High VOLT Interactive

Where power supply design meets collaboration

PFC for not dummies

Peter Meaney

What will I get out of this session?

- Purpose:

Examine key inputs to decide on a PFC solution

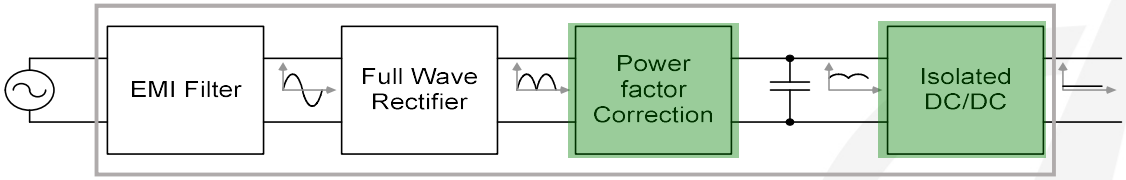
This presentation will help a designer understand trade-offs exploring real designs

UCC28180, UCC28050, UCC28063, UCC28070

TIDA-00701, TIDA-00443, PMP11064, PMP5568, PMP9640,

Industrial, Consumer, Appliances, Motor drive,

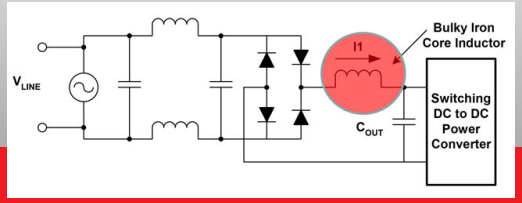
Offline AC/DC Power Supply & Charger >75W

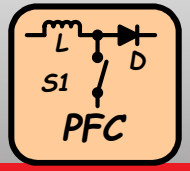


EXTERNAL Power Supply (Adaptor/Charger)

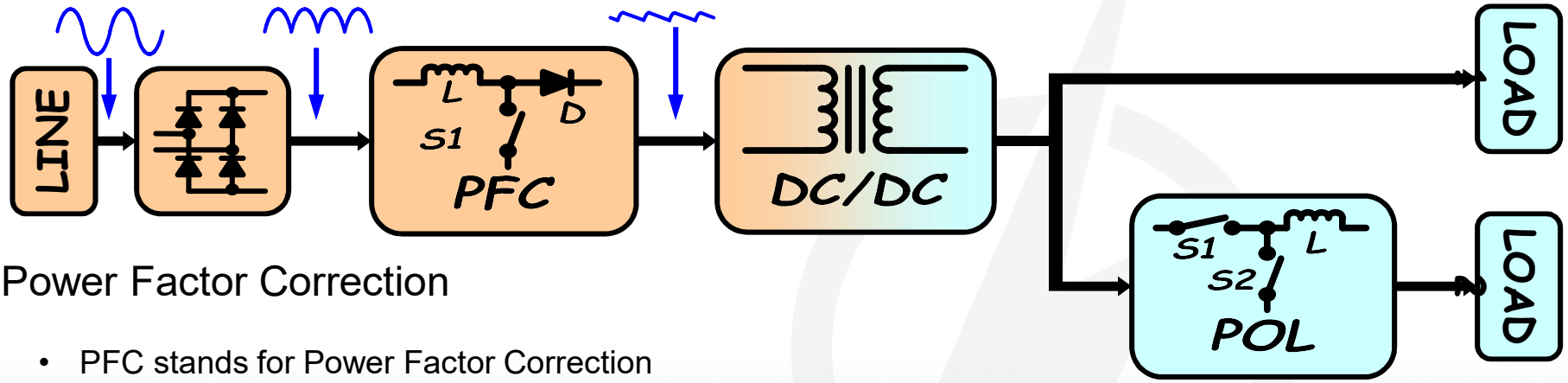
EMBEDDED Power Supply

- Universal input, 85 to 264 VAC
- Power factor correction stage required above 75W
  - Passive PFC (L, C), or Active PFC (AC/DC boost converter)





- Various Isolated DC/DC power topologies, based on power-level/cost
  - Flyback,
  - Half-Bridge or Full-Bridge
  - Soft-switching (LLC, Phase Shift Full-Bridge)
- HPC controllers for various PFC and DC/DC topologies



Power Factor Correction

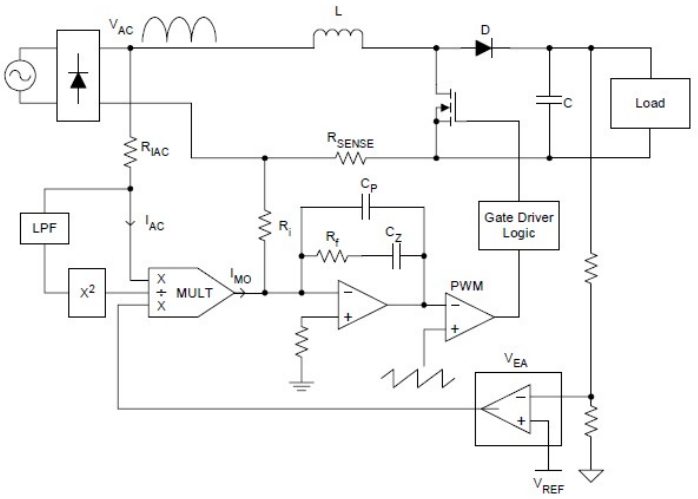
- PFC stands for Power Factor Correction
- Front-End Converter interfaces directly with the utility line
- Utility line can be 115V, 60 Hz or 230V, 50 Hz (many other combinations exist)
- Universal Voltage Range - 85-265V AC (50/60 Hz)
- Some applications like avionics use 400 Hz or higher frequencies

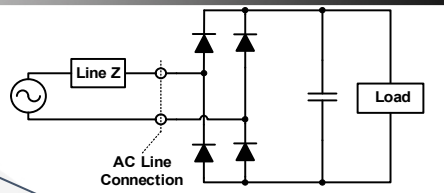
Non-PFC vs PFC

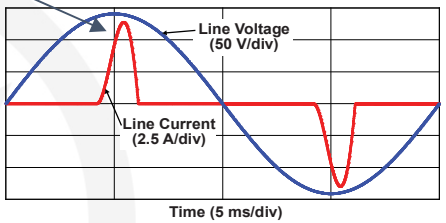
- Non-PFC Waveforms
  - Typical PF ~ 0.5 - 0.6
  - Narrow conduction angle
  - High harmonic content
  - High rms current
  - Increased system distribution loss
  - Distorts line voltage

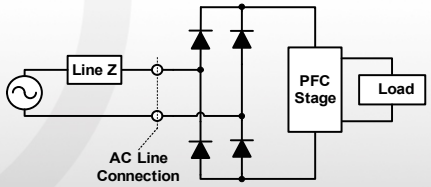
- PFC-Waveforms
  - Target unity PF – sinusoidal current, in-phase, no higher-order harmonics
  - Wider conduction angle
  - Lower harmonic content
  - Lower rms current
  - Lower distribution loss
  - Two control loops
    - Regulate input current to follow a Sine wave, faster loop
    - Regulate output voltage to be DC, slow loop

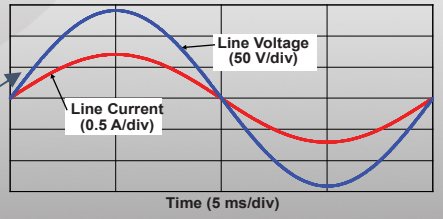
No PFC, current flows to charge the capacitor when the instantaneous AC voltage exceeds the voltage on the capacitor (peak charging).









