Quasi-resonant control with XMC1000 for LED ballast and SMPS

XMC™ Microcontrollers

June 2016
Agenda

1. Overview
2. Introduction
3. Quasi-resonant control
4. Demonstration with Infineon Designer
5. XMC1000 implementation
6. Demo boards & virtual designs
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This training slides begin by introducing the losses in various power converter, especially the switching losses and how quasi-resonant control can be used to minimize switching losses.

The second part of this training slides showcase the implementations of quasi-resonant control with XMC1000 using its peripherals and how they can be implemented on LED ballast and other SMPS.
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Introduction
Power topologies

› Boost
- $V_{out} > V_{in}$
- Power factor correction
- Constant ON time control

› Flyback
- Buck/boost
- Galvanic isolation
- Power factor correction + constant current control

› Buck
- $V_{out} < V_{in}$
- Peak current control
- Useful for LED driver stage
Introduction
Conduction mode

› Continuous conduction mode (CCM)
› Critical conduction mode (CrCM)
› Discontinuous conduction mode (DCM)

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Introduction
Continuous conduction mode

- MOSFET turned on while there is still current in the inductor
- Maximum switching loss. “Hard switching”
Introduction
Discontinuous conduction mode

› MOSFET turned on sometime after inductor current reaches zero
› Zero current isn’t detected
› $V_{DS}$ oscillation is ignored
› This is the simple way
Introduction
Critical conduction mode

› Aka boundary conduction mode
› MOSFET turned on immediately as zero current is detected
  – Reduced turn-on loss
Introduction
LED dimming control

› Analog dimming
  - Need good DAC for accuracy
  - Classical, straightforward method

› Modulation dimming
  - Simple DAC is sufficient.
  - Need modulator. In XMC™: BCCU

› Both dimming controls work on any conduction mode
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Quasi-resonant control
Losses & efficiency

› Conduction losses
   - MOSFET: $I_D^2 R_{DS,\text{on}}$
   - Diode: $I_F V_F$
   - Shunt: $I_D^2 R$
   - Inductor/transformer: $I^2 R_{\text{series}}$

› Optimization strategy:
   - Use larger components
   - Wider PCB trace

› Switching losses
   - MOSFET: $C_{DS}$, $C_{GD}$, $C_{GS}$, $Q_{GD}$, $Q_{DS}$
   - Diode: $I_{\text{RRM}}$, $t_{\text{RRM}}$

› Optimization strategy:
   - Use faster components
   - **Optimize the switching scheme**

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Quasi-resonant control
Losses & efficiency

In CCM steady state, $I_D$ starts from previous current value.

- **T0-T1**: Gate driver charges CGS. VGS slope depends on gate driver current.
- **T1-T2**: VGS passes gate threshold. Conducting channel available. Current starts flowing.
- **T2-T3**: Miller plateau. Depend on CGD and VDS. **Longer plateau results in higher switching loss**.
- **T3 onwards**: MOSFET is conducting, VDS depends on RDS(ON) and $I_D$.

Switching Loss (area under the curve between $I_D$ and VDS)
Quasi-resonant control
One time switching

- MOSFET turned on once
- $V_L$ oscillates once the inductor current reaches zero
  - Frequency depends on main inductance and MOSFET output capacitance
  - High voltage oscillation that is easy to detect (ZCD)
    - Inductive coupling
    - Capacitive coupling
- ZCD circuits don’t measure the actual inductor current!
Quasi-resonant control

Valley switching

› Wait for $V_{DS}$ to fall when output current is fully discharged.

› Start the next switching cycle at the “valley”

› Known as “valley switching” or “soft switching”

› $V_{DS}$ is ringing due to second order system behavior (LC)

› The lower the valley, the lower the switching loss

---

No Switching Loss
(area under the curve between $I_D$ and $V_{DS}$)
Quasi-resonant control
Hard switching vs soft switching

› Hard switching

› Soft switching

Switching Loss
(area under the curve between \( I_D \) and \( V_{DS} \))

No Switching Loss
(area under the curve between \( I_D \) and \( V_{DS} \))
Quasi-resonant control
Valley skipping

QR 1\textsuperscript{st} valley

- MOSFET turned on at the first lowest point of $V_{DS}$ oscillation
  - MOSFET turn-on loss minimized to lowest possible level

QR 2\textsuperscript{nd} valley

- MOSFET turned on at the second lowest point of $V_{DS}$ oscillation
  - MOSFET turn-on loss minimized
  - Switching frequency reduced

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Infineon Designer
Digital prototyping engine

