Meeting Challenging Efficiency Standards with Bridgeless Totem Pole Power Factor Correction

WE MEET @ DIGITAL DAYS

23 Feb 2022

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Agenda

- AC/DC Power supply landscape
- PFC, Why, Solution and CrM control technique
- Higher Efficiency: Bridgeless vs Bridge
- Onsemi NCP1680 Bridgeless Totem Pole CrM PFC Controller
- 300 W NCP1680 CrM board Data
- Q&A

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AC/DC Power supply landscape

AC-DC power supply are extensively used in several verticals market segments

Industrial

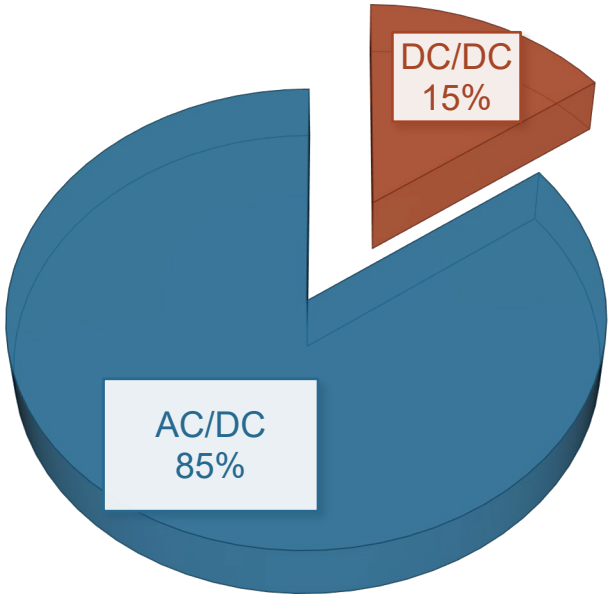
Automotive

Medical

Smart cities

Computing & Clouds

AC-DC power supply are majority of the market



Source: HIS 2014

Increasing Demand with constant growth

CAGR ~5%
(2019 – 2027)

Source: Transparency Market Research

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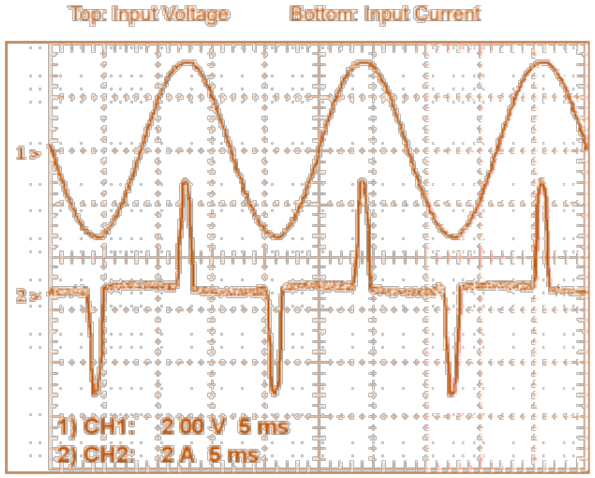
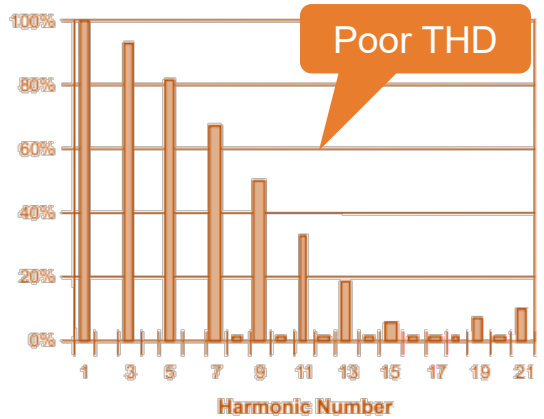
PFC: Why?

