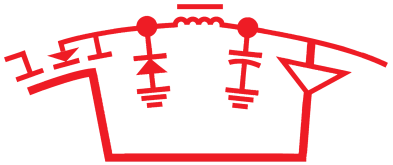


Power Supply Design Seminar

(Demo Hall Presentation)

Design review of 350 W CCM PFC + LLC Module

TI Literature Number: **SLUP361**

Power Seminar topics and online power training modules are available at:ti.com/psds

Texas Instruments

Design review of 350 W CCM PFC + LLC Module

Colin Gillmor, Systems Engineer

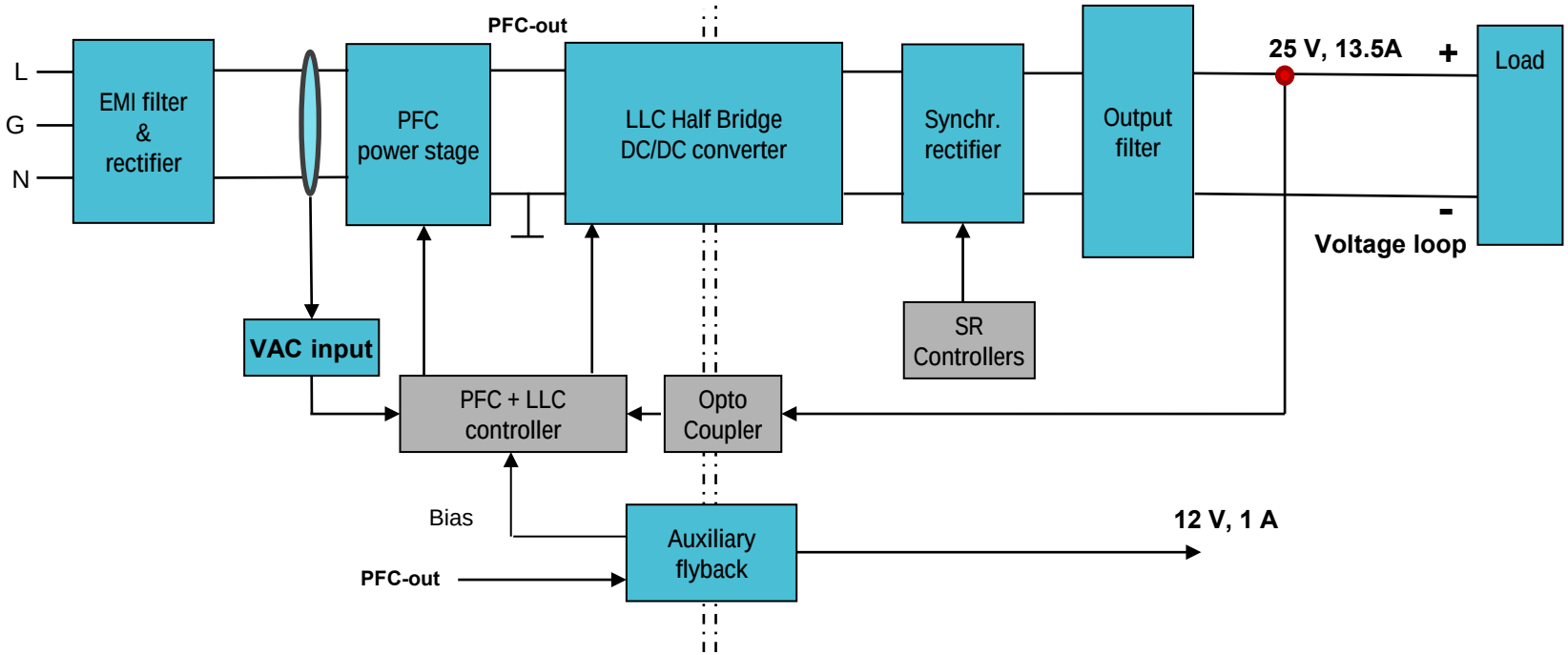
Agenda

- Introduction, Specification
- Topology Introductions:
  - PFC
  - LLC resonant Half Bridge
- Overall System
  - Loss mechanisms
  - Gate driver Options
  - Synchronous rectifiers, SR’s
  - Auxiliary Flyback
- Test data on 350 W module

Specifications

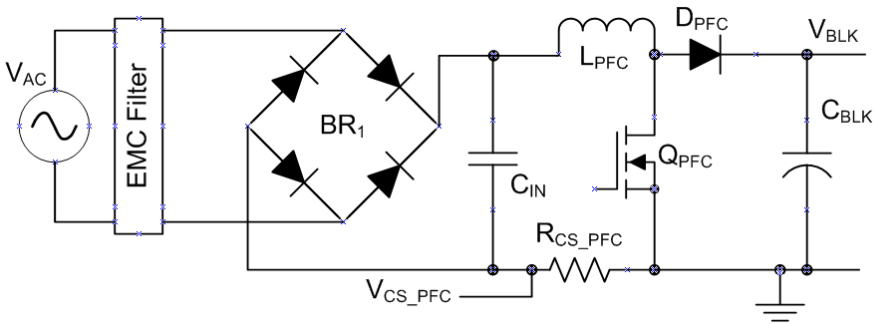
- Nominal input AC voltage: 230 VAC
- Working AC voltage: 90 VAC…265 VAC
- Output voltage 1: 25 V @ 13.5 A
- Output Voltage 2: 12V @1 A
- Harmonic limits: EN61000-3-2 Class A
- Output power: 350 W @ 230 VAC
- Efficiency: 93% peak efficiency, design also meet 80PLUS Gold requirement for 115 VAC Internal power supplies
- No Load Power: 152 mW@230 VAC, (PFC + LLC Off)