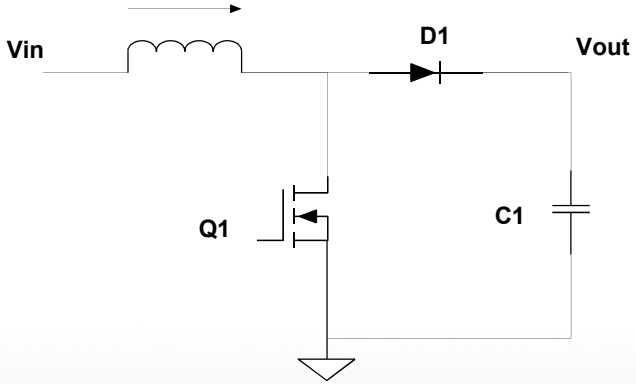


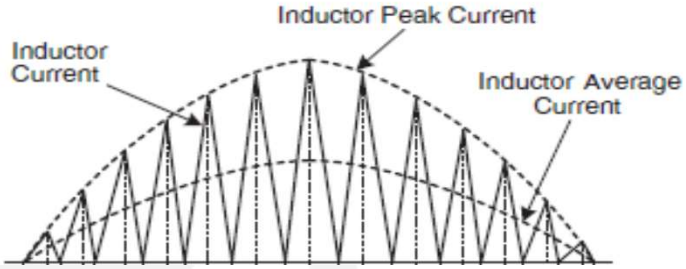
Match Current to Voltage

Types of Active PFC Control

- **BOOST or BUCK PFC topologies**
  - Boost PFC is by far most common, ideal for medium to high power
  - Boost DC voltage output must be higher than the maximum line peak voltage otherwise you will introduce distortion (harmonics)
    - Boost to 400VDC is a typical value for 85 to 265V or wide range mains applications
  - Buck PFC for 30-90W Applications, but uncommon
    - Lower voltage results in smaller inductor and capacitor values
- **Two common Operational Modes for Active PFC**
  - Transition Mode (TM) - or sometimes called Boundary Conduction Mode (BCM) or Critical Conduction Mode (CrCM)
  - Continuous Conduction Mode (CCM)
- **For scaling up power:**
  - Interleave PFC
  - Parallel PFC

Transition Mode Boost PFC





Transition Mode PFC (TM) Characteristics

- Zero Current Switching (ZCS) on MOSFET
- Provides PF of 0.90 or better
- Naturally variable frequency
- The TM boost has an inductor ripple of 200%

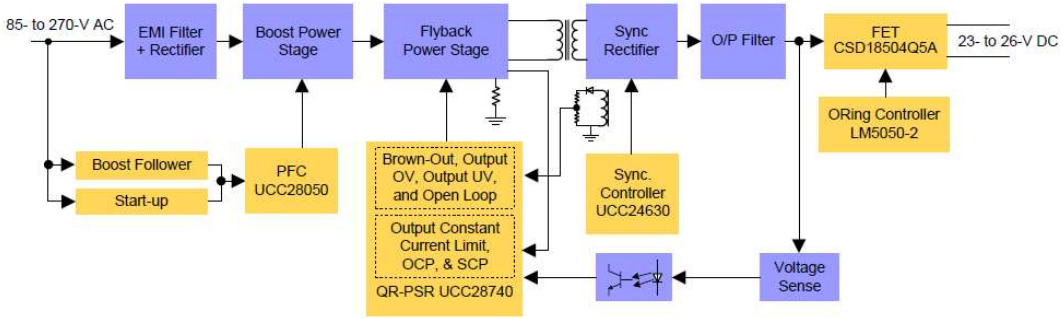
Pros

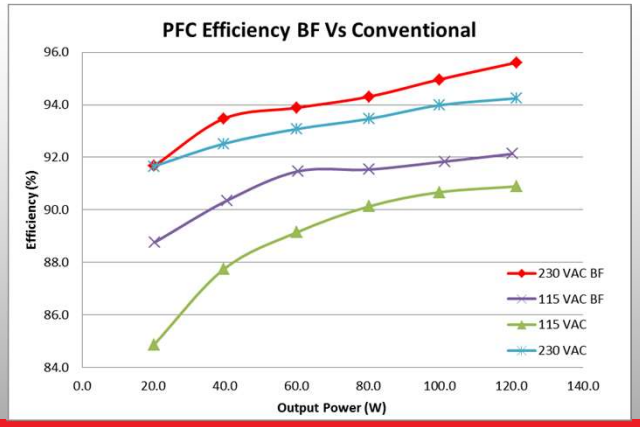
- Simple Design, no current loop
- Smaller inductor
- Lower Cost
- Lower cost boost diode
  - No Reverse Recovery

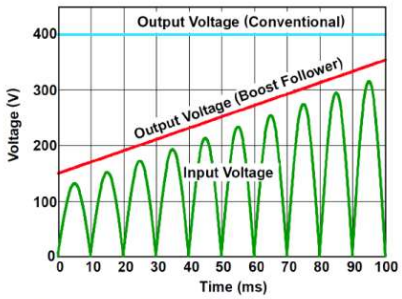
Challenges

- High Ripple Current
- High Peak Currents
- Large EMI Filter

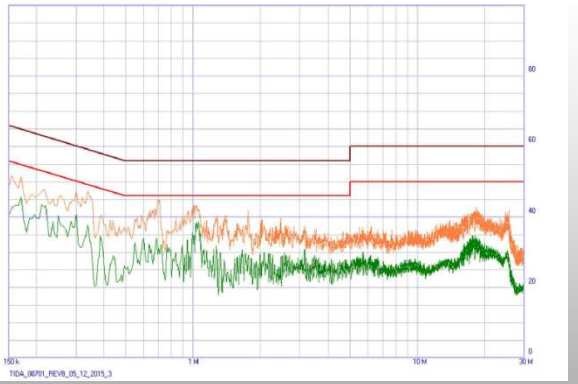
100W, 24V Industrial Power Supply TIDA-00701







