Primary-side regulation
Controllers

October 2015
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PRIMARY-SIDE REGULATION Controllers

- Functions and applications
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Main applications

Computer peripherals
- Workstations
- Desktop PCs
- Servers
- Printers

Industrial
- SMPSs
- Home appliances – White goods
- Metering SMPSs

Consumer
- Games
- Flat panel TVs
- Set-top boxes
- AC-DC adapters

LED lighting
- LED signage
- Street lighting
Competitive advantages

- **Robustness and reliability**
  - Advanced protection features integrated
  - Output overvoltage, brownout detection, inductor saturation detection, and feedback loop disconnection

- **Regulation**
  - Blue Angel, Energy Star, EU Code of Conduct, DOE compliant

- **Easy design**
  - Perfect synergy with ST PFC controllers for all topologies: flyback, quasi-resonant, resonant and half-bridge
  - Full support and tools available

- **WW reference**
  - L6599A LLC resonant controller recognized as worldwide reference
PSR controller topologies & portfolio

- **LLC resonant asymmetrical HB**
  - L6699
  - L6599A/AT/AF
  - L6591
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  - SO16
  - DIP16, SO16

- **Quasi-resonant**
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  - SO16
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- **PWM FF**
  - L6668
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  - SG3524, SG3525
  - UC384 2B/3B/4B/5B
  - L5991, L5991A
  - SO16
  - SO16
  - DIP16, SO16
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  - DIP16, SO16
L6566A multi-mode controller

L6566A multi-mode controller

**FEATURES**

L6566A  For SMPSs with PFC front-end
- Selectable multi-mode operation: fixed frequency or quasi-resonant
- On-board 700 V high-voltage startup
- Advanced light load management
- Low quiescent current (< 3 mA)
- Adaptive UVLO
- Line feed-forward for constant power capability vs. mains voltage
- Pulse-by-pulse OCP, shutdown on overload (latched or auto-restart)
- Transformer saturation detection
- Switched supply rail for PFC controller
- Latched or auto-restart OVP
- Brownout protection
- -600/+800 mA totem pole gate-driver with active pull-down during UVLO
- Package: SO16

**APPLICATION NOTES & EVALUATION BOARDS**

- AN2690: 19 V - 75 W adapter with pre-regulator PFC using the L6563 and the L6566A
- AN2941: 19 V - 75 W SMPS compliant with latest ENERGY STAR® criteria using the L6563S and the L6566A
- EVL6566A-75WES4: 19 V - 75 W SMPS compliant with latest Energy Star criteria using the L6563 and the L6566A
- EVL6566A-75WADP: 19 V - 75 W laptop adapter with tracking boost PFC pre-regulator, using the L6563 and the L6566A

**APPLICATIONS**

- AC-DC adapters/chargers
- Notebook, TV and LCD monitor adapters
- Consumer appliances (DVD players, set-top boxes,..)
- IT equipment, games
- Server auxiliary power supplies
- Metering SMPS

**L6566A 16 pins**
L6566B/BH multi-mode controllers

**L6566B/BH**

**16 pins**

- **FEATURES**
  - **L6566B** → for single-stage SMPS
    - Recommended for power supplies below 75 W
    - Same features and functions as L6566A plus:
      - Programmable frequency modulation for EMI reduction
  - **L6566BH** → for single-stage SMPS
    - Recommended for power supplies below 75 W
    - Same features and functions as L6566B plus:
      - On-board 840 V high-voltage startup

- **APPLICATIONS**
  - AC-DC adapters/chargers
  - TV and LCD monitor adapters
  - Consumer appliances (DVD players, set-top boxes, ...)
  - IT equipment, games
  - Server auxiliary power supplies
  - Metering SMPS

- **APPLICATION NOTES & EVALUATION BOARDS**
  - AN3089: 19 V - 65 W quasi-resonant flyback adapter using L6566B and TSM1014
  - AN4248: 60 W PSU design details for water purifier system
  - STEVAL-ISA161V1: Evaluation board for the SEA01 constant voltage and current controller with online digital trimming
  - EVL6566B-65W-SR: 12 V - 65 W FF flyback adapter with synchronous rectification featuring L6566B, STSR30 and SEA05L
  - EVL6566B-40WSTB: 40 W wide input range flyback converter using L6566BH Multimode controller for SMPS
  - EVL6566B-65W-QR: 19 V - 65 W quasi-resonant flyback adapter board
**QR operating modes**

