

# Power Supply Design Seminar

Power Factor Correction (PFC)  
Circuit Basics

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Authors

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Brent McDonald



# Agenda



**Introduction**

**Feature presentation**

**Live Q&A session**

Enter questions into chat at any time

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# 2025 Power Supply Design Seminar



## Webinar Series

April 30	Common mistakes in DC/DC converters and how to fix them
May 28	Survey of resonant converter topologies
June 25	<b>Power Factor Correction (PFC) circuit basics</b>
July 30	Power-conversion techniques for complying with automotive emissions requirements
August 27	Switch-mode power converter compensation made easy
September 24	Constructing your power supply – layout considerations

**Last Wednesday of every month  
8:00AM & 8:00PM (US Central Time Zone)**



# Welcome to the PSDS 2025 webinar series!



## The history of Power Supply Design Seminar

- In 1977 Bob Mammano, the “Father of PWM Industry,” started the seminar
- 47+ years
- 26+ seminars
- 100+ technical topics
- 50,000+ customers
- A comprehensive archive of white papers, presentations and videos



### *Power supply industry legends associated with PSDS:*

Bob Mammano, Lloyd Dixon, Bill Andreycak, Robert Kollman, Laszlo Balogh

[WWW.TI.COM/PSDS](http://WWW.TI.COM/PSDS) for all prior content

# Objectives & agenda

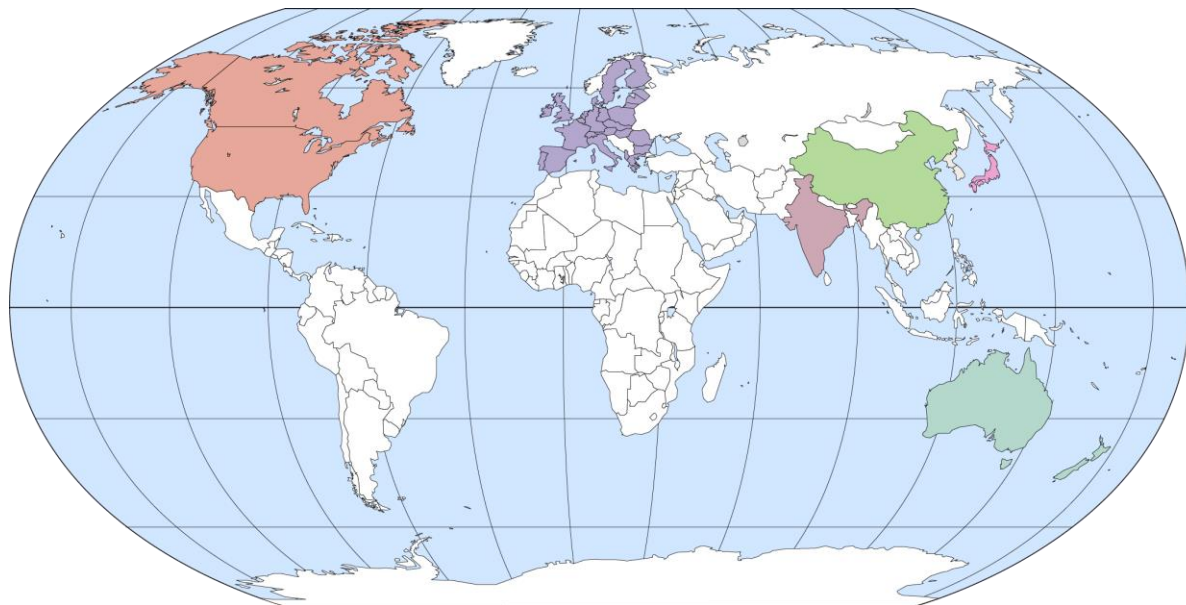
- **Introduction**

- What is power factor correction (PFC)?
- Why is it needed?
- How is it measured?

- **Overview**

- Critical conduction mode (CrCM)
  - Compensation
  - Feed-forward
  - Sources of distortion
- Continuous conduction mode (CCM)
- Interleaved
- Bridgeless

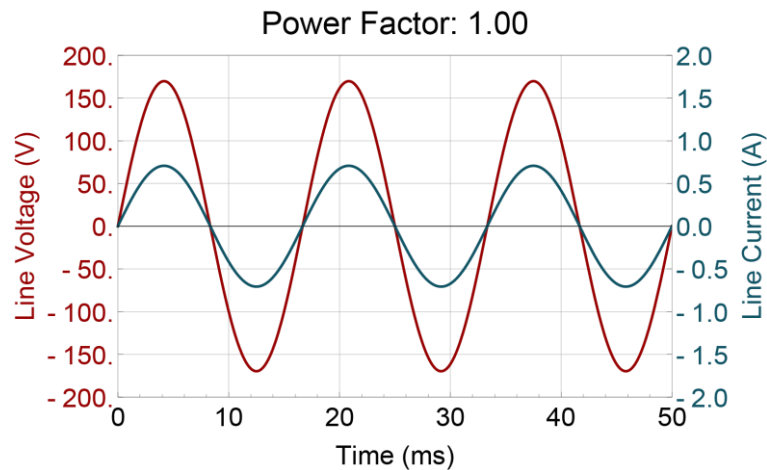
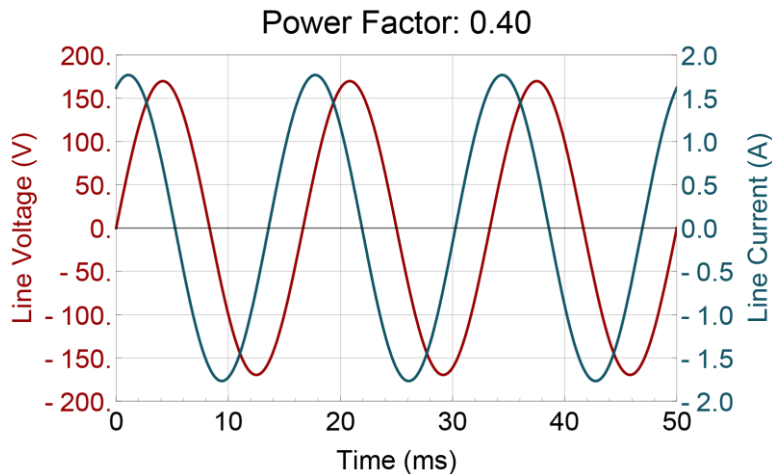
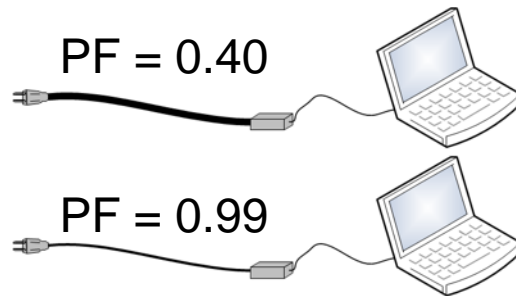
# Regional power quality requirements