Block diagram



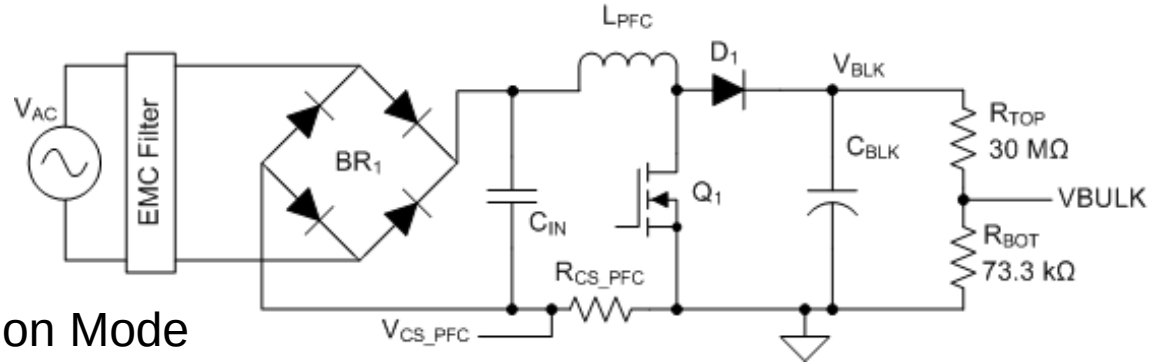
Boost PFC Topology

- Popular Because
  - o Sinusoidal AC line current
  - o Power Factor is high
- Output Voltage is higher than input
  - o Typically 380 V to 400 V
  - o Can provide hold-up time in the event of loss of AC line cycle



Boost PFC Topologies

- TM: Transition Mode
  - Variable Frequency
  - High Peak Currents
  - Low Cost Diode (D_1)
- CCM: Continuous Conduction Mode
  - Fixed Switching Frequency Eases EMI
  - Ultra Fast or SiC Diode (D_1)
  - Lower Peak Currents
- TM 75 W to 250 W
- CCM 250 W to 1 kW

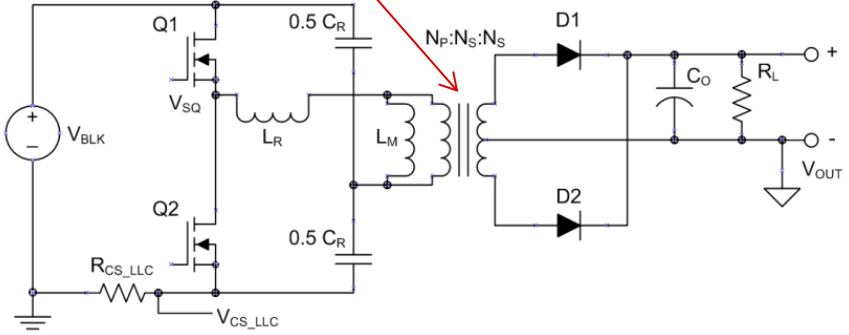


TM = Boundary Conduction Mode
= Critical Conduction Mode

LLC Topology

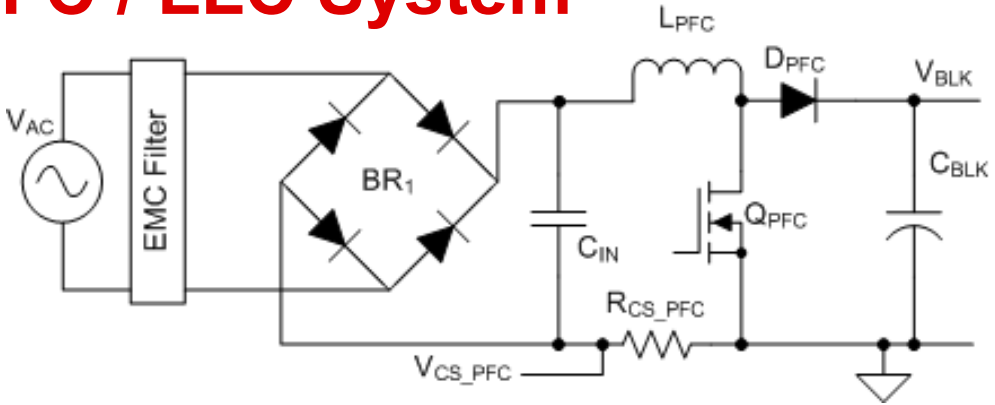
- Full AC/DC system uses a second stage to convert Boost PFC output to an ISOLATED output voltage.

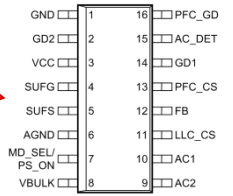
- The LLC Topology is popular because
  - o High efficiency, ZVS
  - o Low EMI
  - o Lower Component Stresses



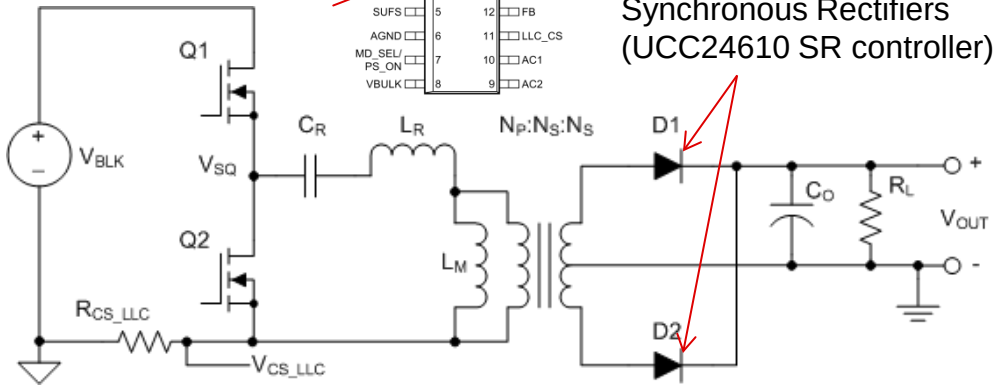
Design: Overall CCM PFC / LLC System

- CCM PFC front end
  - Power Factor Correction
  - V_{BLK} output to second stage
- UCC29950 Controller
- UCC27714 MOSFET Gate Driver
- LLC output stage
  - High Efficiency
  - Isolation



