Application - Power Factor Correction (PFC) with XMC™

XMC™ microcontrollers

July 2016
Agenda

1. Key features
2. Specification
3. System block diagram
4. Software overview
5. Highlight MCU features
6. CCM PFC control scheme
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Power Factor Correction (PFC) with XMC™

Key features

**Target Application**
- Server Power Supply
- Telecom Power Supply

**Key Features**
- Continuous Conduction Mode scheme with XMC4200 & XMC1300
- Average Current Mode Control
  - Pure digital control: Discrete control loops
- Fixed frequency, adjustable depending on input lines
  - 100 kHz at low line, 130 kHz at high line for XMC4200
  - 100 kHz at both lines for XMC1300
  - Duty feed-forward at low line for improved performance
- Includes standard features from analog PFC IC:
  - Soft start, Brown-in/out
  - Protections: OVP, OCP, OPP
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Power Factor Correction (PFC) with XMC™ specification

**Specifications**

- Input Voltage range: $90 \text{ V}_{ac} - 264 \text{ V}_{ac}$
- Output Voltage: $395 \text{ V}_{dc}$
- Power Factor: $>0.95$ at operating range
- Total Harmonic Distortion: $<10\%$
- Efficiency: $\sim 97\%$
Agenda

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A power supply usually has the following elements:

- **Rectifier** (diode bridge or active rectifiers) → rectifies the AC signal into high voltage DC

- **PFC** → ensures a good current shape (PF close or equal to 1) to maximize active power. Commonly a **PFC Boost** stage

- **DC-DC** converter reduces the high voltage. In many cases isolates electrically the power supply into primary and secondary. Common stages converters here are **LLC, Full/Half Bridges, Flyback converters, Forward, etc.**

- **Optional DC-DC „Point of load“** → permits different voltage outputs. Different converters can be used depending on the needs: **Buck, Boost** (if higher DC voltage is needed), **Flyback**, etc.
Power Factor Correction (PFC) with XMC™

PFC basics (1/2)

› **Power Factor Correction**
  - Forcing input current to be in the *same phase* and *same shape* as input voltage, making the load to appear as pure resistive load
  - Improved Power Factor (and THD) results in better overall system efficiency
  - PFC circuit is accomplished by adding a DC-DC Boost Converter after rectifier
  - Two modes of operation: **Continuous Conduction Mode (CCM)** and **Critical Conduction Mode (CRM)**

› **Without PFC**
  - [Diagram of PFC without PFC]

› **With PFC**
  - [Diagram of PFC with PFC]

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Power Factor Correction (PFC) with XMC™
PFC basics (2/2)

› **Critical Conduction Mode**
  - Lower average output current
  - Used for low power application (<300 W)
  - Variable switching frequency, constant ON-time
  - Switched every time inductor current goes to zero
  - Less calculation, only requires voltage loop. The rest of the functionality is done with MCU peripheral

› **Continuous Conduction Mode**
  - Higher average output current
  - Used for high power application (>300 W)
  - Constant switching frequency, variable ON-time
  - Use Average Current Mode control. Current Reference determine ON-time to regulate the inductor current
  - Calculation intensive, high CPU load
Power Factor Correction (PFC) with XMC™

CCM PFC with XMC4200

System block diagram: CCM PFC with XMC4200
Power Factor Correction (PFC) with XMC™
CCM PFC with XMC1300

System block diagram: CCM PFC with XMC1300
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Power Factor Correction (PFC) with XMC™ Software overview

- Possible PFC states with triggers to the next states
- PFC firmware is interrupt-based, not state-machine based to ensure real-time behavior
<table>
<thead>
<tr>
<th></th>
<th>Agenda</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Key features</td>
</tr>
<tr>
<td>2</td>
<td>Specification</td>
</tr>
<tr>
<td>3</td>
<td>System block diagram</td>
</tr>
<tr>
<td>4</td>
<td>Software overview</td>
</tr>
<tr>
<td>5</td>
<td>Highlight MCU features</td>
</tr>
<tr>
<td>6</td>
<td>CCM PFC control scheme</td>
</tr>
</tbody>
</table>
Highlight MCU features
Overview