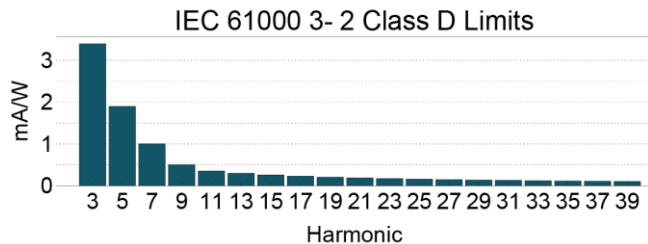
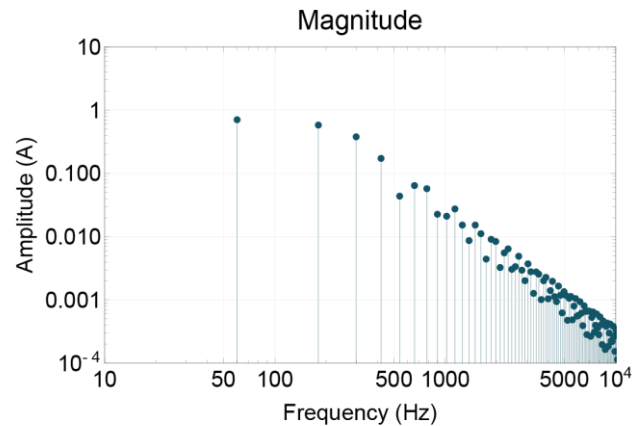
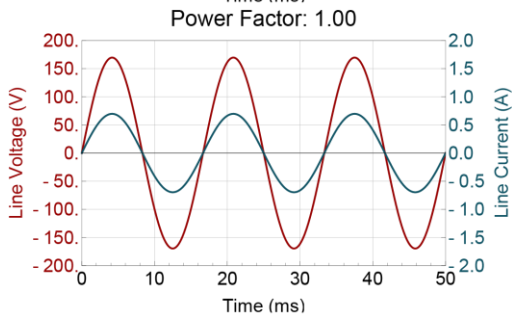
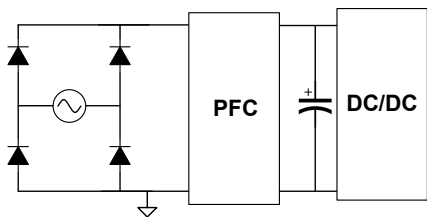
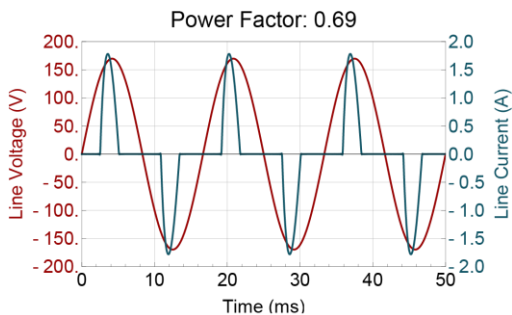
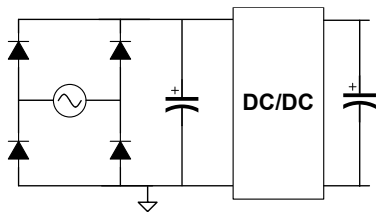
- European Union, EN61000-3-2
- US/Canada, IEC61000-3-2, Energy Star
- China, GB/T 14549-93
- Japan, JIS 61000-3-2
- Australia/New Zealand, AS/NZS 61000.3.2
- India, IS 14700-3-2
- Korea, K6100-3-2

# What is power factor and why should I care?

- Laptop ~ 60 W
- USA > 3.2 TW



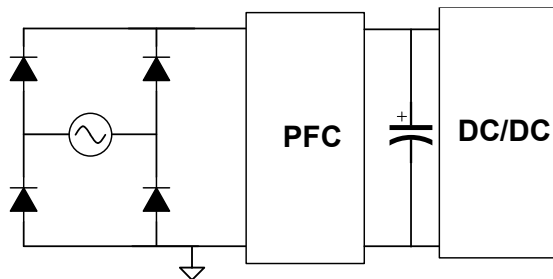
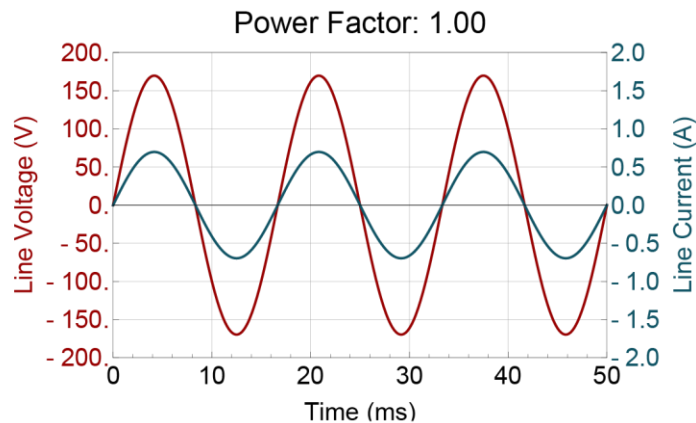
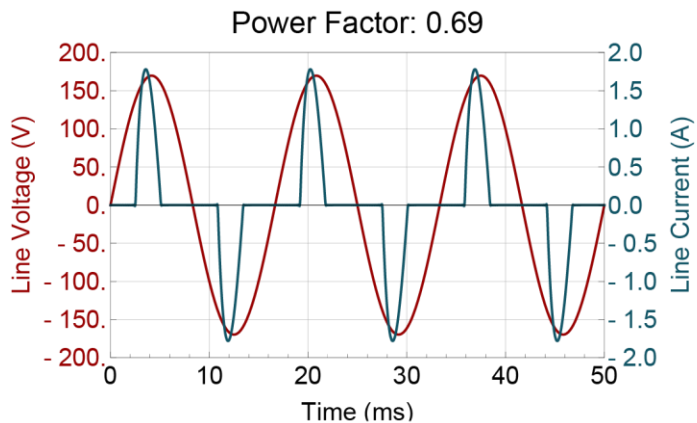
# How is the “PF” measured & regulated?



