



Ultra-High Power Density Power Supplies with Totem-pole PFC & LLC 超高功率密度图腾柱PFC和LLC电源

April 2023

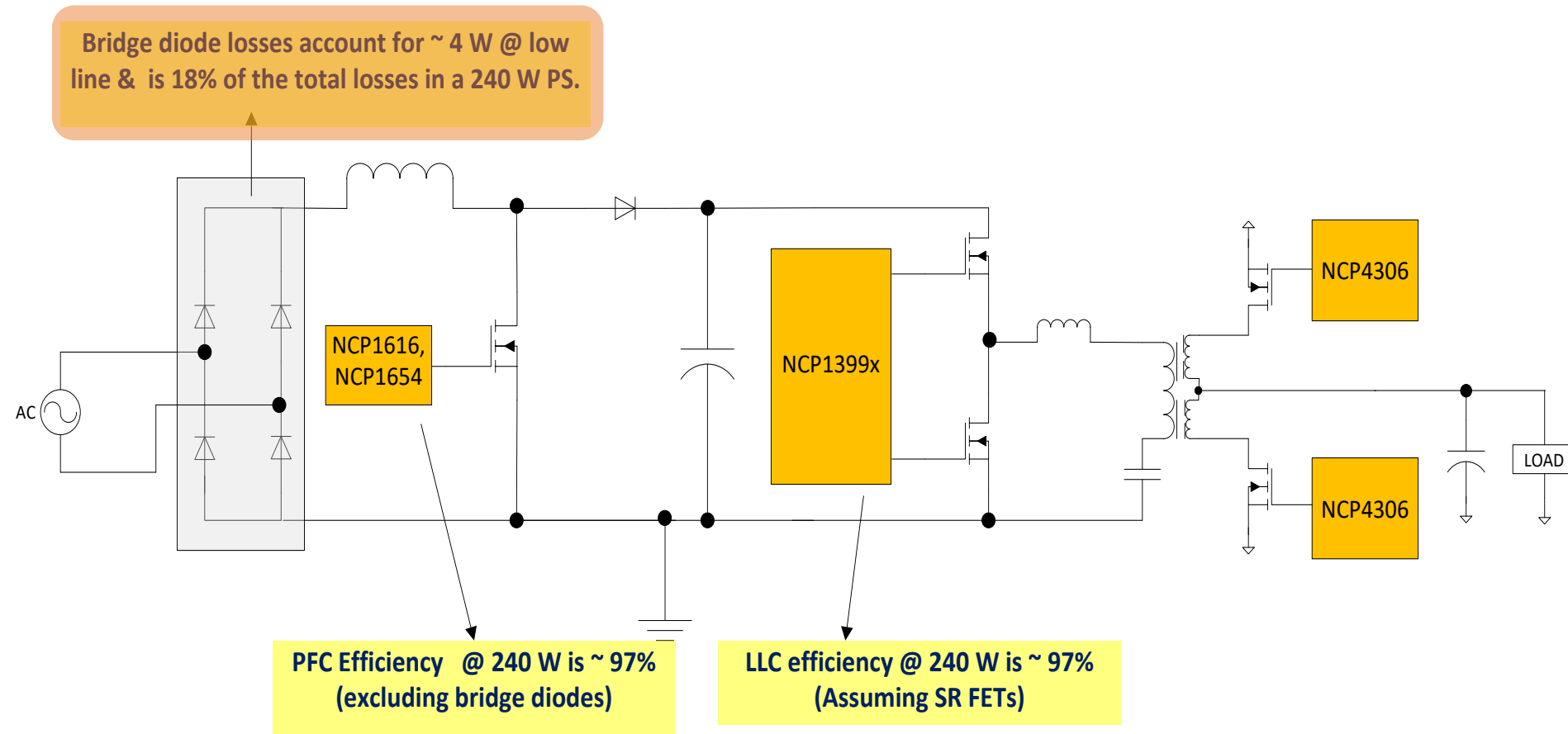
Jeff Jin, Tony Lai

Agenda

- Why do we need Totem Pole PFC?
- Introduction of the 1st Industry Mixed Signal Totem Pole PFC Controllers NCP1680/1
- The Key Value of Current Mode LLC
- Key Features of NCP13994 for High Fsw Operation
- Totem Pole PFC + LLC Turnkey Solutions

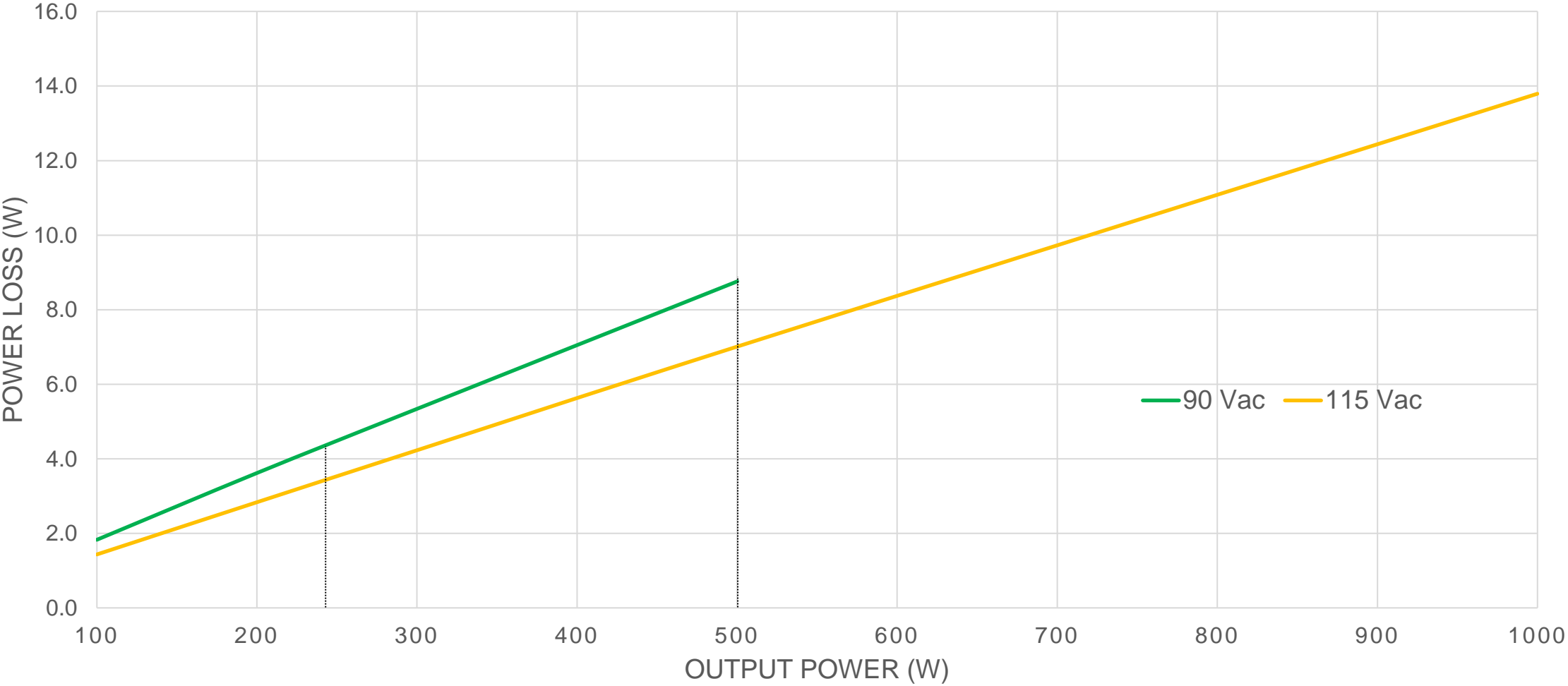
Why do we need Totem Pole PFC?

How Can We Reduce Losses of Input Bridge Diodes?



Efficiency of the boost stage & LLC stage have plateaued.
Bridge Diodes are the major source of power loss!!

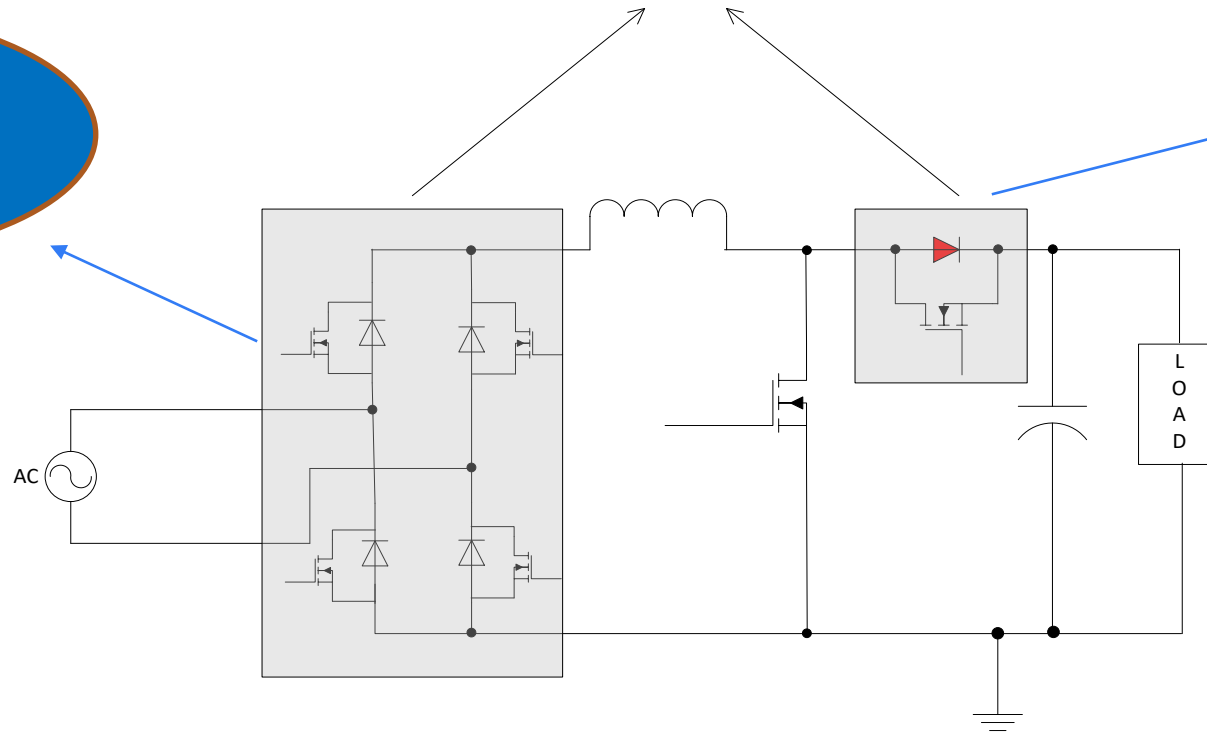
Bridge Diode Power Loss vs Output Power



Active Bridges + Synchronous Boost PFC??

Replace All Diodes with FETs in Bridge Rectifiers and PFC!!!

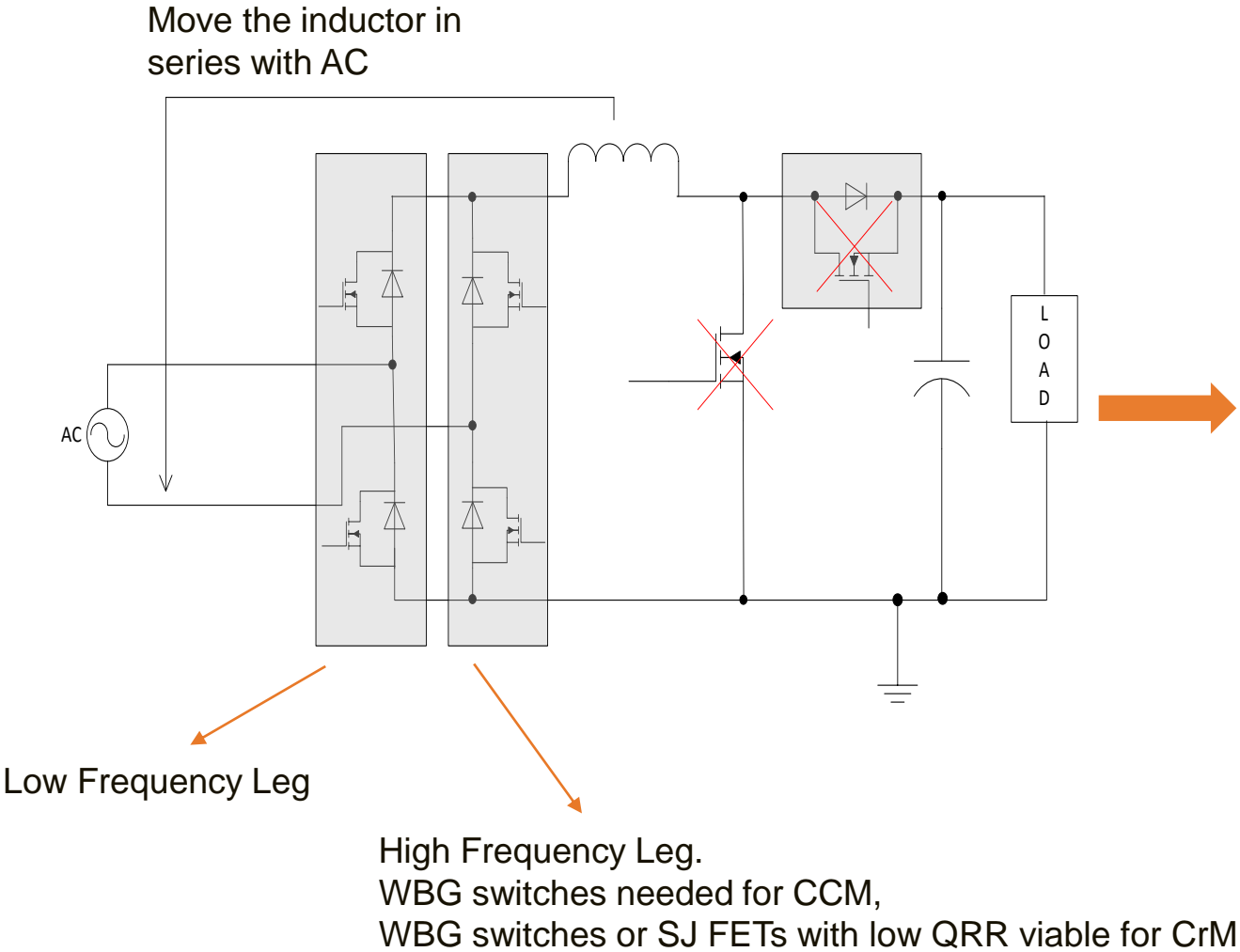
Active Bridge solution is Costly and Clunky



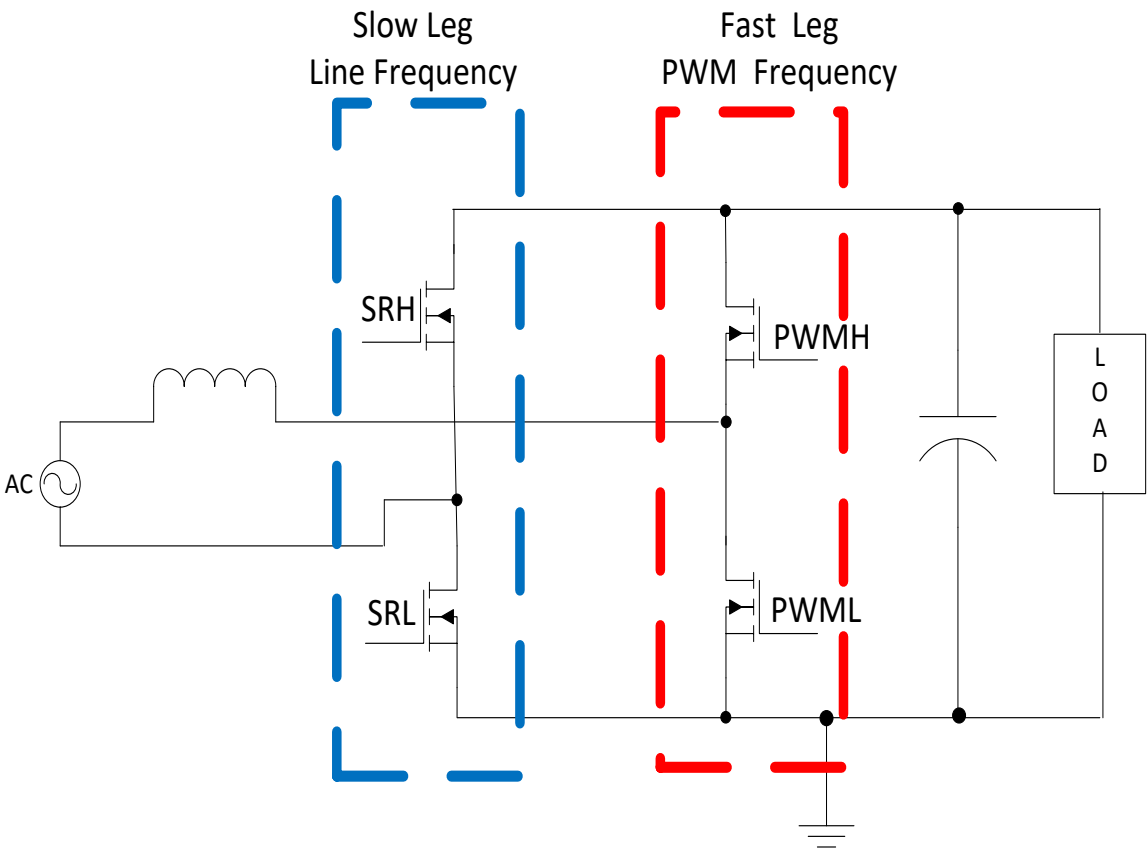
Body Diode of Synchronous FET prevents CCM operation

- Replace all the diodes with FETs. All the front-end diodes have to be replaced with $\sim 50 \text{ m}\Omega$, 650 V FETs.
- Wah! 6 High Voltage FETs Totally!!! **TOO.....COSTLY**

What is Totem Pole PFC?