Variations of Tradition PFC Boost and PFC Boost Follower With Input Voltage

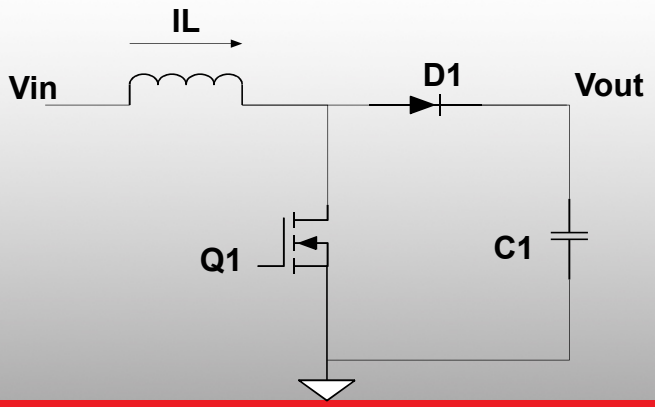


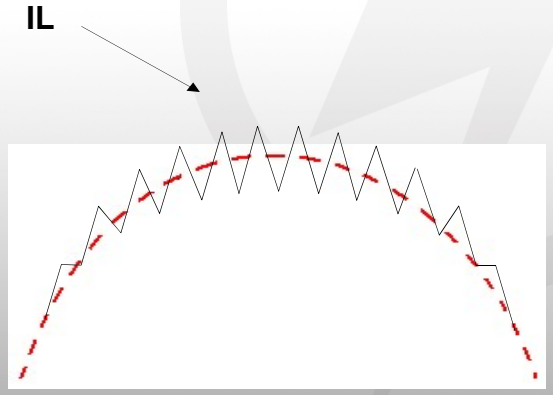
Continuous Conduction Mode Boost PFC

Continuous Current means that the boost inductor always has some average current in it except near zero voltage crossing

Characteristics

- Operates Fixed Frequency
- Provide PF of near unity (1)
- The Inductor size is designed with 20% to 30% inductor ripple





Pros

- Higher Density
- High PF
- Smaller EMI filter
- Lower Ripple Current

Challenges

- More Complex – Voltage loop & current loop
- Larger Inductor
- More Expensive
- Ultra Fast recovery Diode, low Qrr (Reverse recovery), SiC

900W, PFC 98% Efficiency for Inverter Fed Drives TIDA-00443

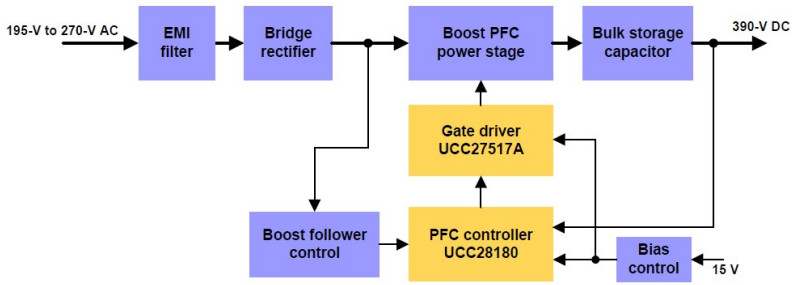
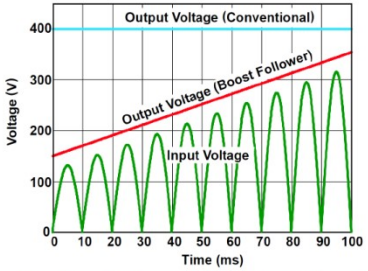


Figure 1. Block Diagram of PFC Regulator for Inverter Fed Drives



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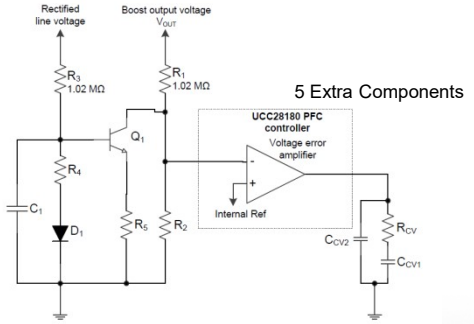
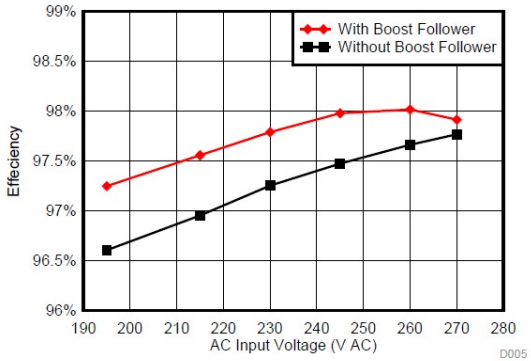
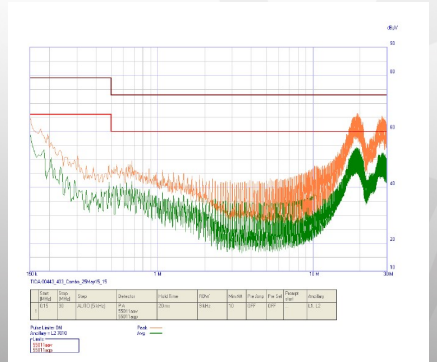
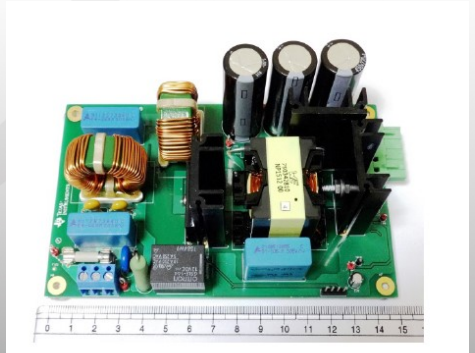






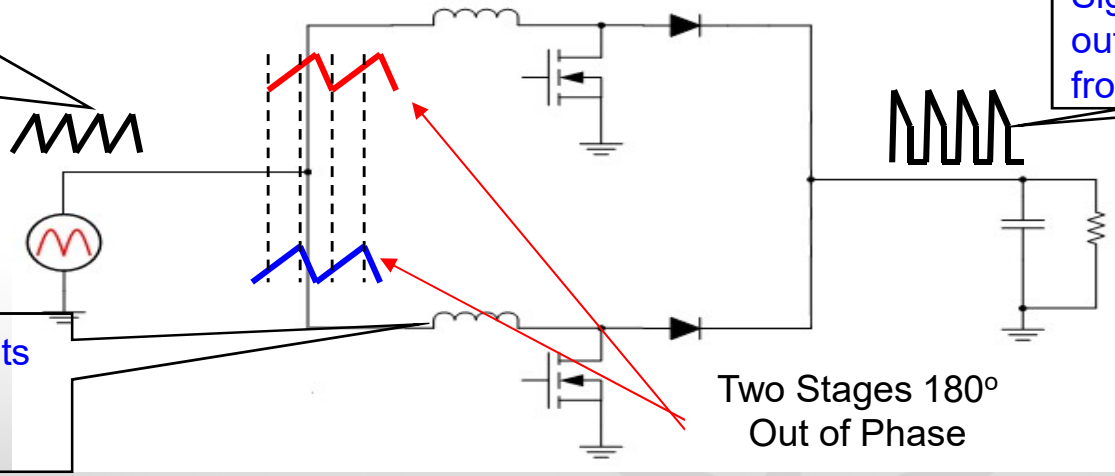


Interleaved PFC Concept

Operate Two PFC Stages 180° Out of Phase – (Works with CCM and TM types)

