ON Semiconductor®

AC-DC LCD TV Power Architecture and LED Backlight
LCD TV Power Architecture and LED Backlight

• **LCD-TV Market**
  – Power Reduction Trend
  – Edge LED LCD TV Backlight

• **26” to 42” H-V LIPS Reference Design**

• **46/47” Power Reference (PSU) for any Backlight solution**
  – Interleaved Frequency Clamp CrM PFC with NCP1631
  – Quasi Resonance Valley lock out Flyback Converter with NCP1379
  – ECO Standby SMPS Solution with NCP1053A

• **46/47” Backlight solution**
  – LIPS Inverter
  – Edge LED Driver

• **Conclusion**
LCD-TV Shipments by Size

2008~2012E CAGR: 16%

Source: Displaysearch 2Q 09
Power Reduction Trend

- Regulatory reduce power consumption in active and standby mode
- New technologies focused on improving efficiency

- Proposed ENERGYSTAR TV regulations (V4.0) will lower average power targets

Power consumption reduction ~ -50% over 2 years
Proposed ENERGY STAR rev4.0 Standards

Target Effective Date: May 2010

Very few LCD-TV pass proposed new standard, most are Samsung LED
LED TVs is forecast to grow to 20-32% (~64 M#) by 2012

Source: DisplaySearch July 2009
# Comparison of LED LCD TV Backlight Options

<table>
<thead>
<tr>
<th></th>
<th>Edge-lit LED BLU</th>
<th>Direct-type LED BLU</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LED driver</strong></td>
<td>High voltage Boost, buck, linear with Vf adjustment</td>
<td>Boost or Buck plus Multi-channel linear</td>
</tr>
<tr>
<td><strong>Merit</strong></td>
<td>• High Power Efficiency</td>
<td>• Deep blacks, better contrast</td>
</tr>
<tr>
<td></td>
<td>• Good system reliability independent LEDs performance.</td>
<td>• Local dimming</td>
</tr>
<tr>
<td></td>
<td>• <strong>Cost down of system</strong></td>
<td>• Scanning for higher frame rate</td>
</tr>
<tr>
<td></td>
<td>• <strong>Slim LCD TV</strong></td>
<td>• Low power consumption</td>
</tr>
<tr>
<td><strong>Concerns</strong></td>
<td>• System Noise &amp; EMI</td>
<td>• Thermal limitations</td>
</tr>
<tr>
<td></td>
<td>• Using lots of external components (Inductor, capacitor, diode)</td>
<td>• High system cost due to number of LEDs and # of Drivers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Picture artifacts</td>
</tr>
</tbody>
</table>

![LED LCD TV Backlight Options Diagram](image)

**Edge LED > 90%?**
Power Architectures Remain Varied

- **PFC**
  - CRM
  - Interleave FCCrM
  - CCM
  - 70 - 400+ W

- **Signal Power**
  - Flyback
  - Resonant HB
  - 30 – 80 W

- **Backlight Power**
  - Flyback / Resonant HB
  - 24V / 150V+ for LED
  - HV-LIPS for CCFL / EEFL
  - 50 – 300 W

- **ECO Standby**
  - < 5 W

Traditional 24 V Backlight and HV-LIPS approach
Thin TV design impacts solutions choices as well
32” HV-LIPS Reference Design

• For 32” (highest volume size) with possible extension to 26/42”
  – Available since March 2009
  – For CCFL (>> 95% of backlight) with possible extension to EEFL
  – Single PCB with LCD and Inverter Power Supply

• Very Cost effective solution
  – No extra Standby SMPS
  – Straightforward CrM PFC

• Key ON Semiconductor ICs
  – NCP1607 as CrM PFC controller
  – NCP1351 or NCP1219 as Flyback with low power standby mode

• LX6503 Microsemi Backlight controller
  – Full Bridge High Voltage Inverter without High Side Driver (discrete circuit)
  – Jin balance solution
32” HV-LIPS LCD TV Block Diagram

- Mains Input 90-130 Vac or / and 140-264 Vac
- CrM PFC NCP1607 200/400 Vdc
  - OFF in Stand-by
- Full Bridge Inverter 4 FETs
  - OFF in Stand-by
- PWM1 control
- PWM2 control
- Auxilary PSU NCP1351/1219 with Stand-by
- Bias
- Std-by / ON
- 14 Vdc-Audio
  - 12 Vdc
  - 5 Vdc
  - 5 Vdc-Stand-by
- LCD TV main board Signal processing and Audio amplifiers
- LCD Back-light
- Current balancing and sensing
- Cold Cathode Fluorescent Lamps
  - Lamp regulation OCP, OVP
- ON/OFF, Dimming, Synchro, 12Vdc

