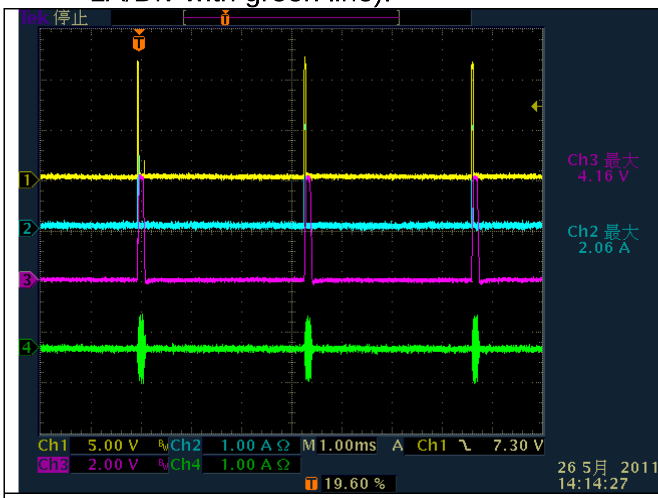


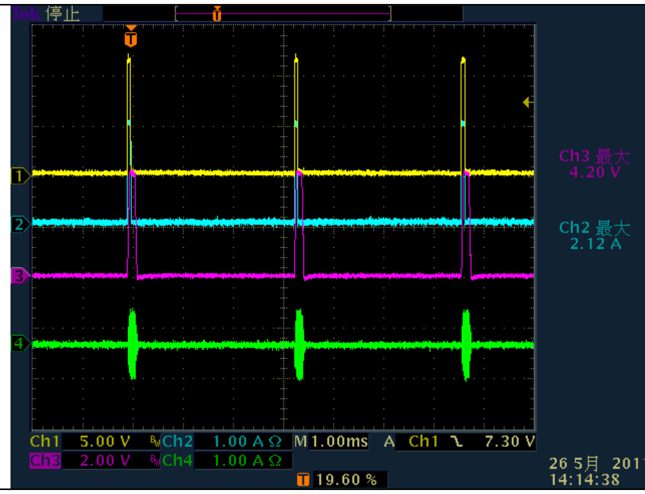
Figure 12. Efficiency curve with dimming

5.5 Dimming waveform

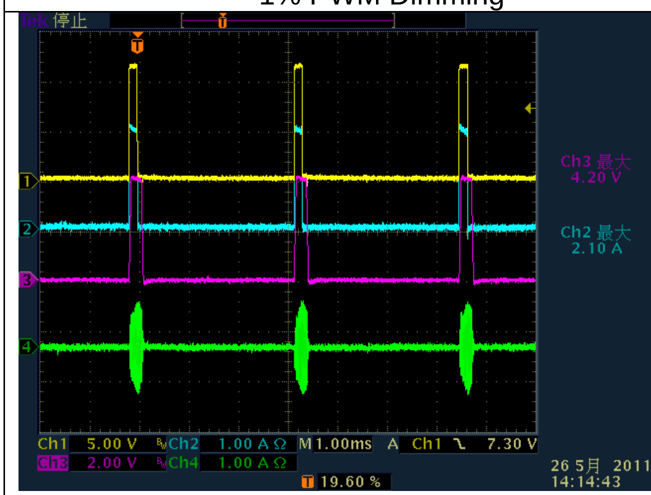
The solution can support group PWM dimming from 1% to 100% range. In order to get a linear dimming performance, UCC25710 has small delay time which allows the current loop maintain control at low PWM dimming duty cycle. Meanwhile, the DSR (Dimming Slew Rate) function is used to control the rise and fall time of the VCO control voltage, allowing potentially audible electro-mechanically induced noise to be minimized. The figure 13 gives the operating waveforms during dimming. (CH1: LEDSW MOSFET Vgs 5V/Div with yellow line; CH2: LED Output Current 1A/Div with blue line; CH3: DSR 2V/Div with red line; CH4: Primary Current 1A/Div with green line).