### Burst Mode @ No Load
- Most switching cycles are skipped
- Average frequency reduction
- Constant peak switch current
- Threshold can be adjusted to get noise-free operation
- Very low stand-by consumption
- No audible noise (low peak current)

### Valley Skipping @ Light Load
- Frequency does not exceed an externally programmed value
- Benefit on switching losses
- MOSFET turn-on always occurs on drain oscillation valleys to minimize losses and noise

### Quasi-resonant @ Heavy Load
- Variable frequency operation
- Possible to achieve ZVS
- Low EMI (auto frequency jittering)
- Low capacitive losses ($C_{oss}$ + parasitic)

![Graph showing fsw, fosc, Burst Mode, Valley Skipping, and Quasi-Resonant MODE]
Typical QR schematic

EMI filter

PFC PRE-REGULATOR (BOOST)

DC-DC CONVERTER (FLYBACK)

Vinac

L6562A
L6563S
L6564

L6566A

Voutdc
**L5991 PWM FF controllers**

**L5991/A**

16 pins

- Current-mode control PWM
- Switching frequency up to 1 MHz
- Low start-up current (< 120 μA)
- High current output drive suitable for power MOSFET (1A)
- Fully latched PWM logic with double pulse suppression
- Programmable duty cycle
- 100% and 50% maximum duty cycle limit
- Standby function
- Programmable soft start
- Primary overcurrent fault detection with re-start delay
- PWM UVLO with hysteresis
- In/out synchronization
- Latched disable
- Internal 100 ns leading edge blanking of current sense
- Packages: SO16 and DIP16

**APPLICATIONS**

- Hi-end AC-DC adapters/chargers
- Desktop PCs, monitors, entry-level servers
- Telecom SMPS

**APPLICATION NOTES & EVALUATION BOARDS**

- AN1049: Minimize power losses of lightly loaded flyback converters with the L5991 PWM controller
- AN1132: 90W SMPS for monitors with standby function
- AN1134: 45W AC-DC adapter with standby function
- AN1215: How to handle short circuit conditions with ST’s advanced PWM controllers
- AN1537: A simple trick enhances L5991’s standby function
- AN1620: 25W off-line autoringing battery charger with L5991A
- AN1621: 300W secondary controlled two-switch forward converter with L5991A
- AN1666: AN L5991-based converter with temporary extra power capability
- AN1842: 60W wide range power supply for LCD monitor or TV, using the L5991
- AN2131: High-power 3-phase auxiliary power supply design based on L5991 and ESBT STC08DE150
- AN2439: 27W Output power ultra wide range input flyback converter
- AN2623: Evaluation board for off-line forward converter based on L5991
L6668 PWM FF controllers

L6668
16 pins

- Load-dependent current-mode control: fixed frequency (heavy load), frequency fold-back (light load), burst-mode (no-load)
- On-board high-voltage start-up
- Improved standby function
- Low quiescent current (< 2 mA)
- Slope compensation
- Pulse-by-pulse and hiccup-mode OCP
- Interface with PFC controller
- Disable function (on/off control)
- Latched disable for OVT/OTP function
- Programmable soft-start
- Reference voltage with 2% precision externally available
- ±800 mA totem pole gate driver with internal clamp and UVLO pull-down
- Package: SO16

APPLICATIONS
- Hi-end AC-DC adapters/chargers
- TV monitors
- Digital consumer goods

APPLICATION NOTES & EVALUATION BOARDS
- AN2242: Reference design: high performance, L6668-based flyback converter for set-top boxes and PVRs
- AN2432: EVALSTSR30-60W: 60W AC-DC adapter with synchronous rectification using L6668 and STSR30
- AN2600: SMPS for high-end PVR based on L6668
- EVAL6668-STB: Reference design: high performance, L6668-based flyback converter for set-top boxes and PVRs
L6565 QR controllers

- Quasi-resonant (QR) Zero Voltage Switching (ZVS)
- Line feed forward to deliver constant power vs. Mains change
- Frequency fold-back for optimum standby efficiency
- Pulse-by-pulse & Hiccup mode OCP
- Ultra-low start-up (< 70 µA) and quiescent current (< 3.5 mA)
- Disable function (on/off control)
- Internal voltage reference 1% precision (@ Tj = 25 °C)
- Totem pole gate driver with UVLO pull-down ±400 mA
- Packages: DIP8 and SO8