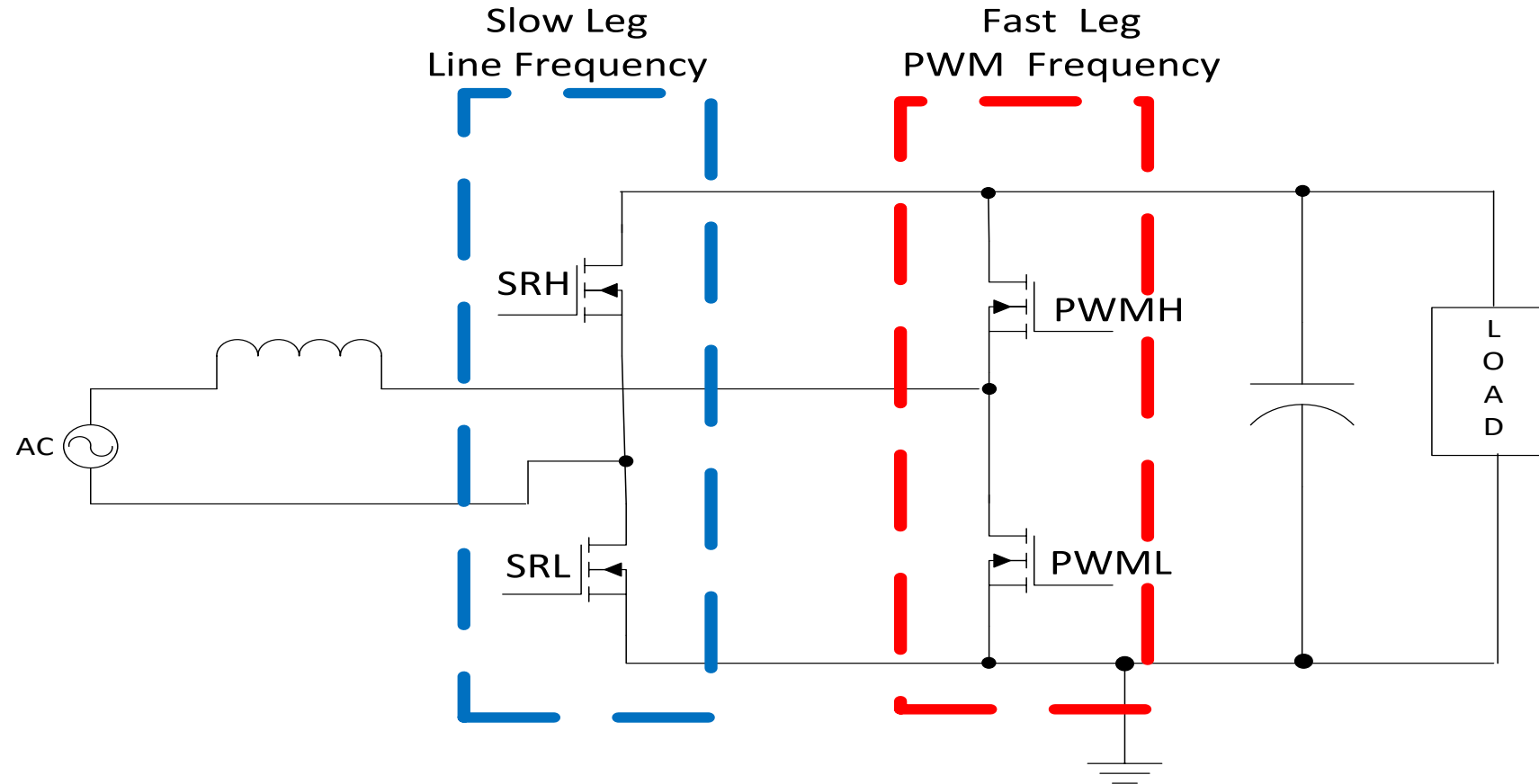


Totem Pole PFC



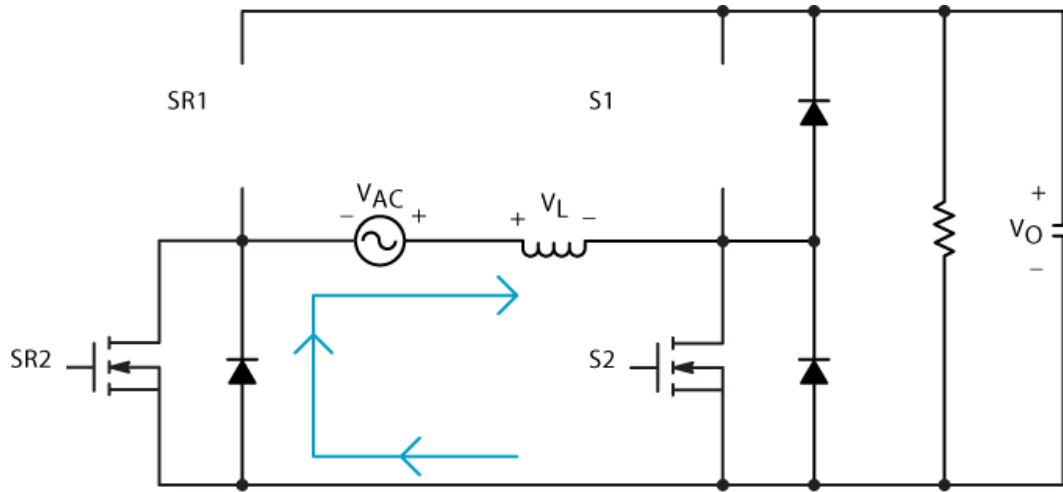
Implement both AC Line Rectification & Boost PFC Functions with Only 4 Switches.

Totem Pole PFC

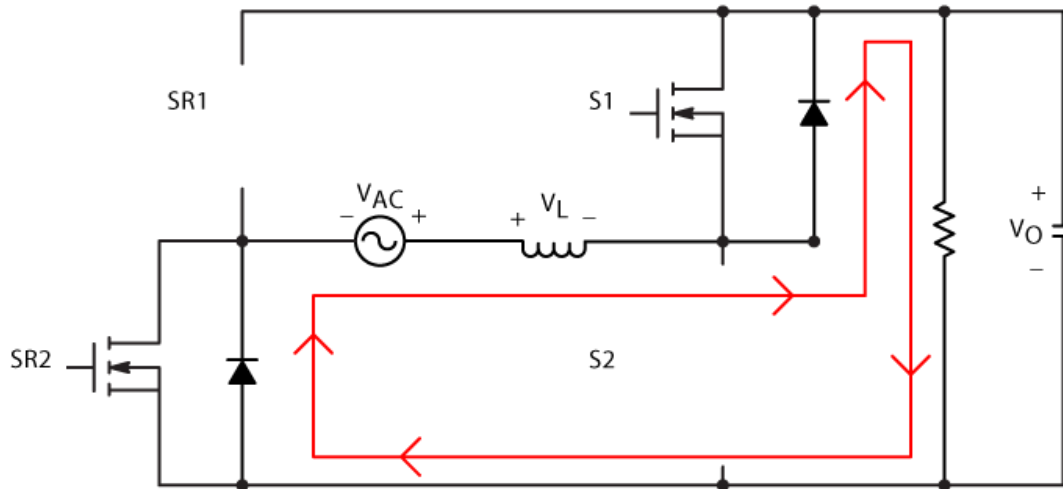


- ❑ **Totem Pole** is an **Elegant 4-Switch Boost** solution that **reduces number of components in the current path**.
- ❑ 1 FET in the “Input Diode Rectifier” section (Low-Freq Leg) and 1 FET in the Boost Section (Fast-Freq Leg) conducting per AC Half Cycle

Positive Half Cycle Operation

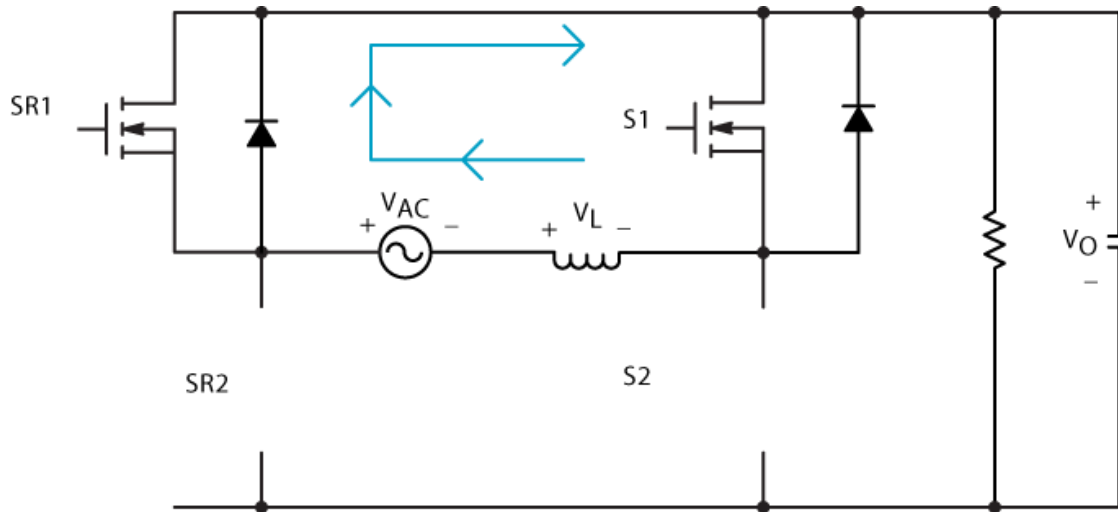


- $S2$ is the duty cycle (d) controlled device and $S1$ is the $(1-d)$ device
- When $S2$ is on, $V_L = V_{AC}$ and current (blue path) circulates through $S2$ and $SR2$

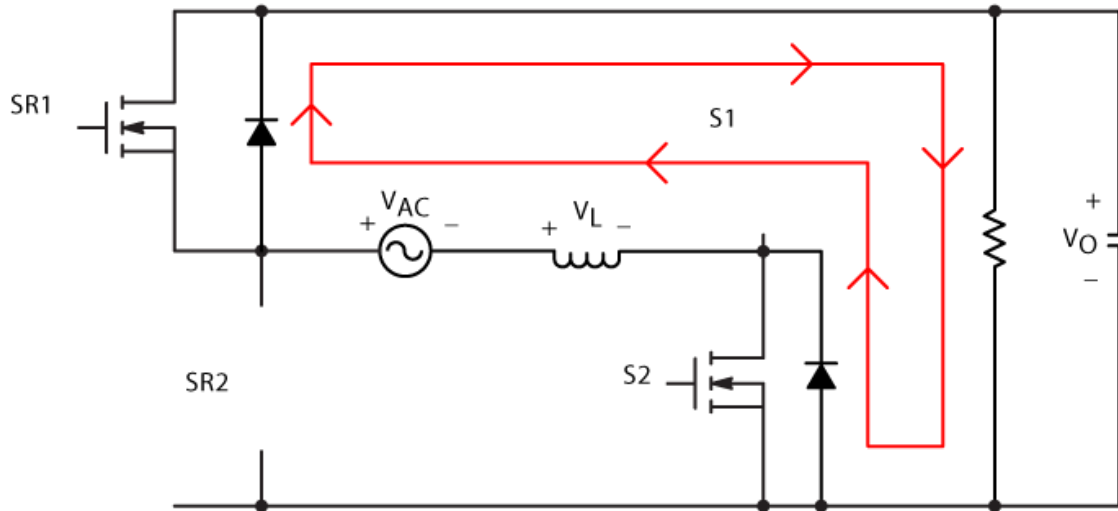


- When $S2$ turns off, $V_L = V_{AC} - V_O$ and current free wheels through $S1$ and $SR2$ (red path). $S1$ can be turned on for increased efficiency
- $SR2$ is returning current to the source for the entire positive line cycle

Negative Half Cycle Operation



- $S1$ is the duty cycle (d) controlled device and $S2$ is the $(1-d)$ device
- When $S1$ is on, $V_L = -V_{AC}$ and current (blue path) circulates through $S1$ and $SR1$



- When $S1$ turns off, $V_L = V_{AC} - V_O$ and current free wheels through $S1$ and $SR2$ (red path). $S2$ can be turned on for increased efficiency
- $SR1$ is returning current to the source for the entire negative line cycle

Introduction of the Industry 1st Mixed Signal Totem Pole PFC Controller NCP1680/1

Totem Pole PFC Market Scenario – onsemi advantages

In the Past

MCU Based Solution in the Market Only!!

Complex Digital Control Solution

- Requires extra effort to write the Software Code
- Requires Costly Current Sensing Element (Current Transformer or Hall Sensor) to implement Topology

Now

Better Choice in the Market Available!!

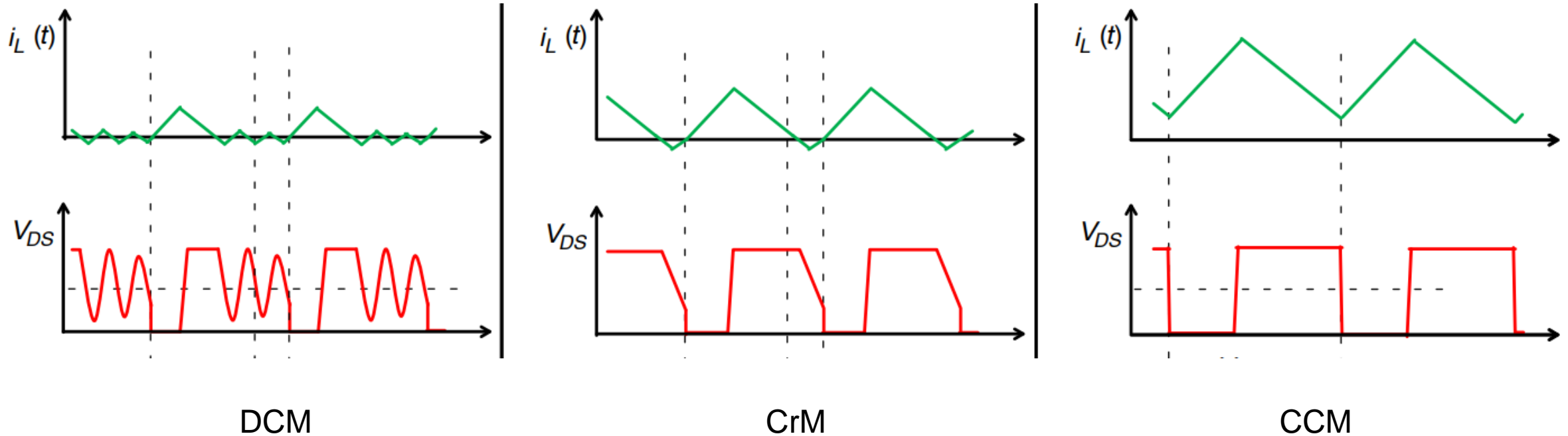
The Industry 1st Mixed Signal Totem Pole PFC Controllers