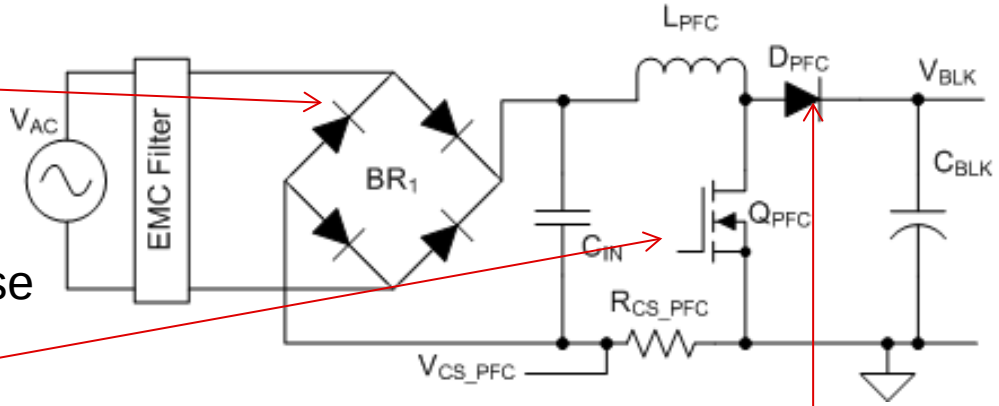


Diodes Or
Synchronous Rectifiers
(UCC24610 SR controller)



Efficiency: Main power loss components - PFC

- BR1
  - o Vf ≈ 1.4V to 2V
  - o Average Input Current
    - Low line, full load is worst case
- Q_{PFC}
  - o Switching loss
  - o Conduction loss
- Other Losses
  - o PFC Inductor
  - o EMC Filter
  - o Inrush Current Limiting (NTC)



D_{PFC}

SiC diode has Zero Reverse Recovery loss

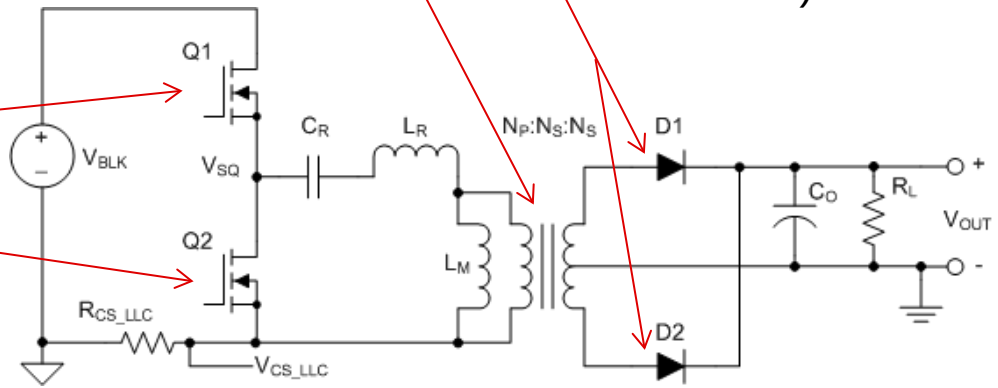
Does have Conduction loss

Efficiency: Main power loss components - LLC

- D1/D2
  - o Schottky Diodes
  - o Synchronous Rectifiers with UCC24610 SR controller
- Transformer
  - o Core losses
  - o Copper Losses
- Q1/Q2
  - o Conduction Loss
  - o Switching Loss

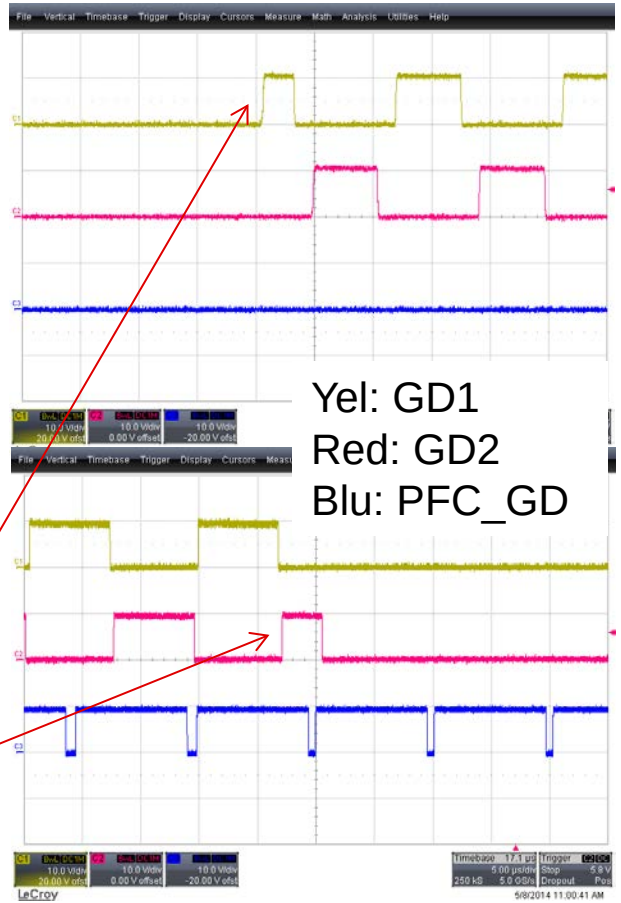
    Negligible if ZVS

Diodes Or Synchronous Rectifiers (UCC24610 SR controller)