APPLICATIONS
- TV/monitor SMPS
- AC-DC adapters/chargers
- Digital consumer goods
- Printers and scanners

FEATURES
- L6565 8 pins

APPLICATION NOTES & EVALUATION BOARDS
- AN1326: L6565 quasi-resonant controller
- AN1376: 25W quasi-resonant flyback converter for set-top box application using the L6565
- AN1439: 30 W AC-DC adapter with the L6565 quasi-resonant PWM controller
- AN1657: SMPS for CRT monitors with the L6565
- AN1729: L6565-based low cost SMPS for TV with less than 1W standby consumption
- AN2487: STEVAL-TSP001V1 power over Ethernet powered device demonstration board
- AN2528: Very wide input voltage range 6 W SMPS for metering
- AN2844: 15 W wide range SMPS for metering based on ESBT™ STC03DE220HV and L6565 PWM controller
- AN2936: 10 W SMPS with HV power MOSFET and L6565 for 3-phase industrial applications
- STEVAL-ISC001V1: 30 W AC-DC adapter based on the L6565
Typical LLC schematic

PFC PRE-REGULATOR (OPTIONAL)

RESONANT HALF-BRIDGE

V_{inac}

L6562A, L6563S/H, L6564, L6564T/H, L4984

L6699, L6599A
L6599A resonant controllers

**L6599A**

16 pins

**FEATURES**

- 50% duty cycle, variable frequency control of resonant half bridge
- High-accuracy oscillator
- Up to 500 kHz operating frequency
- Two-level OCP: frequency-shift and latched shutdown
- Interface with PFC controller
- Latched disable input
- Burst mode operation at light load
- Input for power-on/off sequencing or brownout protection
- Non-linear soft-start for monotonic output voltage rise
- 600 V-rail compatible high-side gate driver with integrated bootstrap diode and high dv/dt immunity
- -300/800 mA high-side and low-side gate drivers with UVLO pull-down
- L6599A SIMPLIS and SPICE macro model available
- Packages: DIP16 and SO16

**APPLICATIONS**

- LED drivers and street lighting
- Flat-panel TVs
- Desktop PCs and entry-level servers
- Telecom SMPS
- High efficiency industrial SMPS
- AC-DC adapters and open-frame SMPS

**APPLICATION NOTES & EVALUATION BOARDS**

- AN3014: 19 V, 90 W resonant converter with synchronous rectification using the L6563H, L6599A and SRK2000
- AN3172: 19 V - 90 W adapter with PFC for Laptop computers using the L6563H and L6599A
- AN3233: 12 V - 150 W resonant converter with synchronous rectification using the L6563H, L6599A, and SRK2000
- AN3329: 170 W power supply with PFC and standby supply for flat TV using the L6564, L6599A, and Viper27LN
- AN3339: 185 W power supply with PFC and standby supply for LED TV using the L6564, L6599A, and Viper27LN
- STEVAL-ISA148V1: 19 V - 90 W adapter with PFC for laptop computers based on L6563H and L6599A
- EVL185W-LEDTV: 185 W power supply with PFC and standby supply for LED TV using the L6564, L6599A, and VIPER27L
L6599AT/AF resonant controllers

L6599AT
- Same features and functions as L6599A except:
  - -300/700 mA high-side and low-side gate drivers with UVLO pull-down
  - Guaranteed over extended temperature range (-40 to 125 °C)

L6599AF
- Same features and functions as L6599A except:
  - -300/700 mA high-side and low-side gate drivers with UVLO pull-down
  - Guaranteed over super extended temperature range (-50 to 125 °C)

FEATURES

• • AN3014: 19 V, 90 W resonant converter with synchronous rectification using the L6563H, L6599A and SRK2000
• AN3172: 19 V - 90 W adapter with PFC for Laptop computers using the L6563H and L6599A
• AN3233: 12 V - 150 W resonant converter with synchronous rectification using the L6563H, L6599A, and SRK2000
• AN3329: 170 W power supply with PFC and standby supply for flat TV using the L6564, L6599A, and Viper27LN
• AN3339: 185 W power supply with PFC and standby supply for LED TV using the L6564, L6599A, and Viper27LN
• AN3105: 48 V - 130 W high efficiency converter with PFC for LED street lighting applications - European version
• AN3106: 48 V - 130 W high-efficiency converter with PFC for LED street lighting applications
• EVL185W-LEDTV: 185 W power supply with PFC and standby supply for LED TV using the L6564, L6599A, and Viper27LN