ON Semiconductor®
HV-LIPS LCD TV Complete Solution

12 CCFL
175 mm x 330 mm x 25 mm
All-in-one board with current balancer

Green Point Reference design documentation:
http://www.ONSemiconductor.com/pub_link/Collateral/TND360-D.PDF
46/47” Power Reference (PSU)

• Higher power LCD-TVs from 40/42” to 52”/55”

• Project focusing on power stage only
  – ECO standby “OFF mode”
  – Interleaved frequency clamp CrM PFC
  – Up to 70 W Flyback
  – Up to 200 W for backlight

• Low profile design
  – 1st phase: < 13 mm
  – 2nd phase: < 8 mm
46” LCD TV Power Block Diagram

Backlight Power Converter

Primary side
High Power
Backlight
Converter

AC or DC
Output

Backlight
Driver

Backlight

ON/OFF, Dimming, Synchro

CrM Interleaved
PFC
NCP1631
400 Vdc
OFF in Stand-by

QR Flyback
SMPS
NCP1379
OFF in Stand-by

12 Vdc
5 Vdc

13 Vdc Audio

Power Good

St-by / ON

ON/OFF

5 Vdc
Stand-by

Mains Input
90-264 Vac

Bias

Relay

Stand by SMPS
NCP1053A

Power (PFC + Flyback + Standby SMPS)

LCD TV Signal processing and Audio amplifiers

ON Semiconductor®
46” LCD TV Power Solution Unit (PSU)

Low Profile design < 13 mm / 17.5 mm total
46” LCD TV PFC Solution

• Up to 300 W Interleaved Frequency Clamp CrM PFC
  – Better EMI and EMC
  – Lower $I_{\text{rms}}$ for output C
  – Better for SLIM design
  – Standard parts (= 32”CrM)

• New controller NCP1631

• Easy SLIM narrow range version

Interleaved FCCrM PFC for > 200 W & SLIM design
## PFC Summary

<table>
<thead>
<tr>
<th></th>
<th>Single FCCrM stage</th>
<th>Interleaved FCCrM stage</th>
<th>Single CCM stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>General</td>
<td>General</td>
<td>General</td>
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<tr>
<td></td>
<td>300 W, wide mains</td>
<td>300 W, wide mains</td>
<td>300 W, wide mains</td>
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<tr>
<td>$\Delta I_{n\text{max}} (A)$</td>
<td>Independent on L</td>
<td>Independent on L</td>
<td>Depends on L</td>
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<tr>
<td></td>
<td>10.0 A</td>
<td>2.6 A</td>
<td>2.6 A (at 90 V_{in} full load if $L = 250 \mu H$)</td>
</tr>
<tr>
<td>Inductor</td>
<td>1 coil</td>
<td>2 coils</td>
<td>1 coil</td>
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<tr>
<td></td>
<td>$L = 75 \mu H$</td>
<td>$L = 150 \mu H$</td>
<td>$L = 250 \mu H$</td>
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<tr>
<td></td>
<td>$I_{L,\text{pk}(\text{max})} = 10 A$</td>
<td>$I_{L,\text{pk}(\text{max})} = 5.0 A$</td>
<td>$I_{L,\text{pk}(\text{max})} = 6.3 A$</td>
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<tr>
<td></td>
<td>$I_{L,\text{rms}(\text{max})} = 4.1 A$</td>
<td>$I_{L,\text{rms}(\text{max})} = 2.0 A$</td>
<td>$I_{L,\text{rms}(\text{max})} = 3.5 A$</td>
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<tr>
<td></td>
<td>$L I_{L,\text{pk}}^2 = 7.5 mJ$</td>
<td>$L I_{L,\text{pk}}^2 = 3.7 mJ$</td>
<td>$L I_{L,\text{pk}}^2 = 9.9 mJ$</td>
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<tr>
<td>Total MOSFET conduction losses (with below MOSFETs)</td>
<td>$4.6 W$</td>
<td>$4.6 W$</td>
<td>$3.5 W$</td>
</tr>
<tr>
<td>MOSFETs</td>
<td>1 * SPP20N60 or 2 * SPP11N60</td>
<td>2 * SPP11N60</td>
<td>1 * SPP20N60 or 2 * SPP11N60</td>
</tr>
<tr>
<td>Diode</td>
<td>Ultrafast</td>
<td>2 * Ultrafast</td>
<td>High speed diode (SiC..)</td>
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<td></td>
<td>MUR550 (TO-220)</td>
<td>2 * MUR550 (axial)</td>
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<tr>
<td></td>
<td>$I_{\text{Clamp}}(\text{max}) (A)$</td>
<td>$I_{\text{Clamp}}(\text{max}) (A)$</td>
<td>$I_{\text{Clamp}}(\text{max}) (A)$</td>
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<tr>
<td></td>
<td>2.0</td>
<td>1.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Characteristics</td>
<td>Compact design</td>
<td>Low profile designs</td>
<td>Compact design</td>
</tr>
</tbody>
</table>

