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 V_{ac} – 264 V_{ac}
- Output Voltage: 395 V_{dc}
- Power Factor: >0.95 at operating range
- Total Harmonic Distortion: <10%
- Efficiency: ~97%

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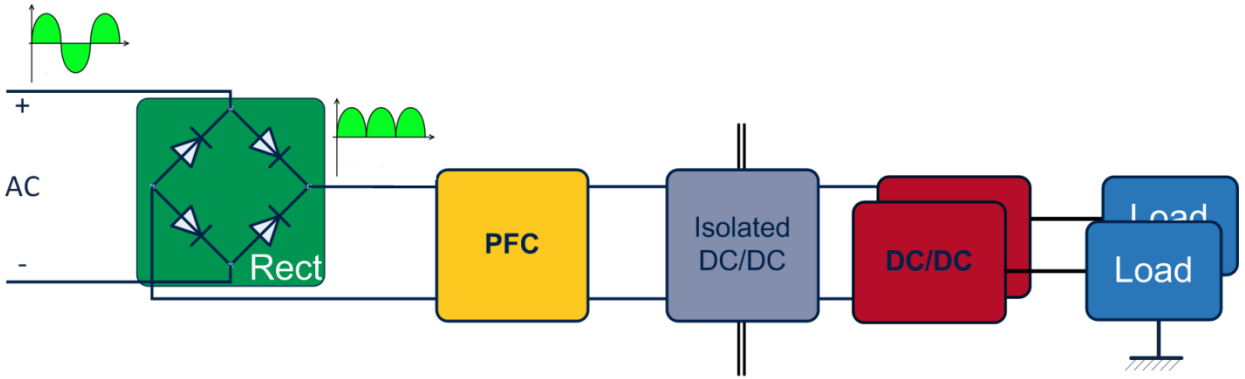
Power Factor Correction (PFC) with XMC™ Typical architecture for PSU

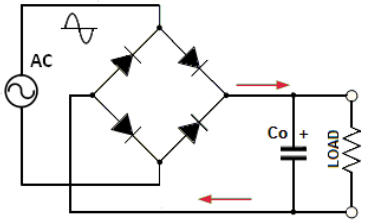
- A power supply usually has the following elements:
  - **Rectifier** (diode bridge or active rectifiers) → rectifies the AC signal into high voltage DC
  - **PFC** → ensures a good current shape (PF close or equal to 1) to maximize active power. Commonly a *PFC Boost* stage
  - **DC-DC** converter 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

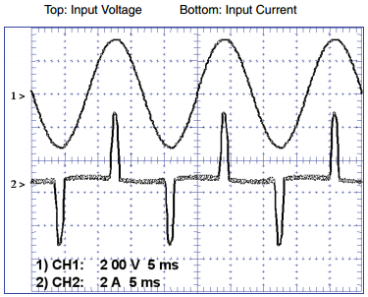


Power Factor Correction (PFC) with XMC™ PFC basics (1/2)

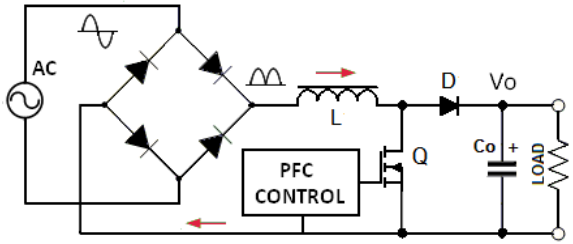
- **Power Factor Correction**
  - Forcing input current to be in the **same phase** and **same shape** as input voltage, making the load to appear as pure resistive load
  - Improved Power Factor (and THD) results in better overall system efficiency
  - PFC circuit is accomplished by adding a DC-DC Boost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

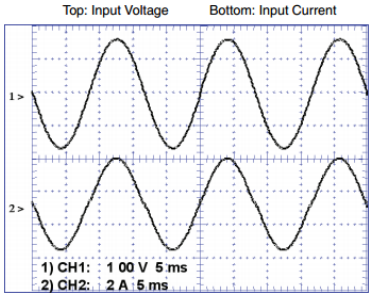
- **Without PFC**





- **With PFC**

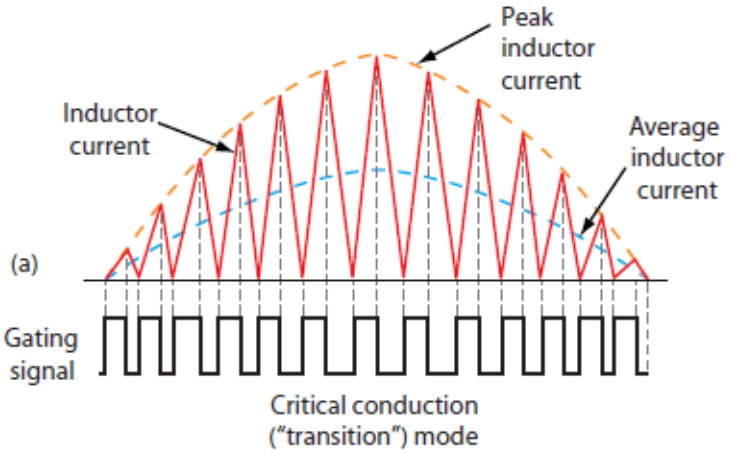




Power Factor Correction (PFC) with XMC™ PFC basics (2/2)