NCP1680 – CRM Totem Pole PFC Controller

NCP1681Bx – Multi-Mode Totem Pole PFC Controller

NCP1681Ax – CCM Totem Pole PFC Controller

Illustration of operating modes of TP PFC



For PFC, V_{IN} will be sinusoidal

- At high current switching periods, CCM will be used, if current is high enough (frequency low enough)
- During medium current switching periods, CrM will be used
- During low current switching periods, DCM will be used
- Special open loop control patterns are used at zero crossing

onsemi Totem Pole NCP168x covers Wide Output Power Range

Output Power

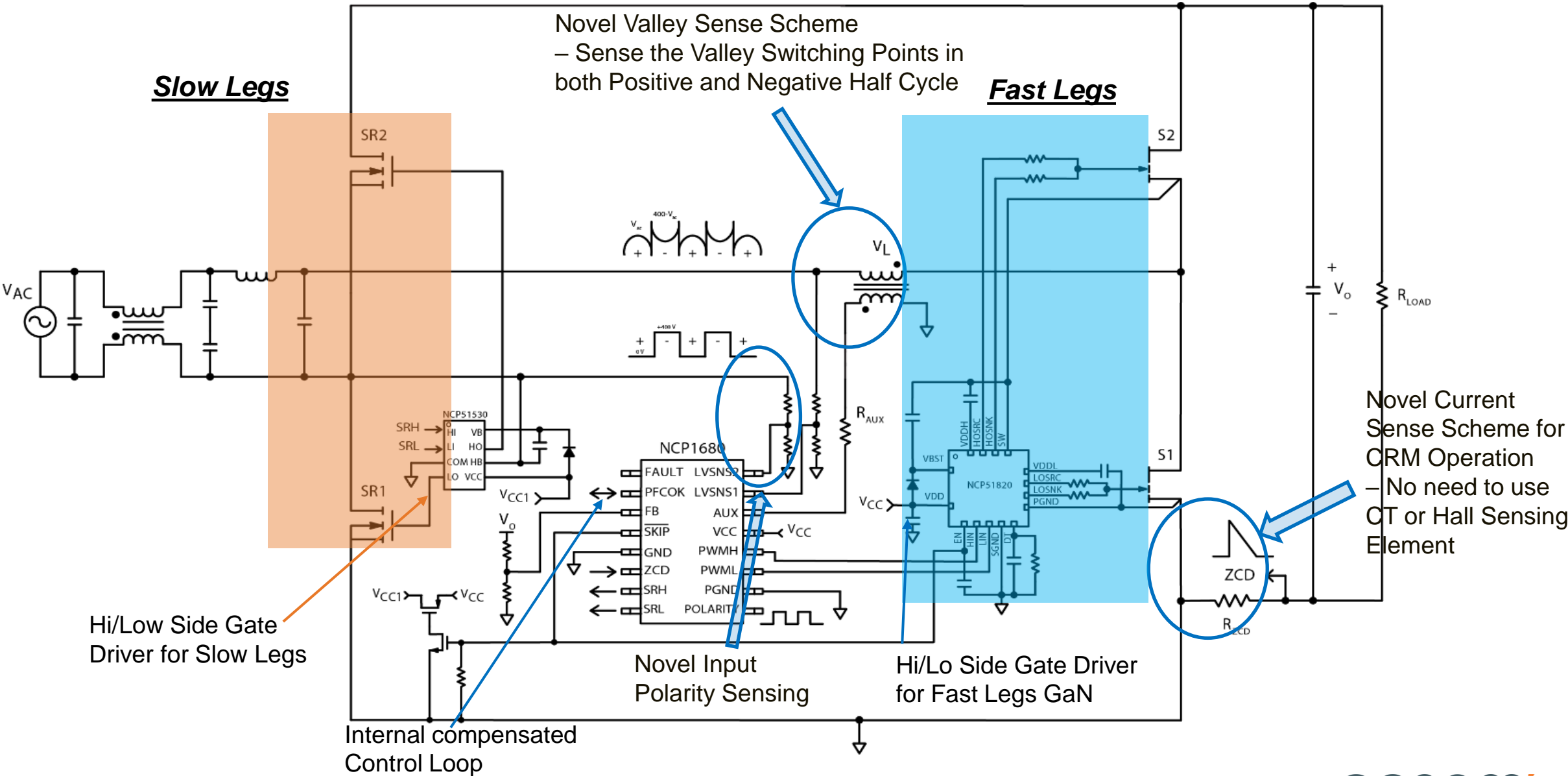


NCP1680
CrM Totem Pole PFC
200W – 350W

NCP1681Bx
Multi-Mode Totem Pole PFC
350W – 1KW

NCP1681Ax
CCM Totem Pole PFC
800W – 3KW

Typical Application Schematic NCP1680 – CrM



NCP1680 Bridgeless Totem Pole CrM PFC Controller

Released Product

Value Proposition

The **NCP1680** is a **CrM Totem Pole PFC Controller** capable constant on time CrM and valley synchronized frequency foldback for optimized efficiency across the entire load range. With proprietary current sensing architectures and proven control algorithms the NCP1680 allows for a cost-effective solution without jeopardizing performance.

Unique Features

- **Constant on-time CrM** architecture with valley switching during foldback
- **Novel Current Sense scheme** provides cycle-by-cycle current limit **without hall effect sensor**
- Line polarity detection
- **Novel valley sense scheme**
- Control loop **Internally compensated**

Benefits

- Optimized performance across power levels
- Cycle-by-cycle current limit **without hall effect sensor**
- Removes external components;

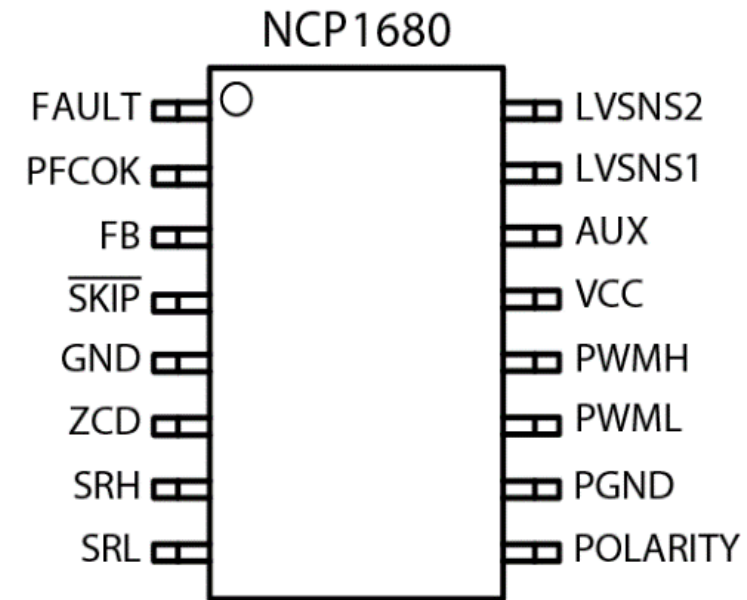
Other Features

- Two low voltage pins for sensing and recreating half-wave sinusoid.
- DCM with valley synchronized turn-on for improved light load efficiency
- Zero Current Detection for CrM Operation
- Integrated Digital voltage loop control

Market & Applications

- Telecom 5G / Networking Power Supplies
- Industrial Power Supplies
- Computing Power Supplies
- Gaming Console Power Supplies
- UHD TV Power Supplies

Device Pin-Out



Ordering & Package information

- SOIC-16

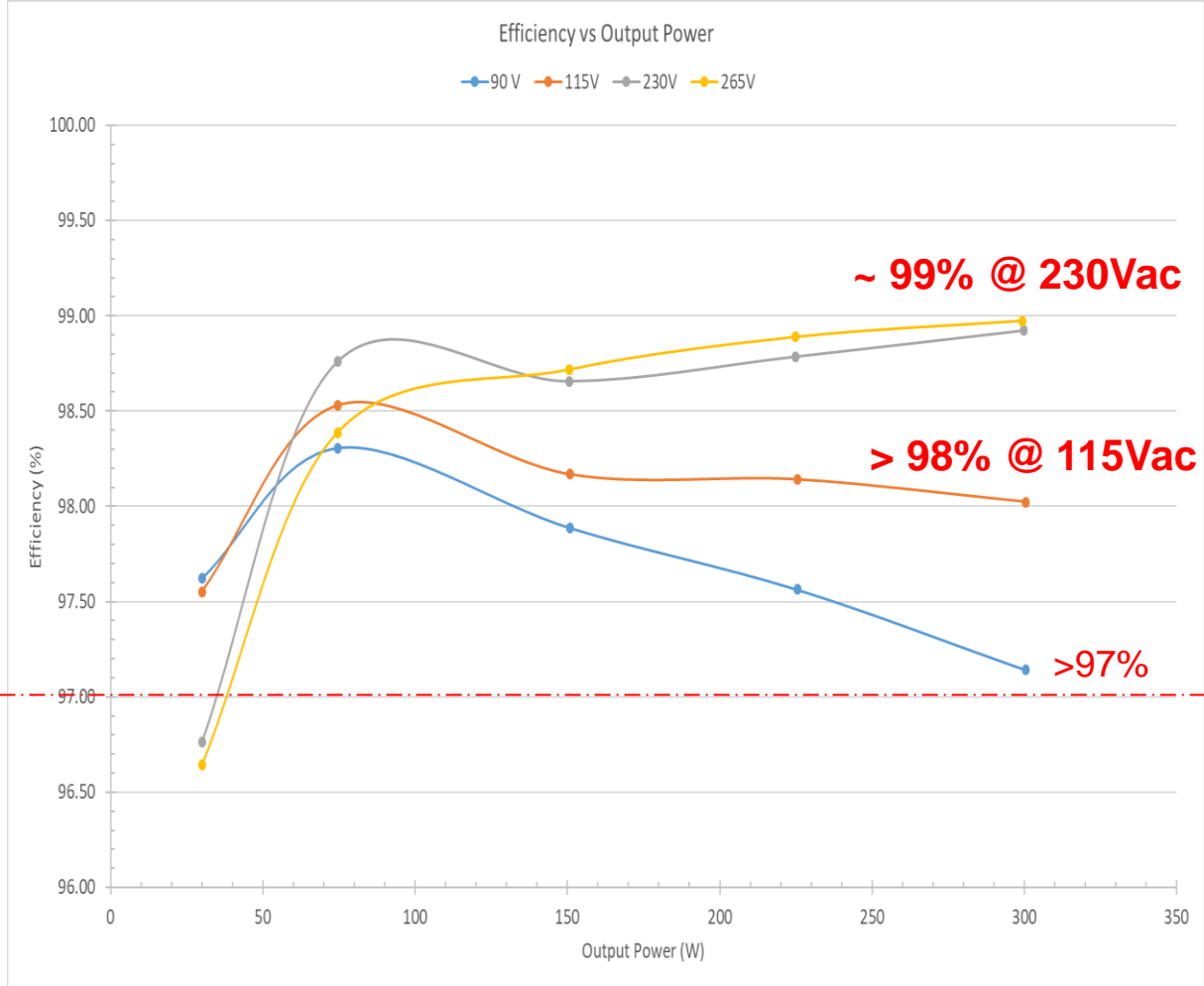
Multiple Patents
Issued/Pending

300 W NCP1680 Evaluation Board

Description	Value	Units
Input Voltage Range	90 - 265	VAC
Line Frequency Range	47 - 63	Hz
Output Voltage	395	V
Output Power	300	W
Boost Inductor	150	μH
Bulk Capacitors	200	μF
Fast Leg Switch	NCP58921	
Slow Leg Switch	FCPF067N65	
ZCD Resistor	125	mΩ

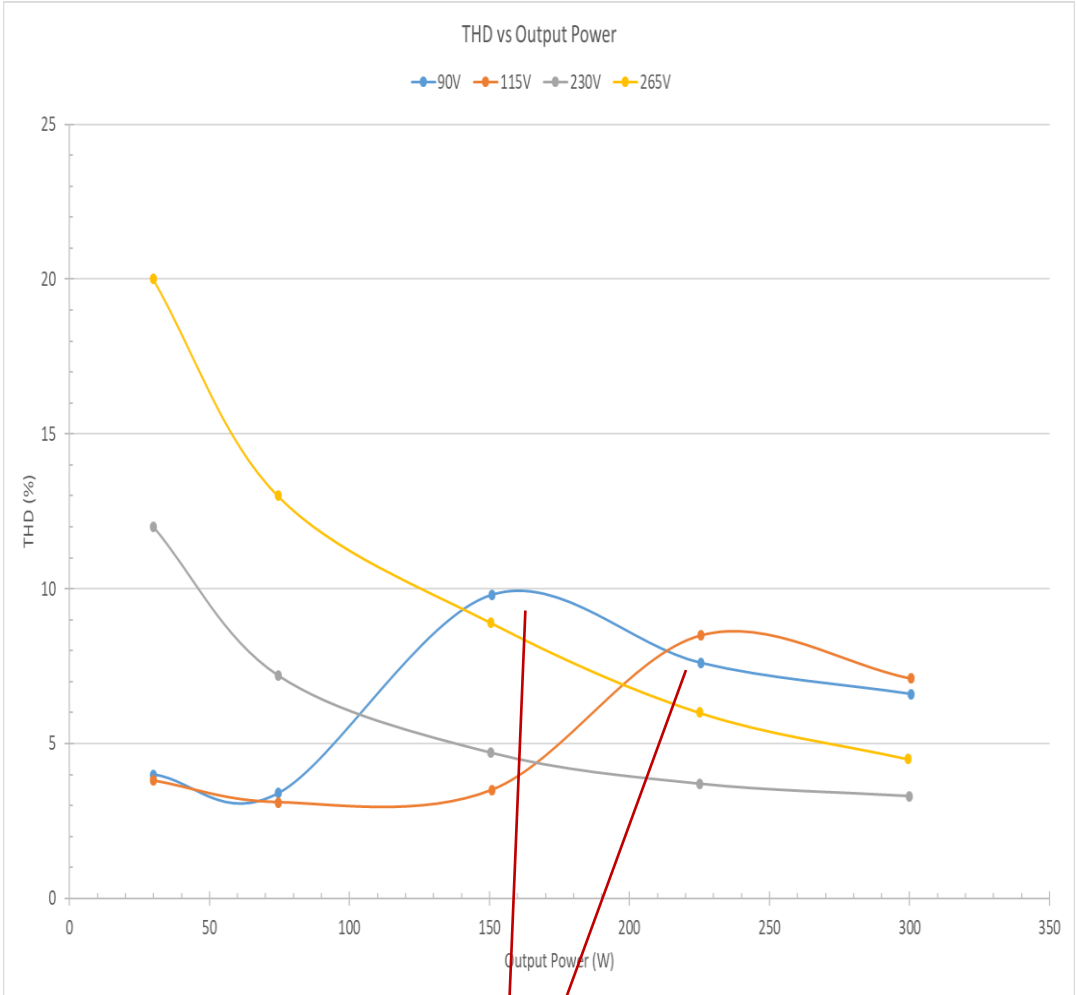
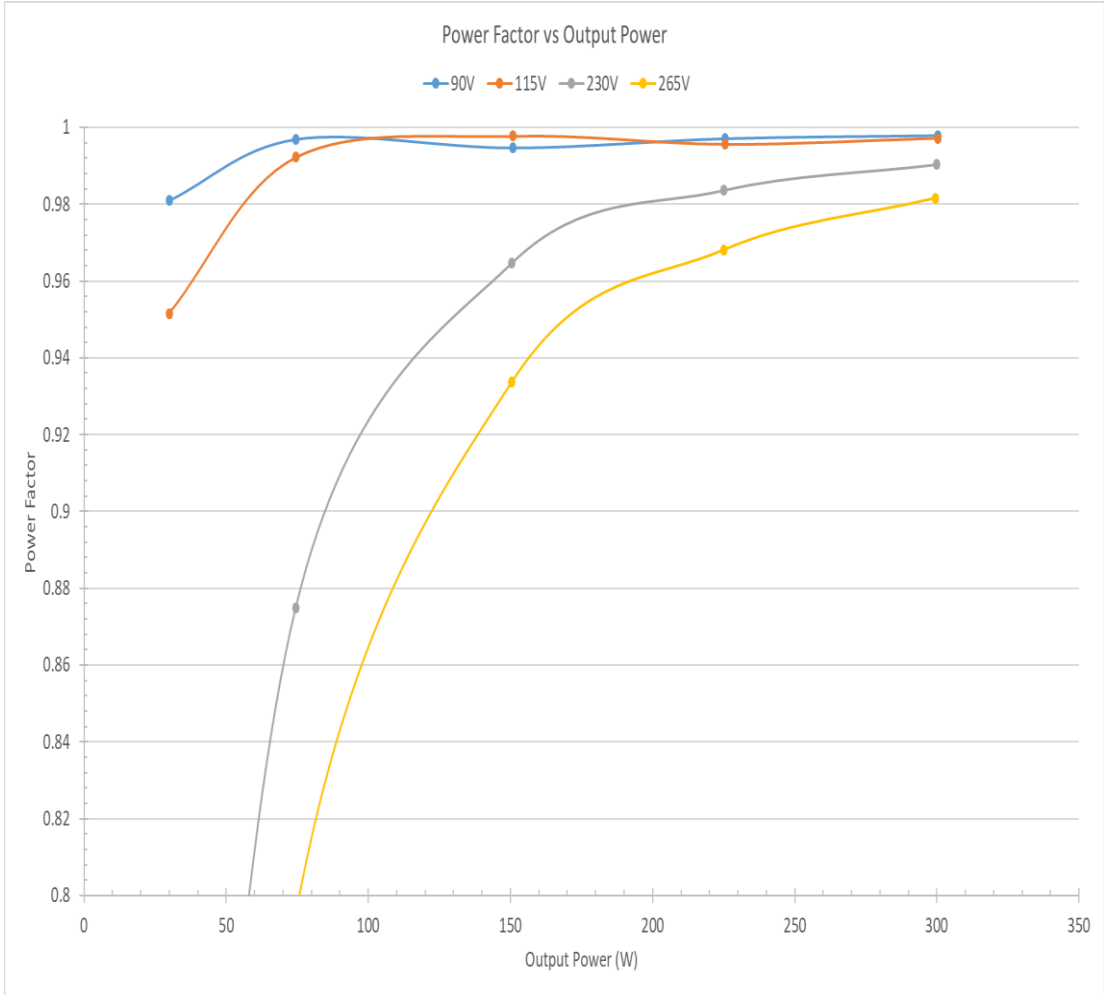


NCP58921
Daughter Card



Very High Efficiency over the Entire load/line range !

