Texas Instruments System Power Solutions
-High efficiency LLC resonant controller and synchronous rectifier

Texas Instruments
Power Management
AGENDA

1. UCC25710 Multi-strings LLC LED driver
   1. Features and Application
   2. Block Diagram
   3. Operating descriptions and evaluation results:

2. UCC25600 LLC controller
   1. LLC operating descriptions
   2. Block diagram and features:

3. UCC24610 Synchronous driver:
   1. Features and Application
   2. EVM and test results:
Typical High Watt (>100W) LED Lighting Driver Topology

1. AC/DC Power Stage
   - PFC
   - LLC Converter
   - UCC28061 (Inter TM PFC)
   - UCC28810/1 (TM PFC)
   - UCC25600 (LLC)

2. Constant Current Driver Stage
   - ~54Vdc Bus
   - BUCK Control
   - TPS4021
   - TPS4020
   - TPS5416
   - ~15pcs LEDs in Series

- Texas Instruments
High Watt (>100W) LED Lighting Efficiency Budget

Outdoor and Industrial >100W

Conventional Topology Issues:
- High cost: PFC+LLC+CC BUCK (multi-chips!!)
- Low efficiency (<~88%)
- Low reliability (many components’ counts)
- EMI issues
TI UCC28810EVM-003 - SIMPLEDDrive™

Series Input, Multiple Parallel Equivalent LED Drive (SIMPLEDrive)

1st stage:
TM Boost for PFC

2nd stage:
TM Buck for LED current

3rd stage:
Resonant Current Half Bridge

>93% (Three stages multi-string transformer solution)
Innovative two stages multi-string LLC topology for LED lighting

Benefits for the proposed topology:
- High efficiency ~92%
- Low cost (no need CC DC/DC driver)
- High reliability
- Easy EMI
- PWM or analog dimming compatible
Why Transformer Can Balance Current

- Transformer current is in reverse proportion to turn ratio
  \[ \frac{I_p}{N_p} = \frac{I_s}{N_s} \]
  \[ I_s = N_s \frac{I_p}{N_p} \]

- When transformer primary is connected together, their primary current must be the same

- When T1 is the same as T2 because of transformer operation principle their secondary current is the same
  \[ I_{s1} = N_s \frac{I_p}{N_p} = I_{s2} \]
Multi-Transformer Architecture
(TI Patented)

AC input

One transformer control two LED strings!
UCC25710: LED driver Controller IC

**Features**

- Industry first single chip LLC controller for driving multiple LED strings directly from PFC output
- Adjustable Fmin (3% accuracy), and Fmax 6% (accuracy)
- Closed Loop LED String Current Control
- PWM Dimming Input
- LLC and Series LED Switch Control for Dimming
- Programmable Dimming LLC ON/OFF Ramp for Elimination of Audible Noise
- Closed Loop Current Control at Low Dimming Duty-Cycles
- Programmable Soft Start
- Accurate VREF for Tight Output Regulation
- Over-voltage and Under-voltage and Input Over-current Protection with Auto-restart Response
- Second Over-current threshold with Latch-off Response
- +400-mA/-800mA Gate Drive Current
- Low Start-Up and Operating Currents
- 20 pin SO Lead (Pb)-Free Package

**Applications**

- General LED Lighting
- LED TV Backlighting
UCC25710
Block Diagram

Current Regulation and VCO Slew Control

Supply Control

LED Switch and Dimming Control

Fault Control

UCC25710
The DIM input controls the ILED-ON and ILED-ON signals.

DSR capacitor C2 and internal 44uA currents control the slew rate of $V_{VCO}$ during dimming off and on transitions.
- Turn-off: DSR is discharged to GND by 44uA
- Turn-on: DSR is charged to ICOMP by 44uA. Charge level is clamped to 1Vbe above ICOMP

Control Clamp output, $V_{VCO}$, tracks the lower of ICOMP and DSR

ICOMP is only driven by GM amp during LED-ON times.