$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1}$$

$$PF = \frac{\cos(\varphi)}{\sqrt{1 + THD^2}}$$

# How is it done?



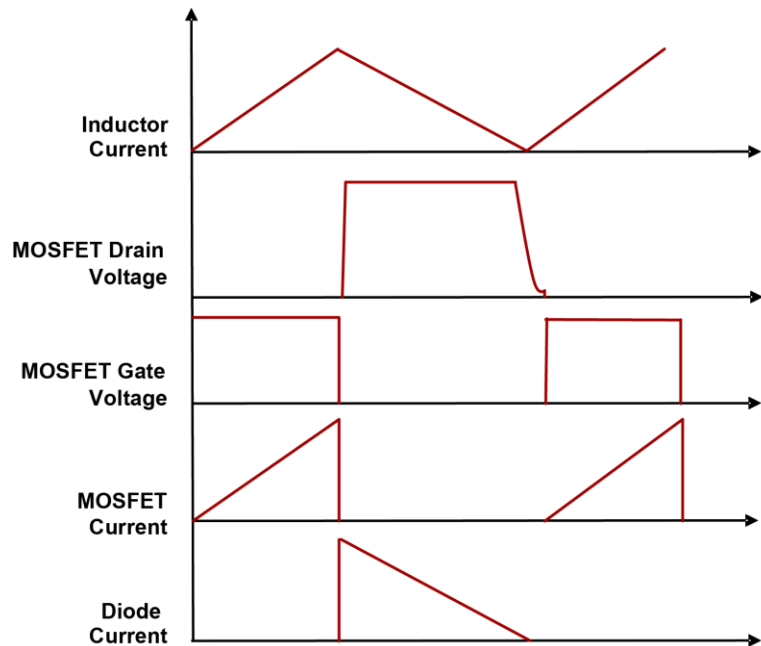
## Solutions include

- Boost
- Flyback
- Sepic
- Buck
- Passive solutions

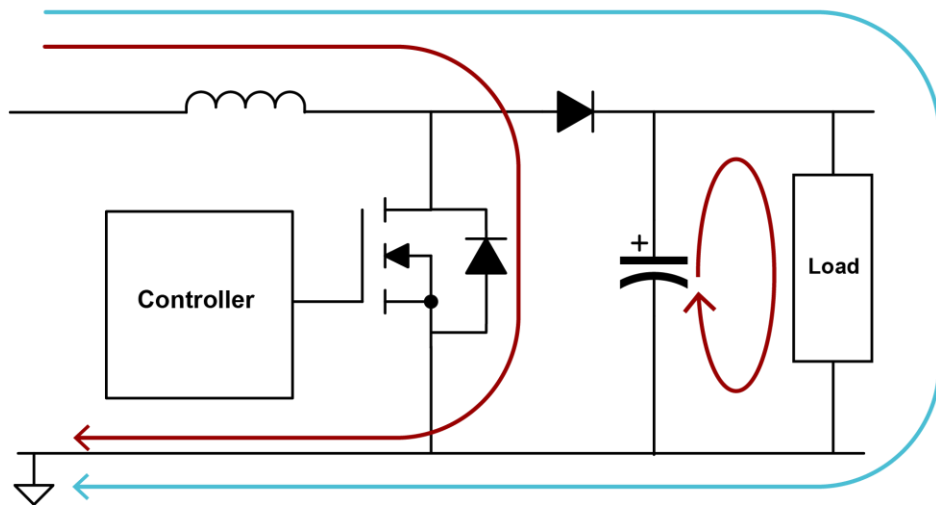
## Benefits

- Achieve unity PF
- Regulated output
- Energy hold up
- Universal input

# The boost converter

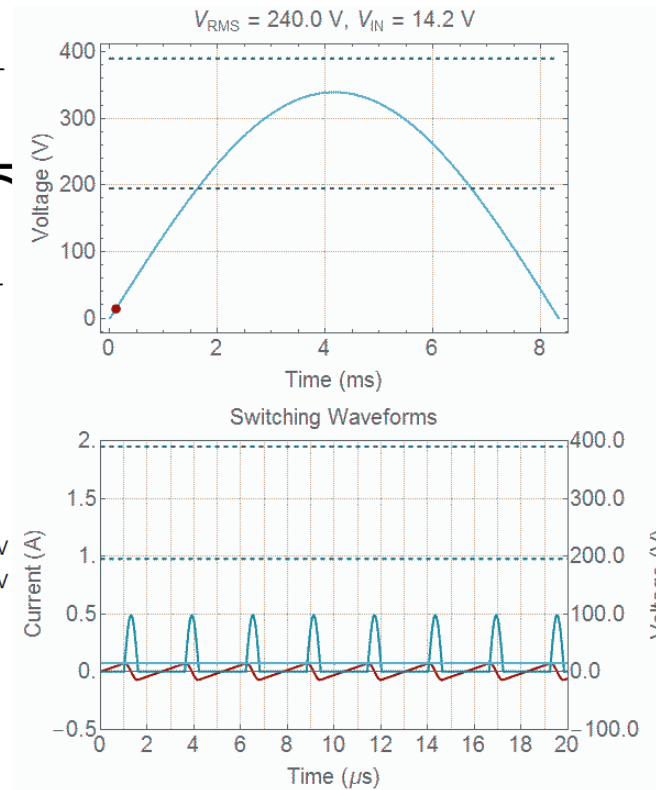
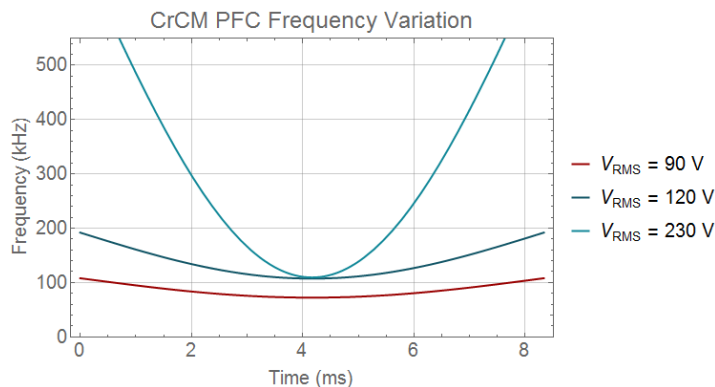
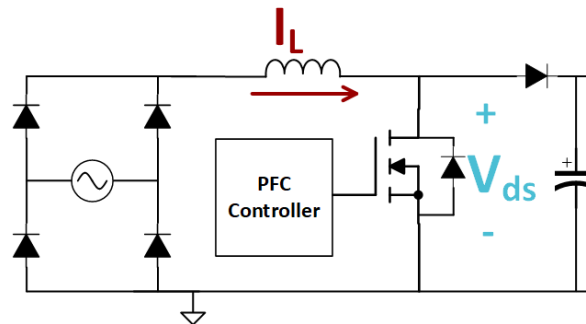