Cancellation produces Significant input ripple current reduction

Significantly lower output ripple current from cancellation



Output Caps

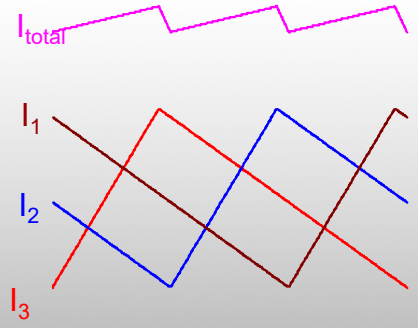
- Distributed components
- Improved thermal management

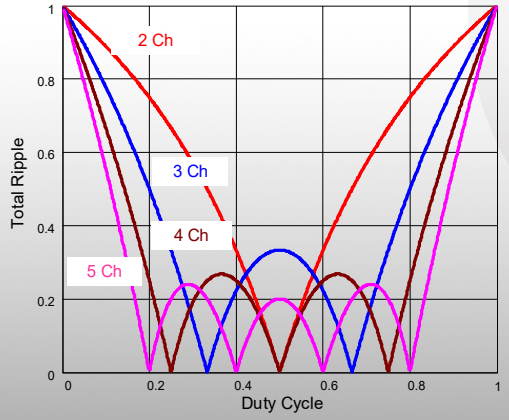
Input and Output Ripple Current Cancellation which allows:

- Physically smaller EMI filter
- Physically smaller output capacitors (less power dissipated because of less ripple current through the caps)
- Physically smaller boost inductors because the current is split in two phases

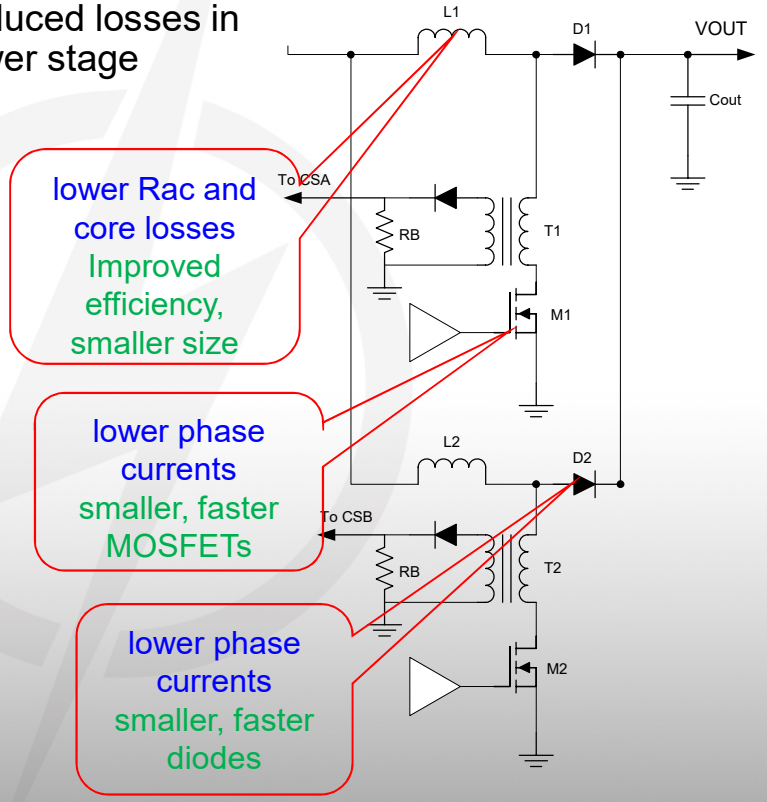
Ripple Current Cancellation by Interleaving More Channels

- Interleaving more channels, HF ripple currents still cancel with each other
- Total ripple cancellation is achievable at certain duty cycles
- No reduction on 100/120Hz ripple





Reduced losses in power stage



lower Rac and core losses
Improved efficiency, smaller size

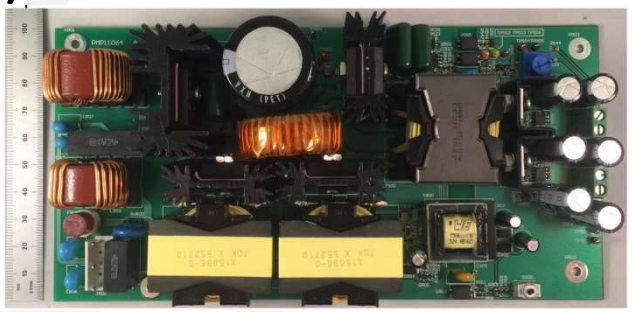
lower phase currents
smaller, faster MOSFETs

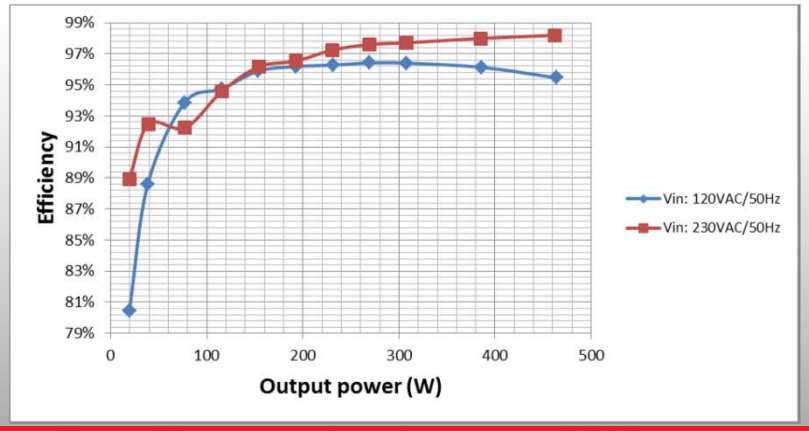
lower phase currents
smaller, faster diodes

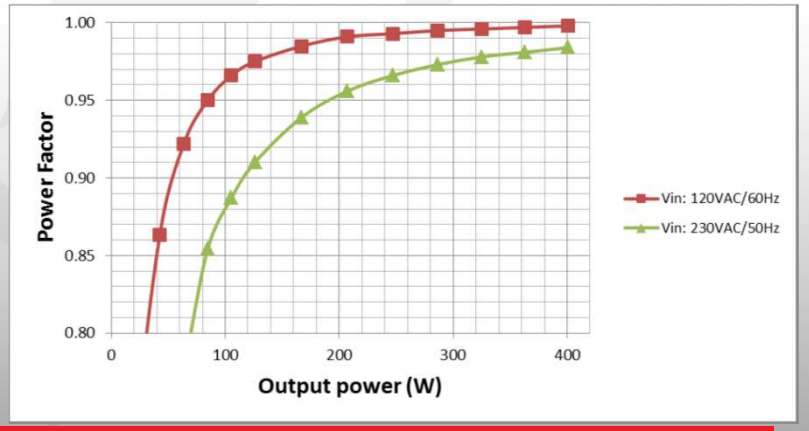
High Efficiency 400W AC/DC Power Supply PMP11064

Features

- 400W 20V/20A PSU with interleaved transition mode PFC UCC28063 and LLC-SRC
- 91.2% efficiency at 120VAC/60Hz and full load
- 93.1% efficiency at 230VAC/50Hz and full load
- 100mm x 200mm board dimension