During LED-OFF times the ICOMP voltage is held by C1
UCC25710: START-UP & DIM WAVEFORMS

- 10ms RESET initiates Soft-Start (SS)
- LLC Soft-Start, VCO control is clamped to SS until SS > ICOMP
- Dimming is disabled during SS
- DSR cap is used to limit LLC control slew rate during dimming
- ICOMP voltage is maintained during dimming

Start-up and UVLO Shutdown

Controller Enabled

Soft-Start

Operation Disabled

VCC

VREF

UVLO

RESET

10ms

SS

ICOMP

DSR

GD1,2

LEDSW

DIM

9.3V

9.0V

10ms

Soft-Start Over

Operation Disabled

9.3V

9.0V

Controller Enabled

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

Operation Disabled

9.3V

9.0V

10ms

Soft-Start

OperationDisabled
• DIM input controls LEDSW
• DIM input triggers soft turn-on and turn-off of LLC converter
• LLC on-time is extended
• On-time extension is proportional to 1-D, D is dimming duty-cycle
• Extended on-time allows ICOMP to maintain current regulation at low D

\[
\text{DTY} = 0.1V + 2.5V(1-D)
\]
1. LLC reaches power level equal to pedestal LED current in region B. Power is under delivered in region A, but is compensated for in region C.

2. Region B is zero, but sum of A+C still delivers correct energy.

3. Energy delivered in region A + C is too low, loop is open and realized peak LED current will drop.

4. On-time is extended. A + C energy/pulse is correct to maintain same peak LED current.
UCC25710: FAULT MANAGEMENT

• Faults
  – OV – highest LED string voltage
  – UV – lowest LED string voltage
  – CL(1V) – input current signal over-current
  – CL(2V) – input current signal latch-off
  – TSD – Chip thermal shutdown

• Response
  – OV, CL(1V) & TSD: The LLC converter and LEDSW are turned off. When the fault clears a RESET and SS are initiated.
  – UV: The LLC converter and LEDSW are turned off. A RESET and SS are immediately initiated, repeatedly, until fault clears.
  – CL(2V): The LLC and LEDSW are latched off until UVLO recycles.
  – During RESET the LLC converter and LEDSW are OFF
  – During SS the LLC converter and LEDSW are ON, i.e. no DIMMING
# PMP4302: Multi-string LLC AC/DC Driver for general LED lighting

## Reference Design

<table>
<thead>
<tr>
<th>Reference Design</th>
<th>TI Parts</th>
<th>$V_{\text{in}}$</th>
<th>Output</th>
<th>Topology</th>
<th>Eff.</th>
<th>Dimming</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PMP4302:</strong> AC input Multi-string LLC converter for general LED lighting</td>
<td>UCC28810 (TM PFC) UCC25710 (Multi-string LLC) UCC28610 (Aux Flyback)</td>
<td>90V~264V</td>
<td>54V@500mA with 4 string</td>
<td>TM PFC+Multi-string LLC converter</td>
<td>92%</td>
<td>PWM dimming</td>
</tr>
</tbody>
</table>

## Features
- Lowest cost than AC/DC + DC/DC
- Highest efficiency to 92%
- PWM dimming compatible
- Integrate LED open/short protection and over current protection

## Applications
- General LED lighting and LED backlight TV

---

### Outdoor and Infrastructure >100W

![Diagram of PMP4302 circuit](image)

- **UCC28810**
- **UCC25710**

---

![PMP4302 Board](image)
PMP4302 demo board

- Input EMI
- PFC Stage
- Multi-string LLC Stage
- Aux Power

LED light bar: 4x15 LEDs
PMP4302: Schematics for UCC25710 after PFC stage

Multi-string transformer LLC topology

PWM dimming & Total current sensing feedback
Table 1: LED current output tolerance