› **Features**
  - Circuit design
  - Circuit behavior (simulation)
  - Sharing
  - No hassle

› Infineon Designer is available to everyone:
  [www.infineon.com/ifxdesigner](http://www.infineon.com/ifxdesigner) *(login with MyInfineon account)*
Infineon Designer
Boost converter

- BSZ340N08NS3 G (OptiMOS™)
- MURS120T3G
  - Ultrafast recovery diode
Efficiency: NA  Frequency: 56 kHz

power_optimos_24V_boost_1_onetime.tsc
Infineon Designer
Continuous conduction mode

Efficiency: 92.7%  
Frequency: 456 kHz  
Large spikes

power_optimos_24V_boost_2_CCM.tsc
Infineon Designer
Critical conduction mode

Efficiency: 97.6%  Frequency: 132 kHz  Medium-sized spikes
Infineon Designer
Quasi-resonant conduction mode – 1st valley

Efficiency: 97.9%  Frequency: 120 kHz  Small spikes

Diagram showing waveforms of V_G, I_L, V_shunt, and V_DS.

power_optimos_24V_boost_4_QR_1v.tsc
Efficiency: 97.9%  
Frequency: 102 kHz  
Small spikes
Infineon Designer
Discontinuous conduction mode

Efficiency: 97.5%  Frequency: 108 kHz  Medium-sized spikes

power_optimos_24V_boost_5_DCM.tsc
Different conduction modes

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<th>Effic.</th>
<th>Freq.</th>
<th>Link</th>
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<td>One time</td>
<td>NA</td>
<td>56 kHz</td>
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<tr>
<td>CCM</td>
<td>92.7%</td>
<td>456 kHz</td>
<td><code>power_optimos_24V_boost_2_CCM.tsc</code></td>
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<tr>
<td>CrCM</td>
<td>97.6%</td>
<td>132 kHz</td>
<td><code>power_optimos_24V_boost_3_CrCM.tsc</code></td>
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<tr>
<td>QR-1</td>
<td>97.9%</td>
<td>120 kHz</td>
<td><code>power_optimos_24V_boost_4_QR_1v.tsc</code></td>
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<td>QR-2</td>
<td>97.9%</td>
<td>102 kHz</td>
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<td>DCM</td>
<td>97.5%</td>
<td>108 kHz</td>
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XMC1000 implementation
Quasi-resonant control

› XMC1000 peripherals + interconnects for quasi-resonant control
  – CCU8/CCU4, ACMP, ERU, BCCU
  – Fully hardware dependent: minimum CPU load
  – Full functionality including valley skipping, leading edge blanking

› Constant ON-time (CON)
  – ON-time is proportional to the amount of power transfer

› Peak current control (PCC)
  – Twofold functionality: power transfer and protection
  – Dynamic OCP
XMC1000 implementation

QR CON

V\text{DS}

I_L

CC82 Timer

ST2 (\sim O UT 2)

CC83 Timer

ST3

counting valleys

valley delay

PERIOD CMP1 CMP2

\Delta X = 28.2000us

1/\Delta X = 36.168kHz

\Delta Y(4) = 440.0mV

\Delta X = 21.4000us

1/\Delta X = 46.728kHz

\Delta Y(4) = 440.0mV

Coupling DC

Coupling

Source

Gain

Mode

Normal

Mode

Normal

Source

Gain

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XMC1000 implementation
QR PCC
XMC1000 implementation
QR PCC
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Demo board
Two-stage LED ballast with XMC1300
Demo board
Two-stage LED ballast with XMC1300

Specification:
- Rated power = 40 W
- Input voltage = 90 V_{AC} to 277 V_{AC}
- Output voltage = 60 V_{DC} max
- Output current = 1 A max

Two-stage LED ballast:
- AC/DC boost PFC for power factor correction
- DC/DC flyback for LED current and dimming control

Quasi-resonant constant ON-time on PFC boost

Quasi-resonant peak current control on flyback

Tuneable white LED light

Communication:
- DALI, 10 V dimming, LEDset
Virtual designs
QR buck LED driver with XMC1400
# Support material:

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Glossary abbreviations

› CON          Constant ON-time
› DAVE™        Free development IDE for XMC™
› OCP          Over Current Protection
› PCC          Peak Current Control
› PF           Power Factor
› PFC          Power Factor Correction
› PWM          Pulse Width Modulation
› QR           Quasi Resonant
› SMPS         Switched-Mode Power Supplies
› THD          Total Harmonics Distortion
› ZCD          Zero Crossing Detection
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