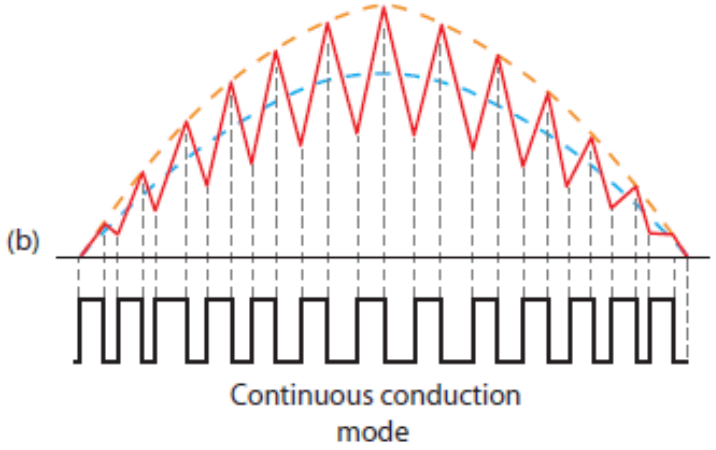
› **Critical Conduction Mode**

- 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

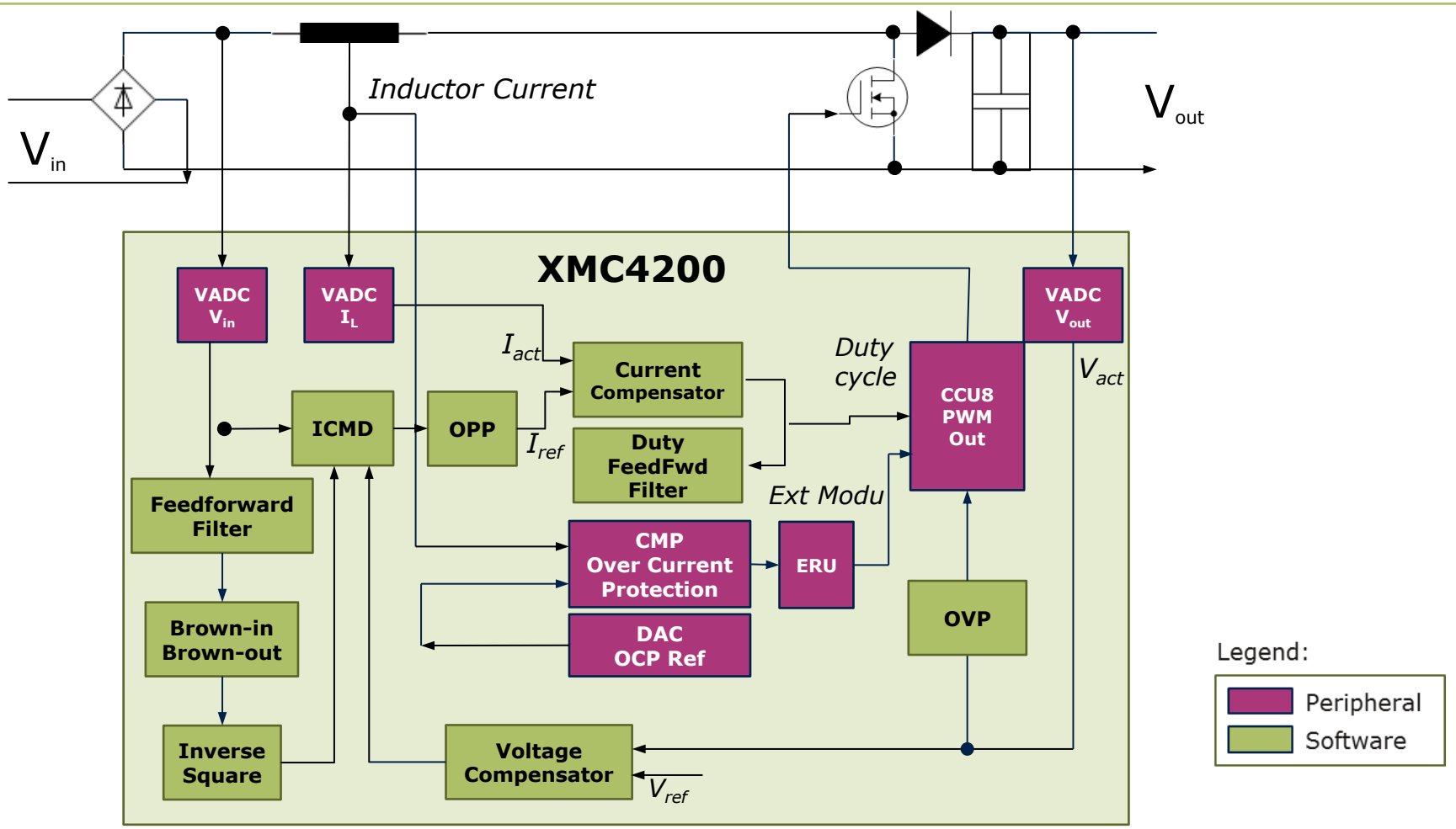


› **Continuous Conduction Mode**

- 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

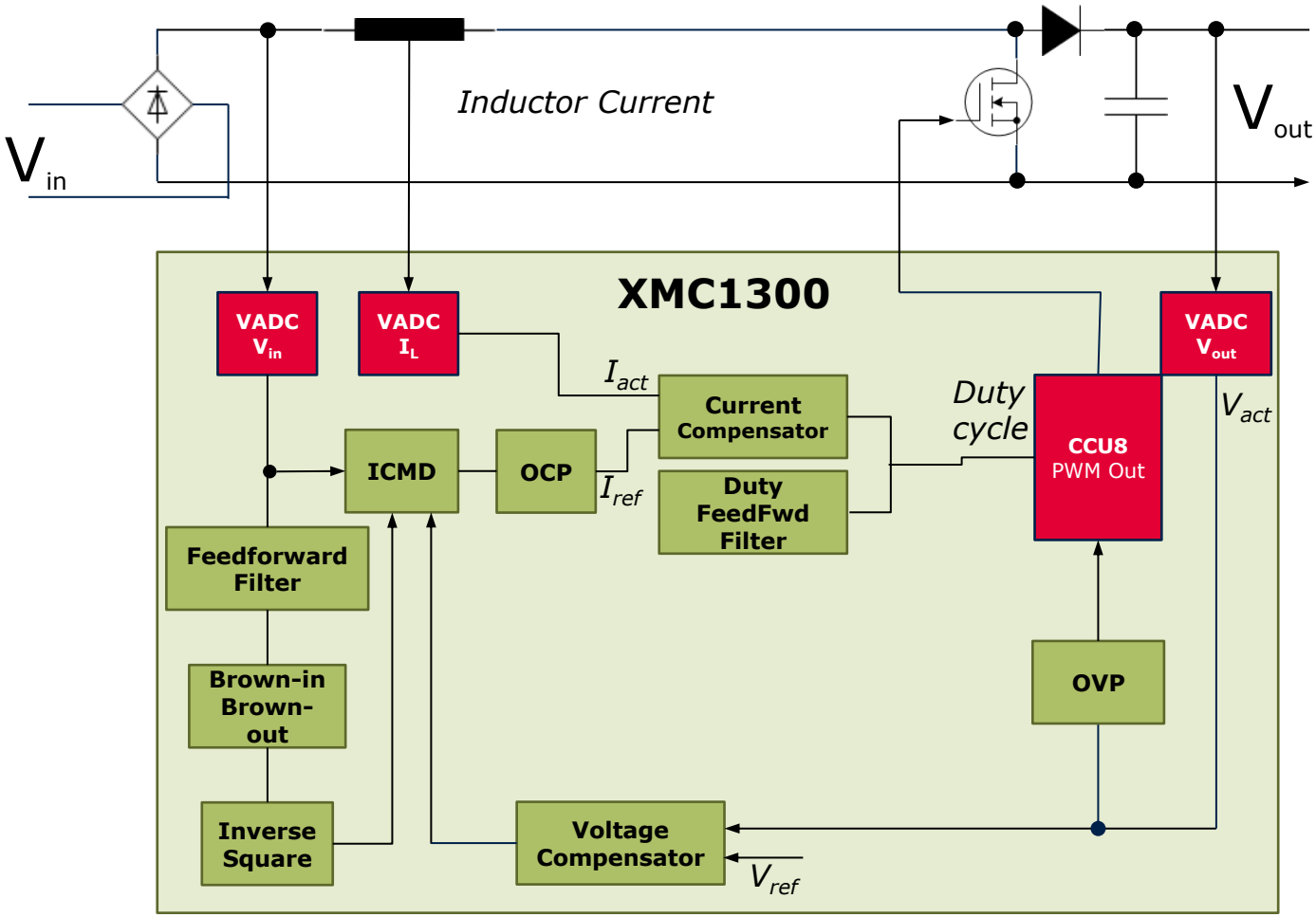


Power Factor Correction (PFC) with XMC™ CCM PFC with XMC4200



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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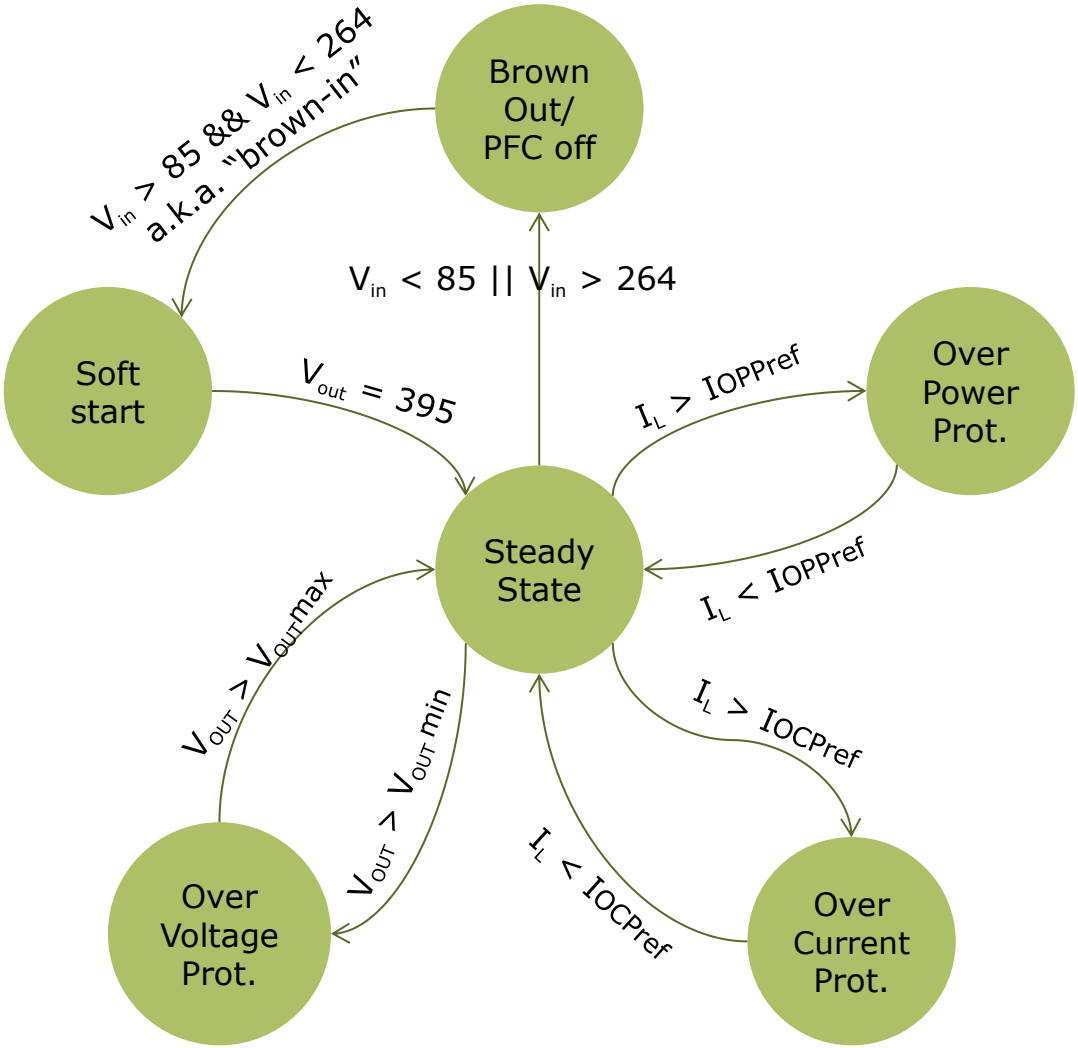
Power Factor Correction (PFC) with XMC™ Software overview



