LIPS Solution for LED TV Backlighting

Aug. 23th, 2010
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Outline

- DTV Market Trend
- Multi-Transformer Current Balancing
- Advantage Compare to Traditional Driver
- Transformer Design & Component Selection
- Feedback, Dimming and Protection
- Test Result
- Conclusion
- Device Introduction
DTV Market Trend

Worldwide DTV Market Forecast

Worldwide Forecast for LCD TV Units with LED Backlight

Source: iSuppli “Worldwide TV Market Tracker Q3 2009”

• DTV market forecasted to grow at 15% CAGR with LCD-TV expected to account for ~90% of total TV market by 2013
• LED backlighting application is hot; 5 year CAGR of 141%
• Edge lit LED TV dominates (90%) market – simpler, enable slim designs & cost effective
• CIP team strategy to support WLED TV backlighting applications; RGB will be supported by C2000 & DCP groups
Multi-Transformer Current Balancing

- Theory on Current Balancing using Transformer

- Multi-Transformer Architecture

- Explanation on why Output Current is not seriously impacted by Transformer Inductance.
Theory on Current Balancing using Transformer

- Transformer current is in reverse proportion to turns ratio
- $\frac{I_p}{N_p} = \frac{I_s}{N_s}$; $I_s = N_s \times \frac{I_p}{N_p}$
- When the transformer primary is connected together, their primary current must be the same
- When $T_1$ is the same as $T_2$, because of transformer operation principle, their secondary current is the same
- $I_{s1} = N_s \times \frac{I_p}{N_p} = I_{s2}$
Multi-Transformer Architecture (TI Patented)
Output Current is not seriously impacted by Transformer Inductance

Because Zone1 is almost the same as Zone2, the transformer inductance do not seriously impact the output current
Multi-Transformer Solution Advantages compare to Traditional Driver (LLC + Boost + Current Balancing)

- Introduction to LED Backlight Driver solutions

- Comparison of the different LED Backlight solutions.
Solutions for Backlight Driver

Power Supply Unit/ LIPS Architecture for LCD-TV

- AC-DC PFC
- Main PWM
- ST-BY PWM
- DC-AC Inverter
- +24V for CCFL-BL Inverter
- +5VSB for MCU
- +12V for Audio-AMP

AC Input

Power Supply Architecture for LED Backlighting TV Today

- AC-DC PFC
- Main PWM
- STBY PWM
- DC-DC Boost
- Controller IC
- LED Current Regulator
- +24V
- +5Vsb for MCU
- +12V Audio

AC Input
Comparison of Different LED Backlight Solutions

Power Supply Architecture for LED Backlighting TV Today

1\(^\text{st}\) DC Boost + 8-16 LED Current Regulators

- DC-DC Boost (Efficiency: 90\%)
- VIN = 24V
- VOUT = 100V
- Cin, Co

94\%, 96\%, 92\%

< 85\% (Traditional Solution)

Power Supply Architecture for LED Backlighting TV in the Future

- Multi-transformer outputs designed on AC/DC LIPS power module (higher efficiency & low cost) inside DTV.

- Today: UCC25600
- UCC28051

> 90\% (Multi-Transformer Solution)
Multi-Transformer Design and Component Selection

- Transformer Design
- Key Component selection
- Feedback and Dimming
- Protection
Transformer Design

For LLC transformer design, firstly we should transfer all parameter into the same unit. In this case we transfer all parameter into primary resistance. Considering 88V, 120mA load and two outputs for each transformer means each transformer output power is

\[ P_{out} = 2 \times V_{out} \times I_{out} = 22.2316W \]

Because there are four transformers in series and half-bridge topology, we got following equation.

\[ R_L = \frac{P_{out}}{(V_{in})^2} \quad V_{in} = \frac{400V}{2(\text{in series})} = 50V \quad R_L = 112.453\Omega \]

To analyze LLC behavior easily we set

\[ Q = \frac{\omega L_k}{R_L} \quad K = \frac{L_m}{L_k} \]

\( L_k \) means leakage inductance, \( L_m \) means magnetizing inductance.