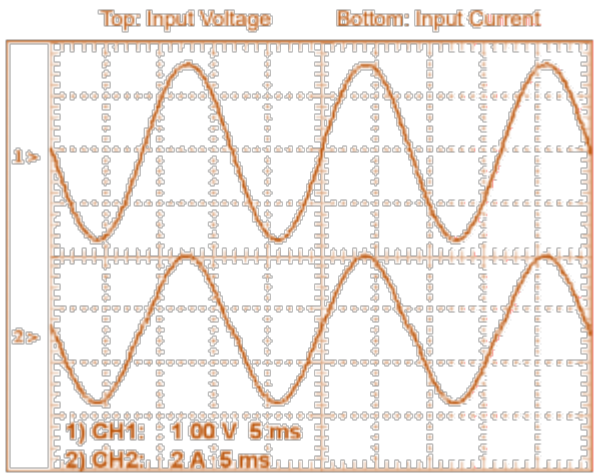
Problem…
When the power factor (load dependent) is not equal to 1, the current waveform does not follow the voltage waveform. This results not only in power losses but may also cause harmonics that travel down the neutral line and disrupt other devices connected to the line. The closer the power factor is to 1, the closer the current harmonics will be to zero since all the power is contained in the fundamental frequency.

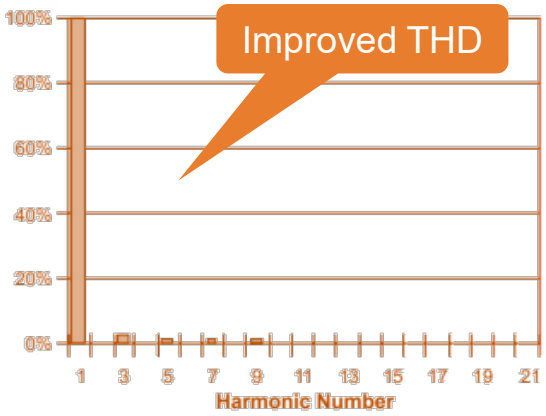
SMPS without PFC:





SMPS with PFC:





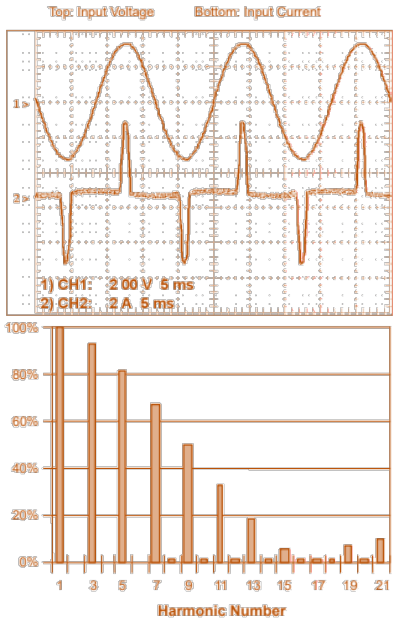
For the US, you need PFC > 75W

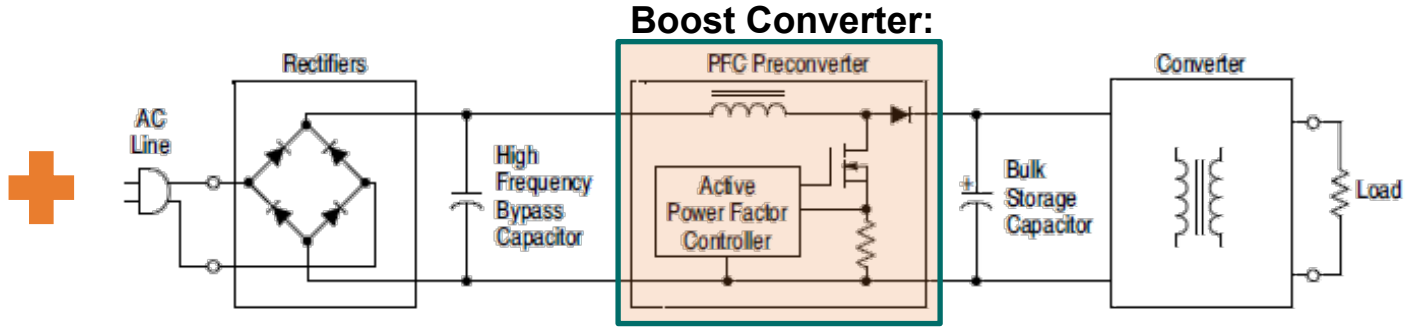
Source: PFC Handbook (HBD853/D)

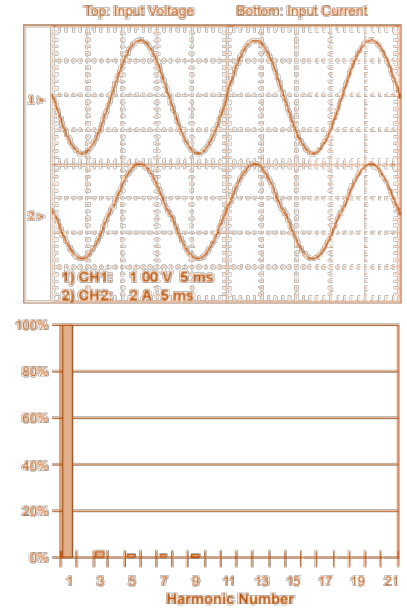
PFC Solution

Solution:
Shape the input current to match the input voltage waveform.