- Possible PFC states with triggers to the next states
- PFC firmware is interrupt-based, not state-machine based to ensure real-time behavior

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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:

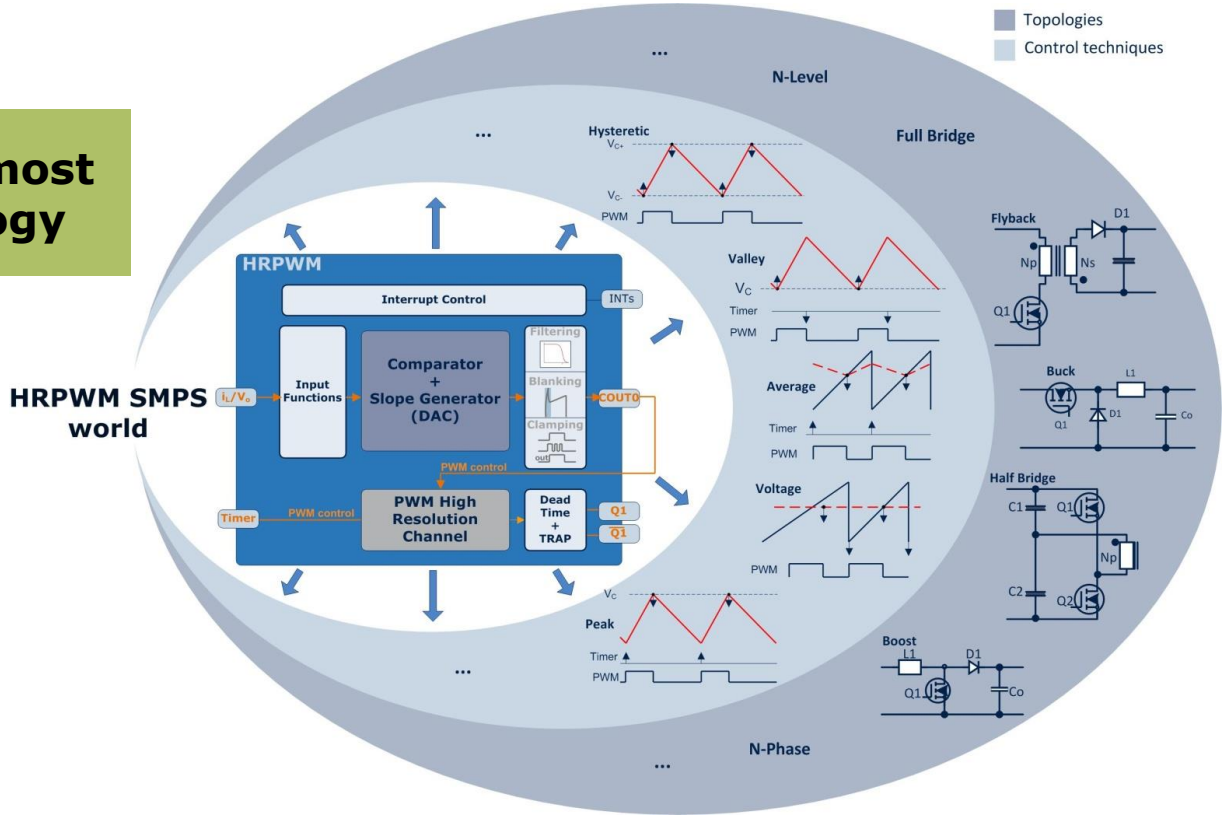
- 80/120 MHz ARM® Cortex™- M4 with built in DSP, FPU, MPU and DMA
- 20 ~ 160 kB RAM, 64 kB ~ 1 MB Flash with ECC and up to 4 kB Cache
- Peripherals running up to 80/120 MHz
- High Resolution PWM (150 ps) and smart comparators with slope compensation
- Operating up to 125°C