Compared to CrM, FCCrM allows the use of smaller inductances (due to frequency clamp). The inductance for the single and interleaved FCCrM stages is based on a 130 kHz frequency clamp (high frequency design). The switching frequency is also supposed to be 130 kHz for the CCM stage.
46” LCD TV QR Flyback Solution

• **Flyback converter**
  – Up to 70 W max
  – Up to 3 output with 4 A Max

• **Quasi Resonance Flyback Converter**
  – Reduced EMI
  – Best safety behaviors

• **New NCP1379 controller**
  – Valley-lockout system
  – Variable frequency mode for ultra low power mode
  – Over current protection with auto recovery internal timer
46” LCD TV PWM Fixed F Flyback Solution

• PWM Fixed Frequency Flyback converter
  – 50 kHz Fixed frequency
  – Allow natural CCM

• New NCP1252 controller
  – Adjustable switching frequency with skip mode
  – Adjustable soft start
  – Over current protection with internal timer

• Alternative solution to previous QR mode
  – Both designs
    • on the same PCB
    • with the same switching frequency
    • with the same key parts

QR Valley lock-out or PWM Flyback SMPS up to 70 W
46” LCD TV QR Flyback Waveforms

- **QR mode with valley lock-out**
  - With valley lock-out for low P
  - With lower frequency by P Max

- **Top Trace**
  - $V_{in} = 400 \text{ Vdc}$  $P_{out} = 34 \text{ W}$
  - $1.75 \text{ A}$ at $42.7 \text{ kHz}$
  - $V_{max} = 572 \text{ V}$

- **Bottom Trace**
  - $V_{in} = 400 \text{ Vdc}$  $P_{out} = 70 \text{ W}$
  - $2.62 \text{ A}$ at $39 \text{ kHz}$
  - $V_{max} = 618 \text{ V}$

Valley lock-out is a Key improvement of QR mode
ECO Standby SMPS Solution

• Dedicated 5W ECO Power Standby SMPS
  – $P_{in} < 90 \text{ mW}$ for $P_{out} = 40 \text{ mW} @ 230 \text{ Vac}$
  – Integrated High Voltage switcher NCP1053A (400 mA / 40 kHz Max)
    • **Hysteretic** mode improves
    • **Low frequency** mode allows DCM
    • Limited current reduces possible noise issues

Hysteretic, Low Freq & DCM for ECO Standby SMPS
**ECO Standby SMPS Solution (2)**

- **Standby relay**
  - Disconnect all “parasitic” standby load (~100-150 mW @ 230 Vac)
  - Directly controlled by TV µP

- **Optional ECO “ON / OFF switch”**
  - Low cost 2A / 10V non-isolated switch
  - OFF mode: $P_{in} < 20$ mW by no load @ 230 Vac

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**ECO switch provides “ON/OFF” without Mains switch**
ECO Standby SMPS efficiency

OFF mode / no load: $P_{in} < 20 \text{ mW @ 230 Vac} \ (15 @ 120 \text{ Vac})$

Standby / 40 mW Out: $P_{in} < 90 \text{ mW @ 230 Vac} \ (86 @ 120 \text{ Vac})$
ECO Standby SMPS Waveforms