Power Factor and THD



Dead-time compensation kicks in after
1st valley enhancing THD

NCP1681 – Totem Pole PFC Controller

Value Proposition

The **NCP1681** is a **multi-mode Totem Pole PFC Controller** capable of operating in **fixed frequency CCM, constant on-time CrM, and valley synchronized frequency foldback** for optimized efficiency across the entire load range. With novel current sensing architectures, proven control algorithms for all operating modes, and a suite of protection features, the NCP1681 allows for a cost-effective solution without jeopardizing performance.

Unique Features

- Fixed frequency CCM w/ Constant on-time CrM and valley switching frequency fold back
- **Novel current sense scheme providing inductor current upslope and downslope sensing**
- Line polarity detection
- Digital loop compensation

Benefits

- Optimized performance across all power levels
- Cycle-by-cycle current limit without hall effect sensor
- Reduces external components

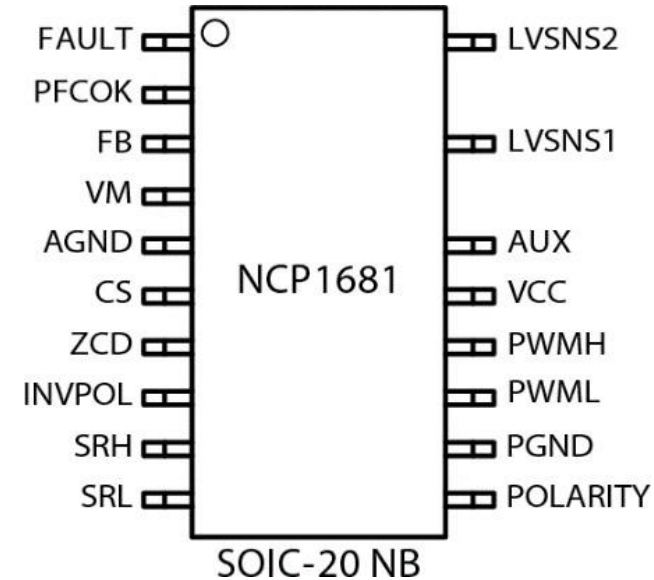
Other Features

- Two low voltage pins for sensing and recreating half-wave sinusoid.
- Fixed frequency pseudo-average current mode control for high performance continuous conduction mode operation
- Constant on-time CrM and valley synchronized frequency foldback at medium and light load
- Skip/Standby mode for optimized light load performance
- PFC OK Indicator

Market & Applications

- Server/Computing PFC
- OBC
- Gaming/TV Power Supplies
- 5G/Telecom Power

Device Pin-Out

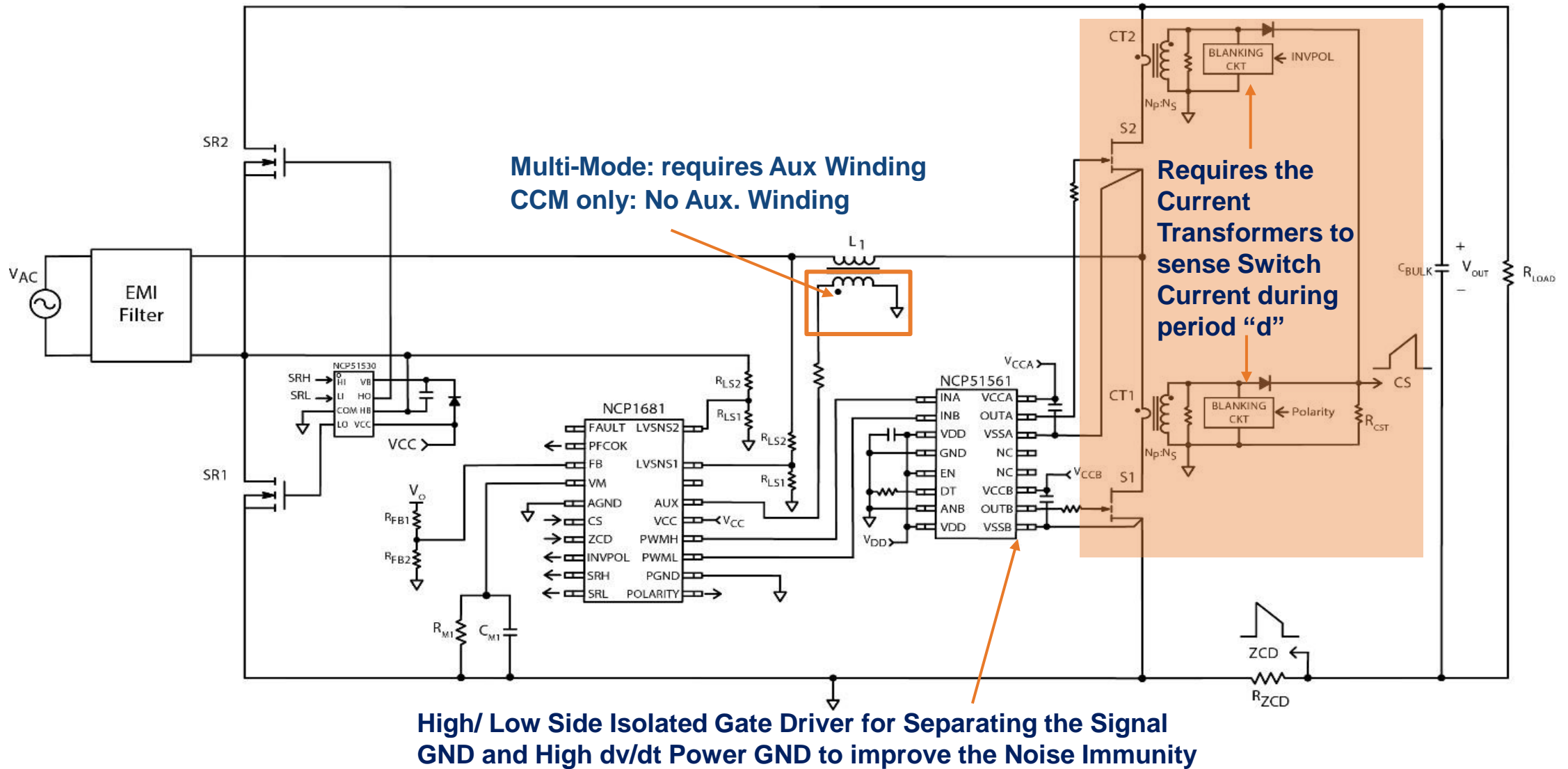


Ordering & Package information

- SOIC-20 NB

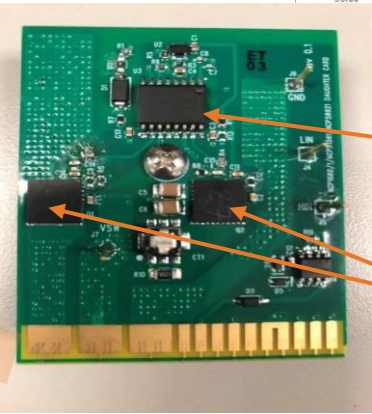
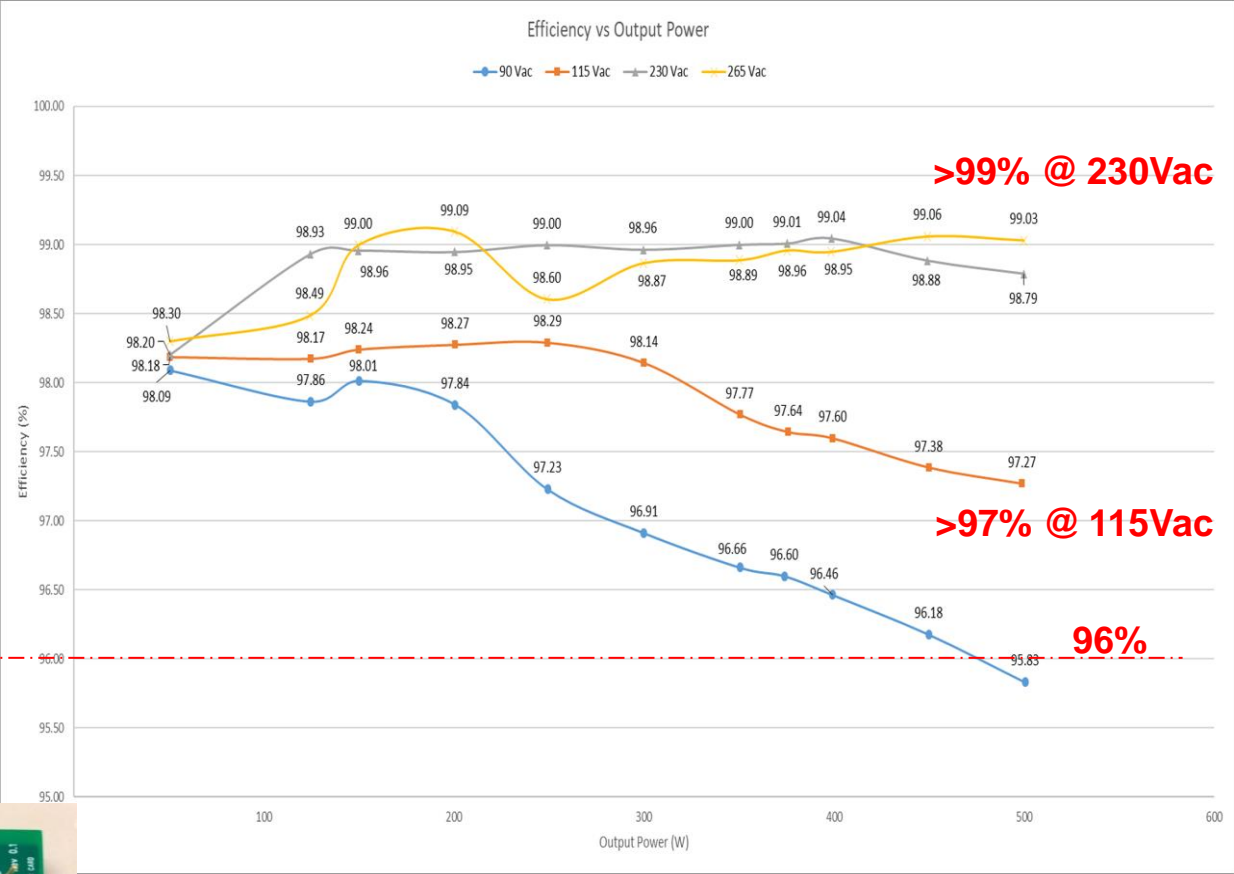
Multiple Patents
Issued/Pending

Typical Application Schematic NCP1681 Multi-mode



500 W NCP1681 Evaluation Board

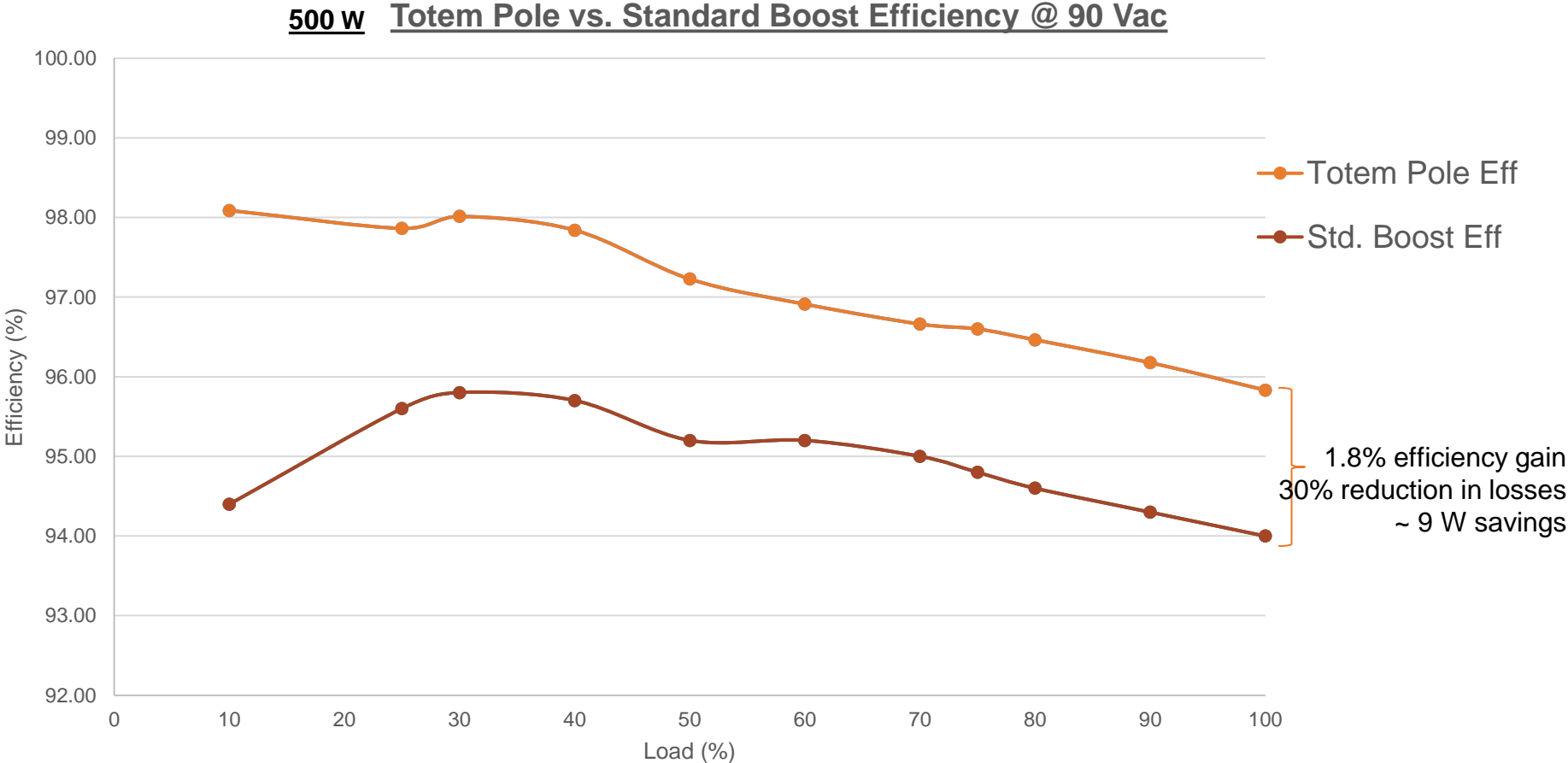
Description	Value	Units
Input Voltage Range	90 - 265	VAC
Line Frequency Range	47 - 63	Hz
Output Voltage	395	V
Output Power	500	W
Power Factor @ Full Load	> 0.95	
THD @ Full Load	< 10	%
Boost Inductor	175	μH
Bulk Capacitors	2x 220	μF
Fast Leg Switch	NCP58921	
Fast Leg Level Shifter	NCP51561	
Slow Leg Switch	FCPF067N65	
ZCD Resistor	100	mΩ



NCP51561:
GI Gate Driver

NCP58921:
Integrated Driver-GaN

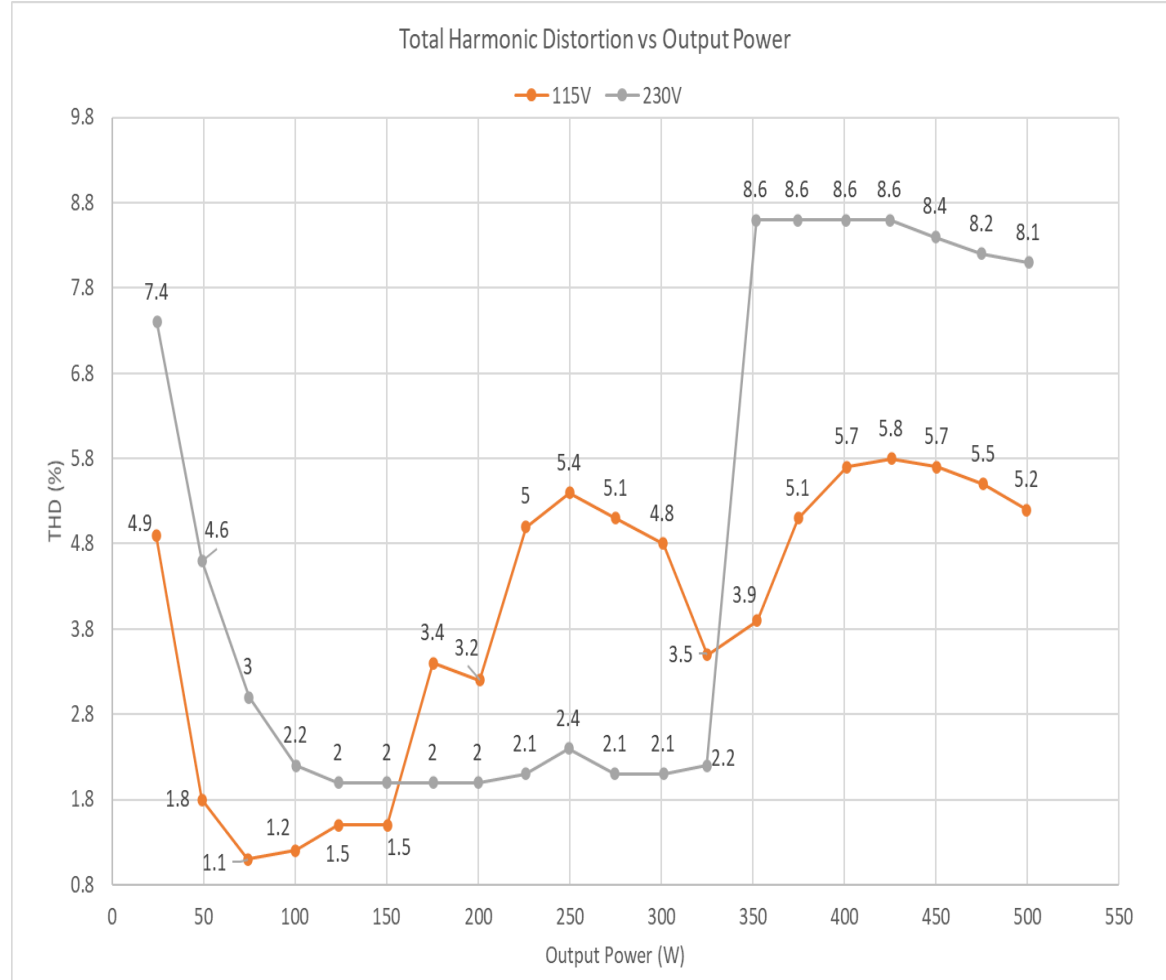
Totem Pole vs. Standard Boost – Efficiency Comparison on a 500 W PFC



