

# How to Design Multi-kW Converters for Electric Vehicles

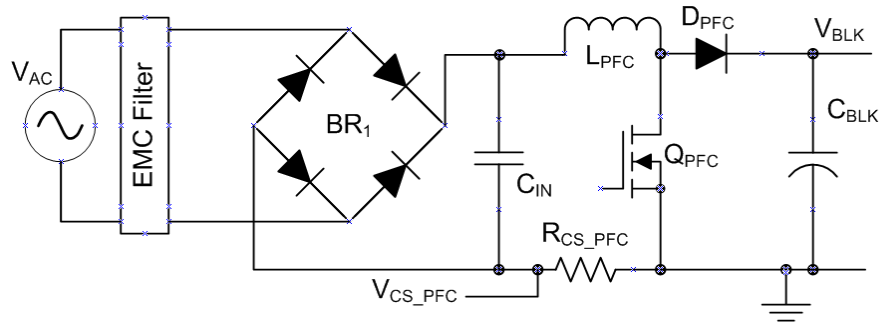
- Part 1: Electric Vehicle power systems
- Part 2: Introduction to Battery Charging
- Part 3: Power Factor and Harmonic Currents
- Part 4: Power Factor Correction**
- Part 5: The Phase Shifted Full Bridge
- Part 6: How the PSFB works
- Part 7: A High Power On Board Charger Design
- Part 8: MOSFET gate driver considerations and References

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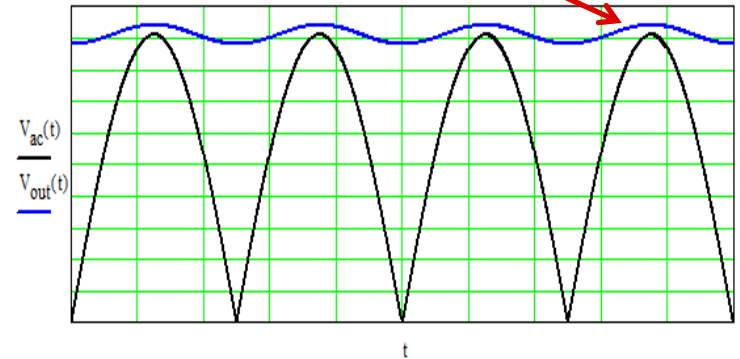
# Boost PFC Topology

- Popular Because
  - Sinusoidal AC line current
  - Power Factor is high
- Output Voltage must be higher than input
  - Typically 400V

DCM: Discontinuous Conduction Mode: 75W to 100W  
TM: Transition Mode: 100W to 300W  
CCM: Continuous Conduction Mode 150W to 1kW  
Interleaved CCM > 1kW



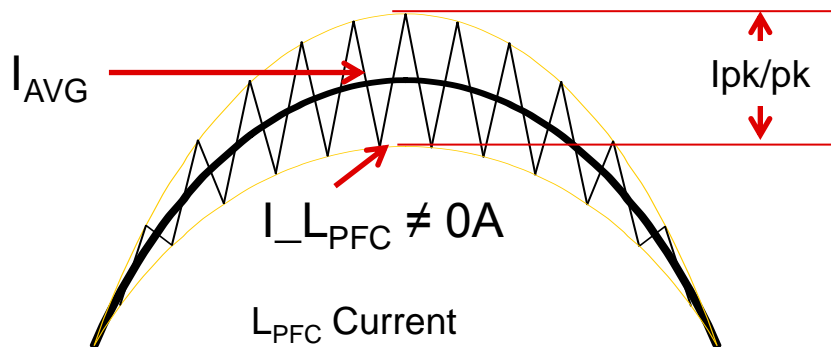
Inherent Ripple voltage on  $V_{out}$  at  $2 \times F_{line}$