$$\frac{V_{OUT}}{V_{IN}} = \frac{1}{1 - D}$$

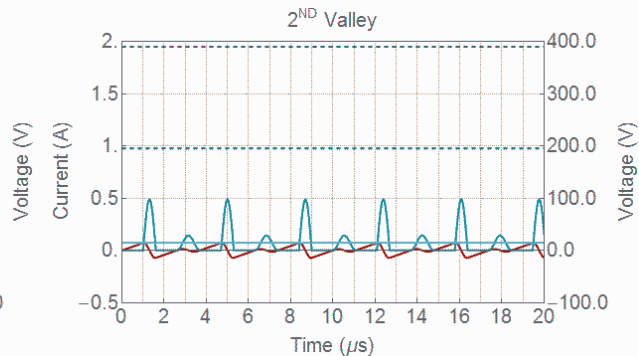
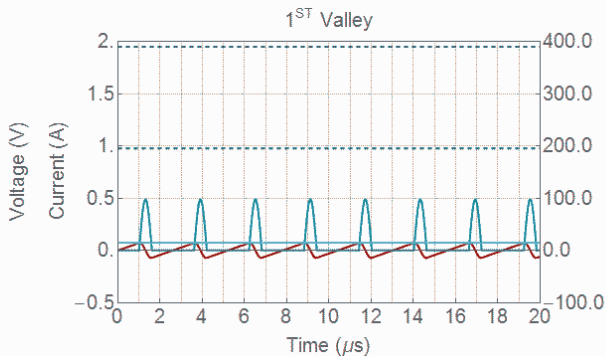
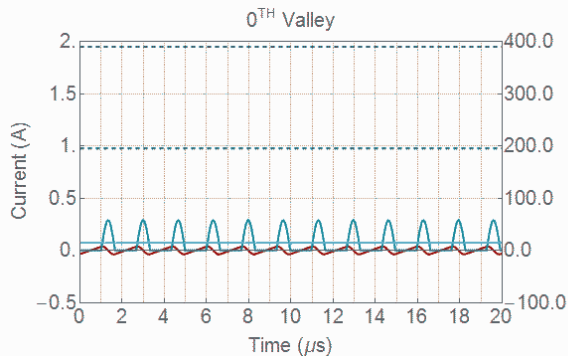
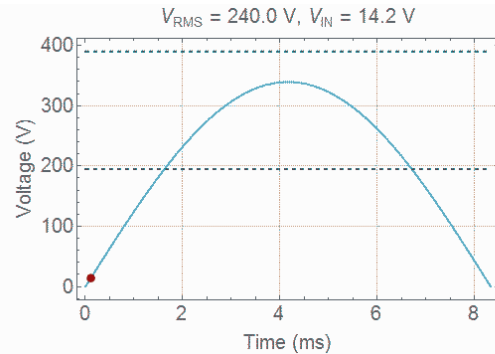
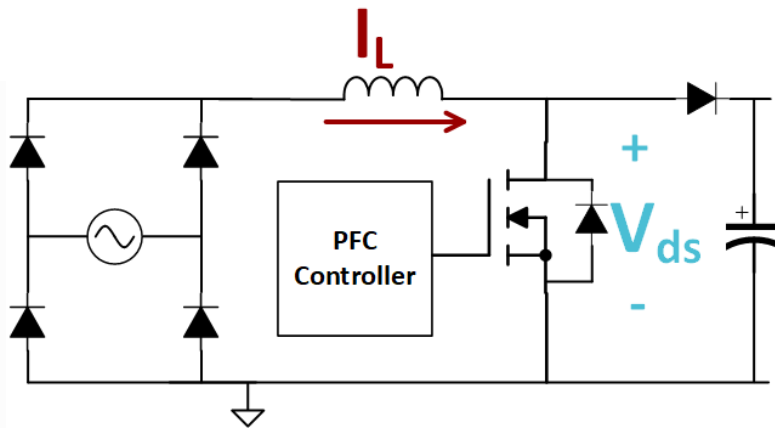


# The CrCM PFC

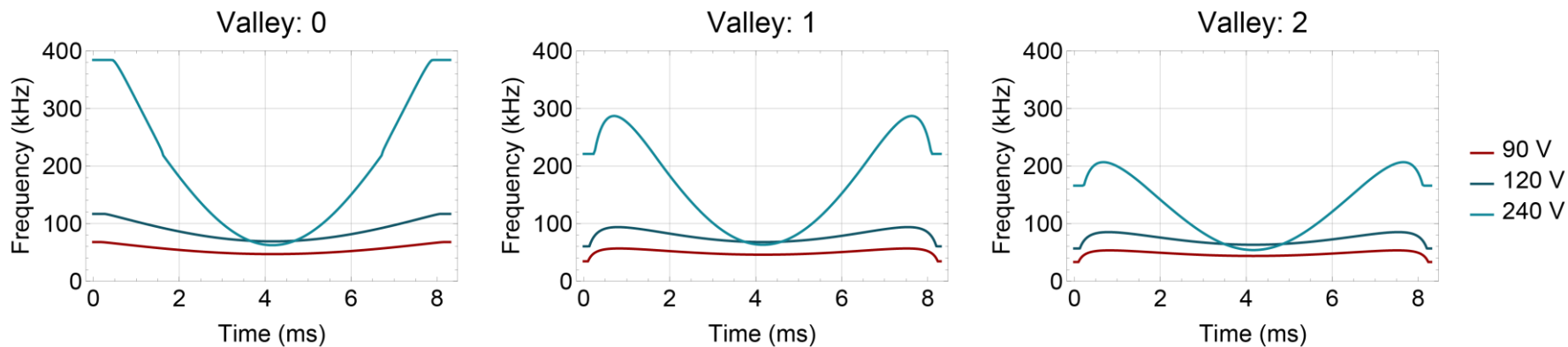
- Constant on time
  - $I_{L(AVG)} = \frac{V_{IN}}{2L} t_{ON}$
- Operates on the boundary between DCM and CCM
- Huge switching frequency variation
- Zero current switching for boost diode, no reverse recovery



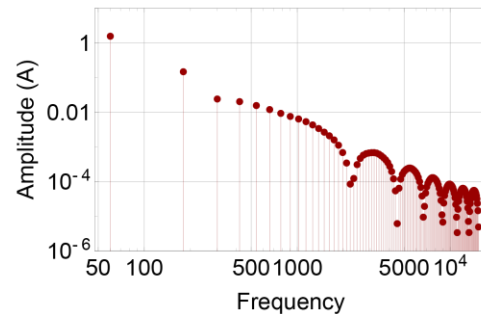
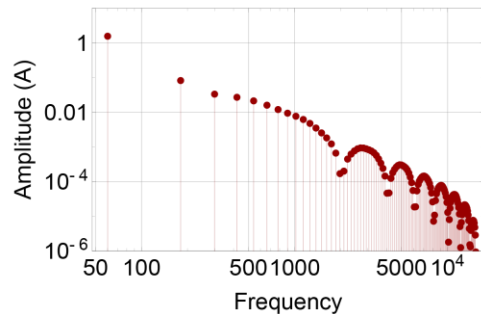
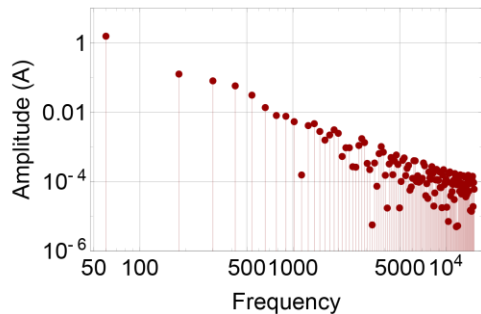
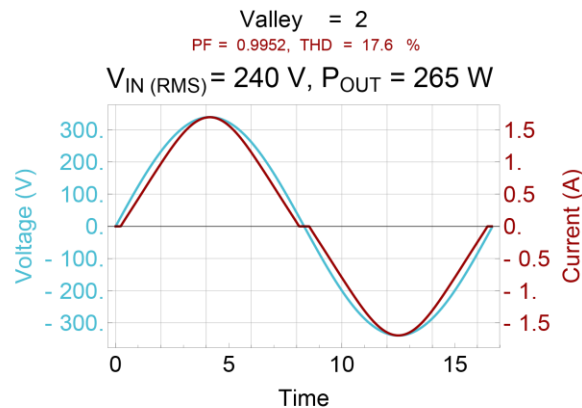
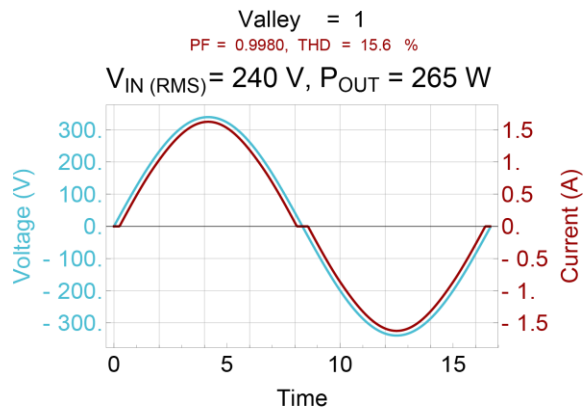
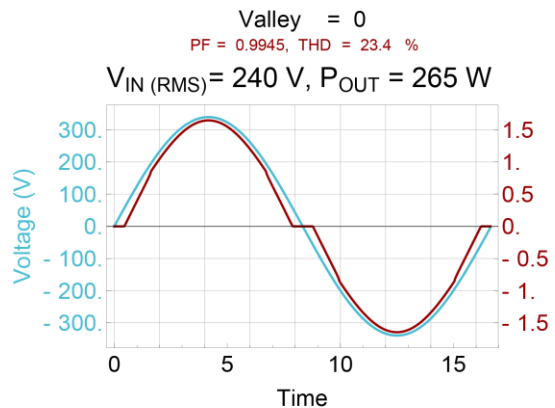
# DCM & Valley Switching