Implementation:
Insert a switched mode boost converter stage between rectifier and bulk storage cap



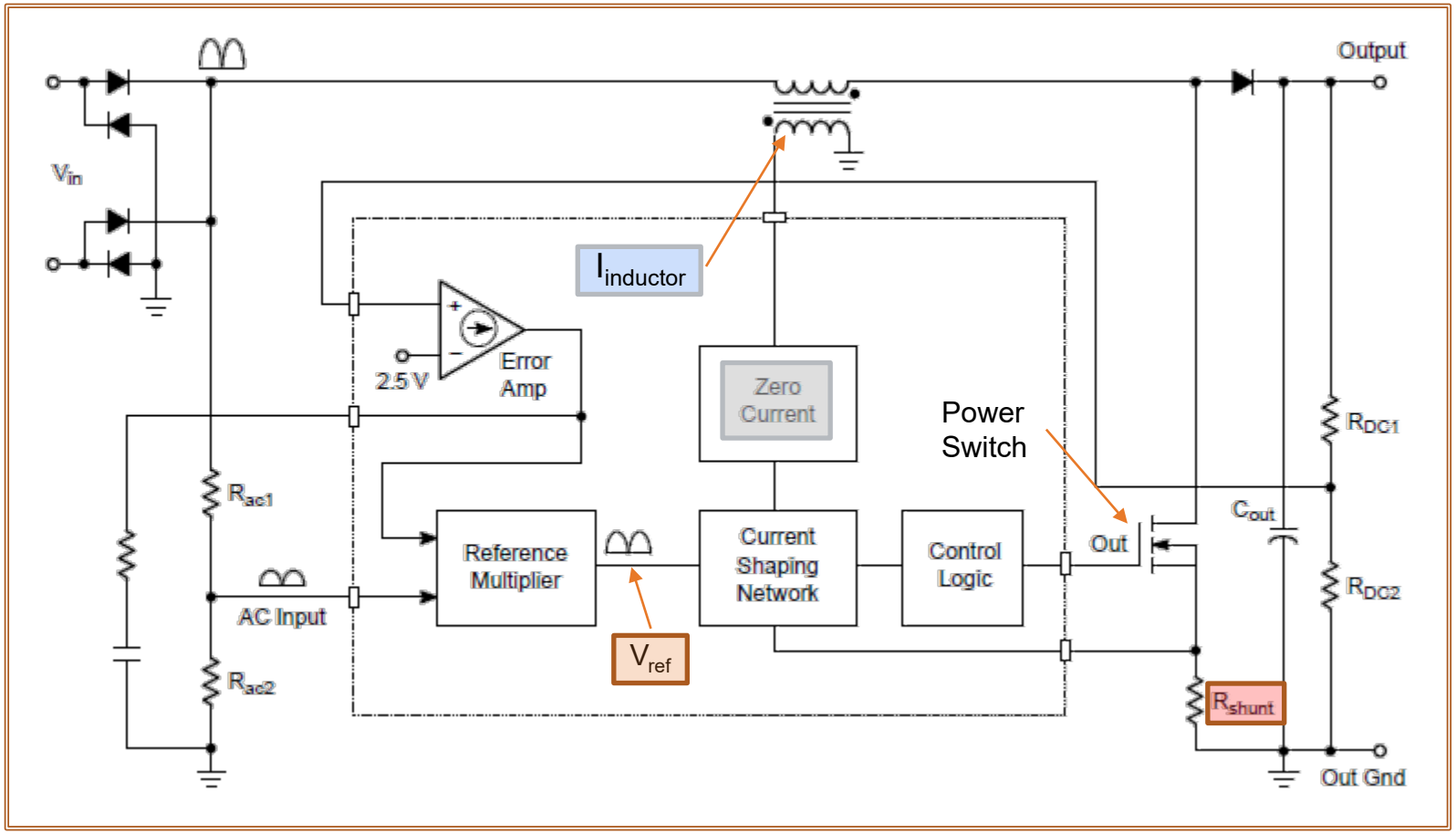




Source: PFC Handbook (HBD853/D)