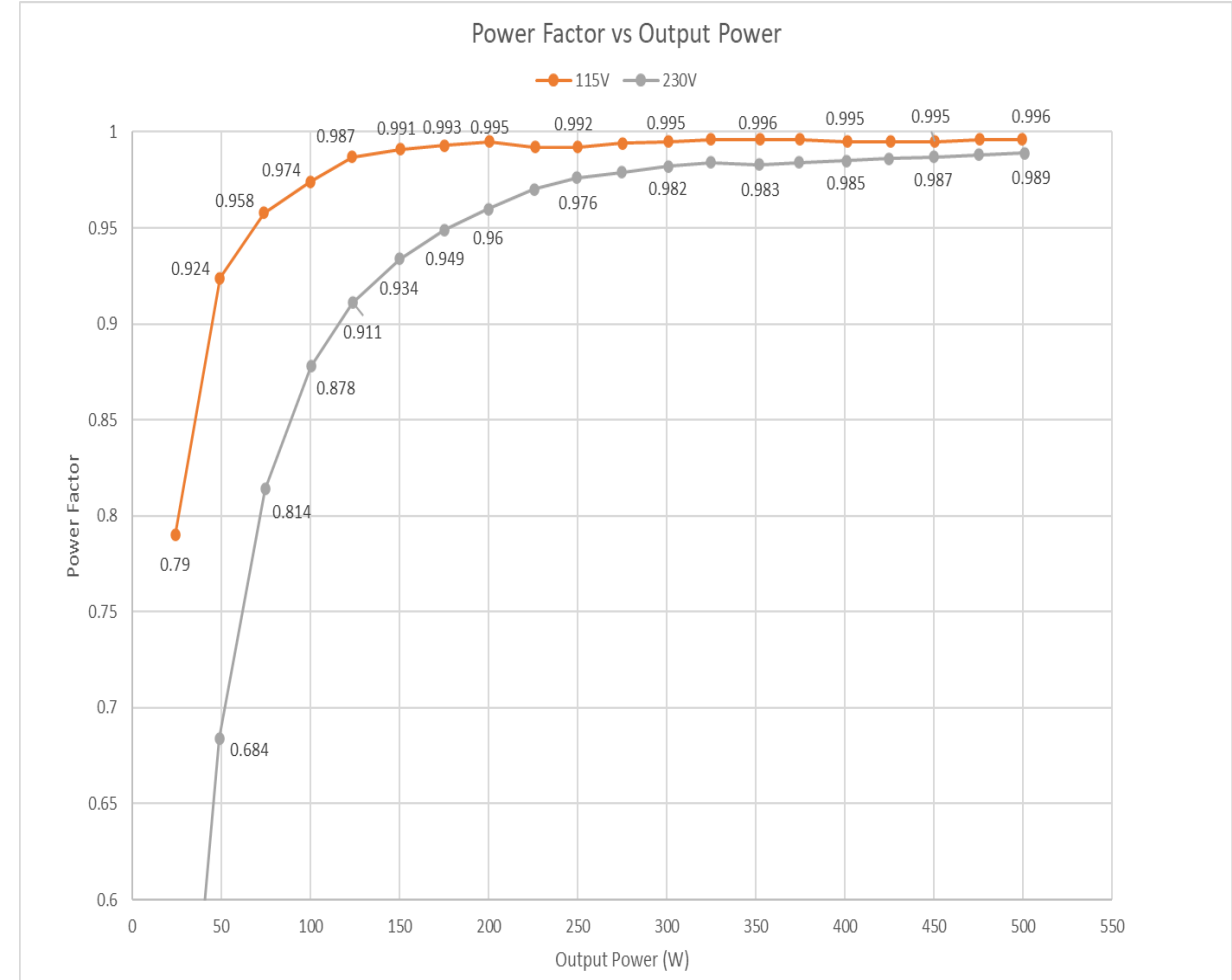
- ❑ Totem Pole utilizes 2 eGaNs & 2 SJ FETs
- ❑ Standard boost uses 2 SJ FETs & 1 SiC diode

MM EVB THD and PFC across line/load

- THD performance at 115 & 230 Vac < 10% across all loads

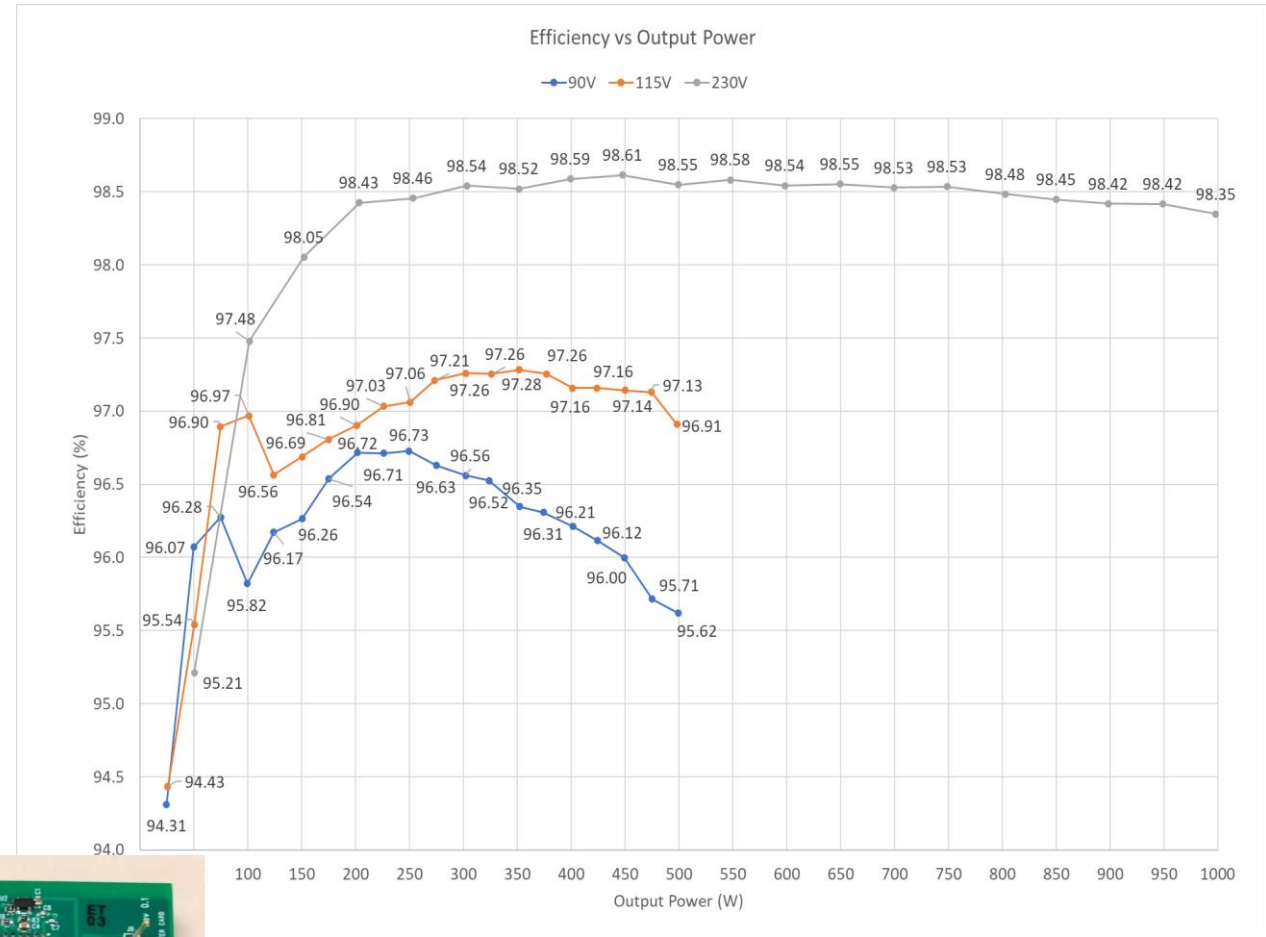


- PF is > 0.9 for loads greater than 25%



1kW NCP1681 Evaluation Board (CCM Only)

Description	Value	Units
Input Voltage Range	90 - 265	VAC
Line Frequency Range	47 - 63	Hz
Output Voltage	395	V
Switching Frequency	65	kHz
Output Power ^{1,2}	500 (LL) / 1000 (HL)	W
Output Voltage Ripple	< 5	%
Power Factor @ Full Load	> 0.98	
THD @ Full Load	< 5	%
Boost Inductor	500	μH
Bulk Capacitors	2x 330	μF
Fast Leg Switch	NCP58921	
Fast Leg Level Shifter	NCP51561	
Slow Leg Switch	FCPF067N65	
ZCD Resistor	100	mΩ

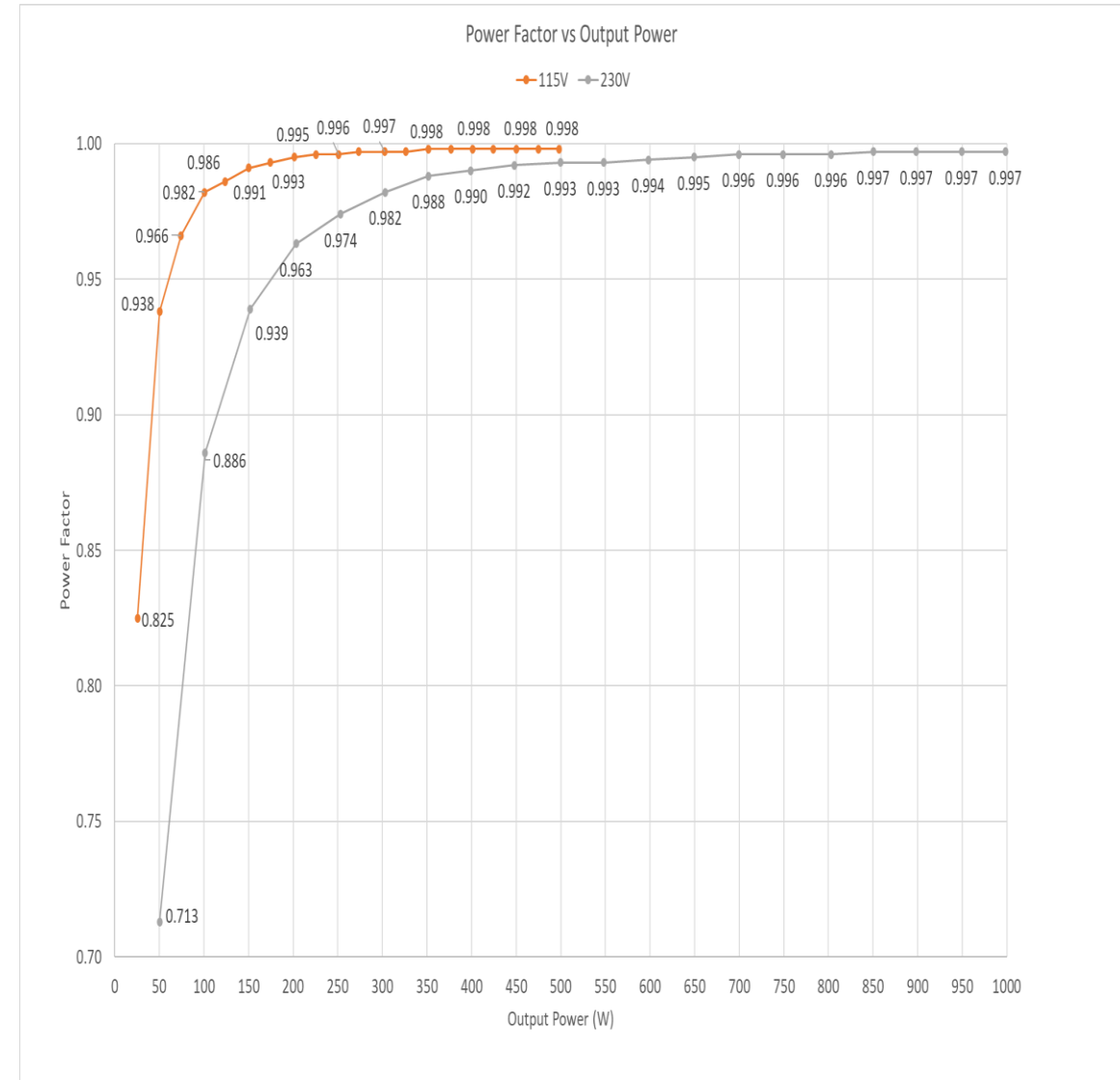
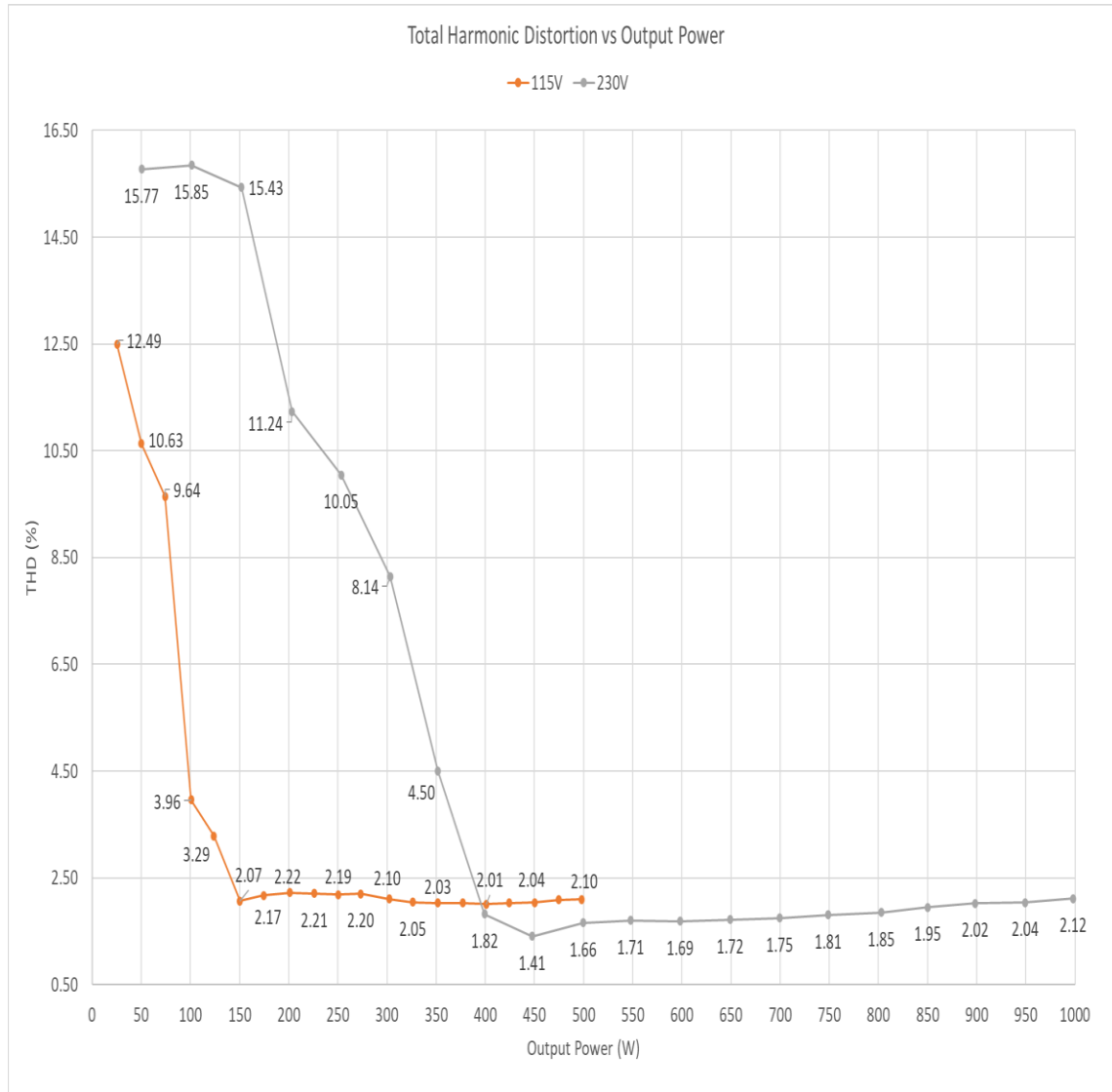