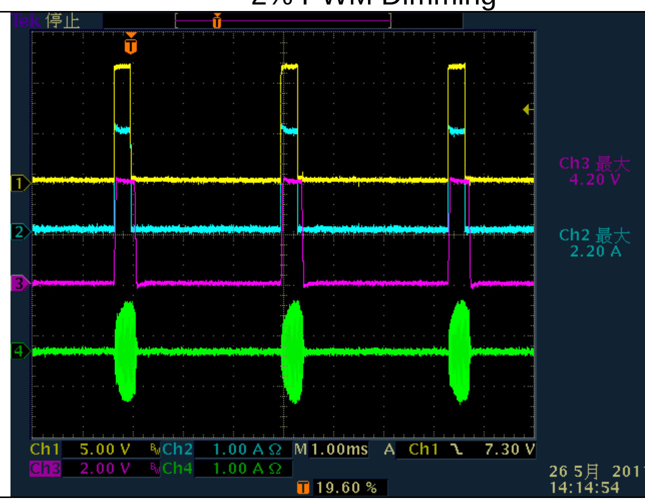
1% PWM Dimming



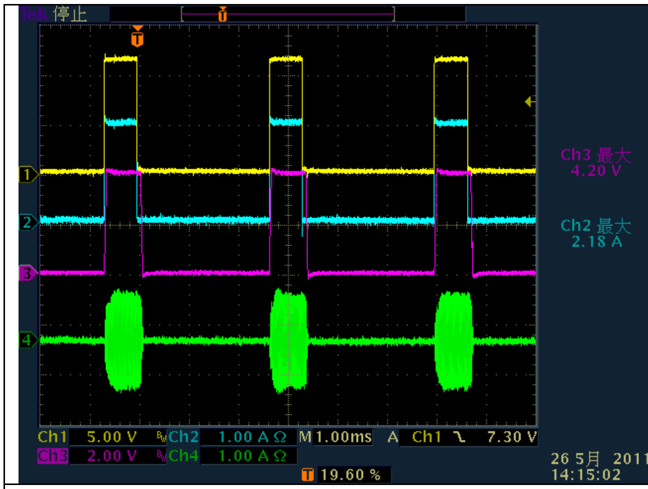
2% PWM Dimming



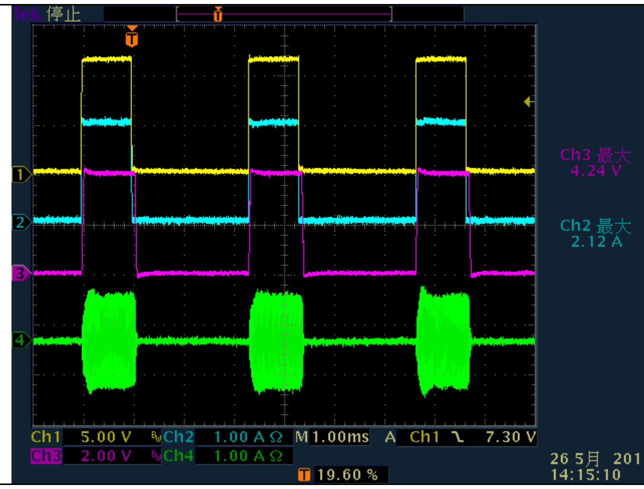
5% PWM Dimming



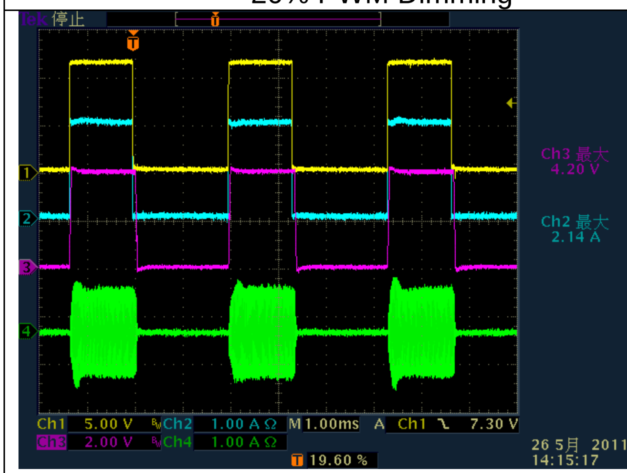
10% PWM Dimming



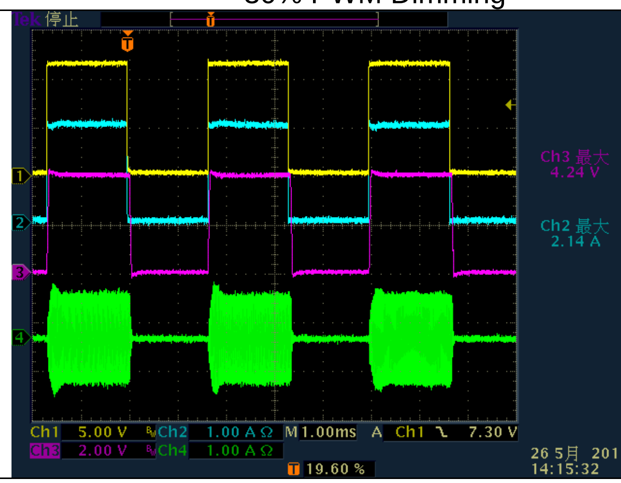
20% PWM Dimming