- **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

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

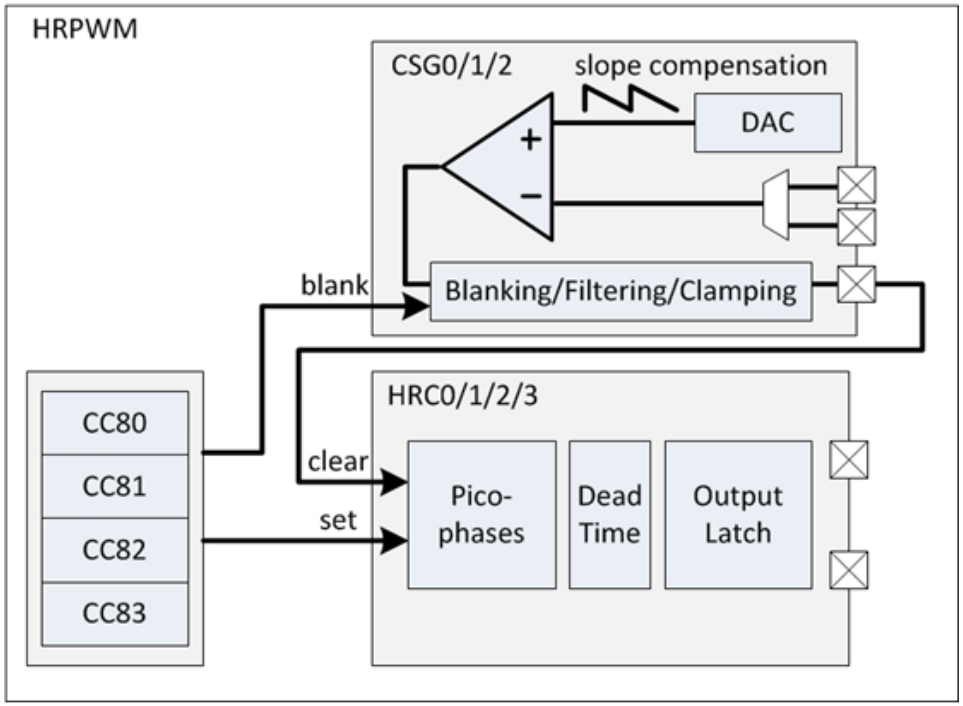


Highlight MCU features
Smart analog comparators (2/2)

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

- **Supports almost any topology and combinations**:
  - Boost/buck
  - PSFB, LLC
  - PFCs
  - Flybacks/forwards
  - Inverters
  - Etc…

- Analog frontend digitally controlled
- Best of both worlds:
  - **Analog performance**
  - **Programmability/flexibility**

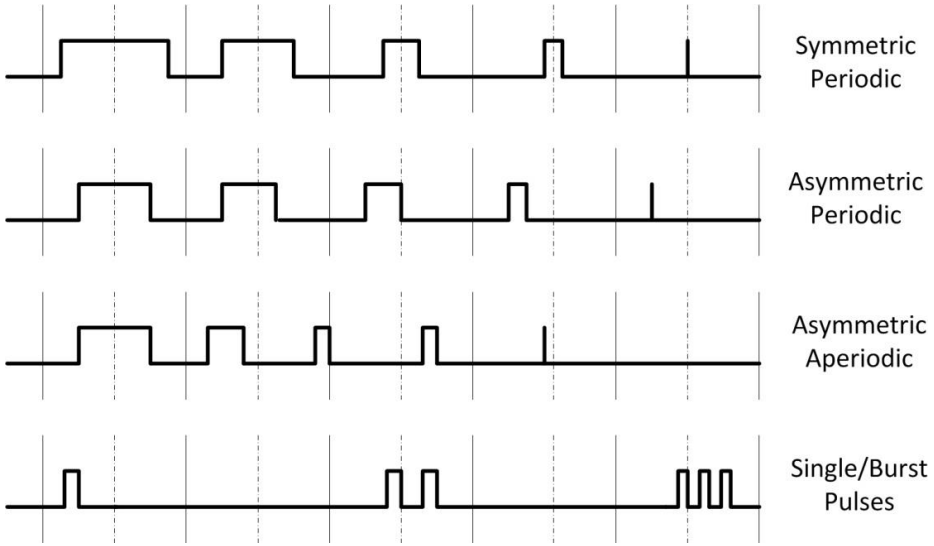


Highlight MCU features
Fast and flexible ADC + timers (1/2)