PFC CrM Control Example (multiplier)

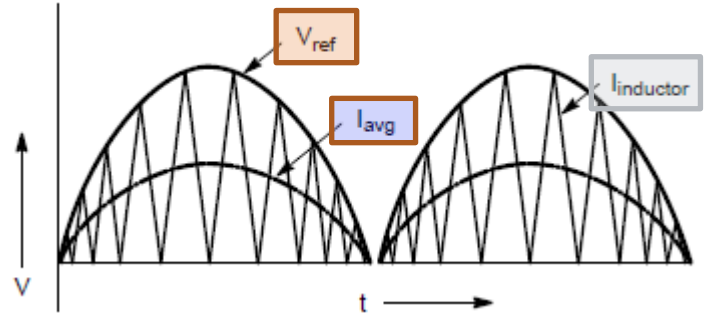
Remember the Goal:
Shape the input current to match the input voltage waveform.



Critical Conduction Mode (CrM):

1) The Reference Multiplier generates V_{ref}
2) V_{ref} = scaled version of the rectified AC Input shape.
3) Power Switch ON:
   a) $I_{inductor}$ ramps up until R_{shunt} = V_{ref}
4) Power Switch OFF:
   a) $I_{inductor}$ ramps down until Zero Current
5) I_{avg} peak $I_{inductor}$ divided by 2 (triangular wave form)

Reshaped Input Current:



Switching Inductor Current from Zero to Peak

Source: PFC Handbook (HBD853/D)

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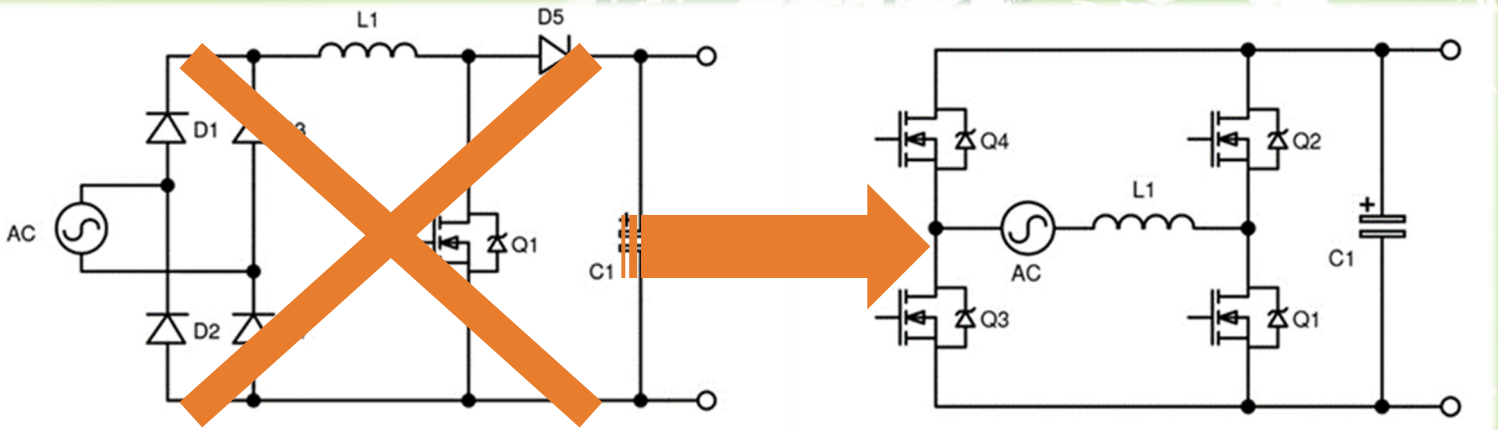
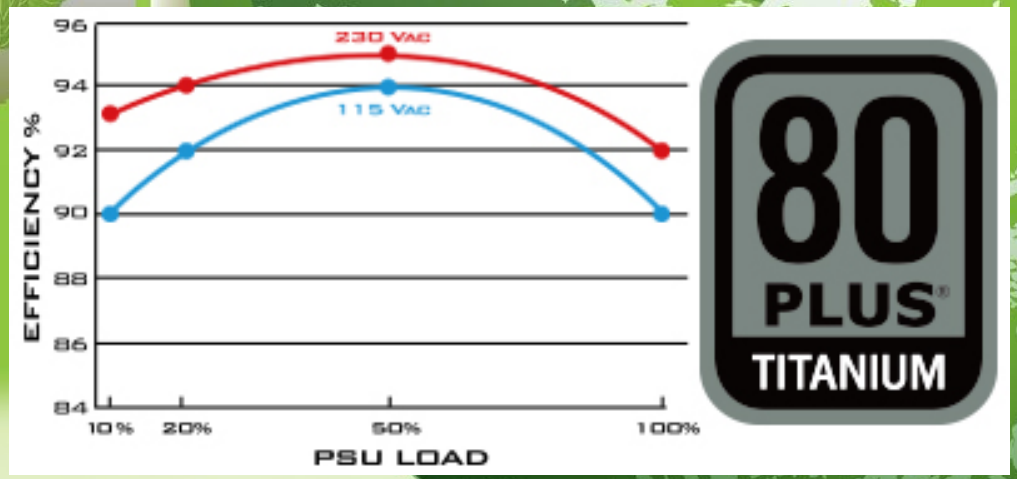
High Demand for Energy-efficient Solutions