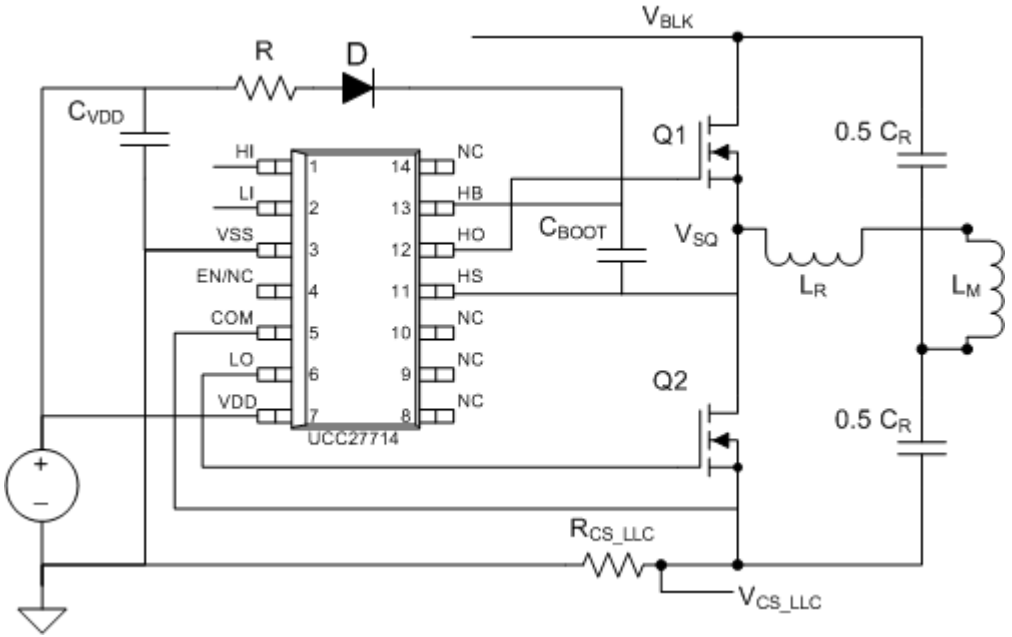
LLC Stage: Gate Driver Options

- UCC29950 on board driver – ok for PFC MOSFET
- External drivers
  - o UCC27714 – TIs first 600V MOSFET driver
  - o Require a VCC supply
- Gate Driver Transformer
  - o Simple, Low-Cost, Bulky
  - o No need for bootstrap cap or diode
  - o Transformer must be chosen carefully
  - o UCC29950 has half width initial and final pulses for transformer flux balancing

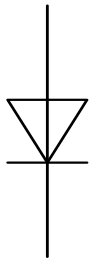


UCC27714: High Voltage Driver

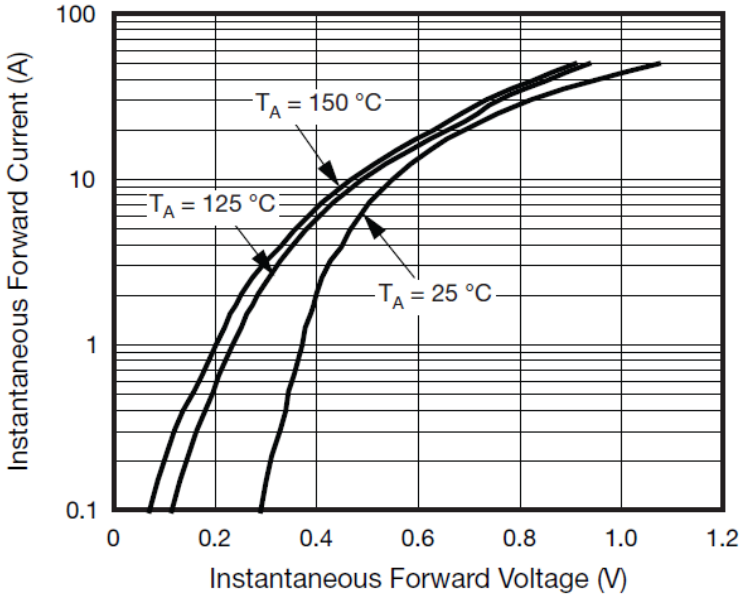
- C_{VDD} > 10*C_{BOOT}
- Position C_{VDD} and C_{BOOT} CLOSE to IC
- D, charging current into CBOOT
- R, limits current in D typ. 2 Ω to 4 Ω
- Voltage spacing at HB, HS, HO
- V_{CS_LLC} between COM and VSS
  - o VSS can be -6 V wrt COM
  - o HS can be -8 V wrt COM
- C_{BOOT} has to charge first so
  - o HO starts 20 µs to 40 µs after LO
  - o Normal for a High Side Driver

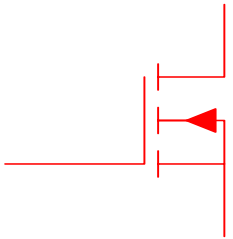


Schottky Diode vs. Synchronous Rectifier



V30100S-E3
100V, 30A TO-220



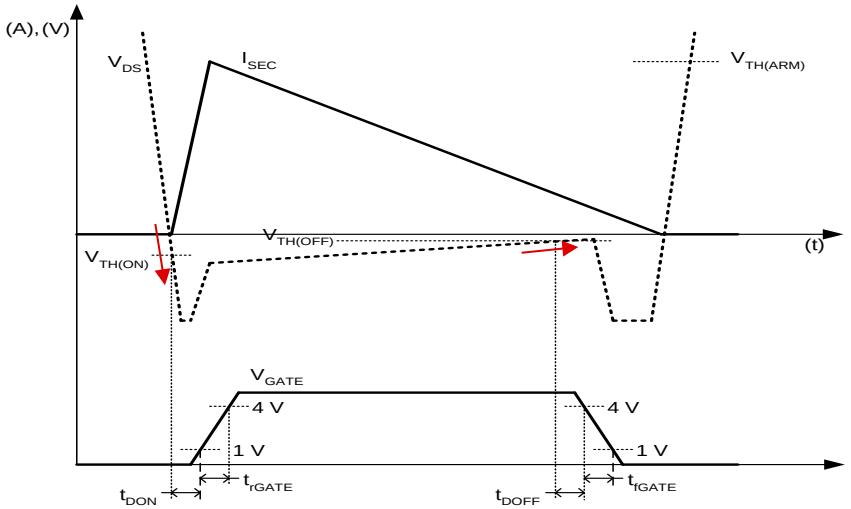


CSD19533KCS
100V, TO-220
RDS(on) = 17.5 mΩ @ 125°C

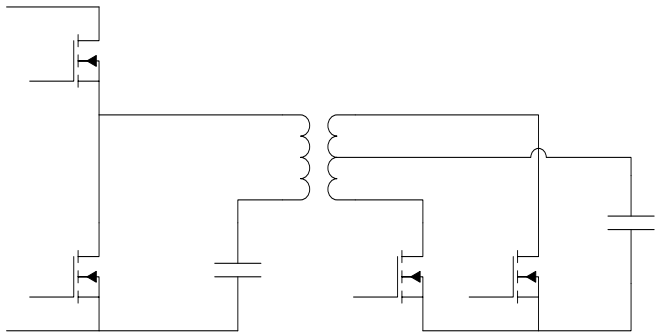
- By replacing diode with synchronous rectifier, the conduction loss can be significantly reduced by low on-resistance
- Higher efficiency can be expected, especially for low voltage applications