<table>
<thead>
<tr>
<th>PWM Dimming</th>
<th>Io1</th>
<th>Io2</th>
<th>Io3</th>
<th>Io4</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1%</td>
<td>4.9</td>
<td>4.8</td>
<td>5</td>
<td>5.1</td>
<td>3.030</td>
</tr>
<tr>
<td>2%</td>
<td>10</td>
<td>9.8</td>
<td>10.4</td>
<td>10.3</td>
<td>2.962</td>
</tr>
<tr>
<td>5%</td>
<td>25.2</td>
<td>24.1</td>
<td>25.2</td>
<td>25.1</td>
<td>2.208</td>
</tr>
<tr>
<td>10%</td>
<td>50.4</td>
<td>49.7</td>
<td>51.5</td>
<td>51.3</td>
<td>1.774</td>
</tr>
<tr>
<td>20%</td>
<td>100.9</td>
<td>100.1</td>
<td>102.7</td>
<td>102.5</td>
<td>1.280</td>
</tr>
<tr>
<td>30%</td>
<td>151.4</td>
<td>150.4</td>
<td>154.1</td>
<td>153.6</td>
<td>1.214</td>
</tr>
<tr>
<td>40%</td>
<td>201.9</td>
<td>200.9</td>
<td>205.1</td>
<td>204.9</td>
<td>1.033</td>
</tr>
<tr>
<td>50%</td>
<td>252.4</td>
<td>251.1</td>
<td>256.4</td>
<td>255.8</td>
<td>1.043</td>
</tr>
<tr>
<td>60%</td>
<td>302.9</td>
<td>301.4</td>
<td>307.7</td>
<td>307</td>
<td>1.033</td>
</tr>
<tr>
<td>70%</td>
<td>353.5</td>
<td>351.8</td>
<td>358.6</td>
<td>357.8</td>
<td>0.956</td>
</tr>
<tr>
<td>80%</td>
<td>403.9</td>
<td>402.2</td>
<td>409.7</td>
<td>408.8</td>
<td>0.923</td>
</tr>
<tr>
<td>90%</td>
<td>454.3</td>
<td>452.2</td>
<td>461.1</td>
<td>460.1</td>
<td>0.973</td>
</tr>
<tr>
<td>99%</td>
<td>499.3</td>
<td>496.7</td>
<td>507.2</td>
<td>506.2</td>
<td>1.045</td>
</tr>
<tr>
<td>100%</td>
<td>503.9</td>
<td>501.4</td>
<td>512.4</td>
<td>511.7</td>
<td>1.084</td>
</tr>
</tbody>
</table>

Current tolerance can achieve <+-3% with dimming range from 1% to 100%
PMP4302: Efficiency
(TM PFC + Multi-string LLC + Aux power)

Dimming version

Non-Dimming version
PMP4302: waveforms

CH1: LEDSW MOSFET Vgs 5V/Div
CH2: LED Output Current 1A/Div
CH3: DSR 2V/Div
CH4: Primary Current 1A/Div

1% dimming

5% dimming

50% dimming

90% dimming
PMP4302: waveforms

CH1: Primary MOSFET Vds 100V/Div
CH2: LED Output Current 200mA/Div
CH4: Primary Current 1A/Div

CCM to get better current tolerance

Lm/Lk=6
Fs=100KHz
Q=0.7

Lm1+Lm2=640uH
Lr=100uH
Cr=30nF
PMP4302: Thermal and Bode Plot

05/26/2011 02:14:32

05/26/2011 02:17:57

Texas Instruments
PMP6251: LED Backlighting for Edge-Lite/ Group Dimming Digital TV Application

Reference design Features

- Support to universal 90~264Vac range
- LED 4 outputs @120mA, 63V, 5Vsb@1A, 5V@3A, 13V@3A
- Eff 83.7%@110Vac, 85.2%@240Vac
- Secondary side 120Hz blanking control for dimming
- 8mm height and 6mm height for LED magnetic component
- Board dimension 300mm(L) * 200mm(W) * 8mm(H)
- LED output common + and LED OVP and UVP
- Integrated the protection ckt to reduce the solution part count.
- Dedicated controller for edge-lit/ group dimming base on the LLC topology – UCC25710
- Providing design package – Schematic, Gerbo file, PCB file, Magnetic components…
PMP6251: PFC+ Multi-string LLC Efficiency

Efficiency Data of PFC+LLC Power Stage from 1% - 100% Dimming

Efficiency exclude standby Power Converter at full load condition ~ 90%
Summary

• **UCC25710 with multi-transformer LLC topology can achieve:**
  - High efficiency
  - Low total BOM cost with high reliability
  - PWM or analog dimming compatible
  - Output LED strings open/short protection
  - Input over current protection
  - Support 1%~100% dimming range
  - Easy EMI
Summary