- 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



Highlight MCU features
Additional features

- 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

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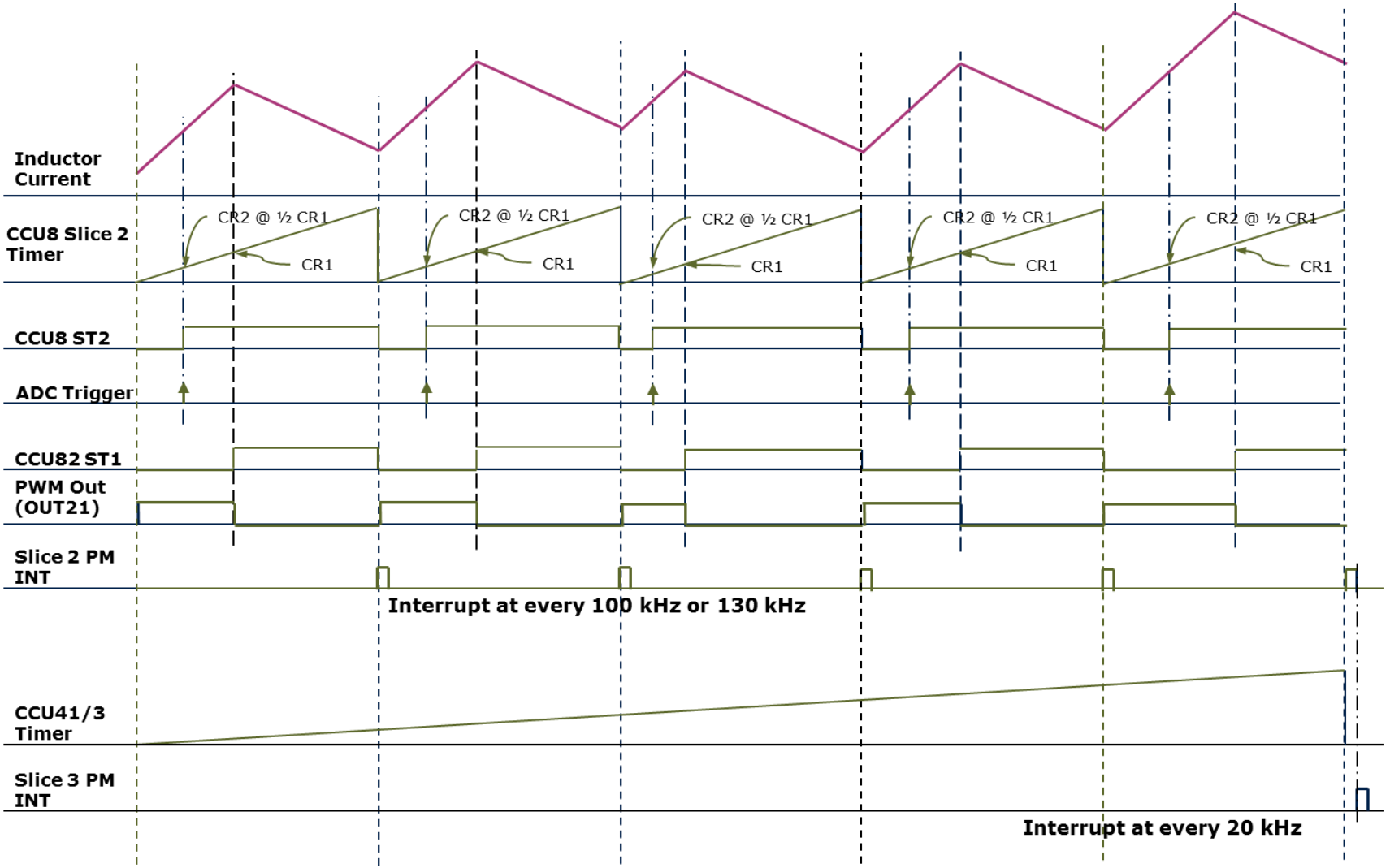
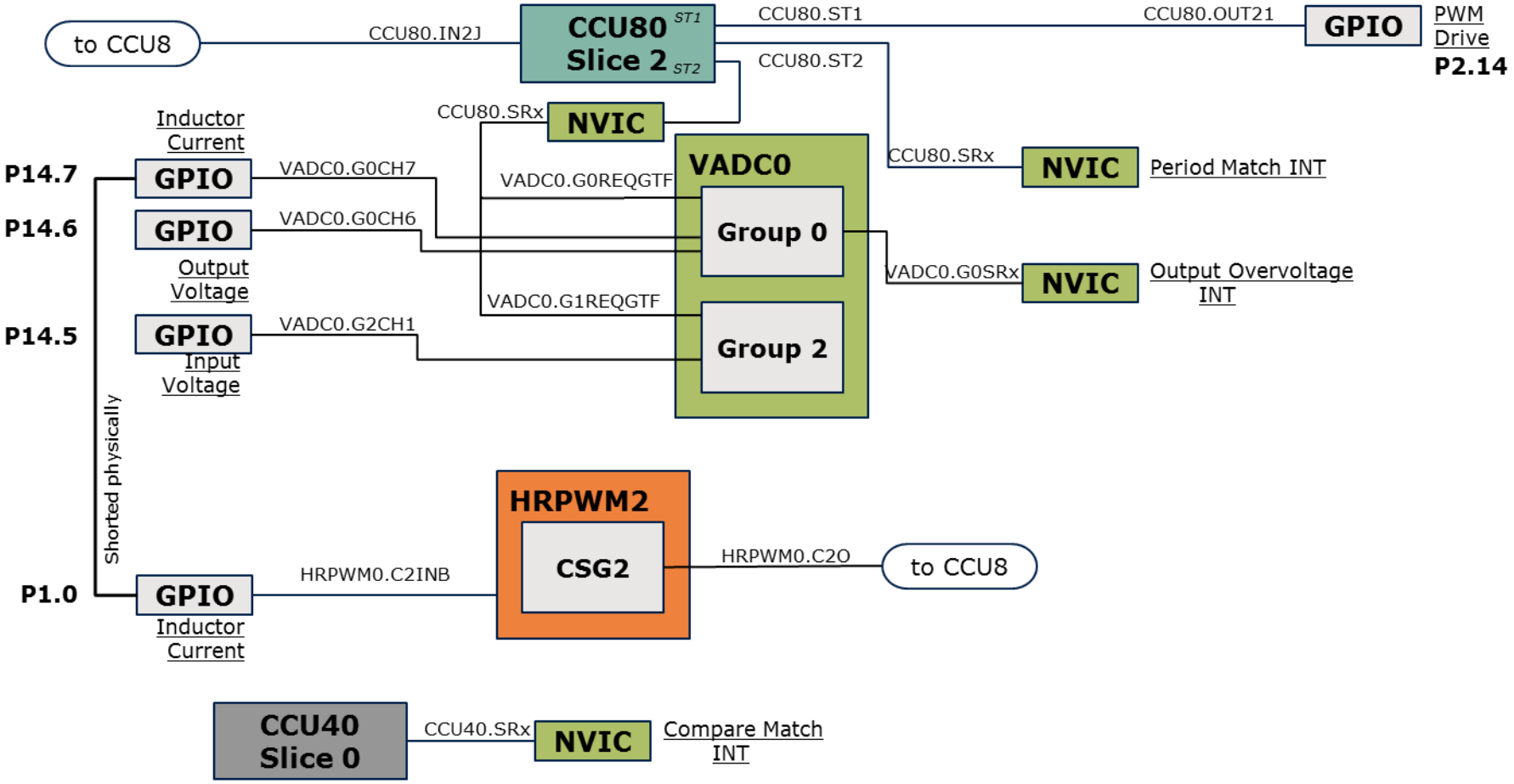
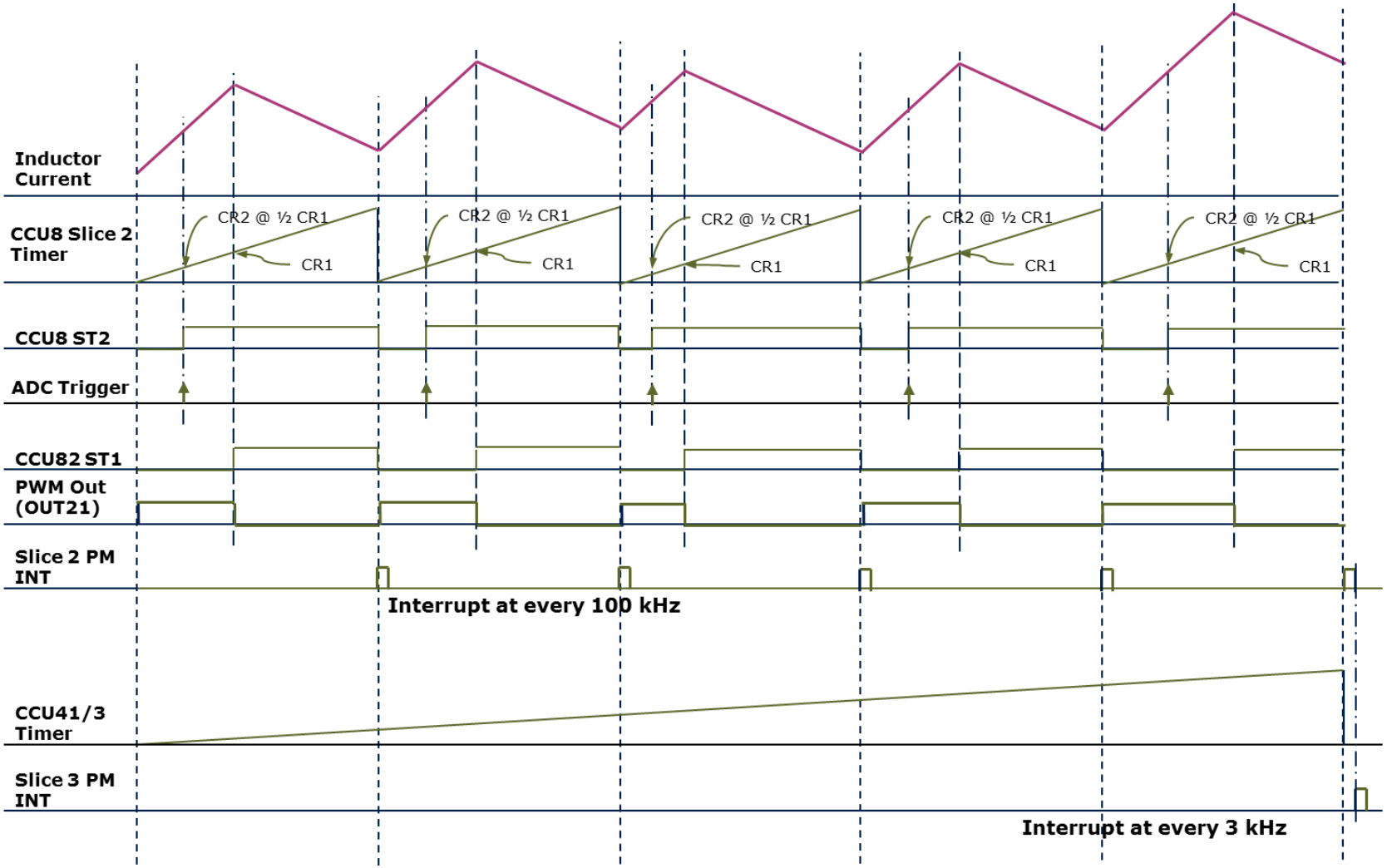
Power Factor Correction (PFC) with XMC™ CCM PFC control scheme with XMC4200