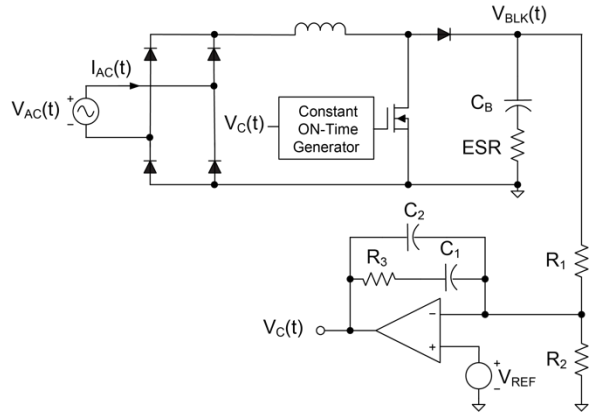
# Valley switching impact on $f_s$



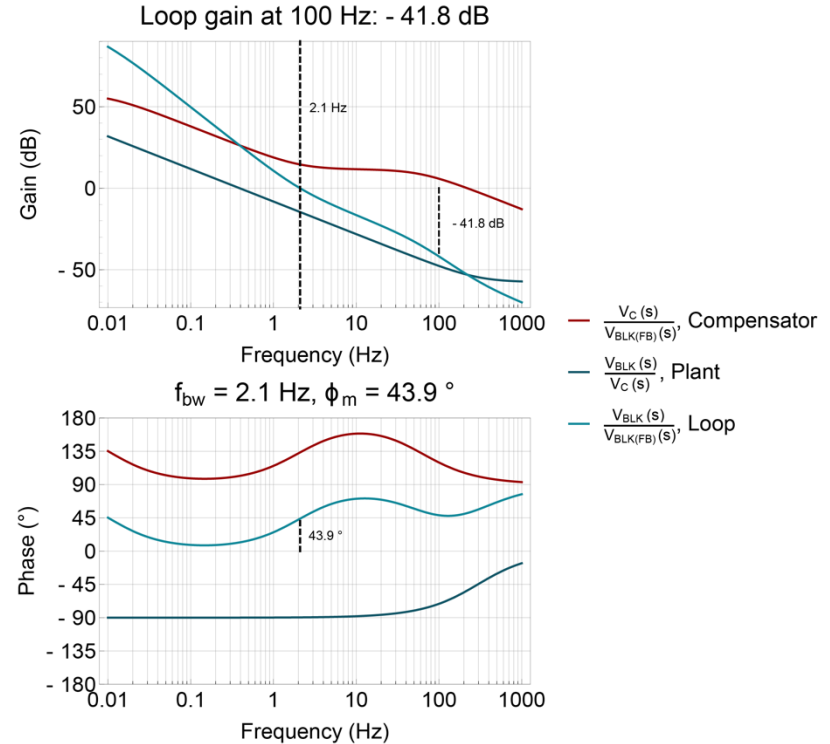
# Distortion



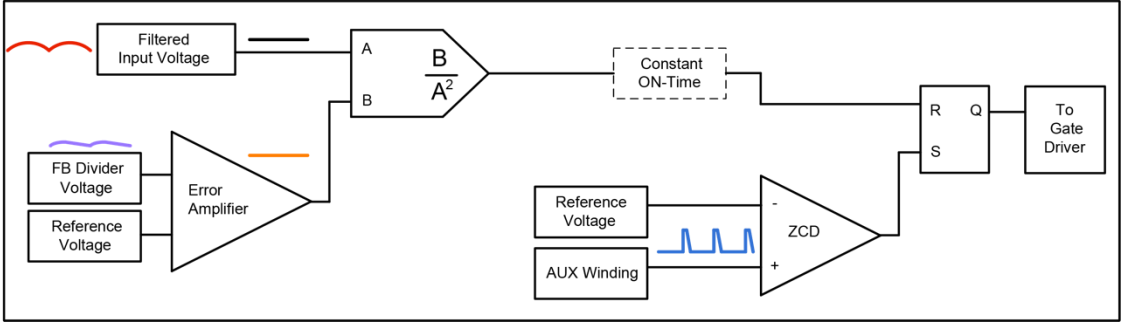
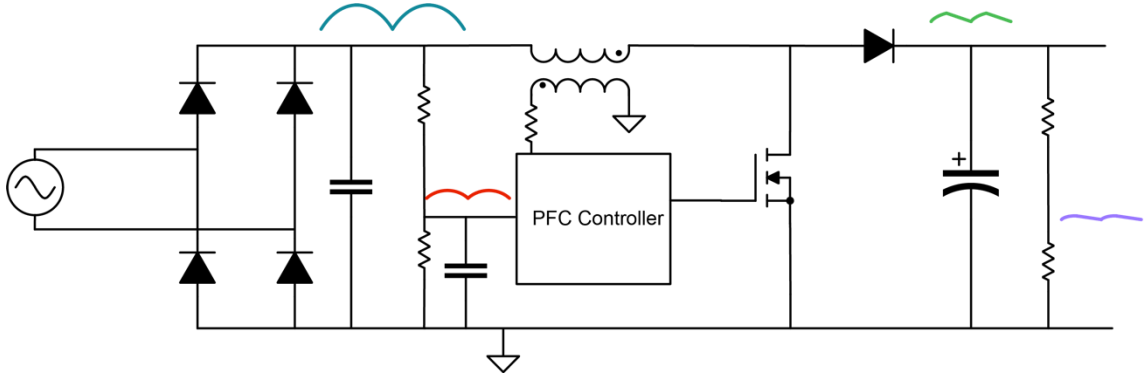
# Compensation



- Feed-forward power delivery independent of line voltage
  - One compensation parameter set works for very wide input voltage range
- Trade-off
  - Good PF requires a slow control loop (<10 Hz typical)
  - Good transient response requires fast control loop
  - Non-linear error amplifier gain helps address transient response performance