- LED backlight becomes a trend for flat screen TVs
- TI proposed multi-transformer backlight solution
  - Simple current matching method
  - Single stage power processing
  - Fault tolerant capability
- UCC25710 provides the IC solution for multi-transformer architecture
  - Multi-Transformer LLC + LED switch control
  - Precision LED current control
  - Soft ramping of LLC for audible noise reduction
  - Extended PWM dimming dynamic range
  - Complete protection features
TI UCC25600
8 Pin Resonant Half Bridge Controller

Features
- Adjustable Soft start (1ms to 500ms)
- Adjustable dead time
- Adjustable $F_{\text{swmax}}$ & $F_{\text{swmin}}$ (3% accuracy)
- $I_o = +1\text{A} / -1.5\text{A}$
- Enable (ON/OFF control)

Protection functions
- Two levels over current protection
  - auto recovery
  - latch
- Bias voltage UV and OV protection
- Over temperature protection
- Soft start after all fault conditions

SOT 8 pin package= Easy design and layout
Application Circuit

Programmable dead time
Frequency control with minimum/maximum frequency limiting
Programmable soft start with on/off control
Two level over current protection, auto-recovery and latch up
Matching output with 50ns tolerance
LLC Resonant Converter with Wide Operation Range

- At 400V input, switching frequency is resonant frequency
- During holdup time, switching frequency is reduced

Resonant frequency: \( f_0 = \frac{1}{2\pi \sqrt{L_r C_r}} \)

Transformer turns-ratio: \( n = \frac{V_{\text{in}} / 2}{V_o} \)

\[ V_{\text{in}} = V_n \frac{2}{V^2} = \text{Transformer turns-ratio} \]

\[ M = V_o / V_{\text{in}} \]

\[ f_n = \frac{\pi}{2 \sqrt{1 - Q^2}} \]

Graph shows regions:
- ZVS Region
- ZCS Region

Q: 0.1, 0.2, 0.5, 0.8, 1, 2, 5, 8, 10

Texas Instruments
Operation Principles

At Resonant Frequency

At resonant frequency, maximum efficiency is expected
When switching frequency is below resonant frequency, magnetizing inductor begins to participate in resonant and increase voltage gain.

Secondary diode becomes discontinuous.
When switching frequency is above resonant frequency, circuit behaves as SRC
Secondary current becomes CCM, reverse recovery loss increases
Benefits of LLC Resonant Converter

- ZVS can be achieved by utilizing transformer magnetizing inductor
- Capacitor filter, less voltage stress on rectifiers
- Smaller switching loss due to small turn off current
- Variable switching frequency control, not sensitive to load change
- Wide operation range without reducing normal operation efficiency
UCC24610
Green Rectifier Controller

Features
- Secondary Side Synchronous Rectifier Controller for Flyback and LLC Converters
- Operates in Continuous and Discontinuous Mode Flybacks and LLC Resonant
- Automatic Light Load Management
- Highly Integrated Control
- Micro Power Sleep Current at light/No load

Benefits
- Enables 90%+ efficiency at full load and Optimized Efficiency Over Entire Load Range
- Zero Glitch Transition between CCM and DCM Operation for varying Line or Load Changes
- Turns MOSFETS Off to Maximize Light Load Efficiency
- Reduces External Components with up to 5% Reduction in Power Supply Costs
- Dissipates less than 1mW in Sleep Mode Making Energy Star Goals easily Achievable

Applications
- AC/DC Adaptors
- Mobile Chargers – Cell Phone, IPod
- Set Top Box
- Appliance Power Supplies
- Bias Supplies

EVM Available

Texas Instruments
Adding Green Solutions to the Portfolio

Green Rectifier

Green PWM Controllers
UCC28610  Green Mode PWM
UCC28600  Green Mode QR PWM
UCC25600  Green Mode Resonant LLC
Expand the Operation Range of UCC24610