Typical PFC circuits: Conventional boost to bridgeless Totem Pole





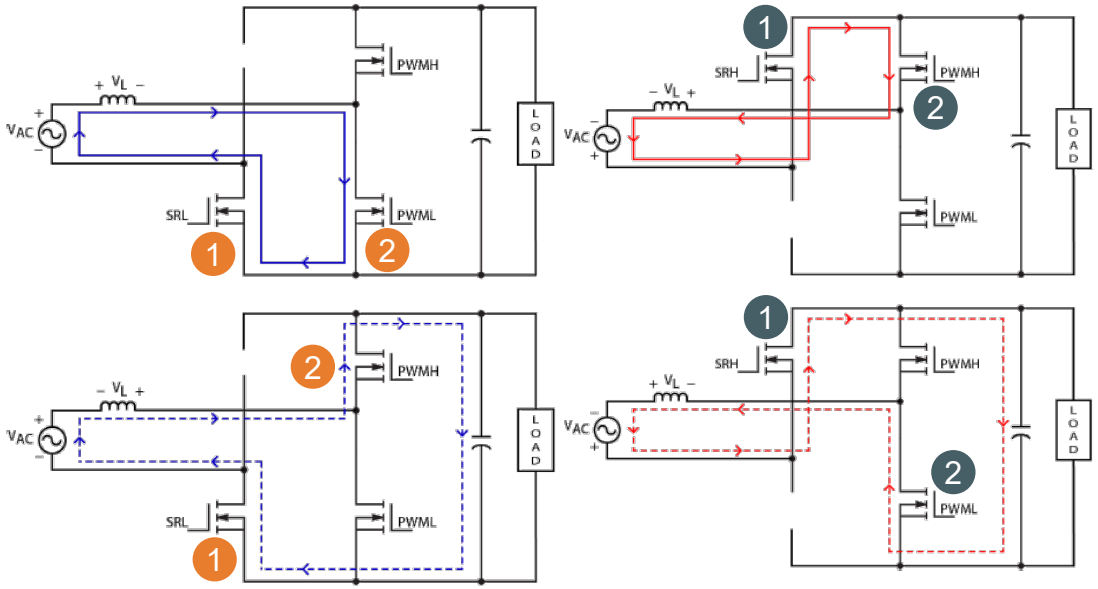
Efficiency: Bridgeless vs Bridge

Elegance = Simplicity
Simplicity = Elegance

Golden Rule: Better Efficiency with fewer devices in the conduction path!!!