- Drain Voltage and Current of NCP1053A Switcher
  - 200 V/div & 200 mA/div
- For 5 V & 1 A = 5 W Output
- Left: Hysteretic Burst mode
  - (100 µs/div)
- Right: Detailed cycle
  - (4 µs/div)
- Top Trace: 90 Vac
- Middle Trace: 230 Vac
- Bottom Trace: 264 Vac
46” Flat TV PSU - Backlight Interface

• Interconnection on Power to any Backlight solutions
  – 400 Vdc / 200 W
  – PFC OK
  – 5 V and 12 V
  – Power Good

• Separated & Dedicated Backlight solutions
  – High Voltage LIPS for CCFL / EEFL
  – High DC Output Voltage HB LLC for LED Driver
  – Classical 24 Vdc HB LLC
  – PDP dedicated Power converter
46” LIPS Inverter

- **Higher power LCD-TVs**
  - With extension to 40/42” or 52”/55” for both CCFL or EEFL
  - Follow on of 32” LIPS Reference Design
  - Full Bridge fixed frequency ZVS with possible synchronization
  - High efficiency, low EMI and sinusoidal lamp current

- **Dedicated LIPS module**
  - To be interconnected with 46” Power Ref Design Step 1 < 13 mm
  - Microsemi Backlight controller LX6503

- **ON Semiconductor IC’s**
  - 2 High Side Drivers NCP5111
  - 1 single signal driver transformer

- **Low profile design**
  - < 13 mm on top of PCB
46” LED Backlight Power

• **Higher power LCD-TVs**
  – With extension to 40/42” or 52”/55”
  – HB LLC dedicated to Backlight power
  – High DC output voltage to power directly LED drivers

• **Separate / Dedicated LED Power module**
  – To be connected with *46” Power Ref Design step 2 < 8 mm*

• **ON Semiconductor IC’s**
  – New *NCP1397*
  – New
  – New LED driver controller *CAT4206*

• **Low profile design**
  – < 8 mm on top of PCB (< 12.5 mm total)
Multiple LED Linear Drivers with CAT4026

- Up to 6 channels with linear bipolar transistors
- "Vf monitoring and supply modulation & control"

Dedicated SMPS to support output voltage modulation
46” Linear Edge LED Driver TV Block Diagram

LED Back-light converter

- Half Bridge LLC SMPS NCP1397
- OFF in Stand-by

LED controller

- Linear LED Controller CAT 4026 Current regulation OVP & OCP
- Regulation ON/OFF, Dimming
- ON/OFF, Dimming

Dedicated SMPS for Backlight with Modulated output voltage

Power (PFC + Flyback + Standby SMPS)

Mains Input 90-264 Vac

ON Semiconductor®
46” Linear LED Driver Backlight Solution

- Special technologies
- PCB size: 250 mm x 165 mm

Ultra SLIM design < 8 mm / 12.5 mm total
HB LLC for Ultra Slim SMPS

- Limited number of components
- Zero Voltage Switching (ZVS)
- Zero Current Switching (ZCS)
- Higher power density

High efficiency and EMI friendly for low profile SMPS
Resonant Inductance Location?

External inductance

Benefits:
• flexibility
• EMI
• use resonant coil for OCP

Drawbacks:
• cooling
• insulation

Internal leakage inductance

Benefits:
• insulation
• cooling
• One component

Drawbacks:
• flexibility
• EMI + stray flux
• window utilization

External resonant coil is better for ultra slim design
Secondary Rectification

Push-pull configuration

Benefits:
• voltage drop
• Single diodes

Drawbacks:
• secondary winding
• matching
• window utilization
• Higher voltage rectifiers

Bridge rectifier

Benefits:
• one winding
• Lower voltage diodes
• Matching

Drawbacks:
• Higher losses

Bridge rectifier is better for HV output applications
NCP1397 - LLC Stage Controller

Features:
- operation from 50 kHz up to 500 kHz
- 600 V driver
- Startup sequence via an externally adjustable soft-start
- Brown-out protection combined with latch input
- Disable input for ON/OFF control (skip mode)

Benefits for backlight application:
- No driver transformer
- Simple skip mode
- Simple OCP

NCP1397 is cost effective and highly safe solution
New OCP Implementation

- Adjustable delayed fault
- Short circuit protection with frequency shift
- New Double phase current information from auxiliary winding of resonance coil