XMC1000 family:
› 32 MHz ARM® Cortex™- M0 with optional 2x peripheral clock boost (64 MHz)
› 16 kB RAM, 8 ~ 200 kB Flash with ECC
› Peripherals running up to 64 MHz
› 1.8 ~ 5.5 Volt V_{DD}
› Operating up to 105°C

XMC4000 family:
› 80/120 MHz ARM® Cortex™- M4 with built in DSP, FPU, MPU and DMA
› 20 ~ 160 kB RAM, 64 kB ~ 1 MB Flash with ECC and up to 4 kB Cache
› Peripherals running up to 80/120 MHz
› High Resolution PWM (150 ps) and smart comparators with slope compensation
› Operating up to 125°C

› Integration of peripherals analog-mixed signal, Timing/PWM and communication with flexible IO muxing in small packages
› Free DAVE™ IDP and DAVE™ Apps (SW Library with optimized and tested code) with GUI and code generation, open to 3rd party tools

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Highlight MCU features
Smart analog comparators (1/2)

- XMC4000 comparators include **filtering, blanking and clamping** capabilities as well as a **DAC** for automatic reference or slope generation.
- XMC1000 comparators can configure **hysteresis** and output **filtering** and have a bandwidth of 30 ns.

Support almost any topology
Highlight MCU features
Smart analog comparators (2/2)

› Can easily and efficiently perform:
  - **Voltage control**
  - **Current control**
  - **Customized controls**
  - **Protection features**

› Analog frontend digitally controlled

› Best of both worlds:
  - **Analog performance**
  - **Programmability/flexibility**

› Supports almost any topology and combinations:
  - Boost/buck
  - PSFB, LLC
  - PFCs
  - Flybacks/forwards
  - Inverters
  - Etc...
In order to cover the crucial requirements of power supplies, it is needed to provide:

- Flexible and safe PWM patterns
- Fast ADC sampling
- Flexible ADC sequencing and synchronization to PWM
- Post processing of conversions including
  - Filtering (FIR/IIR), FIFO, subtraction (for offset compensation), etc.
- Resolution in sampling signal and in PWM for accurate control:
  - 12 bits ADC
  - 150 ps max resolution PWM in XMC4 and 15,6 ns in XMC1000
Highlight MCU features
Fast and flexible ADC + timers (2/2)

› For power conversion continues and discontinues PWM signals have to be generated – switching between the two modes is needed to get efficiency over a wide load range.

› CCU4/CCU8 supports any kind of pulse generation like
  - Asymmetric PWM
  - Aperiodic PWM
  - Single events and pulses

› CCU4/CCU8 can be controlled from external or internal events
  - External start / stop
  - Emergency trap
  - Override/modulation
  - Count gating
  - Capturing

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ERU module allows an almost all to all connection of signals in XMC™. This is helpful in cases such as:

- Detect a peak current with a comparator and send the signal to a timer → usually signal is directly connected
- But if the comparator signal needs to be OR-ed with another one, this can be done with the available logic functions in ERU module

Serial communications, like I2C for PMBUS, and CAN supported
<table>
<thead>
<tr>
<th></th>
<th>Agenda</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Key features</td>
</tr>
<tr>
<td>2</td>
<td>Specification</td>
</tr>
<tr>
<td>3</td>
<td>System block diagram</td>
</tr>
<tr>
<td>4</td>
<td>Software overview</td>
</tr>
<tr>
<td>5</td>
<td>Highlight MCU features</td>
</tr>
<tr>
<td>6</td>
<td>CCM PFC control scheme</td>
</tr>
</tbody>
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Power Factor Correction (PFC) with XMC™
CCM PFC control scheme with XMC4200

Inductor
Current

CCU8 Slice 2
Timer

CR2 @ ½ CR1
CR1
CR2 @ ½ CR1
CR1
CR2 @ ½ CR1
CR1
CR2 @ ½ CR1
CR1
CR2 @ ½ CR1
CR1

CCU8 ST2

ADC Trigger

CCU82 ST1

PWM Out
(OUT21)