PFC: Bridgeless Totem Pole

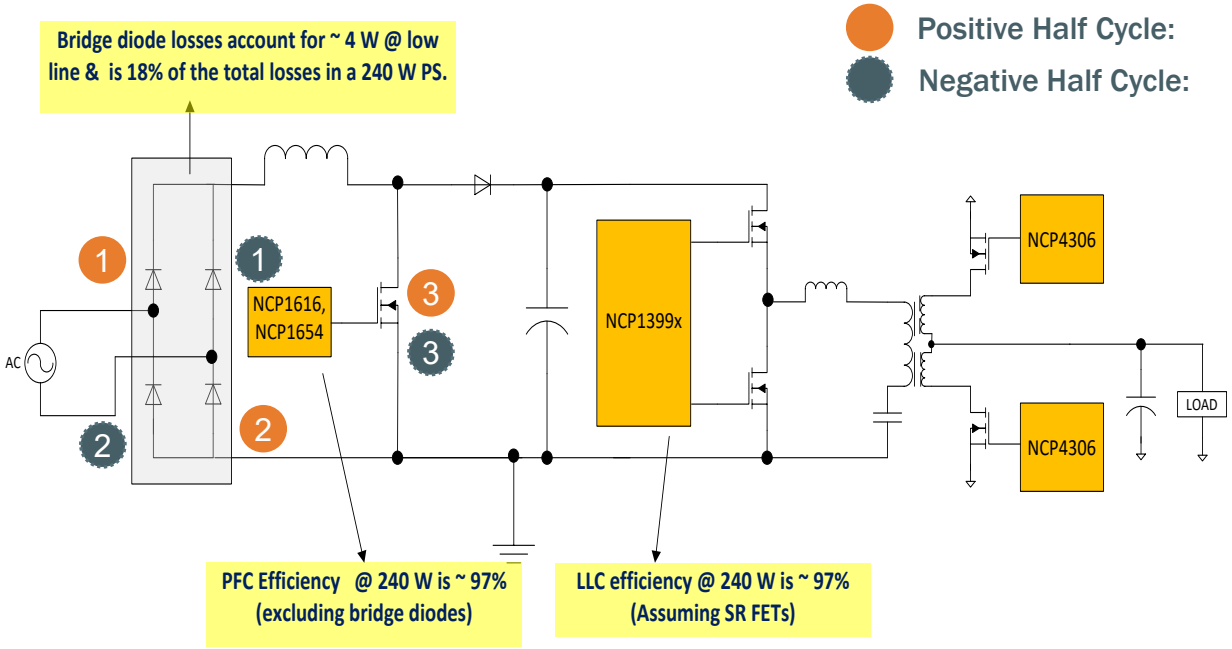
Conduction Path: 2 devices



Positive Half Cycle: Negative Half Cycle:

PFC: Bridge Diode

Conduction Path: 3 devices



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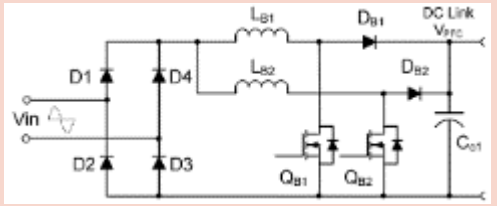
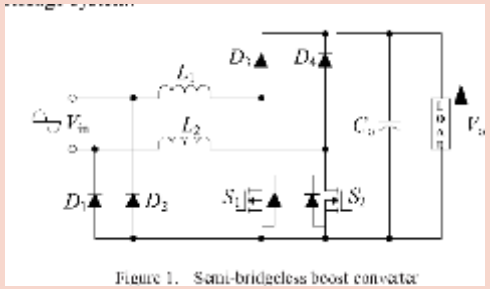
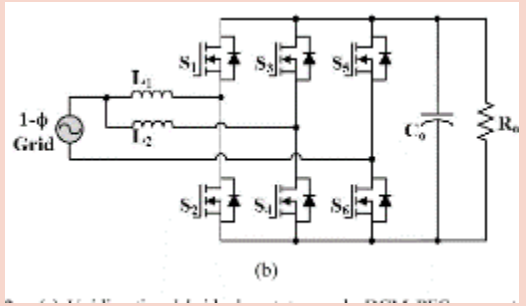
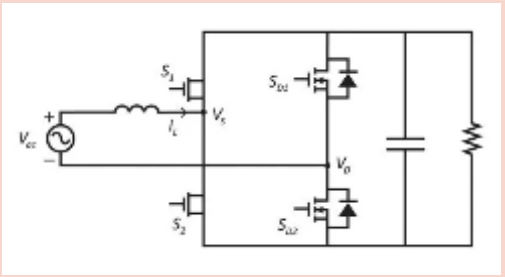
NCP1680