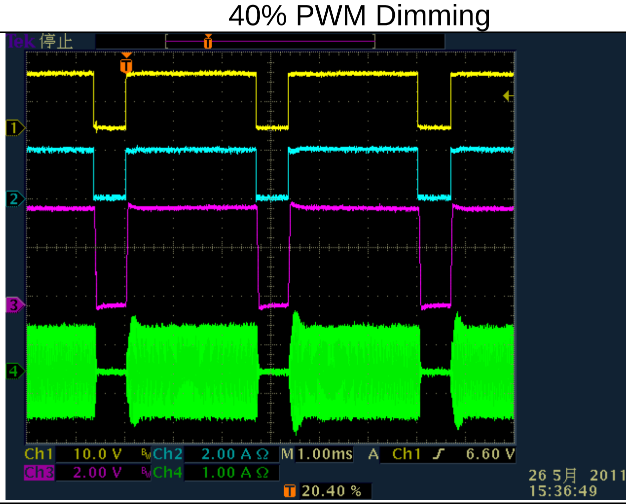
30% PWM Dimming



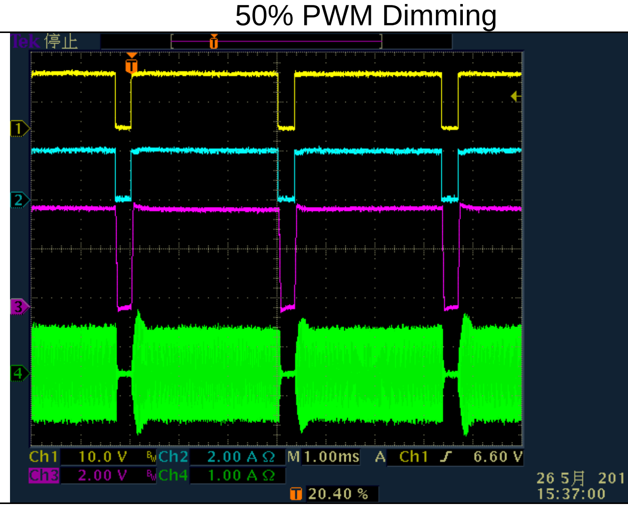
40% PWM Dimming



50% PWM Dimming



80% PWM Dimming

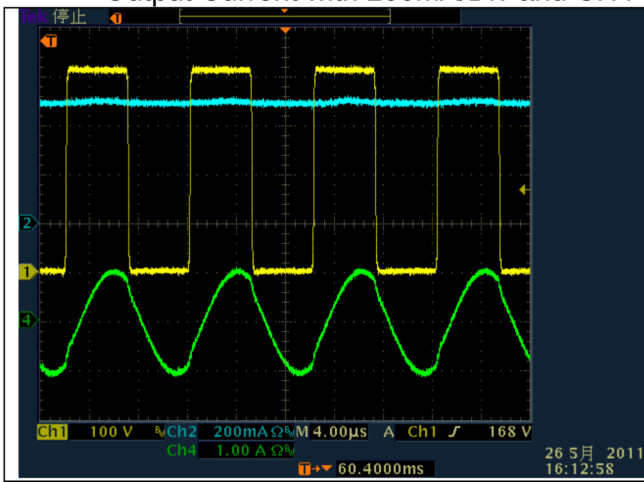


90% PWM Dimming

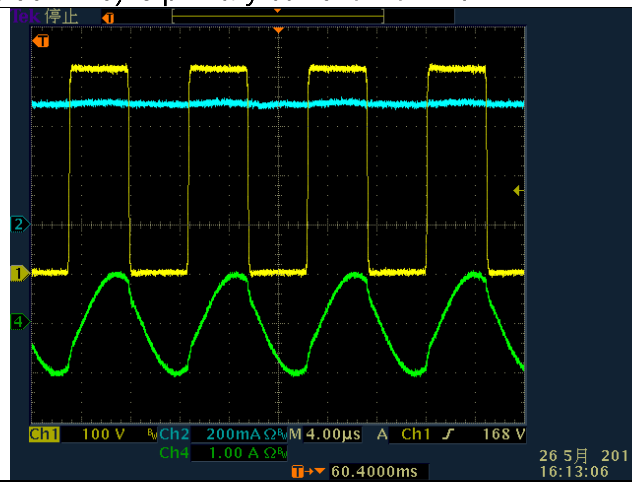
Figure 13. Operating waveforms during PWM dimming