- With 50V maximum rating, UCC24610 has trouble to use in 19V output LLC
- LLC converter with voltage doubler can be used to extend the operation range of UCC24610
  - No center tap, simpler transformer structure
  - Less voltage drop on the SR, better devices can be used
- UCC24610 can be powered up using on aux power source with boots trap diode
# UCC24610 Competitive Analysis

Key Differentiators
- High Gate Drive current
- Auto Light Load Mode
- Open/Short Protection

<table>
<thead>
<tr>
<th>Parameter/Device:</th>
<th>TI</th>
<th>IR</th>
<th>NXP</th>
<th>NXP</th>
<th>ST</th>
<th>ON</th>
<th>ON</th>
<th>Gren</th>
<th>Zerex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter: Vdrain (V)</td>
<td>50</td>
<td>200</td>
<td>120</td>
<td>120</td>
<td>(ext. clamp)</td>
<td>95</td>
<td>200</td>
<td>200</td>
<td>180</td>
</tr>
<tr>
<td>Conduction Modes:</td>
<td>DCM, QR, CCM</td>
<td>DCM, QR, CCM</td>
<td>DCM, QR, CCM</td>
<td>DCM, QR, CCM</td>
<td>DCM, QR, CCM</td>
<td>DCM, QR, CCM</td>
<td>DCM, QR, CCM</td>
<td>DCM, QR, CCM</td>
<td>DCM, QR, CCM</td>
</tr>
<tr>
<td>GATE Ion (Apk)</td>
<td>-3</td>
<td>-1</td>
<td>-0.25</td>
<td>-0.25</td>
<td>-1.5</td>
<td>2.5</td>
<td>2.5</td>
<td>1</td>
<td>2.5</td>
</tr>
<tr>
<td>GATE Ioff (Apk)</td>
<td>3</td>
<td>4</td>
<td>2.7</td>
<td>2.7</td>
<td>1.5</td>
<td>-2.5</td>
<td>-5</td>
<td>-4</td>
<td>-2.5</td>
</tr>
<tr>
<td>Max Freq (kHz)</td>
<td>600</td>
<td>500</td>
<td>?</td>
<td>?</td>
<td>500</td>
<td>250</td>
<td>500</td>
<td>500</td>
<td>n/a</td>
</tr>
<tr>
<td>Packages</td>
<td>PwrQFN-8, SO-8</td>
<td>SO-8</td>
<td>SO-8</td>
<td>SO-8</td>
<td>SO-8</td>
<td>SO-8</td>
<td>SO-8</td>
<td>SO-8</td>
<td>SO-8</td>
</tr>
<tr>
<td>Rthja (C/W)</td>
<td>67.147</td>
<td>128</td>
<td>150</td>
<td>150</td>
<td>160</td>
<td>178</td>
<td>180</td>
<td>128</td>
<td>250</td>
</tr>
<tr>
<td>Tj Range (C)</td>
<td>-40 to +125</td>
<td>-25 to +125</td>
<td>-20 to +128</td>
<td>-20 to +128</td>
<td>-40 to +125</td>
<td>-40 to +125</td>
<td>-40 to +125</td>
<td>Unknown (5)</td>
<td>Unknown (5)</td>
</tr>
</tbody>
</table>

Special Features:
- Enable function: Yes, No
- Auto Light-Load Mode: Yes, No
- Inductance Compensation: No
- Open/Short Protections: Yes, None Indicated, None Indicated, None Indicated, None Indicated, None Indicated, None Indicated, None Indicated, None Indicated
- Regulated Opto-drive: No, Yes
- Gate Voltage Reduction: No, Yes
- Over-temp Protection: No, Yes
5.6V/3A AC Adapter:
12V/40A Server Application:

- Efficiency: 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%
- Load Current (Amps): 0, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40
UCC24610 in 19.5V LLC AC Adapter Application
Synchronous rectifier in LLC converter
System implementation
Test Results

- **Waveforms**
  - YEL (Primary current) 1 A/Div
  - BLU (Lower SR $V_{DS}$) 10 V/Div
  - GRN (Upper SR $V_{GS}$) 10 V/Div
  - RED (Lower SR $V_{GS}$) 10 V/Div

- **Horizontal scale**
  - 2 µs/Div

- **Operating conditions**
  - $V_I =$320 V
  - $I_O =$1.0 Adc (20 W)
  - $f_{SW}$ below resonance
Test Results