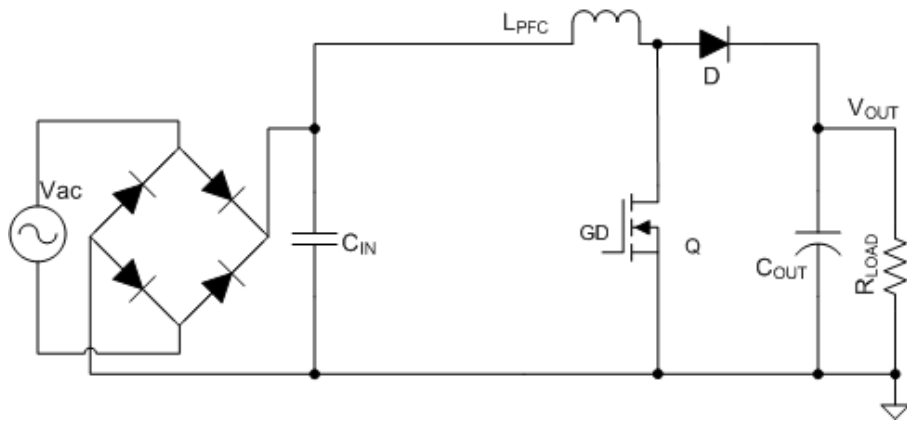
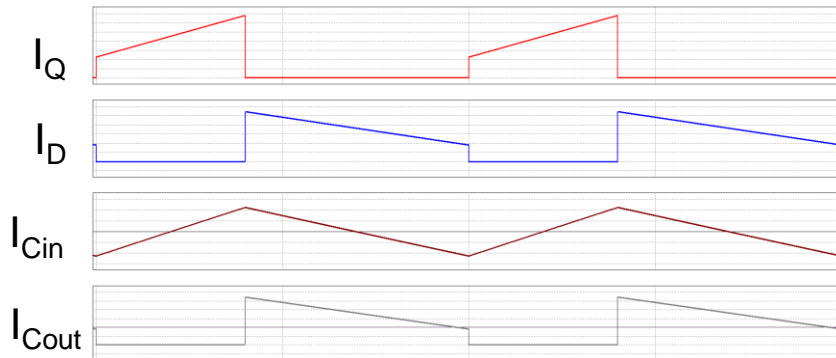
TM = Boundary Conduction Mode = Critical Conduction Mode

# Boost PFC - CCM

- CCM Continuous Conduction Mode
- Fixed Frequency
- Average or Peak Current mode control
- Ultra Fast rectifier Diode (eg SiC)
  - Inductor current not zero at turn-off
  - $Q_{rr}$  is significant
- Sinusoidal current in  $L_{PFC}$



Typical currents over two switching cycles

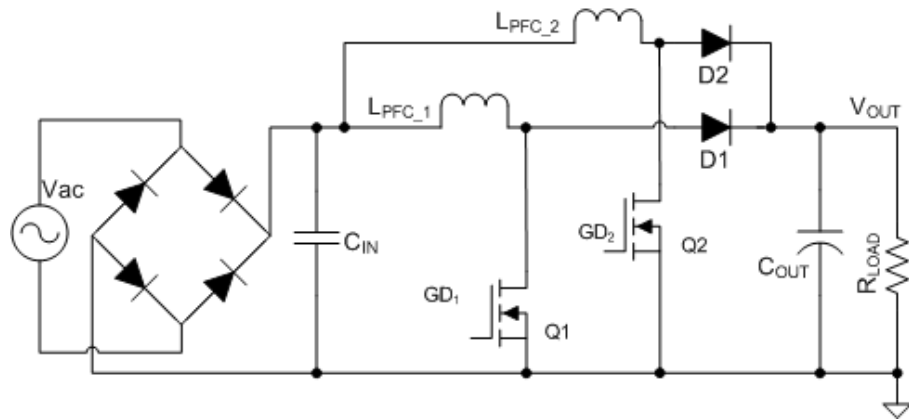
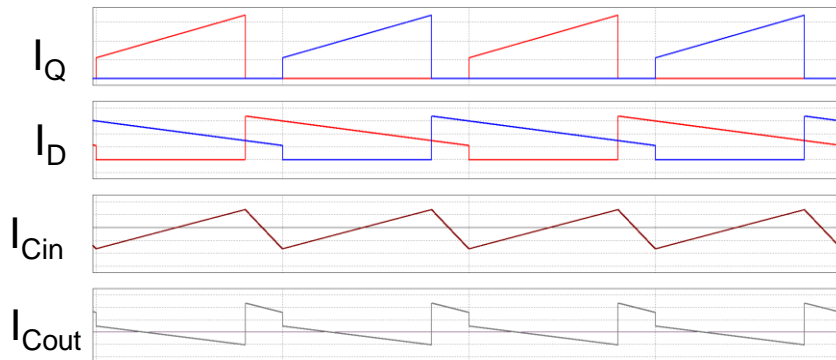