Bridgeless Totem Pole CrM PFC Controller

Power Factor Correction – Topology overview

Topology	Interleaved Boost	Semi-Bridgeless Boost	Interleaved CrM Totem Pole	Bridgeless Totem Pole
		 Figure 1. Semi-bridgeless boost converter		
Modes	CCM or CrM	CCM or CrM	CrM	CrM or CCM
Transistors	Si SJFET	Si SJFET	Si SJFET	Si SJFET, GaN or SiC for CrM Only GaN or SiC for CCM
Fsw	<100kHz	<100kHz	~250kHz	CrM: up to 500kHz (1MHz possible)
Peak eff.	~97%	~98%	~98.5%	>98.8%
Cost	100%	160%	130%	110%
Advantages	• Very straightforward • Well-known technology • Many control options	• Simple bridgeless PFC • Good efficiency above 98%	• ZCS mode with soft-switching • Higher efficiency than boost • Interleaved ripple cancellation	• Highest efficiency • Zero Qrr for GaN • Highest power density • Low component count
constrains	• Low efficiency • Lower power density	• High BOM cost • V/I sensing more complicated • High CM noise • Two large inductors	• High peak current crossing FETs • <1.5kW output power • Large EMI filter	• THD improvements with Zero current detect and new algorithm • Critical PCB layout • Current sensing critical

BTPPFC Applications

Data Center: rack mounted power supply…

high power LED street light

To match all the applications where efficiency and compactness are critical parameters

Industrial: power supply, PSU, UPS…

high power adapter

5G telecom power supply

external adapter power supply…

NCP1680 Bridgeless Totem Pole CrM PFC Controller

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 w. valley switching during foldback
- Novel Current Sense scheme
- Line polarity detection
- Novel valley sense scheme
- Control loop Internally compensated

Benefits

- Optimized performance across power levels
- Cycle-by-cycle current limit w/o hall effect sensor
- Removes external components;

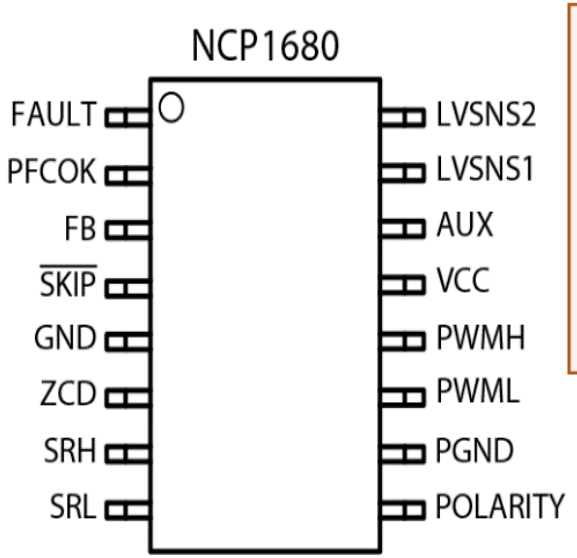
Other Features

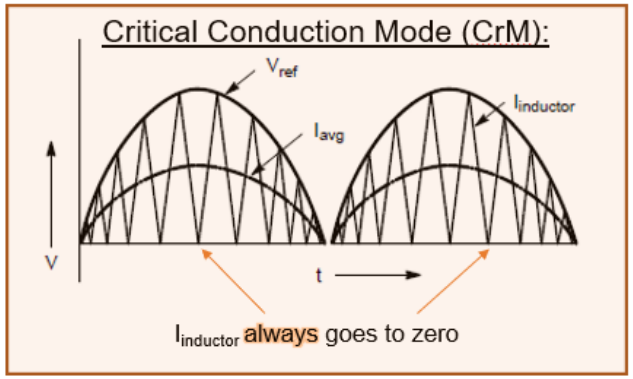
- Two low voltage pins for sensing and recreating half-wave sinusoid.
- DCM with valley synchronized turn-on for improved light load efficiency
- Zero Current Detection for CrM Operation
- Integrated Digital voltage loop control

Market & Applications

- Up to 350W
- Telecom 5G / Networking Power Supplies
- Industrial Power Supplies
- Computing Power Supplies
- Gaming Console Power Supplies
- UHD TV Power Supplies

Device Pin-Out





FCCrM: Frequency Clamped CrM, a derivative of CrM, where the frequency is limited to reduce switching losses during light loads (DCM)… or Frequency Foldback.