In normal design we set frequency to 110K Hz to avoid 150K EMI conduction issue and also minimize transformer size.
Also set Q to 0.2 and K to 5 for better efficiency and enough hold up time.

From the equation of Q we got

\[ L_m = K \times L_k = 163.225\mu H \quad L_k = \frac{Q \times R_L}{\omega} = \frac{0.2 \times 112.453}{2 \times \pi \times 110000} = 32.645\mu H \]
Transformer Design

DC gain of LLC converter \[ M = \frac{V_o}{V_i} \] and \[ \omega_n = \frac{f}{f_o} \]

\( f_o \) is the resonant frequency and it is equal to 110K Hz
\( \omega_n \) means normalized frequency

According the graph, maximum DC gain happens when \( \omega_n = 0.44 \)
Minimum switching frequency is set as \( \omega_n = 0.51 \) to keep enough margin.
So the Minimum switching frequency is \( f_{\text{min}} = 110K \times 0.51 = 56.1KHz \)

\( V_{in} = 50V \) same as calculated above, maximum switching cycle can be calculated as \[ t = \frac{1}{2 \times f_{\text{min}}} = 8.913 \mu s \]

Flux density B set as 0.5T because the flux can be both negative and positive. Cross-section area A is 30.1mm² according to the transformer we choose
According to transformer basic operation rule \[ V_{in} \times t \leq N \times B \times A \]

\[ N \geq \frac{V_{in} \times t}{B \times A} = 30 \text{ turns} \] to avoid saturated.
Transformer Design

Leakage Inductance is high
Use additional cap to isolate
Can not assemble automatically
Litz wire to avoid eddy current
Fit for higher output power

Leakage Inductance is low
Use isolated wire to isolate
Assemble automatically
Thin line to avoid eddy current
Fit for smaller output power
While CCM Zone1 and Zone2 is still almost the same but while DCM Zone1 and Zone2 with obvious different that is why current is more unbalance when DCM.
Transformer Design

1. B1 PFC Vout maximum
2. C1 How many transformer in series
3. A3 output voltage
4. B3 output current per transformer for dual output design it should be doubled
5. A5 output diode Vf for there are 2 diodes in series it should be doubled

(M, Wn)
(0.44, 1.95)
Transformer Design

6. E6 is predicted efficiency (\( M, W_n \))

7. B9 operation frequency, higher means higher core loss and if more than 150K there might be EMI issue, lower means bigger transformer. 100K~120K would be suggested.

8. B10 choose 0.2 is better. Because F10 Lk would be fixed once transformer is selected, change B10 to let Lk fit to transformer selected is necessary.

9. B11 K is ratio between Lk and Lm. Bigger means better current balance, but lower M (voltage rising rating) choose 5 is suggested.
Transformer Design

10. B13 $M_{\text{max}}$ happen when $W_n$ is 0.44 and add 10%~20% for de-rating, so choose 0.51

11. B15 and B16 key in selected transformer data, notice B15 is core $B_{\text{max}} \times 2$ because it can operate from $B^+_{\text{max}}$ to $B^-_{\text{max}}$

12. C20 Choose bigger than B19 to avoid saturated

13. Key in D28 (PFC Vo -2% tolerance -2% ripple) and C29 (system power consumption), choose B27 to key hold up time C30 longer than required
Resonant Capacitor Selection

- Capacitance calculated by transformer design tool
- Voltage rating should be \(1.2 \times \text{maximum voltage of resonant capacitor}\).
- Ripple current rating should be over \((\text{output watts}/200) \times 1.5\)
- Arco R75, R76 or Panasonic ECWH or other capacitor with high ripple current rating is suggested.
DC Blocking Capacitors

- Capacitance value ~ 1 to 3% of $C_{OUT}$ of each channel
  - Large enough for 10% maximum ripple voltage
  - Small enough to settle quickly
- Voltage stress: Equal to VOUT to keep margin during single output short.
- Ripple current stress: 2.5* output current
Output Capacitor selection