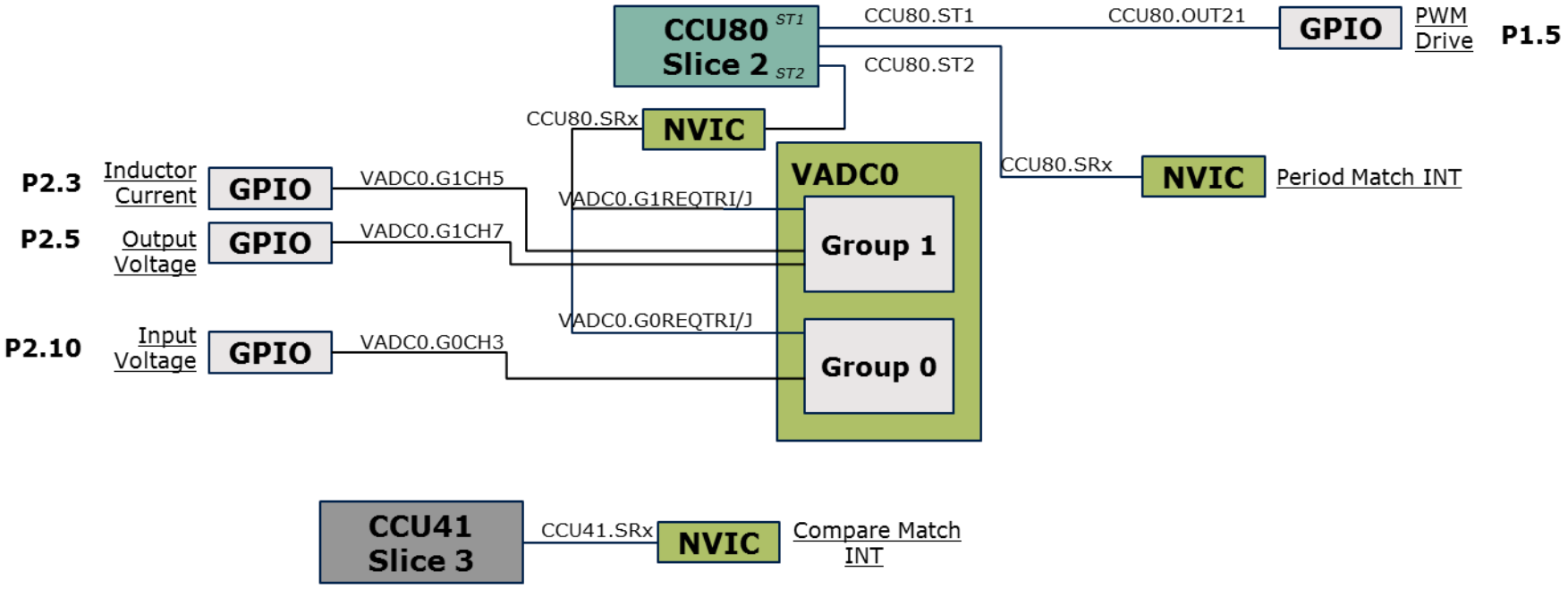
Power Factor Correction (PFC) with XMC™ XMC4200 interconnects



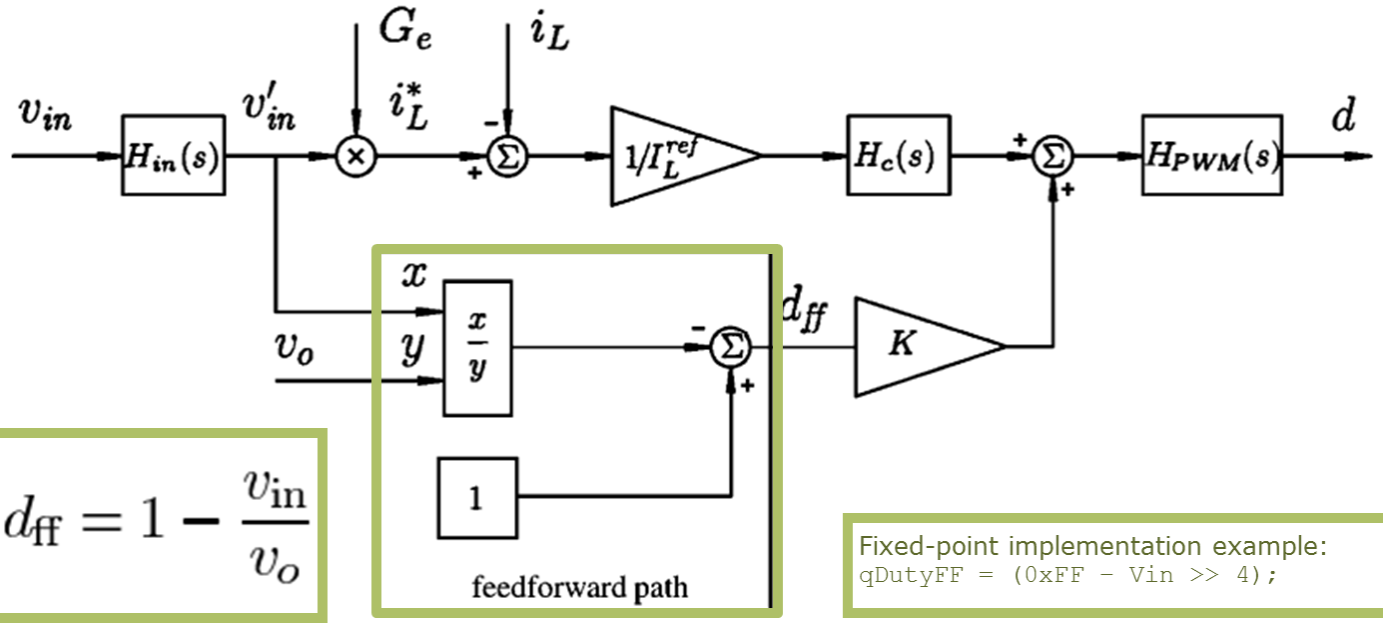
Power Factor Correction (PFC) with XMC™ CCM PFC control scheme with XMC1300