Vds Sensing Theory of Operation

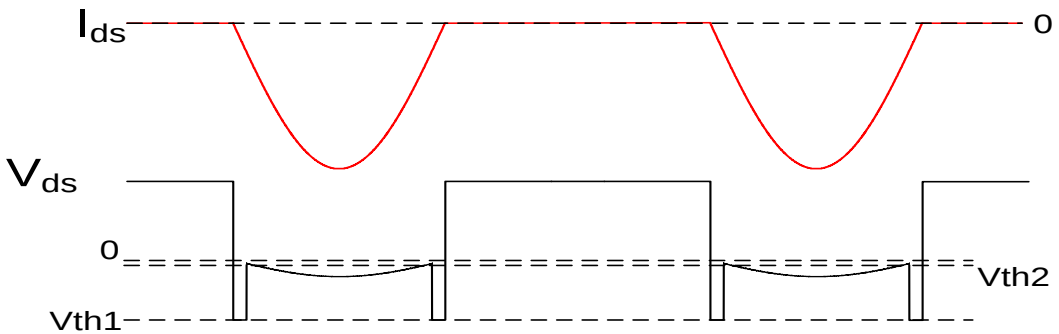
- The SR controller determines the conduction time of the SR MOSFET
  - o V_{DS} compared to internal turn-on and turn-off thresholds
    - GATE output driven high when
      V_{DS} falling = $V_{TH(ON)}$
    - GATE output driven low when
      V_{DS} rising = $V_{TH(OFF)}$
  - o Reduced Body diode conduction time… only:
    - During GATE turn on propagation delay (t_{DON}) and rise time (t_{rGATE})
    - After V_{DS} rising crosses $V_{TH(OFF)}$
- Multiple modes of operation provide highest efficiency over entire operating range



Special Current Waveform- LLC Resonant Converter



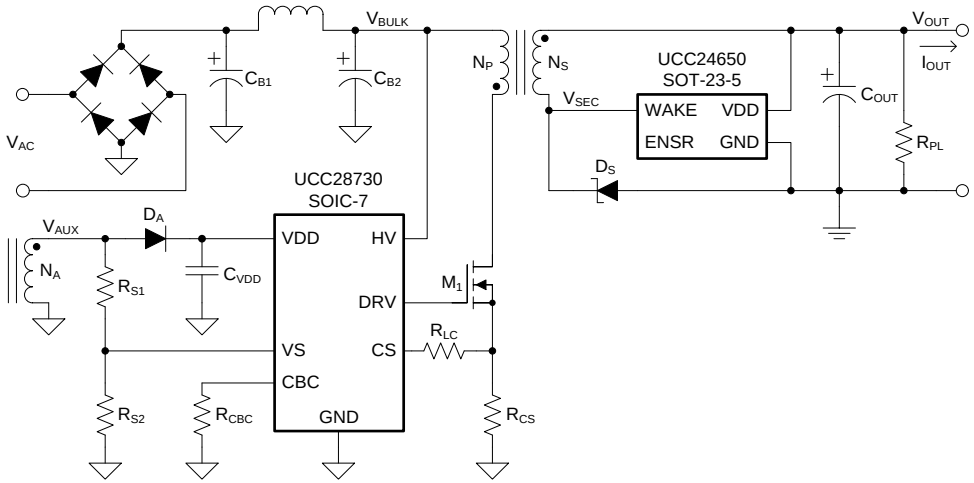
LLC Resonant Converter



SR voltage and current

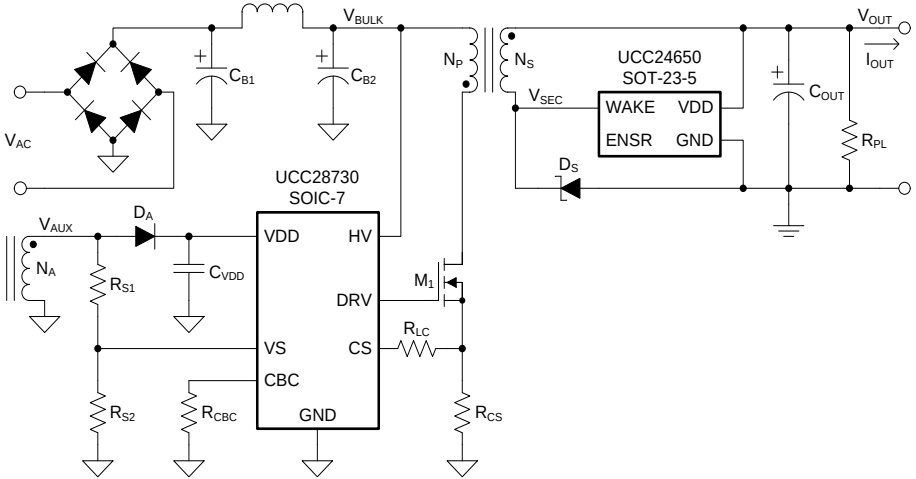
- Due to sinusoidal shape current, when SR turns on the initial voltage drops are very low and IC could interpret this as current approaching zero threshold and turn off the SR too soon
- To avoid early turn-off, a minimum on-time is required until current rises above turn-off threshold (Vth2)