- Voltage rating should be 1.25 * output voltage to keep margin
- Ripple current on capacitor is 1.2 * output current
- Use ripple current rating as 1.5 * output current for margin
Output Rectifier Selection

- Reference design D200~D215
- Super-fast recovery
- 2.5* output voltage
- 1A rating above
- Trr 35ns
- Why?
  - Higher efficiency
  - Better current matching at low duty cycle dimming
Feedback, Dimming and Protection

- Output Current Feedback And Backlight Dimming
- OVP and OTP
- UVP
Feedback and Dimming

Compensator

Pull down output current, feedback and feedback reference during dimming

Detect output current

Compare to reference
OVP and OTP

Detect temperature

Detect output voltage

Compare to reference

Use 2.5V as a base to generate a voltage between 0V and 2.5V.
When any single output voltage is lower than 20V, UVP triggered.

To avoid UVP triggered during dimming, one more circuit to detect if the dimming situation is necessary.

In this case, detect output voltage to enable the UVP function is used.

While any output voltage is over minus 80V, the UVP function is enabled and if there is any output voltage still lowers than 20V, the UVP is triggered.
Test Result

- Reference Design Block Diagram
- Performance
- Cross Regulation
- LED Current Tolerance
- Efficiency
- Dimming Waveform
- Summary
Reference Design Block Diagram

- AC Input 90~265V
- LED Backlighting (8 channels @120mA; 70~88VDC)
- AC-DC PFC
- DC-DC PWM
- TX1
- TX2
- TX3
- TX4
- +12V @3A for Audio-AMP
- +5V @4A for AD board & System
- +5VSB @1A for MCU
- TM PFC UCC28051
- LLC PWM UCC25600
- 8 channels @120mA; 70~88VDC
- GM PWM UCC28610
- Audio-AMP (+12VDC)
- AD Board (+5VDC)
- System- MCU (+5VSB)
- SR Driver UCC24610
Performance

**Specification:**

→ Support to universal 90~264Vac range
→ LED 8 outputs @120mA, 70V~88V, 5Vsb@1A, 5V@4A, 12V@3A
→ Eff 86.1%@90Vac, 89.6%@264Vac
→ Secondary side 160Hz blanking control for dimming
→ 8mm height and 6mm height for LED magnetic components
→ Board dimension
  300mm(L) * 210mm(W) * 8mm(H)
→ LED output common + and LED OVP and UVP
Cross Regulation

<table>
<thead>
<tr>
<th>Load Condition</th>
<th>Output Voltage</th>
</tr>
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<tbody>
<tr>
<td>5Vsb 5V 12V</td>
<td>5Vsb 5V 12V</td>
</tr>
<tr>
<td>20mA 0.5A 0.1A</td>
<td>4.88V 4.88V 13.74V</td>
</tr>
<tr>
<td>20mA 0.5A 3A</td>
<td>4.88V 4.88V 11.46V</td>
</tr>
<tr>
<td>20mA 4A 0.1A</td>
<td>4.86V 4.84V 13.75V</td>
</tr>
<tr>
<td>20mA 4A 3A</td>
<td>4.85V 4.83V 12.5V</td>
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<tr>
<td>1A 0.5A 0.1A</td>
<td>4.87V 4.87V 13.75V</td>
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<tr>
<td>1A 0.5A 3A</td>
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<tr>
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<tr>
<td>1A 4A 3A</td>
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# LED Current

<table>
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<tr>
<th>Voltage</th>
<th>LED1</th>
<th>LED2</th>
<th>LED3</th>
<th>LED4</th>
<th>LED5</th>
<th>LED6</th>
<th>LED7</th>
<th>LED8</th>
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<td>122.04</td>
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<td>125.52</td>
<td>123.12</td>
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<td>97.37</td>
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<td>100.36</td>
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<td>87.66</td>
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<td>73.03</td>
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<td>75.08</td>
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<td>47.24</td>
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<tr>
<td>30%</td>
<td>36.19</td>
<td>36.02</td>
<td>35.92</td>
<td>36.45</td>
<td>37.17</td>
<td>37.21</td>
<td>36.82</td>
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<td>11.18</td>
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<td>1%</td>
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<td>0.655</td>
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# LED Current Tolerance