Power Factor Correction (PFC) with XMC™ XMC1300 interconnects



Power Factor Correction (PFC) with XMC™ duty-ratio feedforward



$$d_{\mathrm{ff}} = 1 - \frac{v_{\mathrm{in}}}{v_o}$$

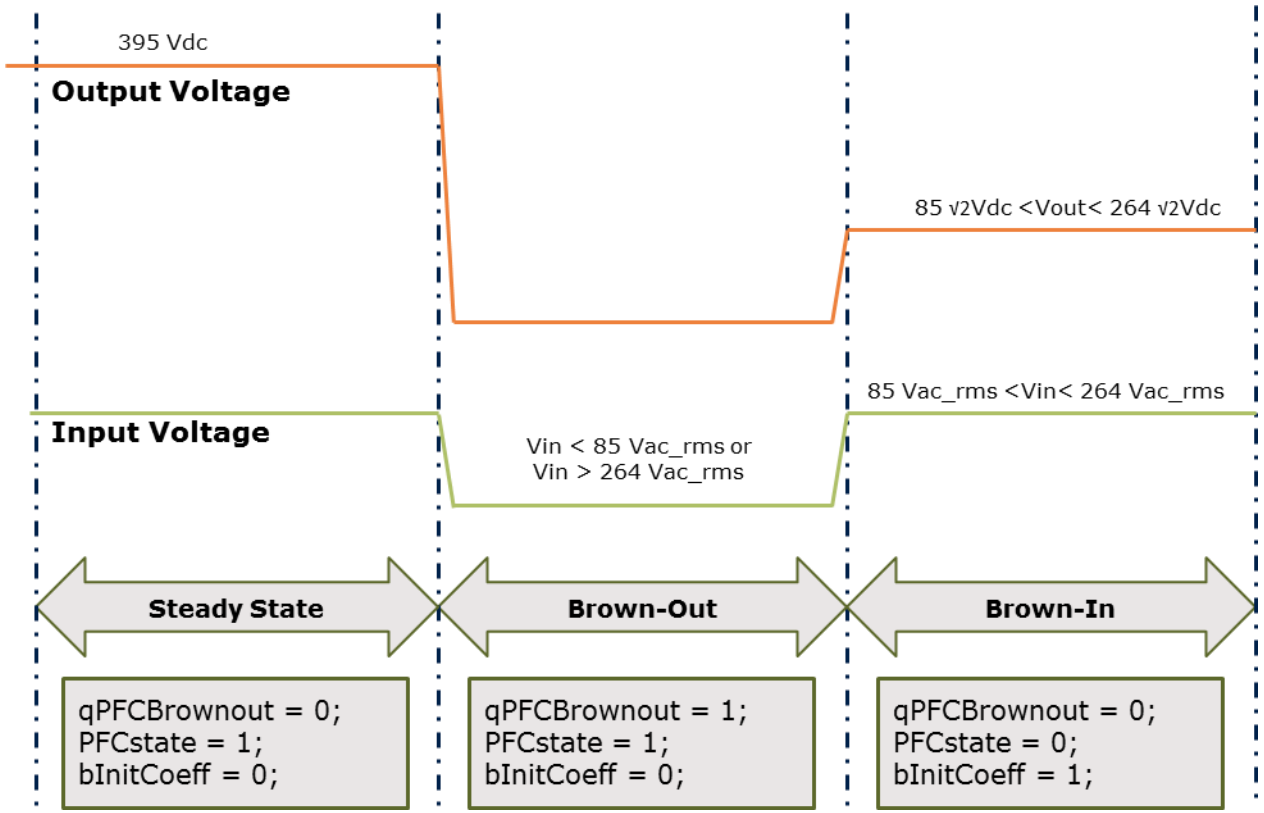
Fixed-point implementation example:

```
qDutyFF = (0xFF - Vin >> 4);
```

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

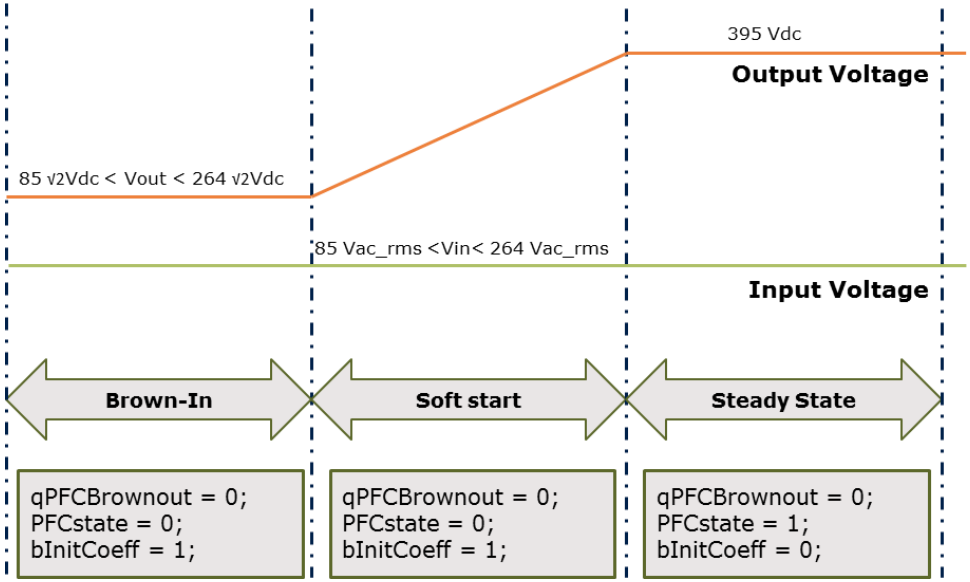
D. M. Van de Sype, K. De Gussemé, A. P. M. Van den Bossche, J. A. Melkebeek, "*Duty-Ratio Feedforward for Digitally Controlled Boost PFC Converters*", IEEE Transactions on Industrial Electronics, Vol. 52, No. 1, February 2005

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

Power Factor Correction (PFC) with XMC™ soft start



Wait until Vin feedforward filter result is stable

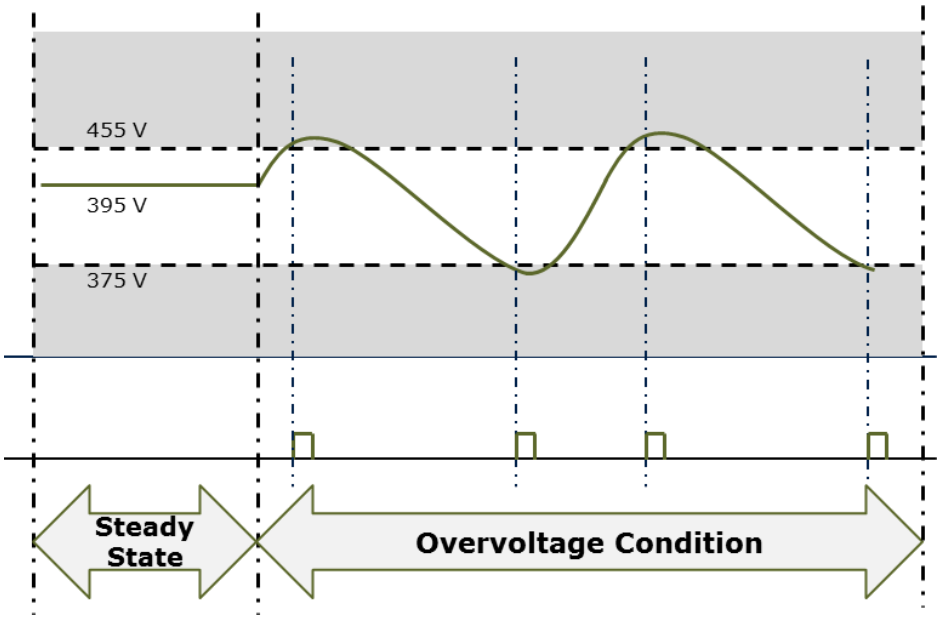
Initialize control loop

Set voltage reference to current output voltage

Increment voltage reference until desired level (e.g. 395 V)