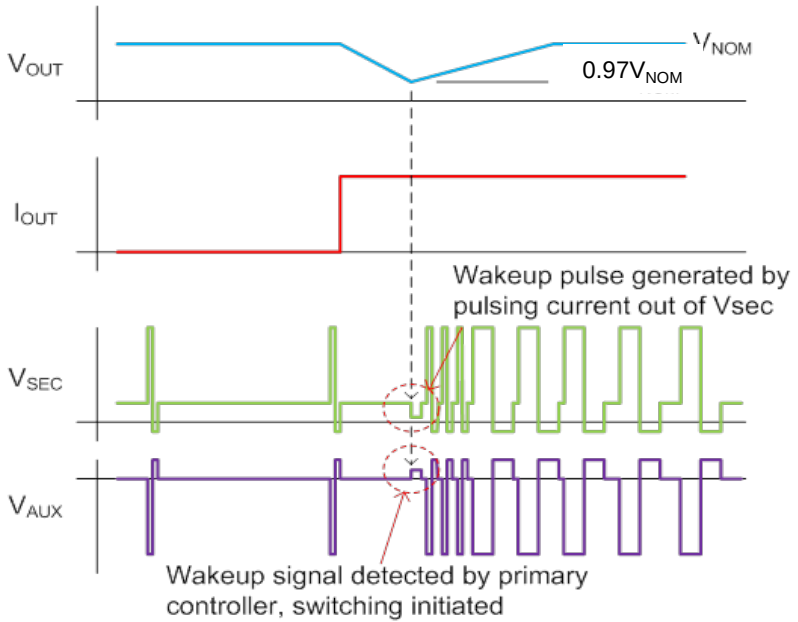
Auxiliary Flyback – UCC28730 + UCC24650



- UCC28730/UCC24650 chip-set is compatible with Diode and Synchronous Rectifier applications
- UCC24650 ENSR can disable UCC24610 to reduce standby power and enable it when a load-step “wakes up” the system
- Test Data from 5 V/10 W Design with Diode Rectification = 2.9 mW @ 230 VAC
- Test data for 10 W with UCC24610 Synchronous Rectifier = 3.5 mW @ 230 VAC

Typical Application



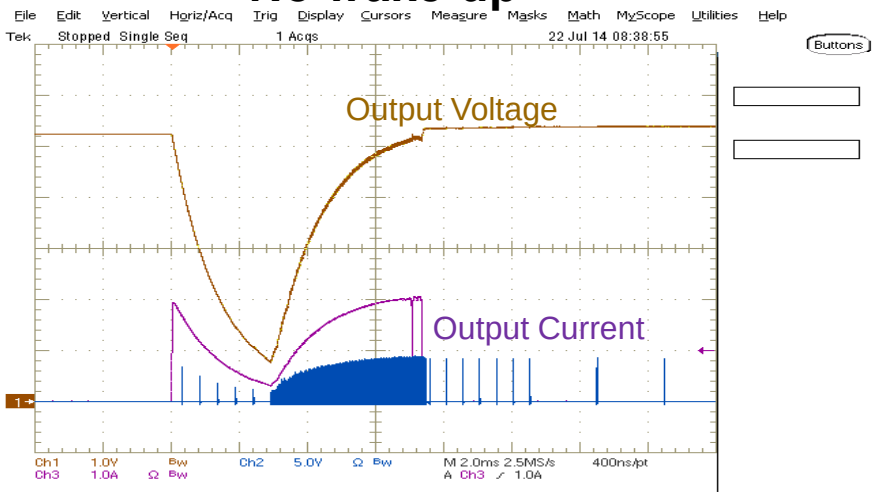


UCC28730: 30 Hz to 83 kHz

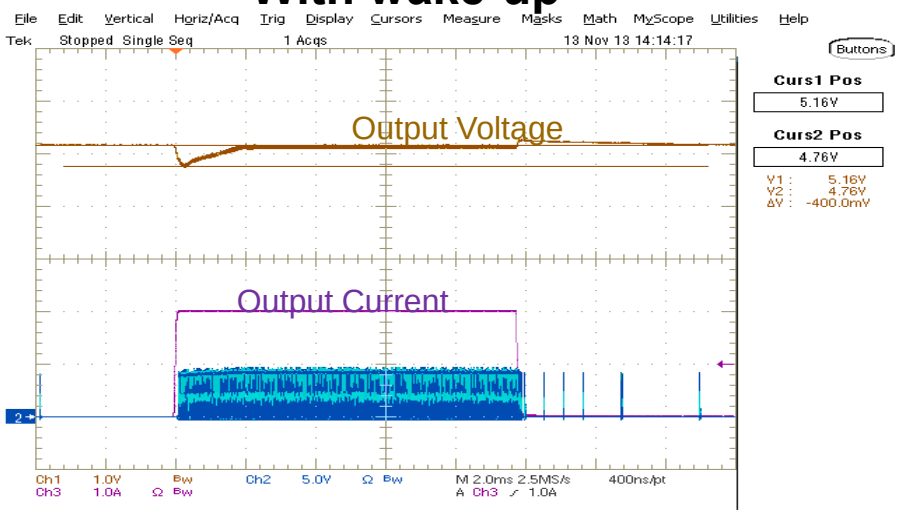
When Wake-Up signal is detected by UCC28730, switching resumes at f_{MAX}, $I_{PK,MIN}$