<table>
<thead>
<tr>
<th>Tolerance</th>
<th>Tolerance1</th>
<th>Tolerance2</th>
<th>Tolerance3</th>
<th>Tolerance4</th>
<th>Tolerance5</th>
<th>Tolerance6</th>
<th>Tolerance7</th>
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<tr>
<td>100%</td>
<td>-0.8616 %</td>
<td>-0.9184 %</td>
<td>-1.0159 %</td>
<td>-0.9347 %</td>
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<tr>
<td>90%</td>
<td>-0.9485 %</td>
<td>-1.0209 %</td>
<td>-0.6229 %</td>
<td>-0.849 %</td>
<td>2.07224 %</td>
<td>2.16268 %</td>
<td>-0.3878 %</td>
<td>-0.40586 %</td>
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<tr>
<td>80%</td>
<td>-1.0317 %</td>
<td>-1.1133 %</td>
<td>-0.491 %</td>
<td>-0.6644 %</td>
<td>2.20233 %</td>
<td>2.38596 %</td>
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<td>-0.62359 %</td>
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<tr>
<td>70%</td>
<td>-0.9553 %</td>
<td>-1.1425 %</td>
<td>-0.4637 %</td>
<td>-0.2999 %</td>
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<tr>
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<td>2.29008 %</td>
<td>2.29008 %</td>
<td>-2.2901 %</td>
<td>-2.29008 %</td>
</tr>
</tbody>
</table>

Inductance tolerance 3% might cause current tolerance 1%
LLC Efficiency

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

Efficiency exclude Stby Power Converter at full load condition ~ 94%
Efficiency Curve of 150Watt LED TV Back Light Reference Design

Vin | 90  | 100 | 110 | 120 | 135 | 150 | 180 | 200 | 220 | 240 | 264  
---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----  
Pin | 167.6 | 166.2 | 165.1 | 164.3 | 163.4 | 162.7 | 162.1 | 161.7 | 161.5 | 161.3 | 161.1  
Eff | 0.86112 | 0.86837 | 0.87416 | 0.87841 | 0.88325 | 0.88705 | 0.89033 | 0.89254 | 0.89364 | 0.89475 | 0.89586  

Vac (v) | 80 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280
---|---|---|---|---|---|---|---|---|---|---|---  
Eff% | 0.86 | 0.87 | 0.88 | 0.89 | 0.9 | 0.91 | 0.92 | 0.93 | 0.94 | 0.95 | 0.96
Standby Mode Power Consumption Performance – @5V/ 0.02A

Standby Power Losses at 5V/ 0.02A with universal AC input

<table>
<thead>
<tr>
<th>Vin (V)</th>
<th>Pin (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90V</td>
<td>216mW</td>
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<td>100V</td>
<td>219mW</td>
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<td>110V</td>
<td>224mW</td>
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<td>120V</td>
<td>229mW</td>
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<td>135V</td>
<td>238mW</td>
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<td>240V</td>
<td>342mW</td>
</tr>
<tr>
<td>264V</td>
<td>393mW</td>
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</tbody>
</table>
Summary

- Two stage will be a market trend for LED-TV backlight power architecture base on cost & performance point of view.
- Simple design concept- cascading the Ls of transformer at primary side (Multi-Transformers Architecture) to implement the current balancing at secondary side for each channel ideally– Achieving <1% tolerance dimming range in reality.
- Fully utilize the transformer – Two-channels common anode LED driven by single transformer.
- Higher efficiency ~89.6%@ 220Vac/ ~86%@90Vac compare to the traditional 3-stages scheme. (<85%)
- Exclude the standby converter, the efficiency of PFC +LLC power stage ~94%.
- Dimming voltage range can work from 1% - 100% and the tolerance of current between each strings less than 1%.
- Saving the heat sinks for MOSFETs of linear regulators at secondary side. – more thinness, cost-saving.
Conclusion

- Digital TV (DTV) vendors are always challenged to provide consumer reliable product with aggressive price point.