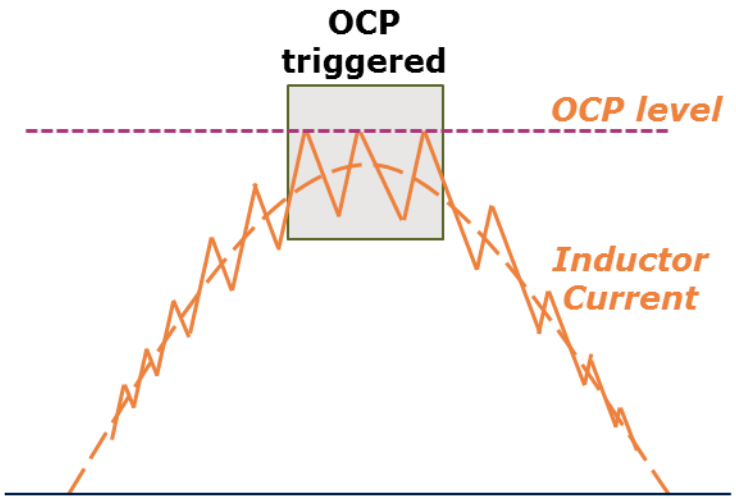
- Designed to ensure smooth PFC start-up with lesser inrush input current
- Accomplished by incrementing voltage loop reference from minimum to desired output voltage (e.g. 395 V_{dc})
  - Embedded in the voltage loop
- Adjustable timing
  - By changing the voltage counter in the firmware

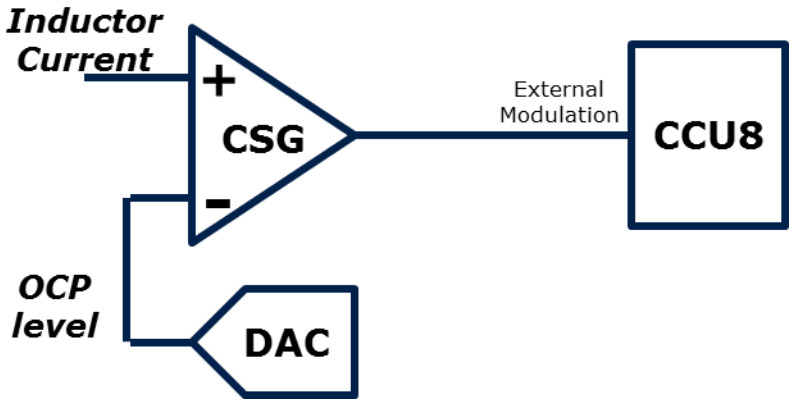
Power Factor Correction (PFC) with XMC™ Over Voltage Protection (OVP)



- 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

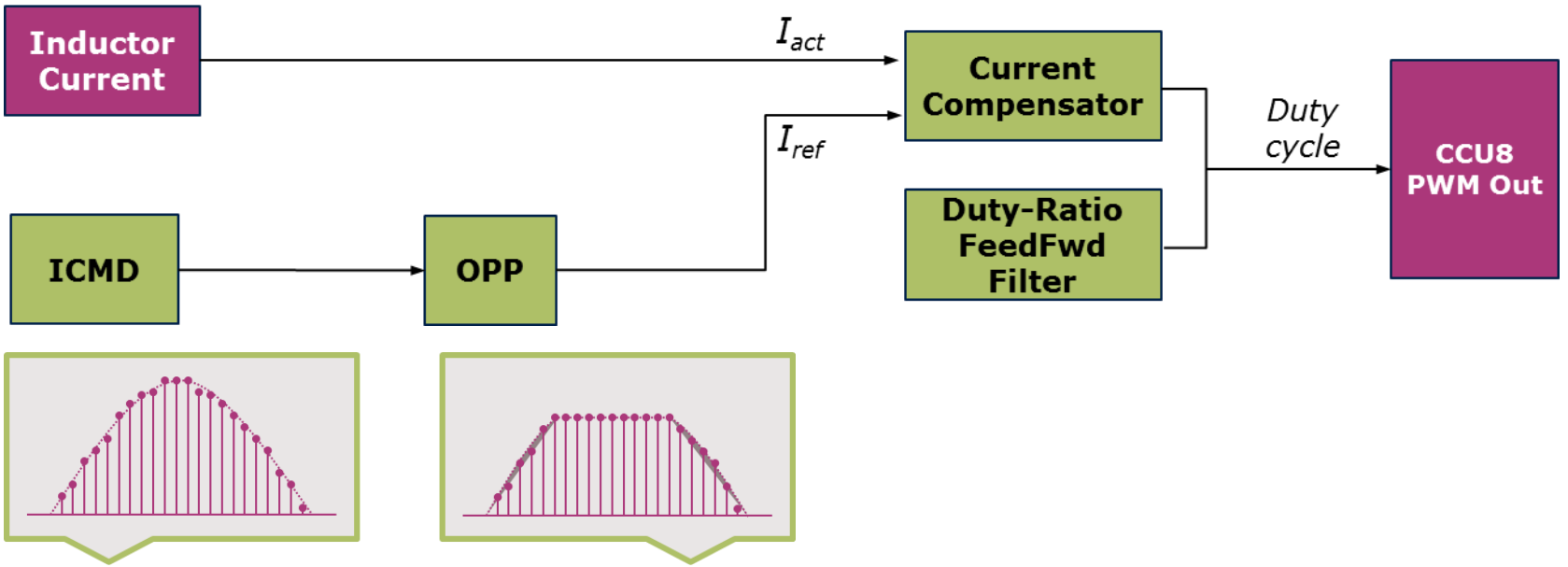
Power Factor Correction (PFC) with XMC™ analog Over Current Protection (OCP)





- 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)

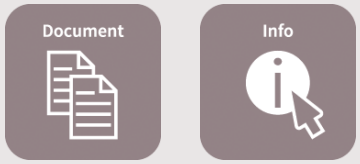
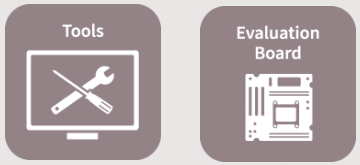


- Designed to limit the maximum power passing through the PFC
- OPP normally happens when PFC has step load from low load close to maximum rated load
- Accomplished by limiting Current Command in the firmware
  - This will clamp inductor current to maximum value defined in the firmware
  - Output voltage 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

Support material

Collaterals and Brochures 	› Product Briefs › Selection Guides › Application Brochures › Presentations › Press Releases, Ads	› www.infineon.com/XMC
Technical Material 	› Application Notes › Technical Articles › Simulation Models › Datasheets, MCDS Files › PCB Design Data	› www.infineon.com/XMC › Kits and Boards › DAVE™ › Software and Tool Ecosystem
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