APPLICATION NOTES & EVALUATION BOARDS

• LED drivers and street lighting
• Outdoor applications working at extreme temperatures
New generation of resonant controllers

- Double-ended controller specific for series-resonant, half-bridge topologies
- Innovative design optimized to reduce power supply unit complexity, form factor and costs
- Pin-to-pin compatible with previous generation devices (L6599A)
L6699 – LLC resonant controller

**FEATURES**
- Symmetrical duty cycle, variable frequency control of resonant half bridge
- Self-adjusting adaptive dead-time
- Anti-capacitive-mode protection
- High-accuracy oscillator
- Two-level OCP: frequency-shift and immediate shutdown
- Interface with PFC controller
- Burst-mode operation at light load and no-load
- Input for brownout protection or power-on/off sequencing
- “Safe-start” procedure to prevent hard switching at startup
- 600V high side gate driver with integrated bootstrap diode and high dv/dt immunity
- -300/800 mA high-side and low-side gate drivers with UVLO pull-down
- L6699 SIMPLIS and ORCAD macro models available
- Package: SO16

**APPLICATIONS**
- High-power (> 90 W) AC-DC adapters
- Notebook, AIO, desktop PC and server power supplies targeting 80 PLUS® initiative
- Flat-panel TVs and game consoles
- High-power LED lighting

**APPLICATION NOTES & EVALUATION BOARDS**
- AN4026: 19 V - 90 W adapter with PFC for laptop computers using the L6563H and L6699
- AN4027: 12 V - 150 W resonant converter with synchronous rectification using the L6563H, L6699 and SRK2000A
- AN4599: STEVAL-ISA132V1 24 V 300 W peak power resonant converter
- AN4677: 12 V - 150 W resonant converter with synchronous rectification based on L6563H, L6699 and SRK2001
- AN4720: Half bridge resonant LLC converters and primary side MOSFET selection
- STEVAL-ISA143V1: 12 V - 150 W resonant converter with synchronous rectification using the L6563H, L6699 and SRK2000
- STEVAL-ISA138V1: 19 V - 90 W adapter with PFC for laptop computers using the L6563H and L6699
- STEVAL-ISA132V1: 300 W peak power (170 W continuous power) LLC resonant converter based on L6899, STB13N60M2 and STPS20M80CG
- STEVAL-ISA170V1: 12 V - 150 W resonant converter with synchronous rectification based on L6563H, L6699 and SRK2001
- STEVAL-ISA170V1: 12 V - 150 W resonant converter with synchronous rectification based on L6563H, L6699 and SRK2000A
- EVL400W-ADP/ATX: 12 V – 400 W SMPS for adapter, desktop and AIO power supplies using L4984D, L6699 and SRK2000A
L6699 key benefits

**Anti-capacitive-mode protection**
- Avoids dangerous hard-switching and potential MOSFET cross-conduction
- Rugged protection in case of improper or unsafe application circuit design
- Increased system reliability

**Self-adjusting adaptive dead-time**
- Improves efficiency even at light load conditions
- Longer dead-time at low load and shorter at high load
- Optimized transformer design – possible to design the resonant tank for a lower magnetizing current

**Enhanced Soft-start for extra-smooth startup**
- A proprietary circuit prevents capacitive mode and hard-switching in the initial switching cycles due to V·s unbalance initially applied to the transformer or pre-charged resonant capacitor
Anti-capacitive-mode protection

- IC checks that tank current lags behind applied voltage (positive phase-shift)
- Pushes frequency up if phase-shift gets too close to zero
- Stops switching for 50 μs and then soft-restarts if phase-shift suddenly becomes negative
- During this idle period, the PFC_STOP pin is pulled low to stop the PFC stage as well
Self-adjustable dead-time

- A dead-time $t_D$ is inserted between the turn-off of either switch and the turn-on of the complementary one to achieve soft switching.
- $t_D$ is automatically adjusted in order to ensure ZVS in all conditions.
- This is done by tracking the transition time $t_T$, time needed for the rail-to-rail swing of the half bridge midpoint.
- It is possible to design the resonant tank with low magnetizing current (high $L_m$) and maximize the efficiency under all loading conditions.
- Efficiency is maximized: at full load with a short $t_D$; at light load with a longer $t_D$. 