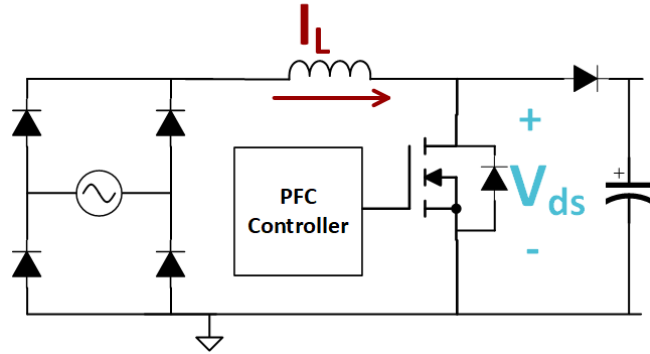
# Putting it all together – CrCM



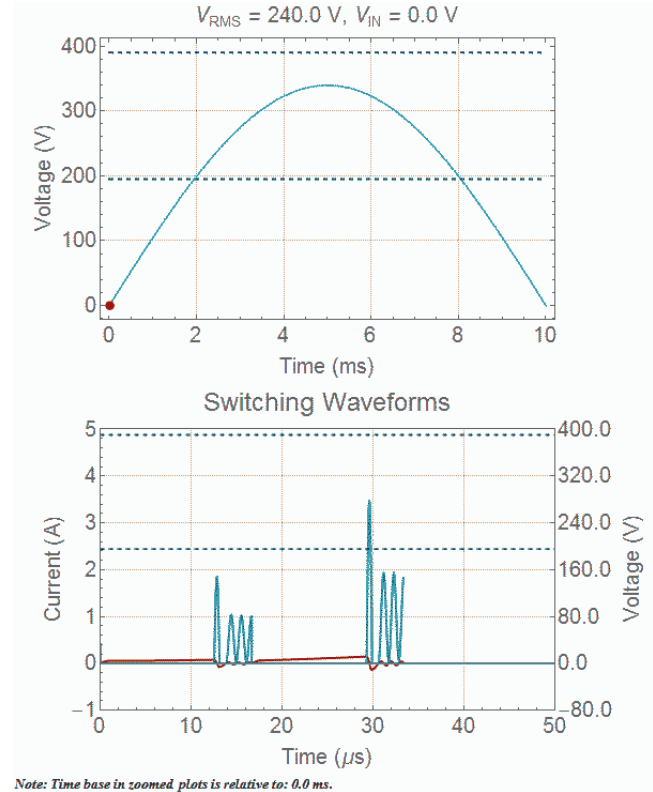
# CrCM wrap up – Low solution \$, <300 W

- **Simple implementation**
- **Valley switched**
  - Low  $C_{OSS}$  loss at MOSFET turn-on
- **No reverse recovery**
  - Able to use lower cost ultra-fast diode
- **Inductor current ripple is large (200%)**
  - Larger RMS currents
  - Larger core loss in inductor
- **Good PF, mediocre THD**
  - THD can be improved using more complex approaches

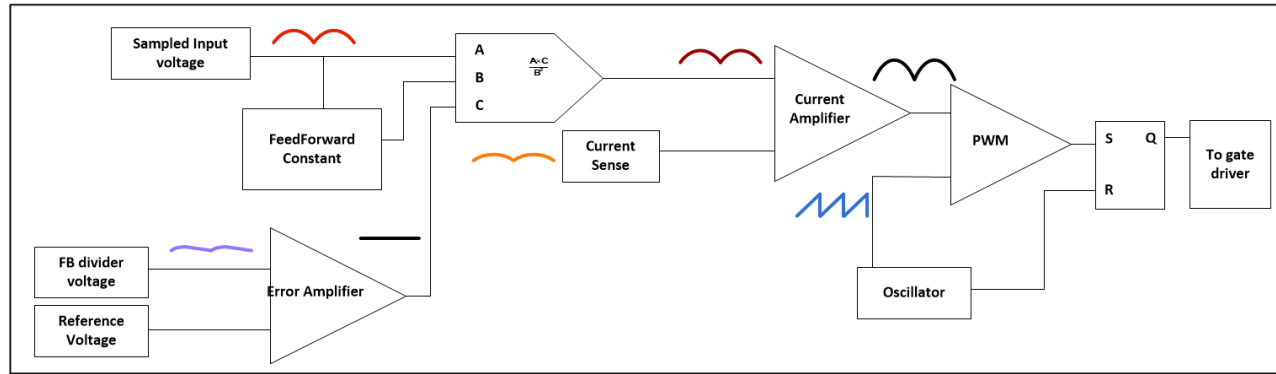
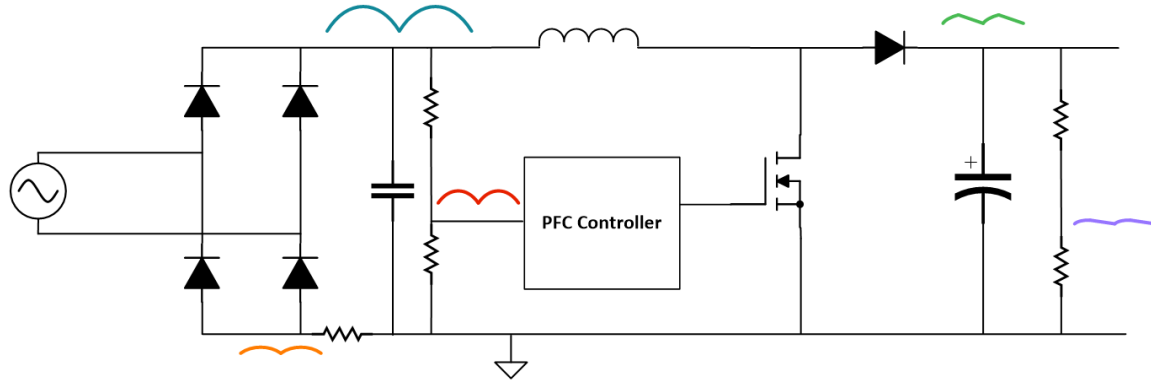
# CCM PFC Operation



- Converter operates at a fixed switching frequency, duty-cycle now a function of instantaneous line voltage
- Much smaller current ripple than CrCM but no longer valley switched
- Non-ZCS switching for boost diode, good  $Q_{RR}$  performance needed
- Capable of delivering a lot more power



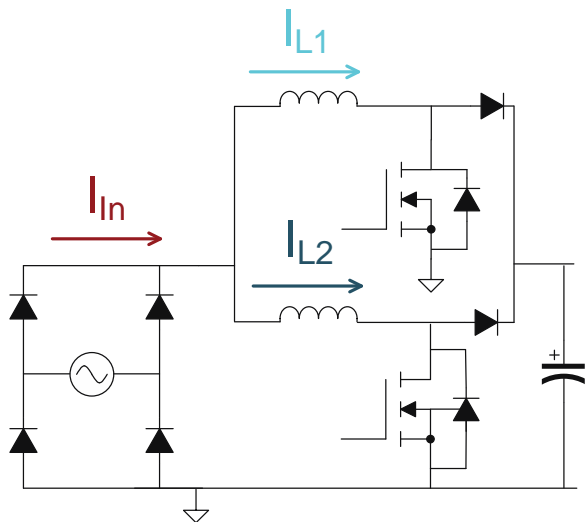
# The CCM PFC



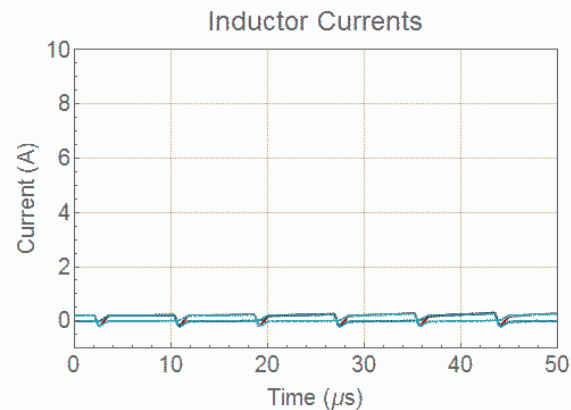
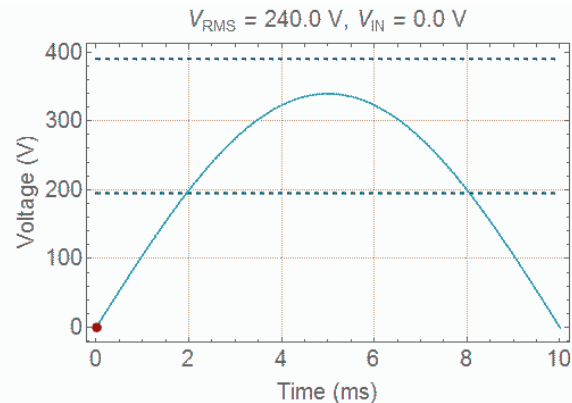
# CCM wrap up – Better PF/THD, >300 W