- **Waveforms**
  - YEL (Primary current) 1 A/Div
  - BLU (Lower SR $V_{DS}$) 10 V/Div
  - GRN (Upper SR $V_{GS}$) 10 V/Div
  - RED (Lower SR $V_{GS}$) 10 V/Div

- **Horizontal scale**
  - 2 µs/Div

- **Operating conditions**
  - $V_{I}$ =390 V
  - $I_{O}$ =1.0 Adc (20 W)
  - $f_{SW}$ close to resonance
Test Results

- Waveforms
  - YEL (Primary current) 1 A/Div
  - BLU (Lower SR $V_{DS}$) 10 V/Div
  - GRN (Upper SR $V_{GS}$) 10 V/Div
  - RED (Lower SR $V_{GS}$) 10 V/Div
- Horizontal scale
  - 1 µs/Div
- Operating conditions
  - $V_I$ =420 V
  - $I_O$ =1.0 Adc (20 W)
  - $f_{SW}$ above resonance
Test Results

- Waveforms
  - YEL (Primary current) 1 A/Div
  - BLU (Lower SR $V_{DS}$) 10 V/Div
  - GRN (Upper SR $V_{GS}$) 10 V/Div
  - RED (Lower SR $V_{GS}$) 10 V/Div
- Horizontal scale
  - 2 µs/Div
- Operating conditions
  - $V_I = 320$ V
  - $I_O = 2.3$ Adc (45 W)
  - $f_{SW}$ below resonance
Test Results

- Waveforms
  - YEL (Primary current) 1 A/Div
  - BLU (Lower SR $V_{DS}$) 10 V/Div
  - GRN (Upper SR $V_{GS}$) 10 V/Div
  - RED (Lower SR $V_{GS}$) 10 V/Div
- Horizontal scale
  - 2 µs/Div
- Operating conditions
  - $V_{I} = 390$ V
  - $I_{O} = 2.3$ Adc (45 W)
  - $f_{SW}$ close to resonance
Test Results

- Waveforms
  - YEL (Primary current) 1 A/Div
  - BLU (Lower SR $V_{DS}$) 10 V/Div
  - GRN (Upper SR $V_{GS}$) 10 V/Div
  - RED (Lower SR $V_{GS}$) 10 V/Div
- Horizontal scale
  - 1 µs/Div
- Operating conditions
  - $V_{I}=420$ V
  - $I_{O}=2.3$ Adc (45 W)
  - $f_{SW}$ above resonance
Test Results

- Waveforms
  - YEL (Primary current) 1 A/Div
  - BLU (Lower SR $V_{DS}$) 10 V/Div
  - GRN (Upper SR $V_{GS}$) 10 V/Div
  - RED (Lower SR $V_{GS}$) 10 V/Div
- Horizontal scale
  - 2 µs/Div
- Operating conditions
  - $V_i = 320$ V
  - $I_o = 4.6$ Adc (90 W)
  - $f_{SW}$ below resonance
Test Results

- Waveforms
  - YEL (Primary current) 1 A/Div
  - BLU (Lower SR $V_{DS}$) 10 V/Div
  - GRN (Upper SR $V_{GS}$) 10 V/Div
  - RED (Lower SR $V_{GS}$) 10 V/Div
- Horizontal scale
  - 2 µs/Div
- Operating conditions
  - $V_I = 390$ V
  - $I_O = 4.6$ Adc (90 W)
  - $f_{SW}$ close to resonance
Test Results

- Waveforms
  - YEL (Primary current) 1 A/Div
  - BLU (Lower SR $V_{DS}$) 10 V/Div
  - GRN (Upper SR $V_{GS}$) 10 V/Div
  - RED (Lower SR $V_{GS}$) 10 V/Div
- Horizontal scale: 2 µs/Div
- Operating conditions
  - $V_I = 420$ V
  - $I_O = 4.6$ Adc (90 W)
  - $f_{SW}$ above resonance
Operating Efficiency with UCC24610

More than 6% efficiency improvement is achieved by using UCC24610 with Synchronous rectifier
Thank You!