NCP51561:
GI Gate Driver

NCP58921:
Integrated Driver-GaN

1kW CCM EVB THD and PFC across line/load

- THD performance at 115 & 230 Vac < 5% down to 50% load and < 16% at all loads
- PF is > 0.93 for loads greater than 15%

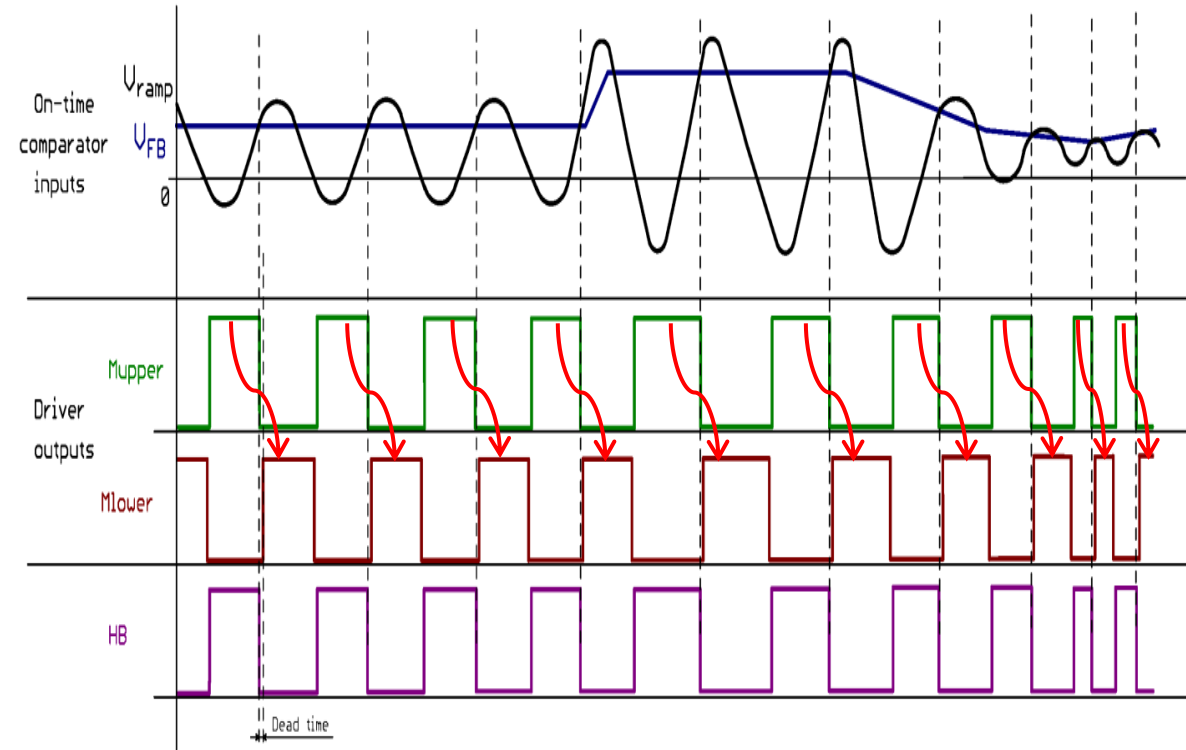
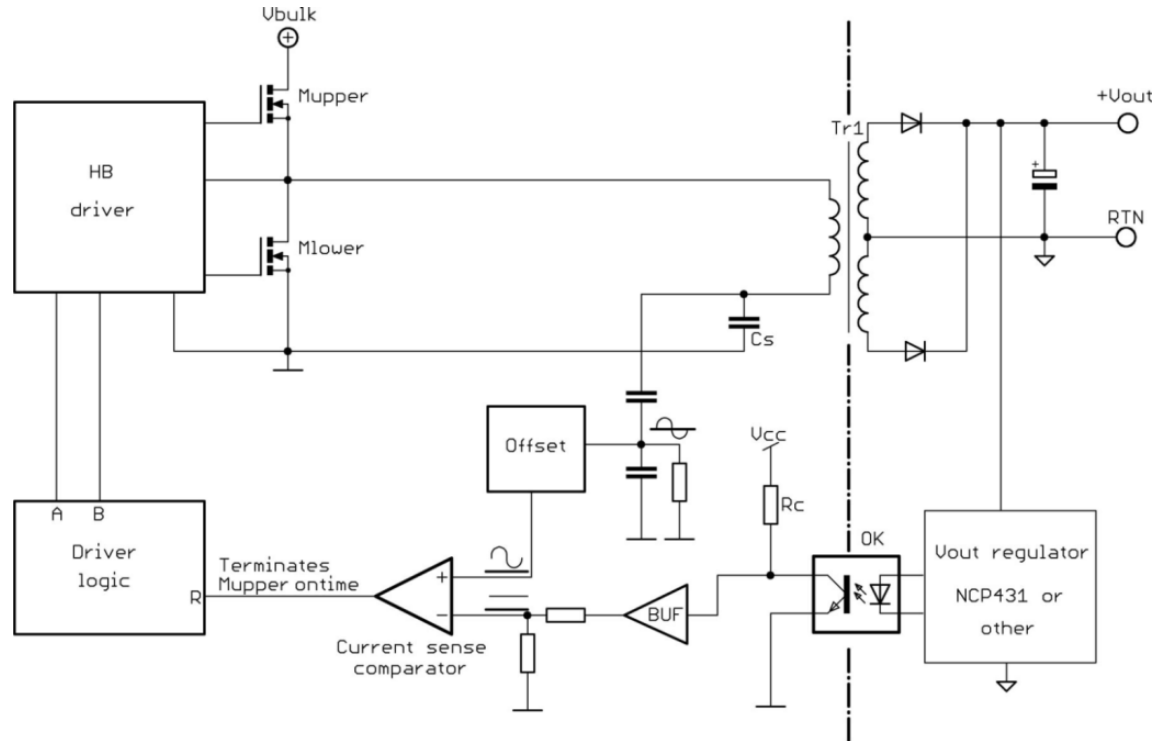


Totem Pole PFC Mixed Signal vs Digital Controller

Digital Controller	Mixed Signal Controller (NCP1680 & 1)
Cloud/High end server	NCP1680 (CrM) -> Telecom 5G/industrial/computing up to 350 W NCP1681 (MM) -> Workstation/gaming console power 350 W to 1 kW NCP1681 (CCM only) -> Network/cloud-server/industrial up to 3 kW
Supports multi-topologies: Boost PFC, Totem Pole PFC, voltage mode LLC etc.	Optimized for Totem Pole PFC: CrM and CCM
Flexibility - Customer can implement custom IP to distinguish from competition	Designed to pass standards for computing & gaming power supplies
Poor standby power. Icc of DSP/MCU is high	Excellent light load efficiency and standby power
THD <2% possible, look-up tables and custom IP	NCP1680 (CrM) -> THD better than standards set for computing NCP1681 (CCM only) -> THD <5%
Telemetry: Input voltage and current. Accuracy 5 %. PM Bus possible	No telemetry

The Key Value of Current Mode LLC

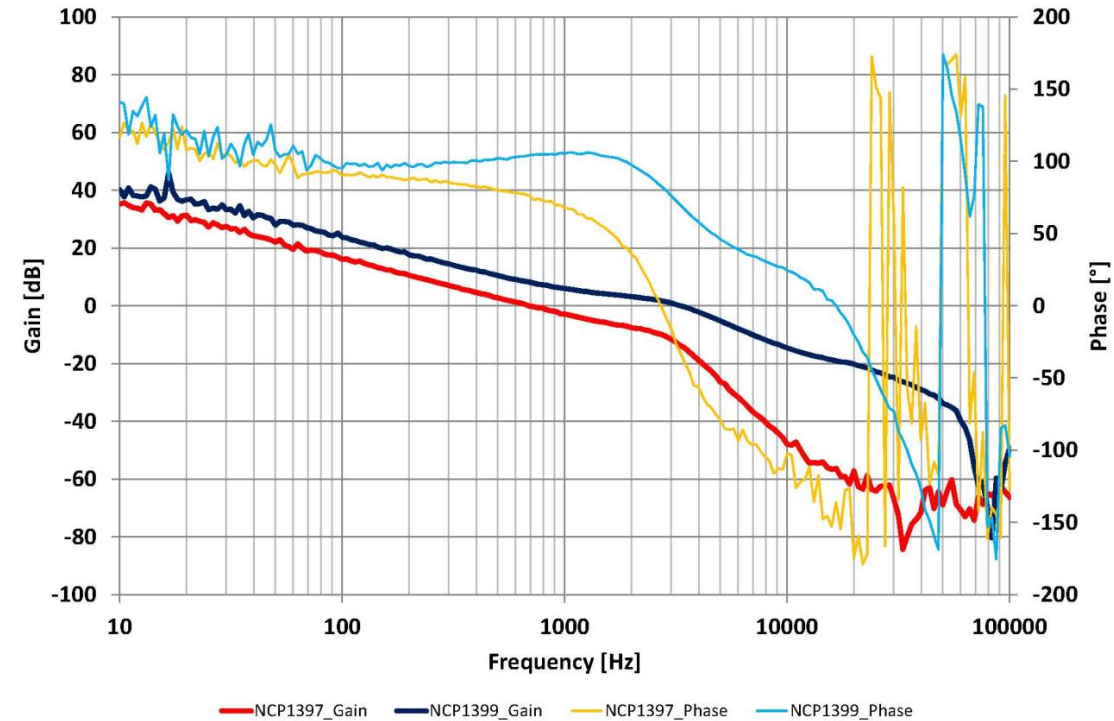
How is CM control implemented in NCP1399X?



- Uses only positive res. cap voltage slope to define Mupper on-time
- Mupper on-time is automatically adjusted by the system based on the FB pin voltage and Vcs voltage ramp (which reflects line and load conditions through primary current)
- Same on-time is then replicated for Mlower MOSFET which assures perfect DC symmetry

The Key Value of Current Mode LLC

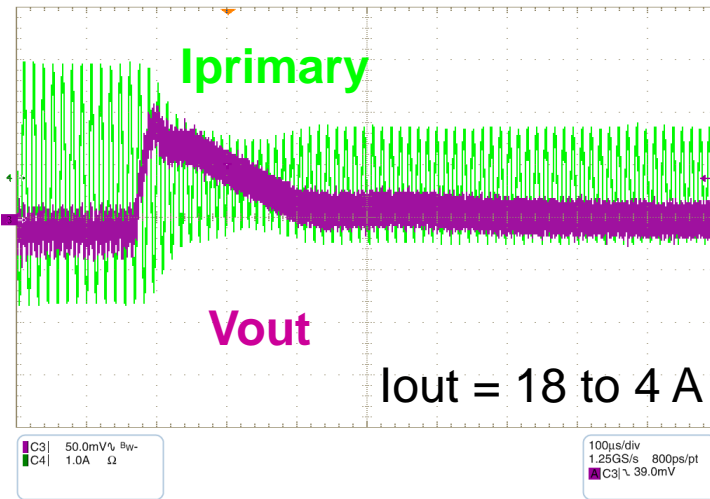
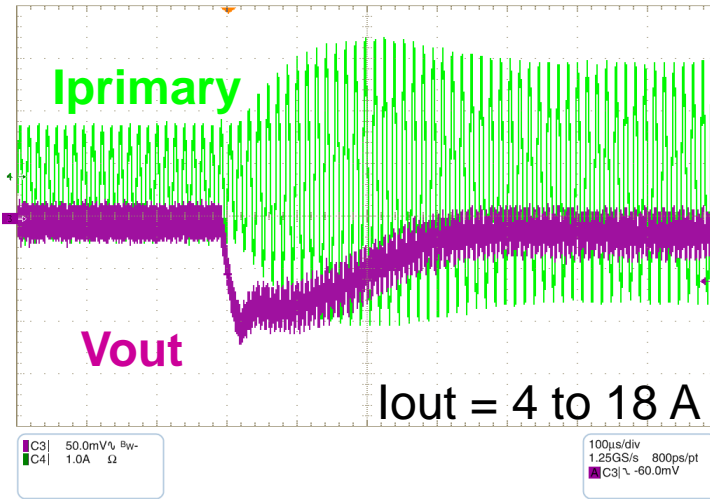
- NCP1399x uses newly proposed current mode control technique
- The main advantages of the current mode control for LLC are:
 - ✓ Inherent over-current and short circuit protection => inherent anti-capacitive switching protection
 - ✓ Excellent load transient response
 - ✓ Excellent line transient response thanks to natural feed forward
 - ✓ 1st order system only



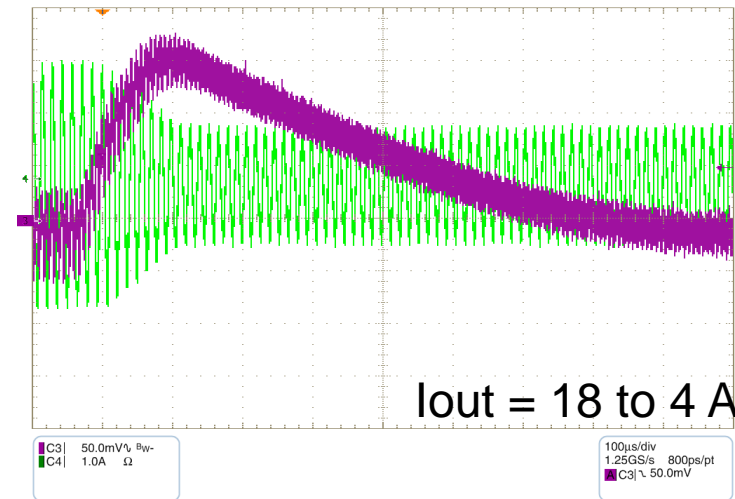
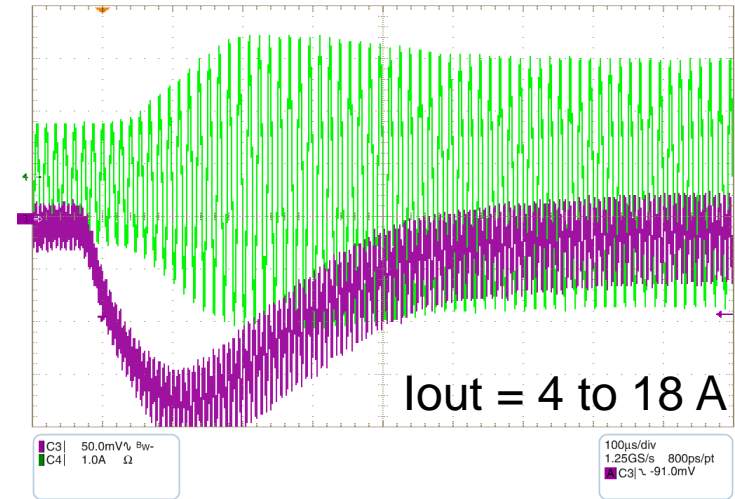
Current mode control provides much higher f_0 than traditional voltage mode!!