- **Fixed frequency with limited inductor current ripple**
  - Smaller RMS currents
  - Smaller conduction losses than CrCM
  - Lower cost core material
- **Hard switching for both boost MOSFET and boost diode**
  - Higher switching losses than CrCM
  - Good  $Q_{RR}$  performance is essential
  - SiC diode often used
- **More complex control scheme**
  - Slow voltage loop, fast current loop
  - Most modern CCM PFC controllers will simplify complexity for the end user

# Interleaved PFC



- Two converters operated 180° out of phase
- Works with TM or CCM types
- Ripple cancellation at 50% duty cycle



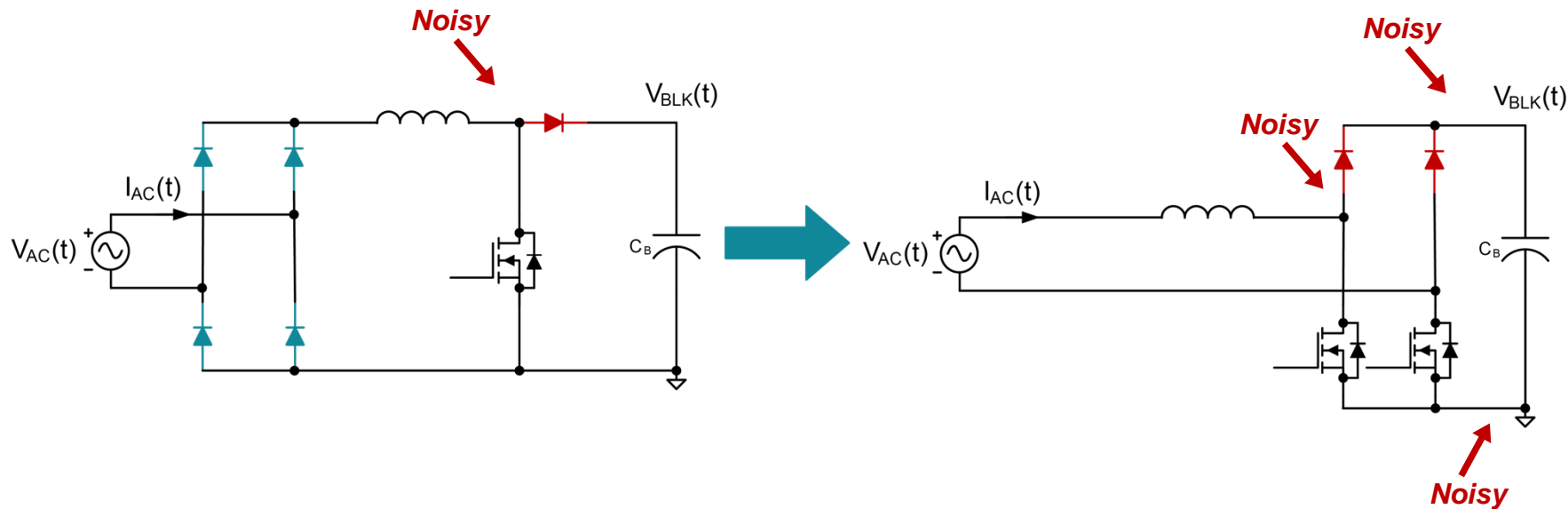
Note: Time base in zoomed plots is relative to: 0.0 ms.

# When to consider interleaving

- **Power loss distributed between two power stages**
  - Improved thermal management
  - More component choices
- **Power density**
  - Reduced z-height at the expense of x/y space
- **Lower input and output current ripple**
  - EMI filter may be physically smaller

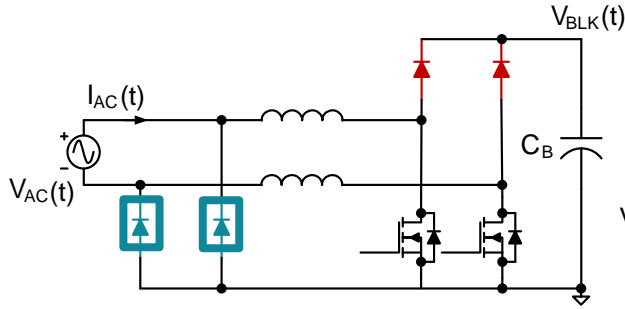
# I want bridgeless, can I do this?

Slow  
Fast



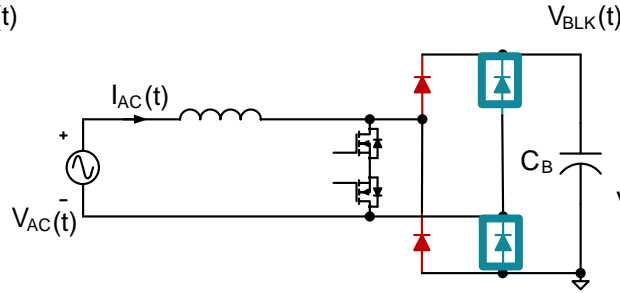
# Bridgeless PFC

Slow  
Fast



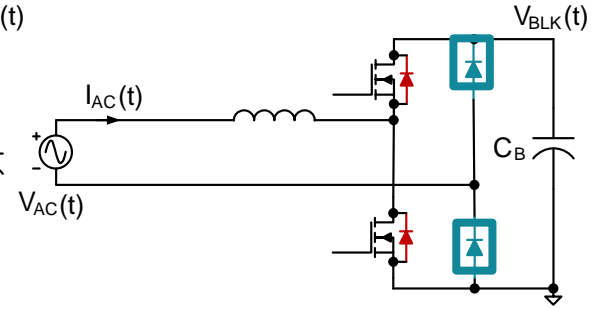
**Semi-Bridgeless**

- Advantages
  - Simple control
  - Ground referenced gate drive
- Disadvantages
  - 2 power stages
  - 6 semiconductors
  - Poor core utilization



**AC Switch**

- Advantages
  - Lowest ON-state conduction
  - Balanced EMI
- Disadvantages
  - Isolated drive
  - Current sense
  - 6 semiconductors