Transient Response Comparison

No wake-up



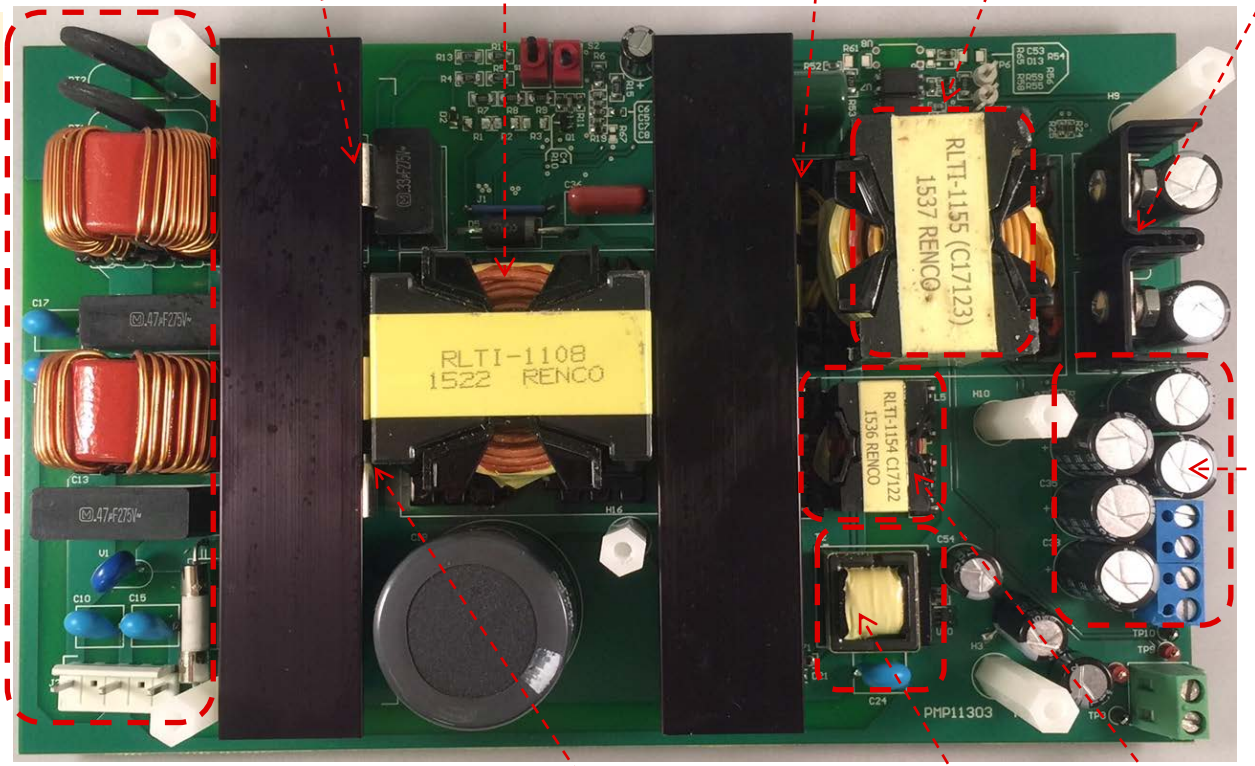
With wake-up



Response to 0-2 A load step without Wake function. Vout droops -4.36 V from 5 V before control-loop can respond to restore regulation.
Cout = 540 uF

Response to 0-2 A load step with Wake-Up function. Vout droops only -0.40 V from 5 V before control-loop responds to restore regulation within 2 ms.
Cout = 540 uF