Step Load Response Comparison

CM LLC



VM LLC



- The CM LLC provides lower undershoot/overshoot and faster stabilization response

Key Features of NCP13994 for High Fsw Operation

NCP13994 – High Performance Current Mode LLC Controller

Value Proposition

The NCP13994 is an enhanced, high-performance current mode controller for half bridge resonant LLC that focuses on improved light load efficiency, no-load consumption, PFC vs. LLC communication, reduced acoustic noise in skip, enhanced protection features and higher frequency applications

Unique Features

- Line sensing with X2 cap discharge
- Dedicated light load control
- PFC / LLC communication
- Current mode control
- Ded. Start up sequence

Benefits

- Improved light load efficiency
- Optimized operation with latest PFCs
- Fast transient response
- Reduced soft-start current

Other Features

HV Startup Current Source

Operating frequency from **20 kHz up to 1 MHz**

Automatic Dead-time with Maximum Dead-time Clamp

Off-mode for Extremely Low No-load Consumption

Inherent out of Resonance Switching Protection

Overload and short circuit protections

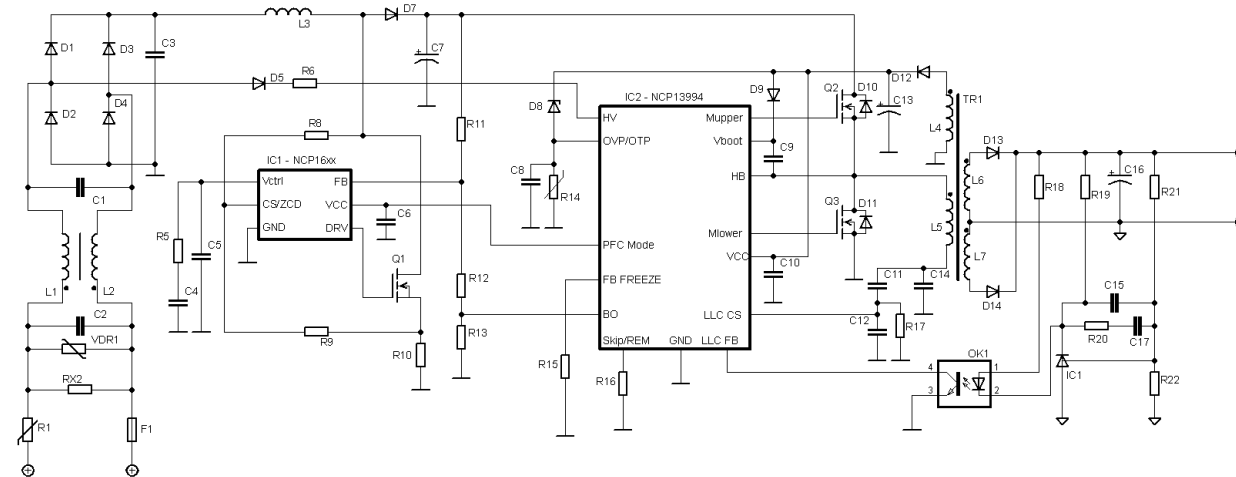
Peak power timer / OLP threshold

Pin to Adjacent Pin / Open Pin Fail Safe

Market & Applications

- High Power Density Offline Power Supplies
- High Performance Computing (USB PD 3.1, AIO)
- Industrial Power Supplies (Telecom, Lighting, Battery Charging)

Typical Application Schematic



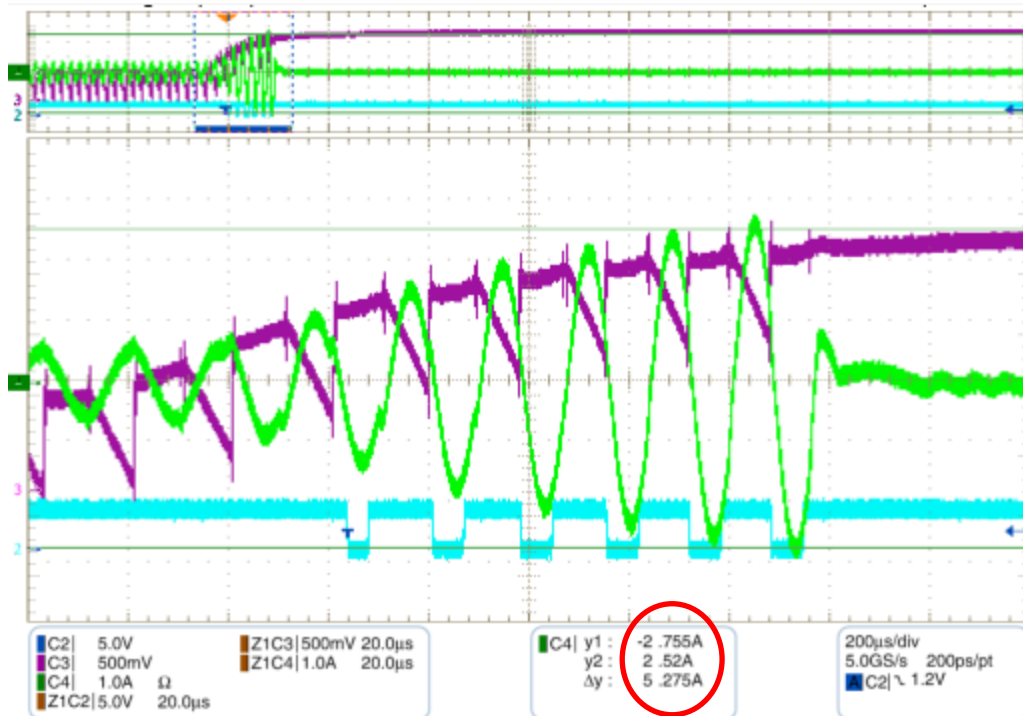
Ordering & Package information

- Standard SOIC-16 (less 2 pins) package
- Pin to pin compatible to NCP1399 and NCP13992
- Design flexibility via IPT options of key parameters

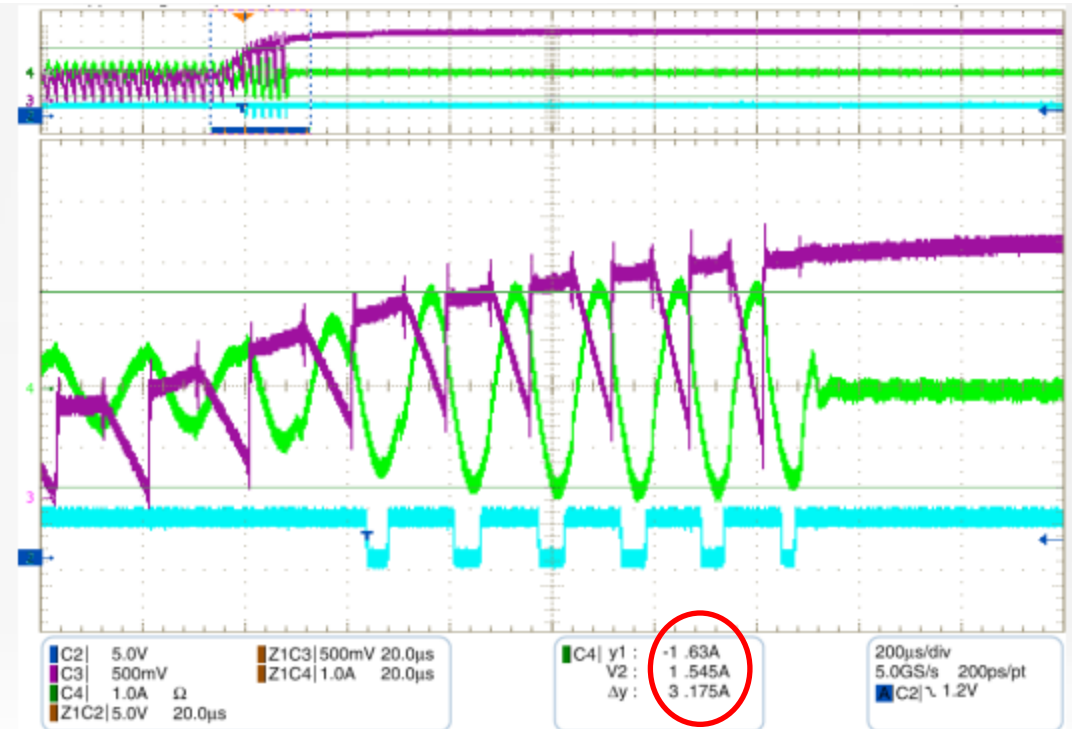
Product Comparison

Features	NCP13992	NCP13994	Benefits
Maximum switching frequency	300 kHz Full Load	500 kHz Full Load	Enable higher power density
Light load operation	Quiet skip mode	Quiet skip mode + extended normal operation range w/o skip + reduced ICC consumption + OFF mode	Improve operating range and light load performance
PFC stage control	Yes, via PFC MODE pin	Yes, via Vbulk pin or PFC MODE pin. Using Vbulk for one wire communication with PFC provides option for skip out level adjust	
Skip operation	Yes	Yes, lower skip out level, more stable skip frequency and lower ripple	
Maximum HV	600 V	700 V	Improve robustness
Maximum VCC	20 V	30 V	
Maximum Vboot	620 V	730 V	
Clamped DRV outputs	No	YES	
X2 discharge	No	YES	
Line BI/BO & OVP	No	YES	Enhance protection
Power Good based on Vbulk level	No	Yes	
Startup sequence with HB discharge before startup	Yes	Yes, improved to overcome incorrect user setting	
Peak power capability	No	Yes, available via IPT. Enable a well-balanced design with low skip out level and peak load capability to be achieved	
Primary current stress reduction in case of CS fault	No	Yes, via ramp compensation	
Automatic dead time (DT) generation	Yes	Yes, more options for DT clamp or fixed DT operation	
OVP/OTP Fault pin hysteresis	No	Yes, option to set as AR/latch or hysteresis mode	

Over-Current Protection (CS fault) with Ramp Compensation



Without OCPRC



With OCPRC

CH2 – CS_stop_cmp_inv, CH3 – internal FB with RC, CH4 – I_{primary}

- New function in NCP13994
- Ramp compensation gain adjusted based on Over-current event
- Significantly reduced primary and secondary current under stress conditions

Totem Pole PFC + LLC Turnkey Solutions

240 W TPPFC+LLC+DC-DC 3 Stages USB PD3.1 Solution

Value Proposition

This design used Onsemi's NCP1680 TPPFC and NCP13994 LLC controller plus GaN and NCP4306 synchronous rectified controller combining FAN65004 buck converter for 240W USB PD3.1 adapter solution.

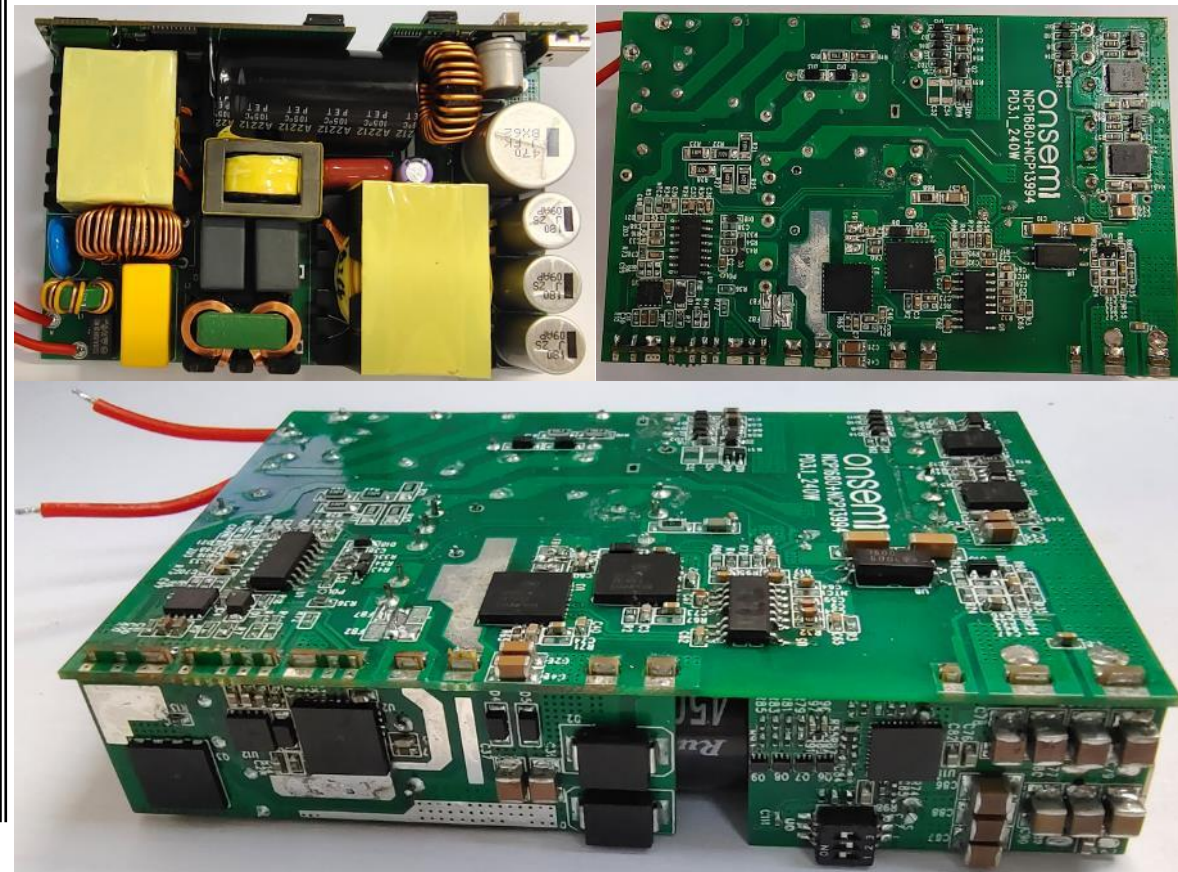
Specifications and Features

- AC input from 90V to 264V
- TPPFC+LLC+DC-DC topology
- High Frequency operation with iGaN
- Skip operation for PFC and LLC at light load and PFM mode for DC-DC converter
- External discrete circuit to simulate PD3.1 multi-output
- Output voltage 5V, 9V, 12, 15V, 20V, 28V, 36V, 48V
- Max Output power: 240W
- Support PD3.1 up to 48V
- Ripple&Noise: <100mV
- **AVG efficiency: 94.5% & 95.2% at 115 Vac & 230 Vac and 48 V 5 A**
- **Full load efficiency: 95.2% & 96.2% at 115 Vac & 230 Vac and 48 V 5 A**
- Output precise OVP
- Output OCP, SCP
- Open loop protection
- 2 layers PCB used and small size with compact design
- PCBA size: 98mmx62mmx21.5mm
- **Power Density: 30W/in³**