# Boost PFC - Interleaving

- Two Boost stages with 180° phase shift
- Reduces ripple current in  $C_{in}$  and  $C_{out}$  \*
  - Smaller EMI filter
  - Smaller  $C_{out}$
- Distributes power loss over more parts
- Extends operating power range
  - CCM: 4kW +
- Phase shedding.
  - Turn one phase off at light load
- Controller
  - UCC28070-Q1, Interleaved CCM

\* See Ref 1, 2, 3, 4, 5 for more information

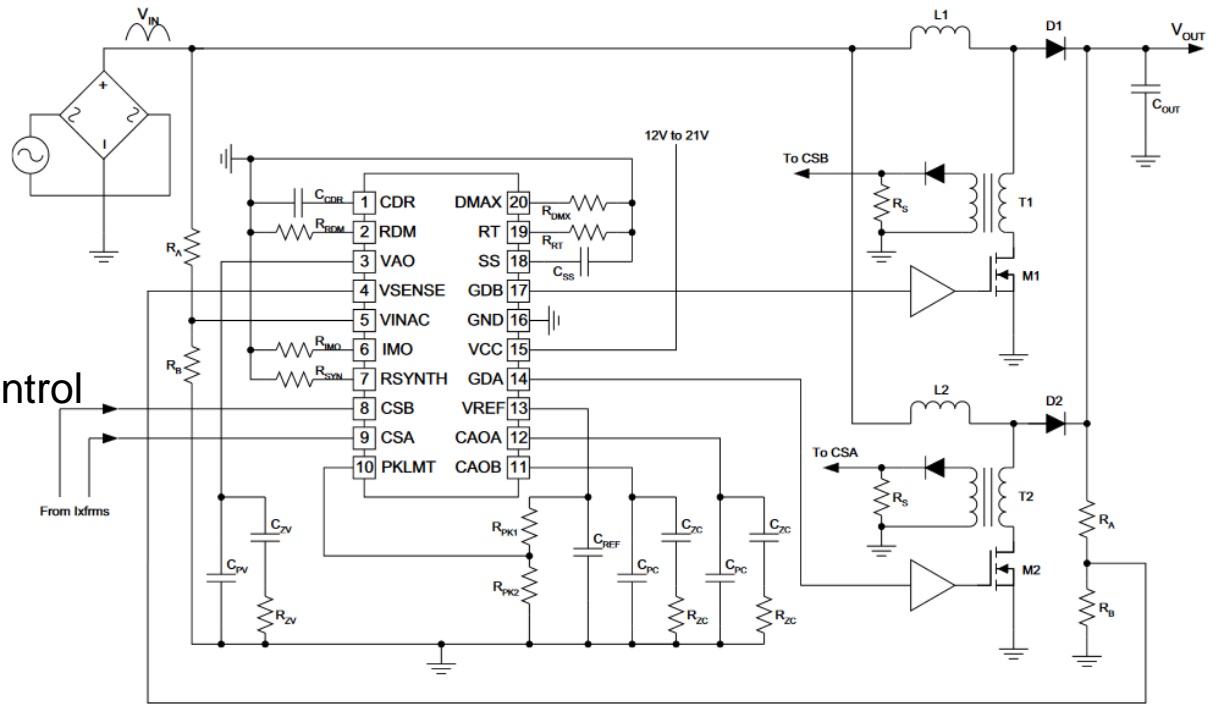
Typical currents over two switching cycles