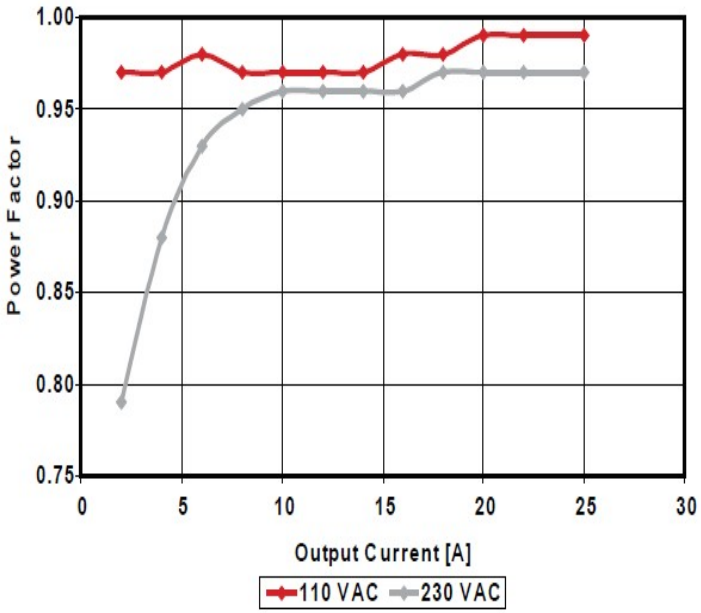


350W Offline High Performance Power Supply PMP5568

Features

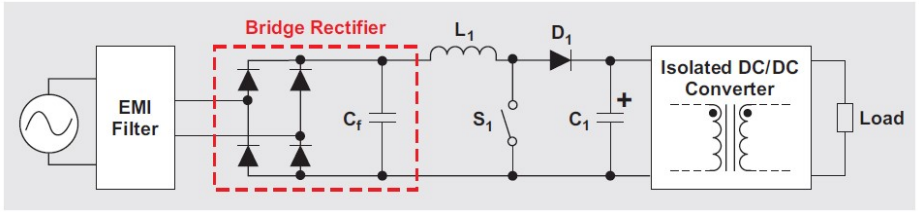
- Fanless, 1U height (1.752”)
- Efficiency +93% at high line (plug-to-plug)
- Interleaved CCM PFC using UCC28070 + Phase Shifted Full Bridge with UCC28950:
- System Monitoring & Control by MSP430F2252:
- AC input voltage & intermediate PFC voltage via isolated I2C-interface Output voltage & current Temperature of left/right heat sink and case temperature
- Output voltage is adjustable between 12 and 14V with a resolution of 100mV
- All controllers are synchronized by µC; switching frequency could be adjusted for “out of RF band operation”

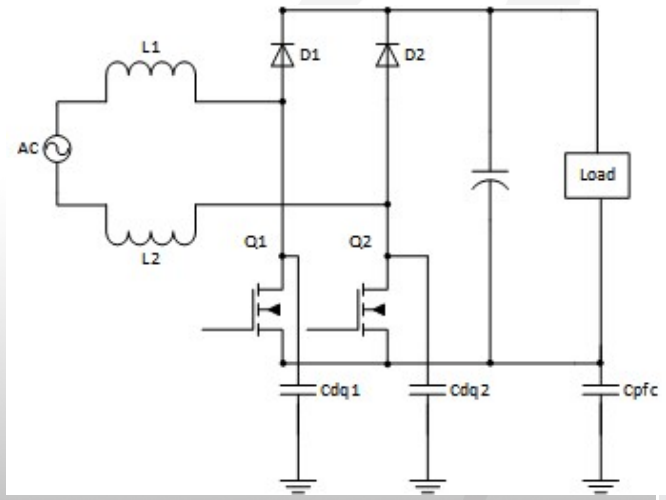
µC is able to vary the switching frequency, too (“Dithering”)

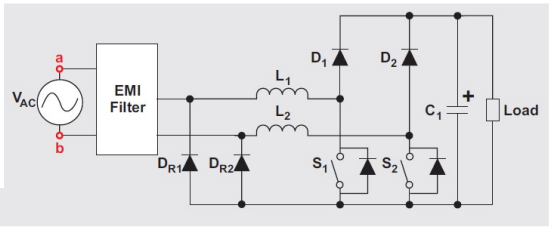


Bridgeless PFC

- Circa 1% higher efficiency than conventional PFC at 100W to 300W
- Same PWM signal can be used to drive both MOSFETs, reduced control complexity and cost.
- Over 97% efficiency can be achieved with the TM-bridgeless PFC at 120 VAC
- BUS is not connected to AC line, Cdq1&2 and Cpfc parasitic capacitance allow CM currents to return to ground
- Slow-recovery return diodes, DR1 and DR2 are added to link the PFC ground to the input line. Simplifies AC line sensing and EMI.

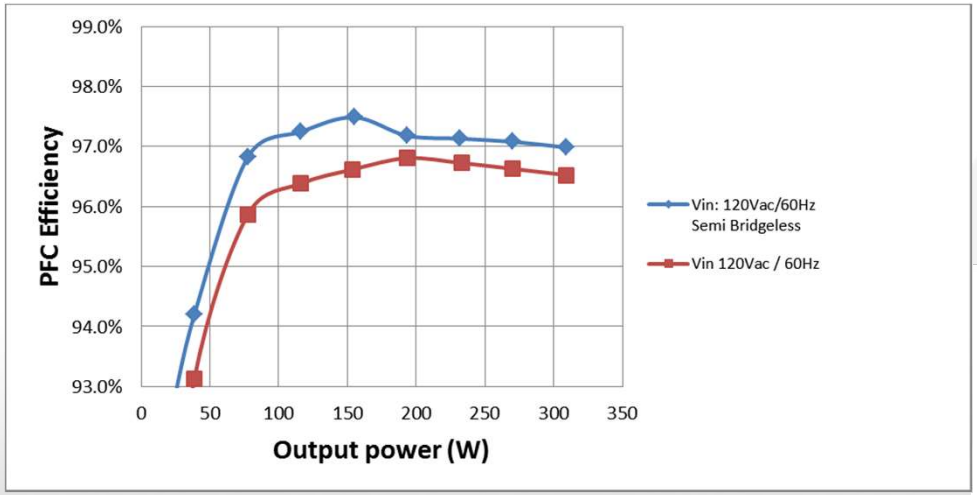


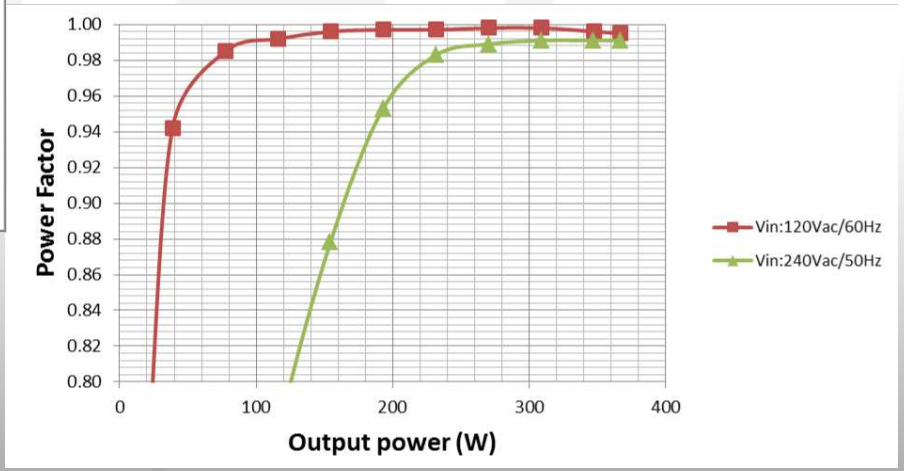




http://www.ti.com/lit/an/slyt599/slyt599.pdf

310W PSU TM Bridgeless PFC and LLC-SRC, 28V PMP9640





http://www.ti.com/tool/PMP9640

http://www.ti.com/product/UCC28051/datasheet

New PFC Development Trends

Transition-Mode Totem-Pole PFC (for MHz PFC design)