![Diagram of self-adjustable dead-time circuit](image)
L6699 competitive advantages

**Efficiency**
- Internal self-adjusting adaptive dead-time optimizes efficiency from full to light load conditions
- Optimized transformer design makes it possible to design the resonant tank for a lower magnetizing current

**Reliability & protections**
- Anti-capacitive-mode protection prevents the converter from working in or too close to the capacitive mode
- Smooth start-up prevents hard-switching from occurring in the initial cycles
- 600 V high-side gate driver with integrated bootstrap diode and high dV/dt immunity
- Two-level OCP: frequency-shift and immediate shutdown
- Input for brownout protection or power ON/OFF sequencing

**Performance**
- Improved burst-mode operating at light-load and no-load conditions
- Reduced audible noise when entering burst-mode operation
- The first driver pulse length is shorter to prevent the initial peak current
L6591 – ZVS half-bridge controller
Asymmetrical half-bridge (AHB) topology

**FEATURES**

- Complementary PWM control for soft-switched half-bridge with programmable dead-time
- Fixed-frequency peak-current mode
- Up to 500 kHz operating frequency
- Onboard 700 V high-voltage startup
- Advanced light-load management
- Adaptive UVLO
- Pulse-by-pulse OCP
- OLP (latched or auto-restart)
- Transformer saturation detection
- Interface with PFC controller
- Latched disable input
- Input for power-on sequencing or brownout protection
- Programmable soft-start
- 4% precision external reference
- 600 V-rail compatible high-side gate driver with integrated bootstrap diode and high dV/dt immunity
- Package: SO16

**APPLICATIONS**

- ATX desktop PCs
- Entry-level servers
- Telecom SMPS
- Audio systems
- LED high-current signage

**APPLICATION NOTES & EVALUATION BOARDS**

- AN2852: EVL6591-90WADP: 90 W AC-DC asymmetrical half-bridge adapter using L6591 and L6563
- AN3203: EVL250W-ATX80PL: 250 W ATX SMPS demonstration board
- EVL6591-90WADP: 90 W AC-DC asymmetrical half-bridge adapter using L6591 and L6563
- EVL250W-ATX80PL: 250 W ATX SMPS demonstration board
Typical AHB schematic

PFC PRE-REGULATOR (OPTIONAL)

RESONANT HALF-BRIDGE

V_{inac}

L6562A, L6563S/H, L4981

L6591

V_{outdc}
# LLC versus AHB resonant topologies

<table>
<thead>
<tr>
<th>Control method</th>
<th>LLC resonant</th>
<th>Asymmetrical half-bridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable frequency with fixed duty cycle ((D_{HS} = D_{LS}))</td>
<td>Fixed frequency with asymmetrical duty cycle ((D_{HS} \neq D_{LS}))</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>High-power capability</th>
<th>Voltage</th>
<th>Current</th>
</tr>
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</table>

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<thead>
<tr>
<th>Secondary-side rectifier voltage stress</th>
<th>Twice the output voltage (center tapped transformer)</th>
<th>Usually about 3 to 6 times the output voltage for powering and freewheeling diodes, respectively (center tapped transformer)</th>
</tr>
</thead>
</table>

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<tr>
<th>Output capacitor current ripple</th>
<th>Almost twice the output current (peak-to-peak) Smooth waveform but higher ripple</th>
<th>Few tens % of output current (peak to peak) Lower ripple</th>
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<table>
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<tr>
<th>Secondary-side capacitor</th>
<th>Bigger</th>
<th>Smaller</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Inductor on secondary side</th>
<th>No</th>
<th>Yes, small</th>
</tr>
</thead>
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<tr>
<th>Switching conditions</th>
<th>ZVS easily achieved from full load to light load</th>
<th>ZVS difficult to achieve at light load ZVS relatively easy at full load</th>
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</thead>
</table>

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<tr>
<th>Other features</th>
<th>Tight tolerance of the resonant components ((L, C)) required Control loop difficult to stabilize ((2^{nd} order, voltage mode))</th>
<th>Tight tolerance for the resonant components ((L, C)) not required Control loop easy to stabilize Good cross regulation thanks to the output inductor</th>
</tr>
</thead>
</table>
Thank you!

ST stands for life.augmented