Res. Coil aux. winding provides accurate and fast OCP
Output Voltage Modulation

CAT4026 sinks current from FB divider to increase output voltage

- Linear LED Drivers impact
  - Dedicated SMPS to support output voltage modulation
  - Does not allow to get added auxiliary voltages for Audio & Signal processing

Single Output Voltage modulated for Linear Driver
HB LLC Schematic for Linear LED Driver
• Strong load variation (0 to 100%) on HB LLC with 100 Hz dimming

• Traces:
  – Top: Output current from 0 to 1 A (0.5 A/div)
  – Middle: Primary current 2 A/div
  – Bottom: Output voltage ripple 2 V/div (120 Vdc)

• Top picture: 50% dimming
  – HB LLC works in Burst
  – Up to 3 V_{peak} ripple on V_{out}

• Bottom picture: 5% dimming
  – HB LLC works in Burst
  – < 0.5 V_{peak} ripple on V_{out}
Edge-LIT LED Backlighting Trends

- ‘LED Light bars’ vary in configuration
  - Single LED Strings of High Power (~ 200 V+ , 100 mA+)
  - Multiple LED Strings (up to 4) of Lower Power (~ 100 V+ , 50 mA+)

LED Driver solutions must handle from 4 to 16 channels
Existing Large Panel Backlight Solution

Advantage: Independent Channel
- Efficiency and LED-Fault handling
- Loosely regulated input supply

Drawback: Cost and Complexity

For each LED channels!
Existing LED Driver Backlight Solution

- Large-size panel power Module used for 6 Channel Edge-LIT LED TV
- Each channel has a Dedicated Driver IC + inductive DC/DC boost + switch

6 Ch = 6 x (DC-DC Boost + additional switch)

6 Ch = 6 x Driver IC
Multi-channel “Linear” Edge-Lit Solution

- Cost effective solution to address a wide number of channels
- VF Monitoring to dynamically adjusts Anode voltage
- Efficiency target range >90%, 94% typ. (varies with LED mismatch)
- Thermal dissipation addressed by external Power BJT’s
- Address various LED string faults

“Linear LED Driver”: A cost effective solution for multiple channels
Multi-channel “Linear” Edge-Lit Solution

- 6 channel configuration shown

LED-Anode: dynamic adjustment

LED Cathode regulation ~3 V

Fault diagnostics

LED Cathode OVP

External power devices (low $\theta_{JA}$)
Multi-channel “Linear” Edge Driver Schematic

Connection to the 6 Edge LED segments

OVP

UVP

DPAK or TO220FP Power stage

Current sense
Optimized Dynamic LED-Anode Control

- Efficiency depends on LED string matching
- 200V LED strings (with 10% mismatch) delivers ~ 94% efficiency
- Thermal power dissipation levels: ~ 5 to 10 watt range

V modulation & control to limit overall Power dissipation
LED Channel Current Matching

- Initial channel matching tolerance ~ ± 0.5%
- Variation with BJT Base current : < 0.25%
- Variation with Cathode to 30V : < 0.15%
- Overall Channel matching less than ± 2%

Very good current matching < ±2%
Optimized Wide PWM Dimming Range

- No concept limitation for very short "ON" time
- CAT4026 Linear Driver is optimized for PWM dimming
- Strong power variation managed directly by SMPS

Down < 1% for 400Hz PWM dimming
Edge LED Linear Backlighting Summary

- Provides reduced total solution cost
- VF monitoring minimizes & optimizes power dissipation
- Minimizes EMI
- Offers competitive Channel to Channel LED matching
- Offers competitive wide range PWM dimming with good linearity
- Supports Fault diagnostics against Open-LED and Short-LED modes

The Linear is a easy to design and cost effective solution
Conclusion

• Complete roadmap of LCD TV solutions
  – 32” LIPS
    • A cost optimized solution for CCFL from 26” up to 42”
  – 46” Power
    • Power for any type of Backlight from 40” up to 55”< 13 or 8 mm
  – 46” LIPS
    • < 13 mm with separate LIPS
  – 46” Edge LED
    • SLIM < 8 mm with separate LED Drivers with very efficient Linear Edge LED driver solution

• Approach
  – Synergy by re-use solutions, speeding up the design process
For More Information

• View the extensive portfolio of power management products from ON Semiconductor at www.onsemi.com

• View reference designs, design notes, and other material supporting the design of highly efficient power supplies at www.onsemi.com/powersupplies