Slice 2 PM
INT

Interrupt at every 100 kHz or 130 kHz

Slice 3 PM
INT

Interrupt at every 20 kHz
Power Factor Correction (PFC) with XMC™
XMC4200 interconnects
Power Factor Correction (PFC) with XMC™
CCM PFC control scheme with XMC1300
Power Factor Correction (PFC) with XMC™
XMC1300 interconnects

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**Power Factor Correction (PFC) with XMC™**

**XMC1300 interconnects**

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**Diagram Description**

- **CCU80 Slice 2**
  - Connected to CCU80.ST1
  - Connected to CCU80.ST2
  - CCU80.OUT21
- **GPIO**
  - PWM Drive
  - Period Match INT
- **NVIC**
  - Compare Match INT

**Connectors**

- **CCU80.SR**
- **VADC0.G1CH5**
- **VADC0.G1CH7**
- **VADC0.G0REQTRI/J**
- **CCU41.SR**

**Groups**

- **Group 0**
- **Group 1**

**Pins**

- **P2.3** Inductor Current
- **P2.5** Output Voltage
- **P2.10** Input Voltage

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Power Factor Correction (PFC) with XMC\textsuperscript{TM} duty-ratio feedforward

- Smoothen the duty cycle value produced by current loop with feedforward filter
- Improved Power Factor and THD
- Implemented in firmware current loop


Fixed-point implementation example:
qDutyFF = (0xFF - Vin >> 4);
Power Factor Correction (PFC) with XMC™ brown-in/ brown-out

- Designed to ensure PFC is able to reset itself if a brown-out is detected and start itself if a brown-in is detected
- Accomplished by detecting the input voltage rms value
  - Embedded in the voltage loop

- qPFCBrownout = 0; PFCstate = 1; bInitCoeff = 0;
- qPFCBrownout = 1; PFCstate = 1; bInitCoeff = 0;
- qPFCBrownout = 0; PFCstate = 0; bInitCoeff = 1;
Power Factor Correction (PFC) with XMC™ soft start

- Designed to ensure smooth PFC start-up with lesser inrush input current
- Accomplished by incrementing voltage loop reference from minimum to desired output voltage (e.g. 395 V<sub>dc</sub>)
  - Embedded in the voltage loop
- Adjustable timing
  - By changing the voltage counter in the firmware

| PFCBrownout = 0; PFCstate = 0; bInitCoeff = 1; | PFCBrownout = 0; PFCstate = 0; bInitCoeff = 1; | PFCBrownout = 0; PFCstate = 1; bInitCoeff = 0; |

Wait until Vin feedforward filter result is stable
Initialize control loop
Set voltage reference to current output voltage
Increment voltage reference until desired level (e.g. 395 V)
Output overvoltage normally occurs at sudden no-load or step load from high-load to low-load.

PWM output is switched off until the output voltage goes down to certain level and it will be switched on again.

Use VADC0 Group 0 boundaries set at 455 V and 375 V.

Ideally, interrupt should happen once. Practically, it will happen many times.

- Counting mechanism to ensure overvoltage/undervoltage conditions are met.
- The ISR will be disabled after it is served.
Power Factor Correction (PFC) with XMC™ analog Over Current Protection (OCP)

- Designed to protect MOSFET
- OCP level is set according to MOSFET rating
- Accomplished with XMC4200 CSG and DAC and CCU8 external modulation feature
- Inductor current is compared with OCP level
- OCP level is set in firmware
- CSG output is passed through ERU
  - Technically it is possible to pass through CSG output to CCU8
- PWM output is modulated by CSG output
Power Factor Correction (PFC) with XMC™ Digital Over Current Protection (OCP)

- Designed to limit the maximum power passing through the PFC
- OPP normally happens when PFC has step load from low load close to maximum rated load
- Accomplished by limiting Current Command in the firmware
  - This will clamp inductor current to maximum value defined in the firmware
  - Output voltage will drop. As a result, constant power is maintained
- Similar to OCP but it is set at lower current level
General information

› Where to buy XMC™ starter kit?
  - http://www.infineon.com/xmc-dev

› For latest updates, please refer to:
  - http://www.infineon.com/xmc1000
  - http://www.infineon.com/xmc4000

› For support:
  - http://www.infineonforums.com
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