PMP11303



Bridge

PFC BOOST

LLC FETs

Main transformer

Sync. FETs

EMI Filter & inrush limit

Output caps

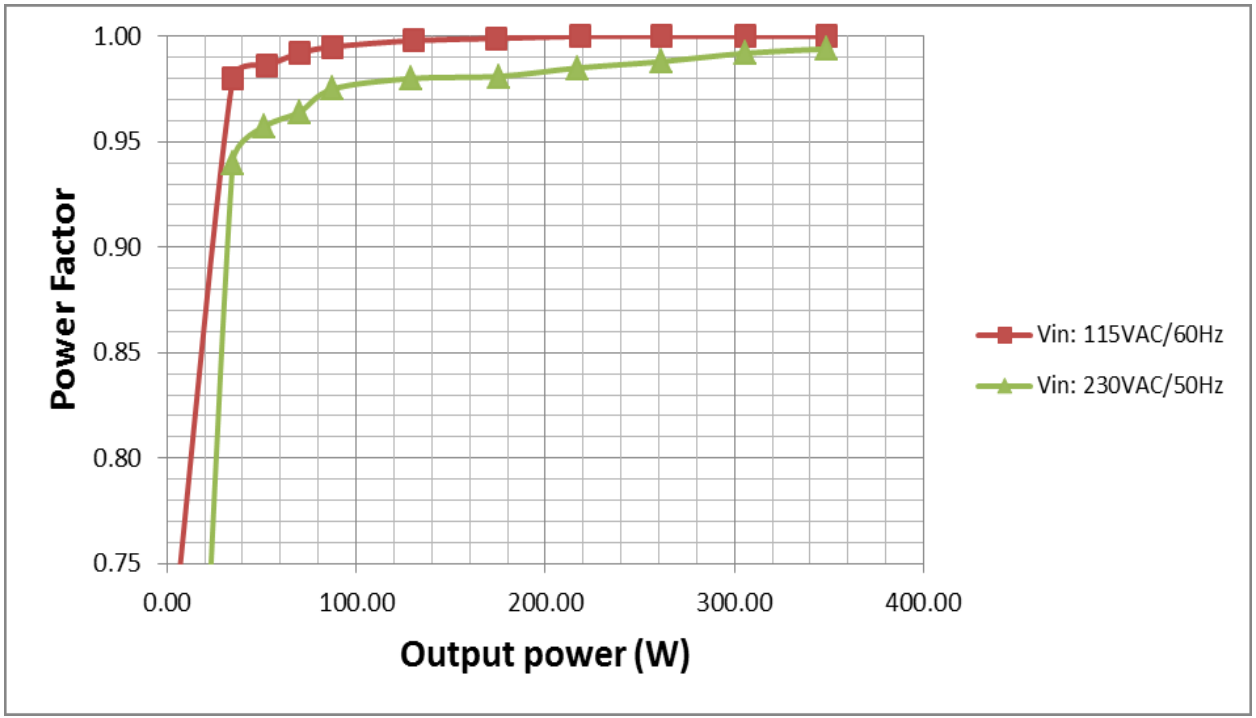
PFC FETs and diode on heatsink

LLC Resonant Inductor

Aux. power supply

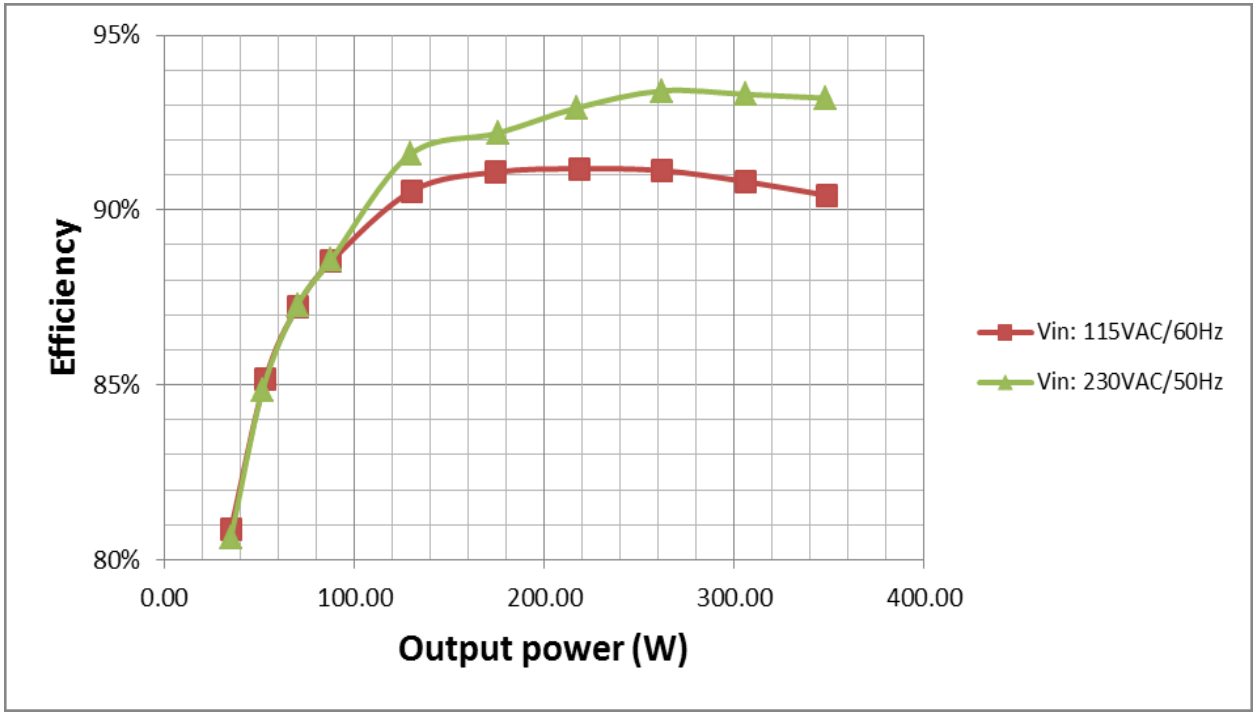
Module Test Data

Power Factor 115V & 230Vac



Module Test Data

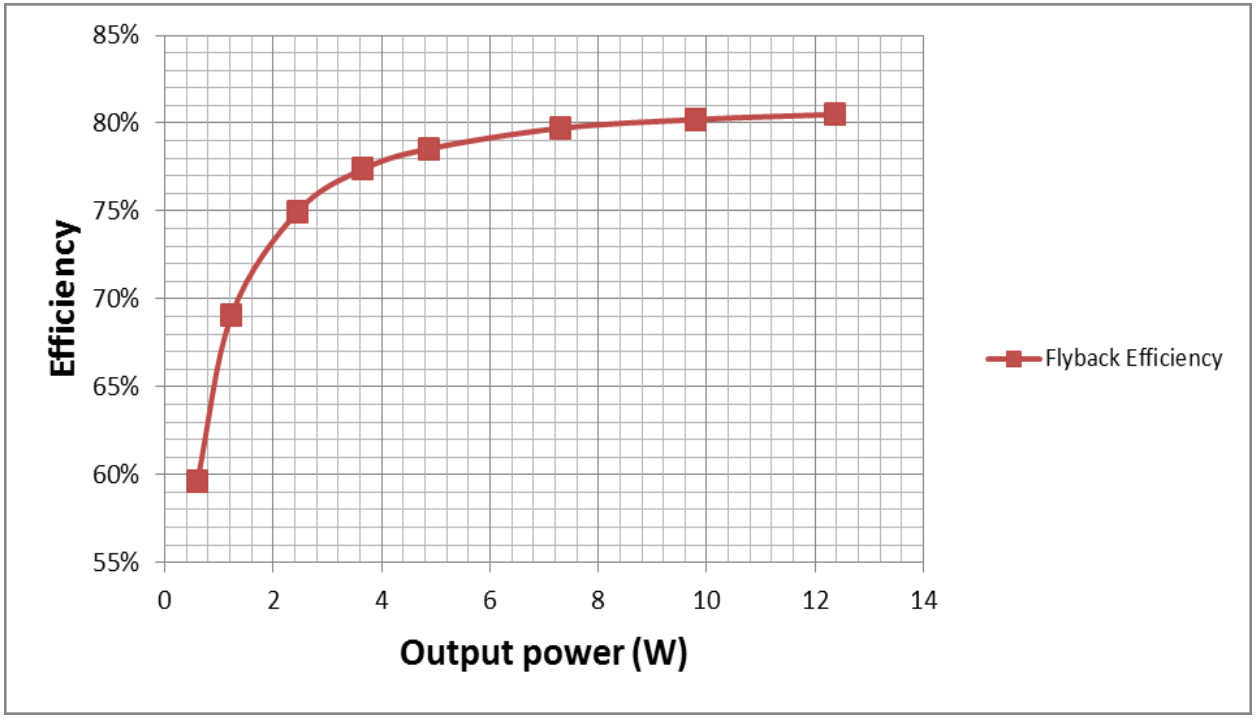
Active mode Efficiency: Total (PFC+LLC+Flyback)



	115V		
	20%	50%	100%
80 Plus Gold	87%	90%	87%
PMP11303	87.24%	91.08%	90.42%

Module Test Data

Standby mode Efficiency: Flyback Converter



No load power consumption at 230VAC/50Hz: 152mW

PSON signal was low to disable PFC and LLC operation

Summary

- Complete design of 350W AC/DC module: **PMP11303**
- A single centralized controller for PFC and LLC stages: **UCC29950**
- High voltage half-bridge driver for LLC MOSFETs: **UCC27714**
- Primary side regulated Flyback controller for bias supply with 5% voltage accuracy and low standby losses: **UCC28730**
- SR MOSFETs with V_{DS} voltage sensing SR controller to enable low output rectifier losses: **UCC24610**

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