- Multi-transformer design helps:
  1) To decrease parts count so reliability is increased and cost is decreased.
  2) Improve efficiency, decreases cost in dealing with thermal issue, thereby increases the life time of the solution.
  3) Eliminate MOSFET consuming power, enabling wider output tolerance and more LED failures are acceptable.

- With these three advantages, we can conclude that multi-transformer design is a better solution.
Conclusion

<table>
<thead>
<tr>
<th></th>
<th>Flyback</th>
<th>Flyback + LLC</th>
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<tbody>
<tr>
<td>Efficiency</td>
<td>about 88%</td>
<td>Efficiency</td>
</tr>
<tr>
<td>Loss on LDO circuit</td>
<td>some load condition</td>
<td>Loss on LDO circuit</td>
</tr>
<tr>
<td>Regulation</td>
<td>about +20% / -10%</td>
<td>Regulation</td>
</tr>
<tr>
<td>Minima load for cross regulation</td>
<td>200mA</td>
<td>Minima load for cross regulation</td>
</tr>
<tr>
<td>12V/24V load effect when standby</td>
<td>yes</td>
<td>12V/24V load effect when standby</td>
</tr>
</tbody>
</table>

65W Flyback cost is higher than 25W Flyback + 40W LLC because of following point

1. 65W Flyback slim transformer cost is high.
2. 65W Flyback require additional linear regulator to keep regulation.
3. Flyback required double time of output cap than LLC.
4. Flyback required additional output filter choke.
5. Flyback Required Snubber and 800V MOSFET, LLC only need 600V MOSFET.

According to performance and cost comparison shown above, the use of 5V only standby power and 12V/24V LLC is strongly suggested.
Device Introduction

- UCC28051
- UCC28610
- UCC25600
- UCC24610
UCC28051 Transition Mode PFC Controller

**Features**

- Slew Rate Comparator for Improved Transient Response
- Zero Power Detect to Prevent Over Voltage Conditions under Light Load
- Over Voltage Protection
- Open Feedback Protection and Enable Circuits
- Low Startup & Operating Current
- 750mA Source/ Sink Peak Gate Drive to Reduce Switching Losses

**Applications**

- LCD-TV Power Board
- AC-DC Open Frame Power
- Mid to High Power AC Adapters

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*Diagram showing internal components and connections of the UCC28051 controller.*

- Line Voltage Follow
- Over Voltage Protection
- Slew Rate Comparator
- Open Feedback Loop Protection
- 750mA Source/Sink
- ZCS Detection
**Features**

- Quasi-Resonant Green Mode PWM Operation
- Multiple Modes: Pulse Position Modulation (PPM); Discontinuous Conduction Mode (DCM); Burst Operation
- Surge Protection is Externally Set
- Valley Switching is always Engaged – Limits Primary and Secondary RMS Currents
- Fast Latched Fault Recovery for Output OVP, Timed OCP, Over Temperature Protection
- External Shutdown & Latched Shutdown at MOT Pin
- Current Sensing for Current Limit uses Rds(on) of Internal FET

**Applications**
UCC25600 Resonant (LLC) 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 Gate output with 50ns tolerance
UCC24610 SR Controller for 5V Systems

Features

- Up to 800kHz operating frequency
- VDS MOSFET-sensing
- 1.4 ohm sink, 2.0 ohm source gate-drive impedances
- Micro-power Sleep current for 90+ designs
- False-triggering filter; SYNC input for CCM operation
- 20ns typical turn-off propagation delay
- Available in 8-pin SOIC and QFN packages

Applications

- AC/DC 5V Adapters
- 5V Bias Supplies
- Low Voltage Rectification Circuits
Question?

Thanks for Your Time!
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