5.6 LLC stage waveforms

The figure 14 gives operating waveform for LLC stage at full load, and it shows the output current is operating at CCM in order to achieve perfect current matching performance. Here, CH1 (yellow line) is Primary MOSFET Vds waveform with 100V/Div; CH2 (blue line) is LED Output Current with 200mA/Div and CH4 (green line) is primary current with 1A/Div.



90Vac input



230Vac input

Figure 14. LLC stage waveforms at full load

5.7 EMI performance

EMI is another benefit for this multi-string LLC topology. The figure 15 shows the test result of conduction noise for this PMP4302A reference design.

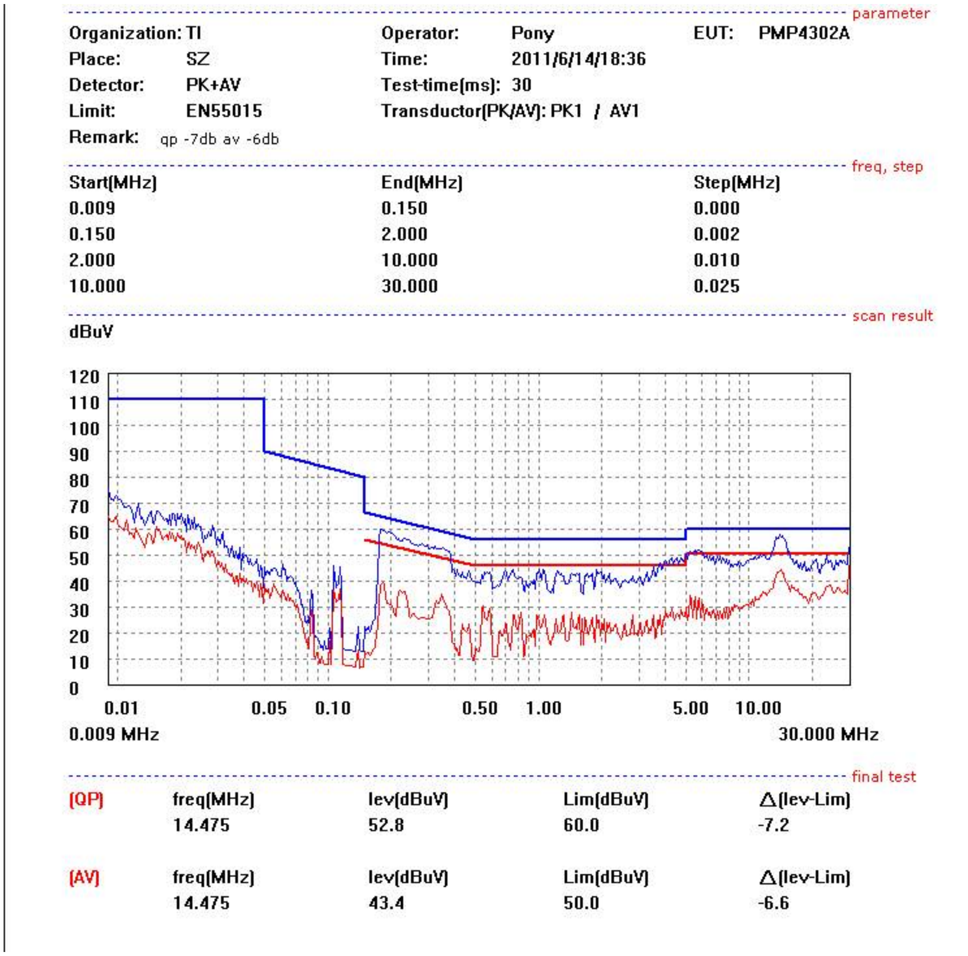


Figure 15. EMI conduction test results

6 Conclusion

This application note presents a new multi-transformer LLC topology for general LED lighting with high efficiency and PWM dimming. A 100W LED lighting driver to drive 4 LED strings verified the performance for this proposed topology.

References

1. *UCC25710 datasheet, Texas Instruments* (SLUSAD7A)
2. *UCC28810 datasheet, Texas Instruments* (SLUS865)
3. *UCC28610 datasheet, Texas Instruments* (SLUS888D)

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