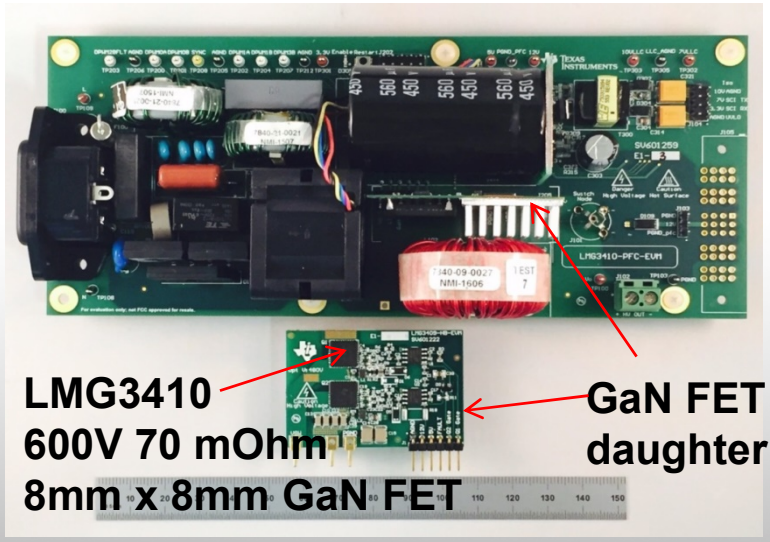
- ZVS operation for MHz switching design
- Interleaved configuration for high power applications.
- Variable frequency control
- Phase shedding and adding to optimize light load efficiency
- Suitable for Si MOSFET applications

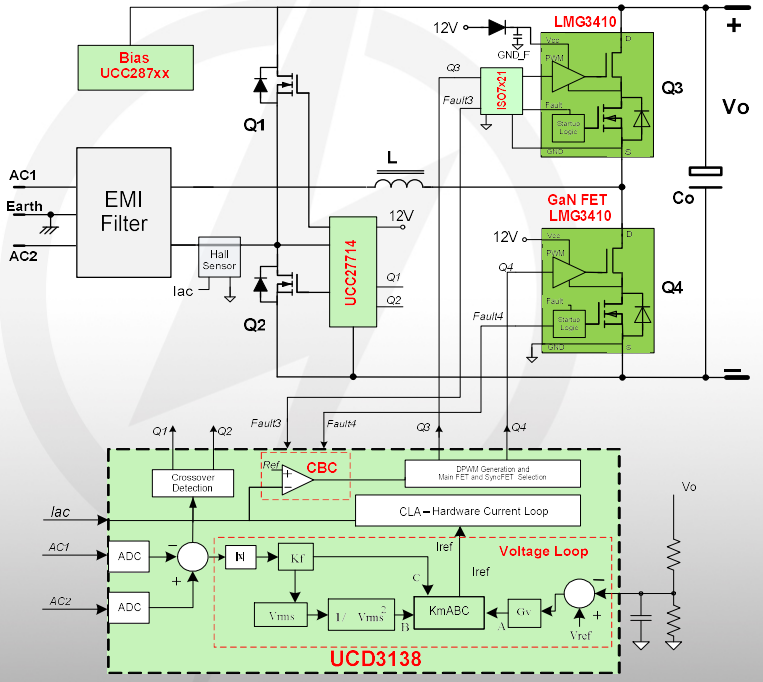
Continuous-Conduction-Mode Totem-Pole PFC (for <150KHz design)

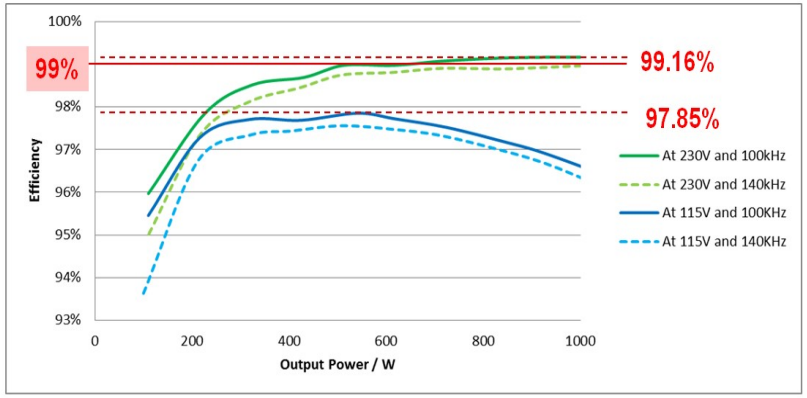
- Low component count
- Fixed switching frequency, zero reverse recovery switch should be used
- GaN is a good candidate for the application
- Possible to operate TM and ZVS at light loads