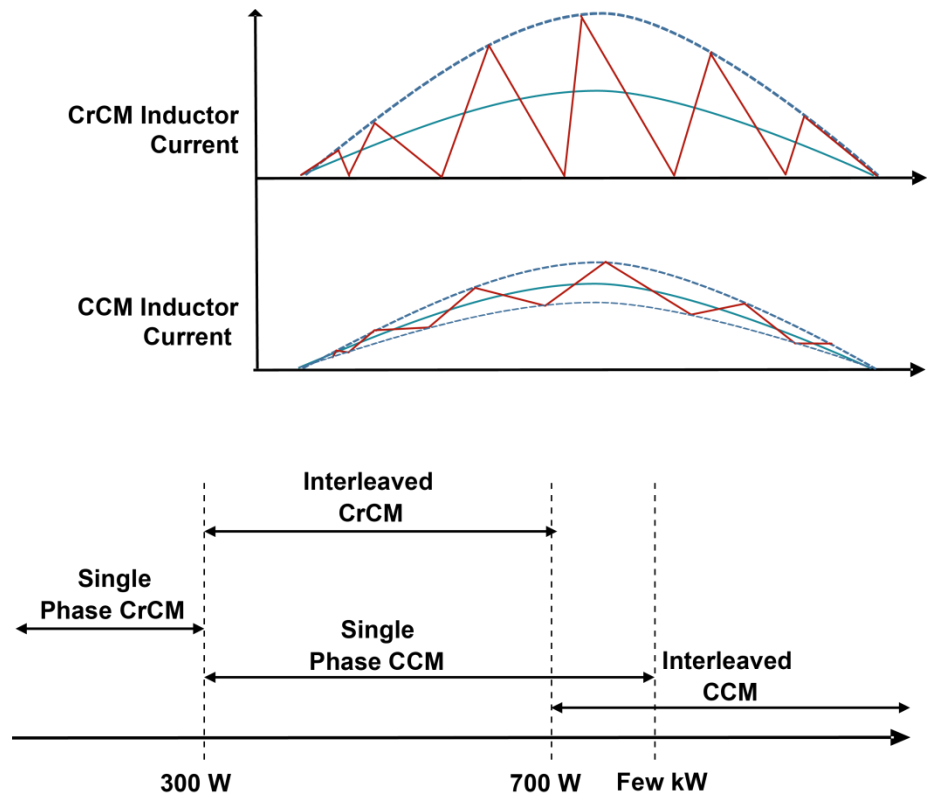


**Totem Pole**

- Advantages
  - Minimum components
  - Good efficiency
- Disadvantages
  - Complex
  - High side drive
  - Current sense
  - Common mode
  - Reverse recovery

# Selecting the right PFC topology: Output power

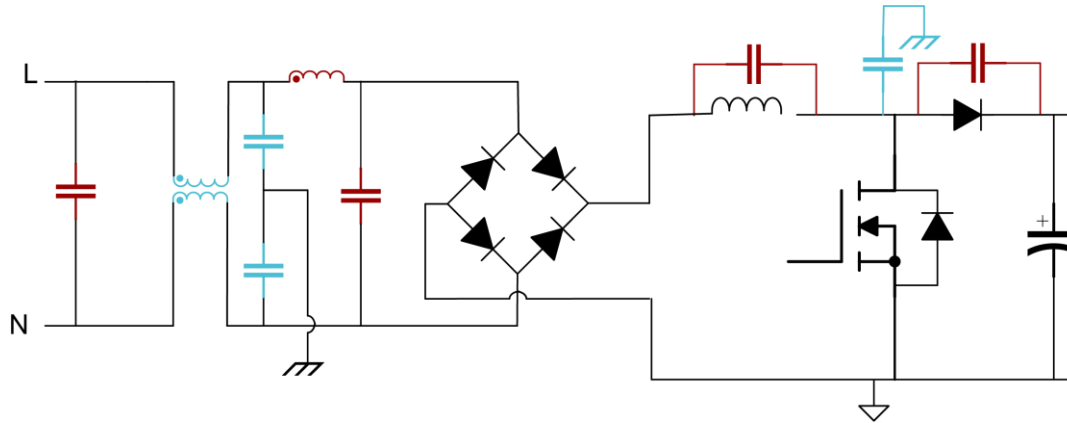
- How does output power influence decision?
- Peak inductor current comparison at 500 W
  - Single phase CCM: 8.84 A
  - Single phase CrCM: 17.49 A



# Selecting the right PFC topology: Interleaved CrCM vs single phase CCM

Design Characteristics	Interleaved CrCM	Single Phase CCM
Component stress	Conduction loss split between two power stages, valley switched	Single power stage, hard switched
Power density	Lower	Higher
Height	Smaller overall component height	Single inductor, larger heatsinks
Thermal management	Power dissipation spread over greater X/Y space	More challenging
Complexity	High power stage component count	Single power stage
Cost	Higher	Lower

# Selecting the right PFC topology: EMI comparison



- **Critical conduction mode**

- Inductor current ripple is 200%, requires physically larger EMI filter
- Variable frequency – noise less concentrated in one frequency

- **Continuous conduction mode**

- Physically smaller filter but fixed frequency

- **Interleaved**

- Ripple current cancellation allows for physically smaller EMI filter

- **Bridgeless**

- Common mode challenging for some variations

# Topology selection exercise

## Design specification

- Laptop adaptor
- USB-C, 100 W output
- 100 V<sub>AC</sub> to 240 V<sub>AC</sub> input
- Smallest form factor critical

# Topology selection exercise

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- Laptop adaptor
- USB-C, 100 W output
- 100 V<sub>AC</sub> to 240 V<sub>AC</sub> input
- Smallest form factor critical

## TIDA-01623

- Single phase CrCM PFC + active clamp flyback
- Form factor: 70 mm × 42 mm × 16.5 mm
- 93.4% efficiency end-to-end at full load
- <http://www.ti.com/tool/TIDA-01623>



# Topology selection exercise

## Design specification

- Class-D audio amplifier
- 90 V<sub>AC</sub> to 265 V<sub>AC</sub> input
- 200 W continuous, 750 W peak
- Small solution size preferable (length, width and height)

# Topology selection exercise

## Design specification

- Class-D audio amplifier
- 90 V<sub>AC</sub> to 265 V<sub>AC</sub> input
- 200 W continuous, 750 W peak
- Small solution size preferable (length, width and height)



## TIDA-00776

- Single phase CCM PFC + 2-switch forward
- Form factor: 88 mm x 173 mm x 35 mm
- <http://www.ti.com/tool/PMP30183>

# Topology selection exercise

## Design specification

- OLED TV
- 85 V<sub>AC</sub> to 265 V<sub>AC</sub> input
- Peak output power: 480 W
- AC/DC supply embedded within panel:  
thin profile needed

# Topology selection exercise

## Design specification

- OLED TV
- 85 V<sub>AC</sub> to 265 V<sub>AC</sub> input
- Peak output power: 480 W
- AC/DC supply embedded within panel:  
thin profile needed



## TIDA-01495

- Interleaved CrCM PFC + half-bridge LLC
- <17 mm height
- <http://www.ti.com/tool/TIDA-01495>

# Summary

- **Overall**
  - Huge benefit to infrastructure
  - Regional regulatory requirements
- **Control method impacts power stage behavior**
  - Conduction losses
  - Switching losses
  - Switching frequency profile
- **PFC solution considerations**
  - Output power capability
  - Size
  - Complexity vs performance



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