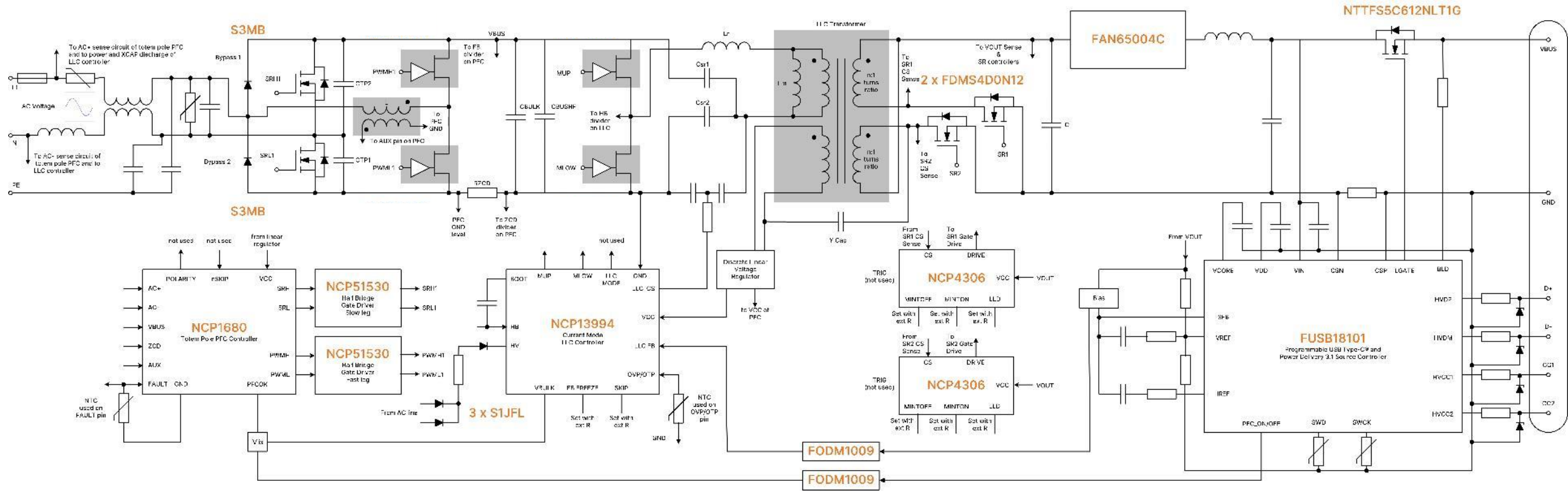
Market & Applications

- Mobile phone Quick Charger
- Laptop computer
- Other applications

Demoboard Photo

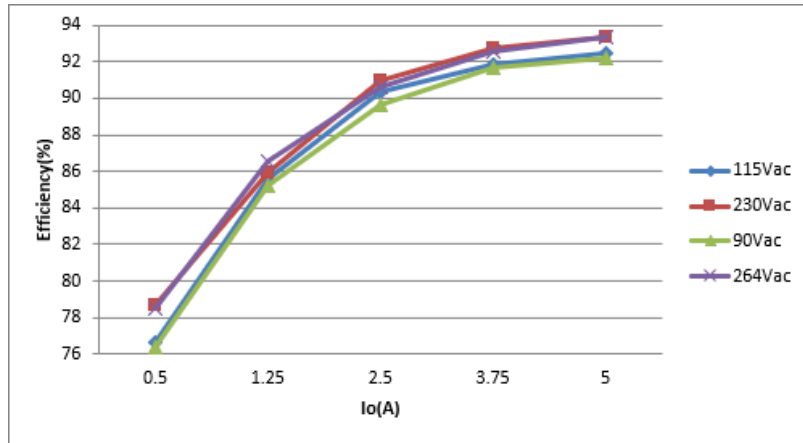


240 W USB LLC GaN Power Supply

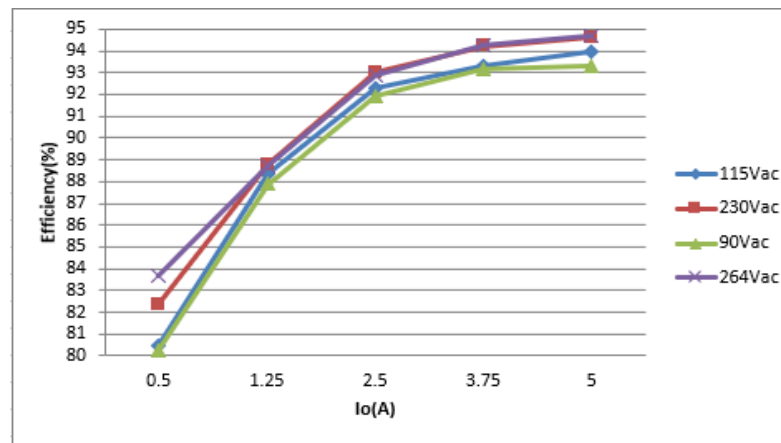


Efficiency, No-Load Consumption, PF

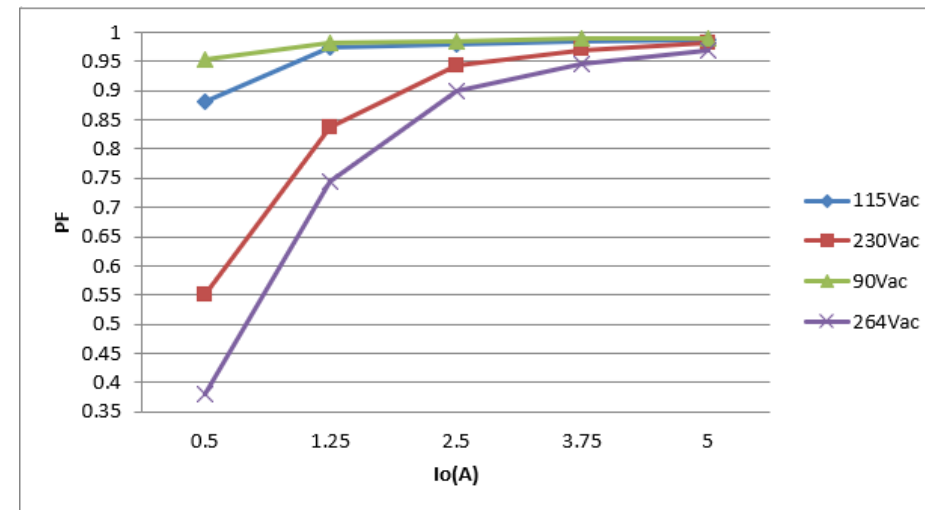
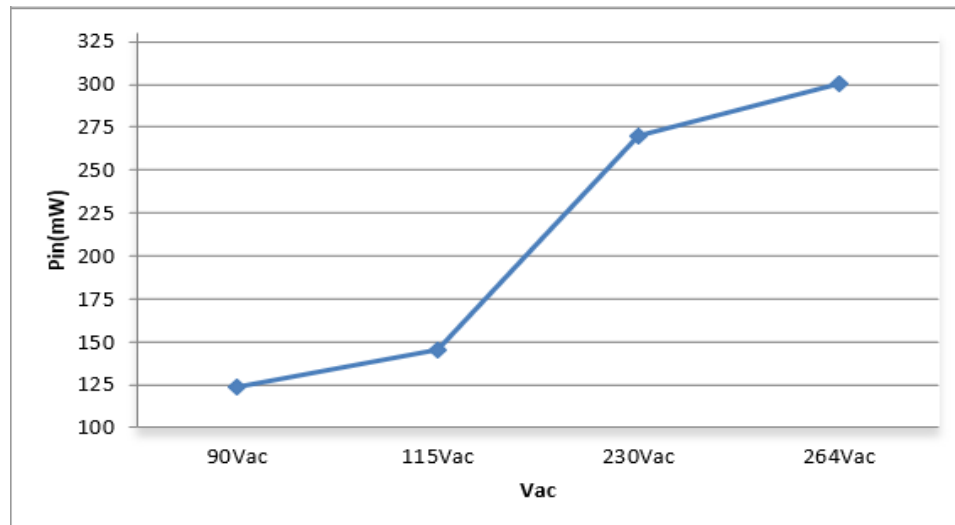
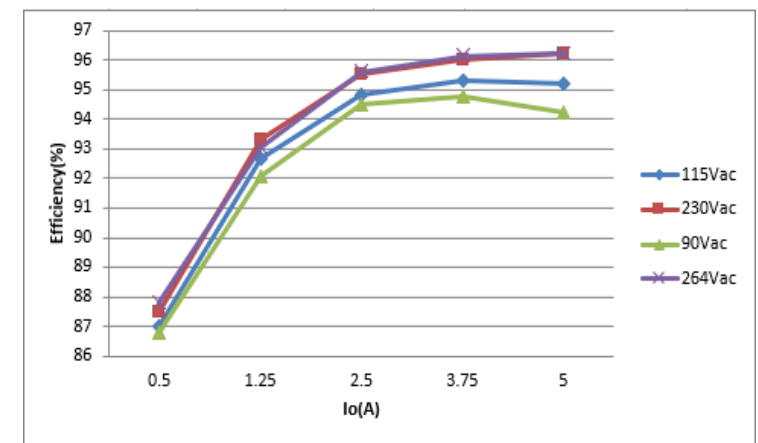
20V



28V



48V



300 W, 20 V Ultra High-Power Density GaN Based Adapter

Value Proposition

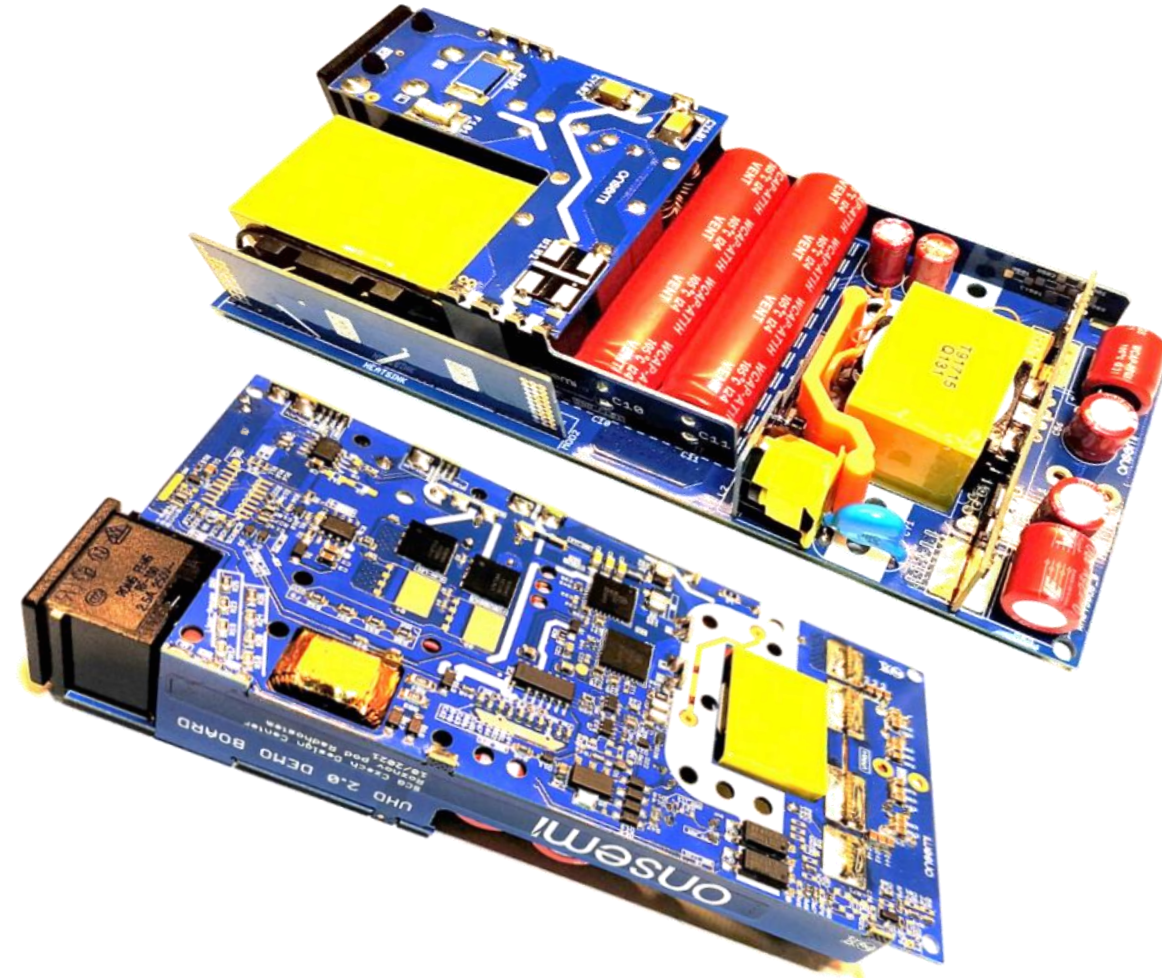
Smallest power adapter for Gaming Laptop and Ultra-thin TV utilizing high voltage Single Channel Driver GaN switches together with market-leading CrM TP PFC and LLC controller. At over 36 W/in³, high efficiency, the design is 30 % smaller than previous best in class today by operating at 500 kHz nominal switching frequency.

Value Advantage

- ✓ Overall Efficiency: 94.55% (230VAC), 93.25% (110VAC) @ 300W
- ✓ Compact low-profile design: 134 mm x 62 mm x 18mm
- ✓ Ultra High Density: >36W/ inch³ including line socket
- ✓ Max output power: over 330 W
- ✓ Modular design allows flexibility for power scaling or enhancing
- ✓ True bridge-less Totem-pole PFC stage operating in CrM
- ✓ Implements Single Channel Driver GaN Switches
- ✓ Multiple protection features
- ✓ Small size with compact design based on simple 2-layers PCBs
- ✓ Robust production ready reference design

Current Proposition

- ✓ Industry-first Integrated Totem-pole PFC Controller, NCP1680
- ✓ 650 V -150m Ω , Single Channel Integrated Driver GaN
- ✓ High performance current mode LLC resonant controller, NCP13994
- ✓ 700 V Best in class propagation delay HB Driver, NCP51530
- ✓ Synchronous rectifier controller, NCP4306



Improving Size & Efficiency in 300W power supply

Step 1: Use Totem Pole PFC

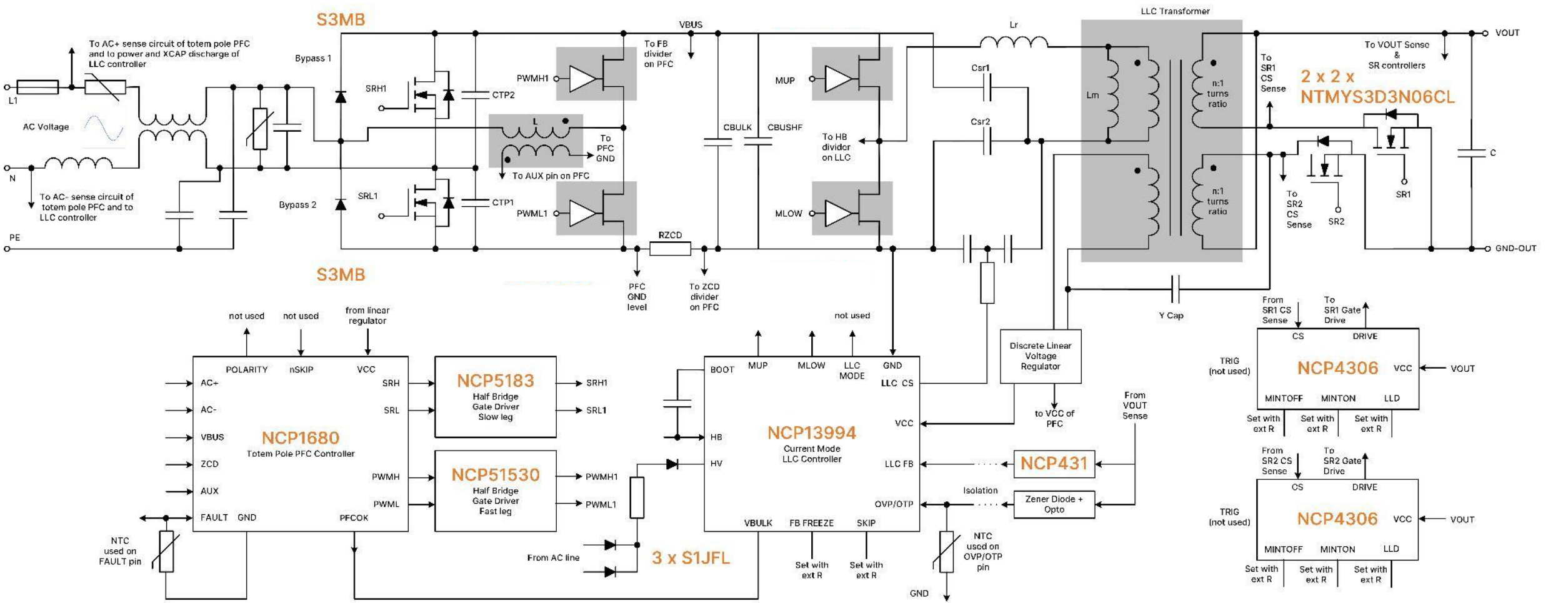
Lower loss as rectifiers removed

Step 2: Use high speed LLC

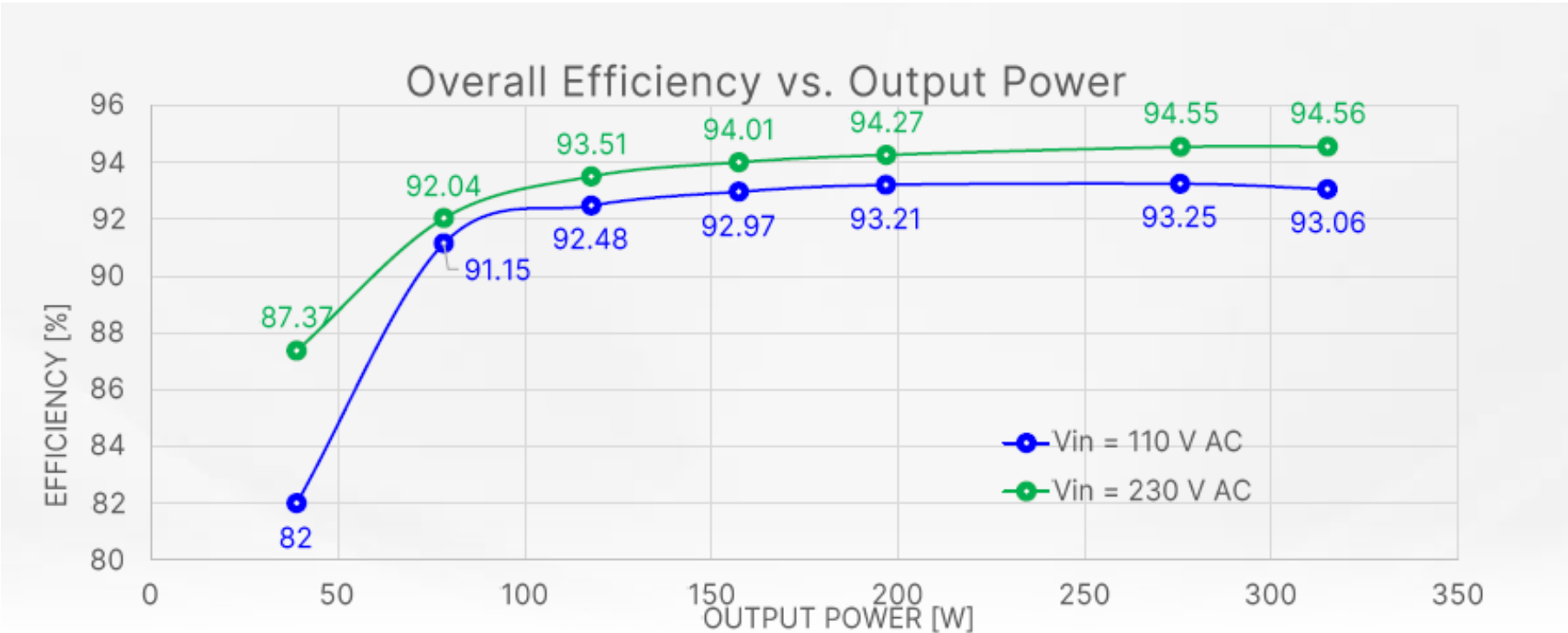
Lower loss as transformers smaller

Step 3: Use Integrated GaN

Lower loss as switching loss is very low



Efficiency, No-Load Consumption



No-load Consumption [mW] @ Line			
90 Vrms	110 Vrms	230 Vrms	265 Vrms
131	133	158	164

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