99% Efficiency 1kW Totem-Pole PFC Prototype

Frequency: 100 – 140KHz

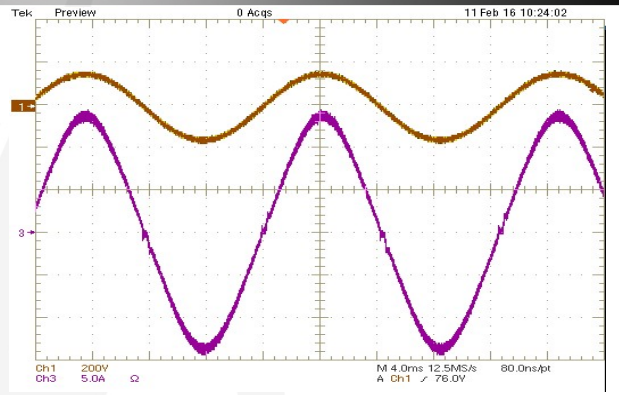




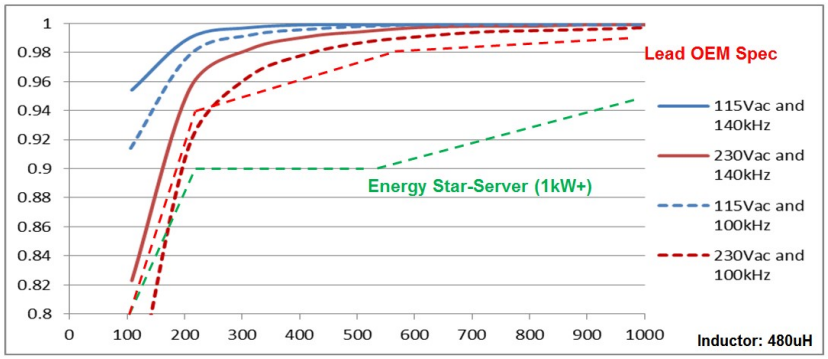


Efficiency

Note: Bias loss not included

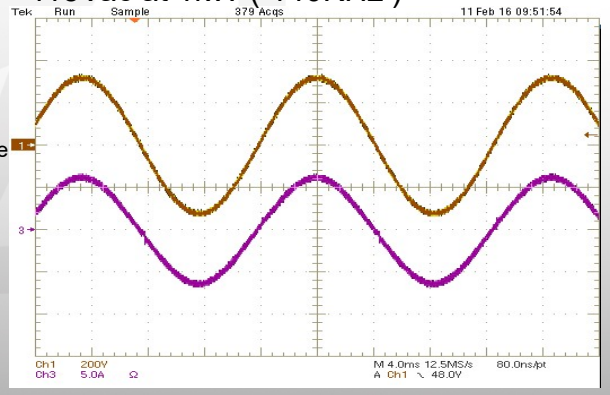


115Vac at 1kW (140KHz)



Higher switching frequency increases current loop bandwidth and improves PF.

Improving Power Factor by Using Higher fs



230Vac at 1kW (140KHz)

Conclusions & Key Take-Aways

- TM PFC most suitable for lower power, lower cost applications
- CCM PFC provides higher performance, power factor, compared to TM and can be scaled to from a few hundred watts to relatively high power, kW's
- Interleaving reduces ripple currents in the input and output stages as well as distributing thermal losses and help to reduce component size to help meet low profile form factors constraints
- Possible to implement bridgeless PFC with low cost controllers with efficiency gain
- Excellent performance in terms of efficiency and power factor possible with UCD digital control of totem pole PFC stage using GaN devices

Appendix

High VOLT Interactive

UCC28050/1 – Transition Mode PFC Controller

Features

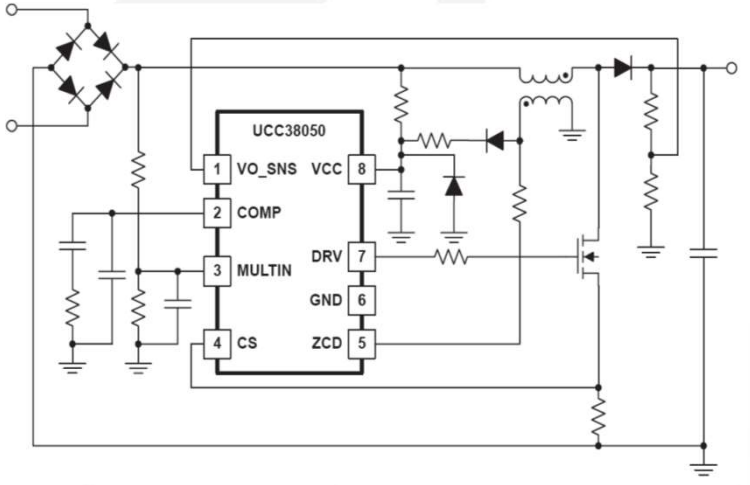
- Improved transient response with slew rate comparator
- Zero power detect to prevent OVP during light load conditions
- Accurate internal reference for tight output voltage regulation
- Two UVLO options
- Output over-voltage protection
- Open feedback protection and enable circuit
- ±750mA gate driver
- Low start-up and operating currents
- 8-pin PDIP (P) and SOIC (D) lead free packages

Application

- Digital TV
- AC-DC Adapters
- Electronics Ballast

Benefit

- Low cost 8-pin TM Power Factor Solution using Few External Components
- Industry pin compatibility with improved feature set



Texas Instruments

High VOLT Interactive

UCC28180 – Programmable Frequency CCM PFC IC

Features

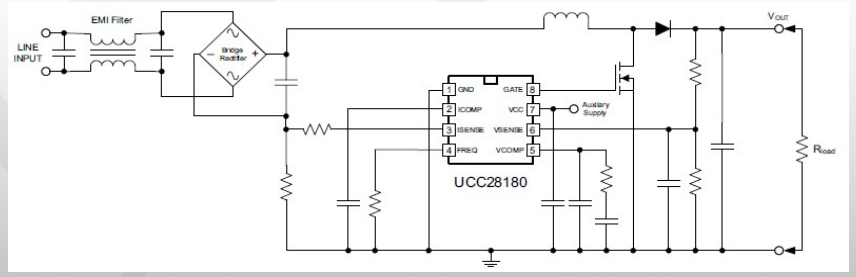
- Wide Range Programmable Switching Frequency (18KHz to 250KHz)
- Integrated 1.5ASRC/2A SNK integrated Gate Driver, with 15.2V Clamped output for IGBT drive
- Audible Noise Minimization circuitry
- Reduced Current Sense Thresholds
- Enhanced Dynamic Response During load transient
- Trimmed Current Loop Circuit for low iTHD
- Rich Protection Functions

Application

- Universal AC Input, Boost PFC converters
- Server & Desktop Power Supplies
- White Good Appliances (A/C, Refrigerators)
- Industrial Power Supplies (DIN Rail)
- Flat Panel TV (PDP/LCD/LED) TVs

Benefit

- Flexible CCM PFC controller optimized for variety of applications
  - from 300W to few-kW, from IGBTs (18kHz) to GaN/SiC/Si switches (250kHz)
- Reduced Power Dissipation in current sense shunt, eliminates need for paralleled resistors
- Low iTHD (<5%, medium-to-full load)



Pin-to-Pin compatible with Infineon ICE2PCSO1/5

High VOLT Interactive

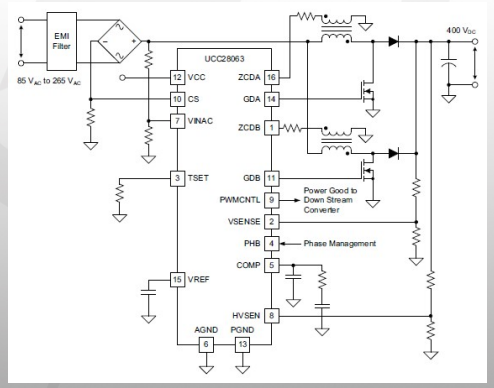
UCC28063 – 2-ph Interleaved Transition-Mode PFC Controller

Features

- TI Proprietary Natural Interleaving™ control
- Transition Mode PFC with Zero Current Turn-on
- Sensorless current shaping, with Crossover Notch Reduction for low iTHD (TON modulation)
- Phase Management at Light Loads
- Enhanced Dynamic Response non-linear gain of voltage error amplifier (5x @ +/-5% deviation)
- Protections: Failsafe OVP (dual path), AC Brown-Out & Drop-out, Pin Open/Short, Overcurrent, Thermal SD
- Power Good flag for downstream DC/DC