# Boost PFC - Interleaving

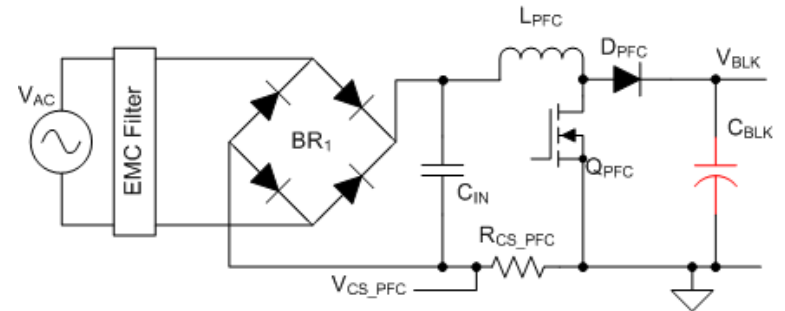
- UCC28070-Q1 controller      Simplified Application Schematic

- Near Unity PF
- 2 Phase Interleaving
- Average Current Mode Control
- Current Sharing
- Enhanced Load and Line Transient Response



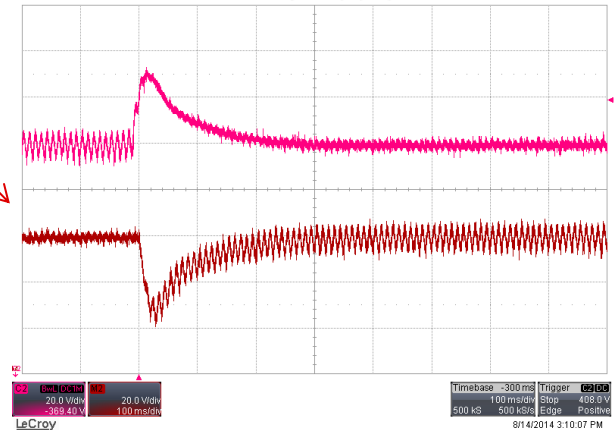
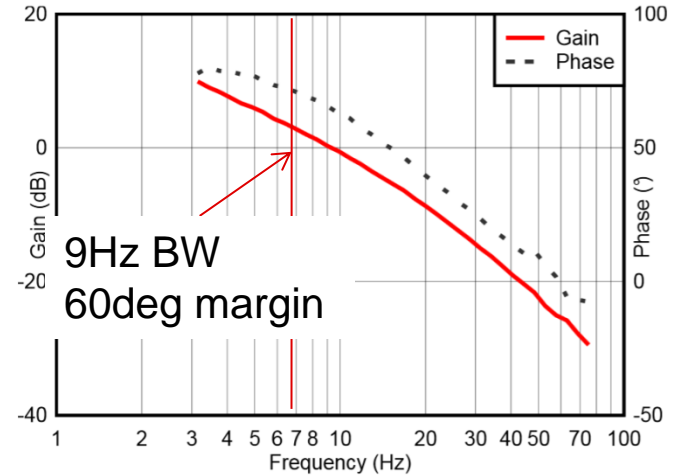
# PFC Bulk Capacitor

- Bulk Caps store a lot of energy
  - Make sure you discharge them before handling
- Ripple current rating –
  - HF ripple at switching Frequency, Complex calculation
  - Interleaving gives typically 40% to 50% reduction over non-interleaved case
    - See Ref 1, 2, 3, 4, 5, 6
  - Low Freq at 2x Line frequency, not affected by interleaving.  $\longrightarrow I_{Cout\_LF} = \frac{\eta P_{in}}{\sqrt{2} V_{OUT}}$
  - Increases as frequency increases.
  - Decreases as Temp increases
- ESR
  - Reduces as Freq increases
- Temperature and Lifetime rating considerations
  - Lower Temperature implies longer lifetime



# PFC Control – Compensation

- Loop stability tests ensure stable operation
  - Bode Plots, Small Signal
  - Look for gain and phase margin
  - Transient Tests, Large Signal
  - Look for acceptable voltage deviations and
  - Both types of test are necessary
- Overall Loop
  - Good PFC / low iTHD
  - Good output voltage regulation
- L\_PFC value does not appear in loop transfer equations



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## Thank You

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