Benefit

- Interleaving offers smaller size Ls & Cs, higher power density & slim AC/DC designs
- Ripple current cancellation reduces EMI filter
- Control protocol offers inherently strong matching and 180° phase shift
- ZCS enables low SW loss, low COND loss even with Si diode & low-cost MOSFET



High VOLT Interactive

UCC28070(A) - 2-ph Interleaved CCM PFC Controller

Features

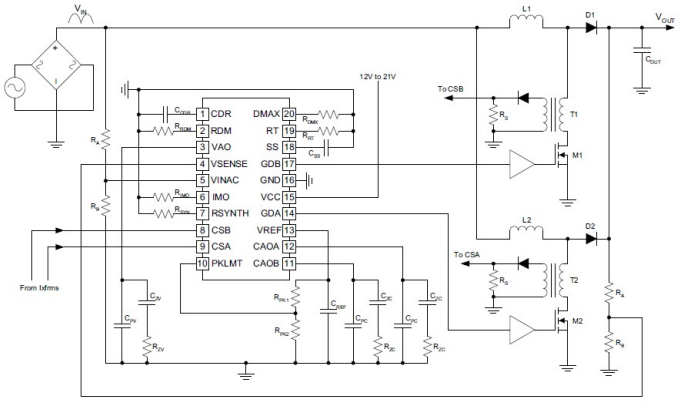
- Programmable switching frequency & MAX duty clamp
- External Clock Synchronization capability
- Enhanced Dynamic Response During load transient
- Frequency dithering (programmable rate, magnitude)

Application

- Universal AC Input, Boost PFC converters
- Server & Desktop Power Supplies
- White Good Appliances (air-conditioners, commercial refrigerators)
- Industrial, Welding Power Supplies
- Large screen Flat Panel TVs (PDP/LCD/LED)

Benefit

- Support for broad range of applications
  - few-100W to few-kW, IGBTs (10kHz) to GaN/SiC/Si switches (300kHz)
- No need for BST diode CT (current x-former)
- No VFF pin, reduced pin & BoM count
- Ease of filter design for EMI compliance



High VOLT Interactive

UCC28056 CRM/DCM Mixed Mode PFC Controller

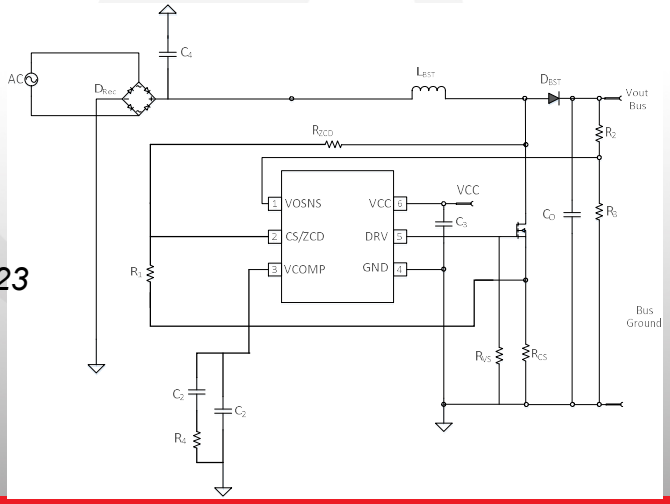
Features

- 6-pin TM PFC Controller with Valley Switching , Unity power factor and optimized THD
- <50mW no-load power consumption
- Fast, Enhanced Dynamic Response (non-linear control)
- Robust Protection:
  - Bypass diode short protection
  - Fast response 2nd OVP on a dedicated Pin
  - Cycle-by-cycle OCP with leading edge blanking
  - Soft-start and soft recovery after OVP
  - Input voltage brown out detection
  - Open-loop protection and under voltage protection
- Strong drive capability: -1.0A and 0.8A
- User tunable delay for precise valley switching
- Unified algorithm for working in CRM and DCM with High power factor across the entire operating range
- Industry best light load efficiency with advanced light load efficiency management
- No aux winding needed for ZCD
- Innovating DCM control law to prevent valley jumping within a single half line cycle

Benefits

- Provides High Efficiency & Low THD with Fewest External Components
- Superior No-Load and Light Load Efficiency
- Allows Fast Load Transient Response w/ Small Output Cap
- Option for UCC25630 to provide Vc to UCC28056
- No Inductor ZCD Winding Required Flexible Design Options
- Full, Robust Protection (Same as 8-pin PFC ICs)

SOT23

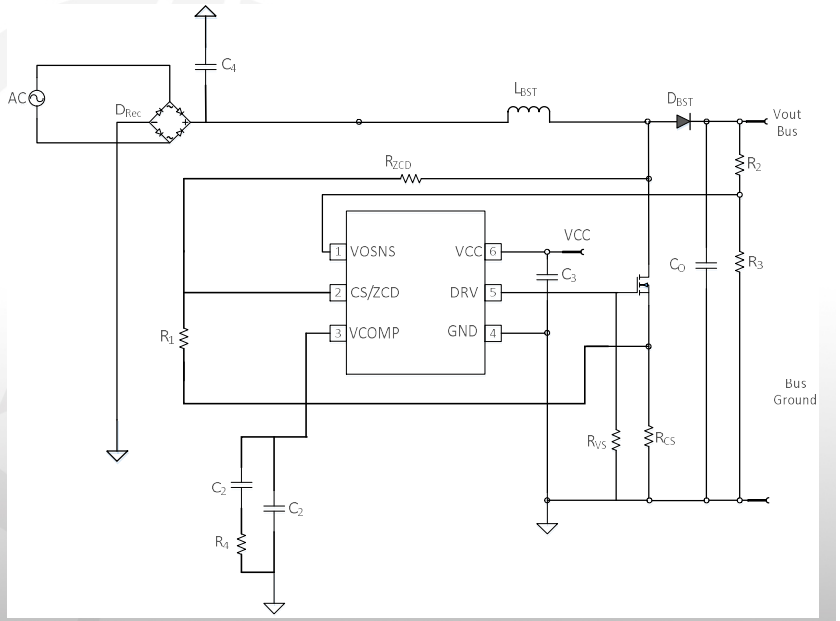


Texas Instruments

High VOLT Interactive

UCC28056 CRM/DCM Mixed Mode PFC Controller

1. **Best in class light load efficiency**
   - 6% higher efficiency than CRM
   - ~1.5% higher efficiency than NCP1602 @ High line
   - 0.5% Higher Efficiency @ Low Line
   - No compromise in heavy load efficiency
2. **Best In Class standby power**
   - PFC in burst mode during standby mode
   - <150mW standby power with PFC always enabled
   - <100uA of standby IC current consumption
3. **Best in class audibility performance**
   - Soft Burst mode transitions & constant TDCM and valley locking
4. **Reduce BOM cost**
   - 6 pin package (8 pin functionality)
   - No Aux winding needed for valley sensing
   - No opto-coupler needed (PFC always ON – eliminates need to shutoff PFC during standby



Sample 3Q17
MP 4Q17