Ordering & Package information

- SOIC-16

Multiple Patents Issued/Pending

Totem Pole market scenario. onsemi advantages

Existing solutions on the market

Complex MCU based solution, customers need to write software code and costly current sensing method to implement the topology

NCP1680 and NCP1681

industry first mixed signal controller (state machine core) dedicated to totem pole PFC topology

Choose Your Path Wisely

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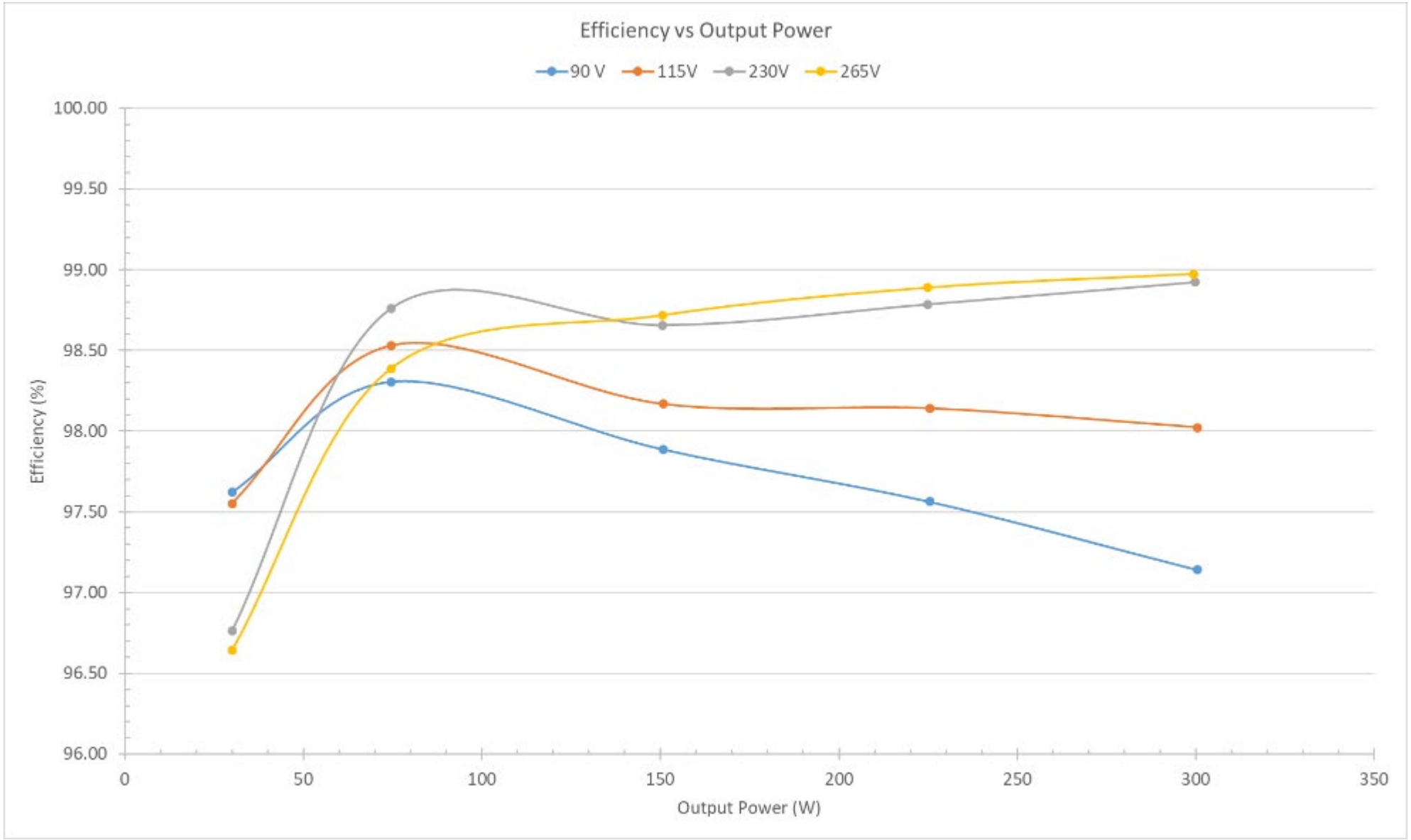
Evaluation Board Data

300 W NCP1680 CrM board utilizing 50 mΩ GaN HEMTs

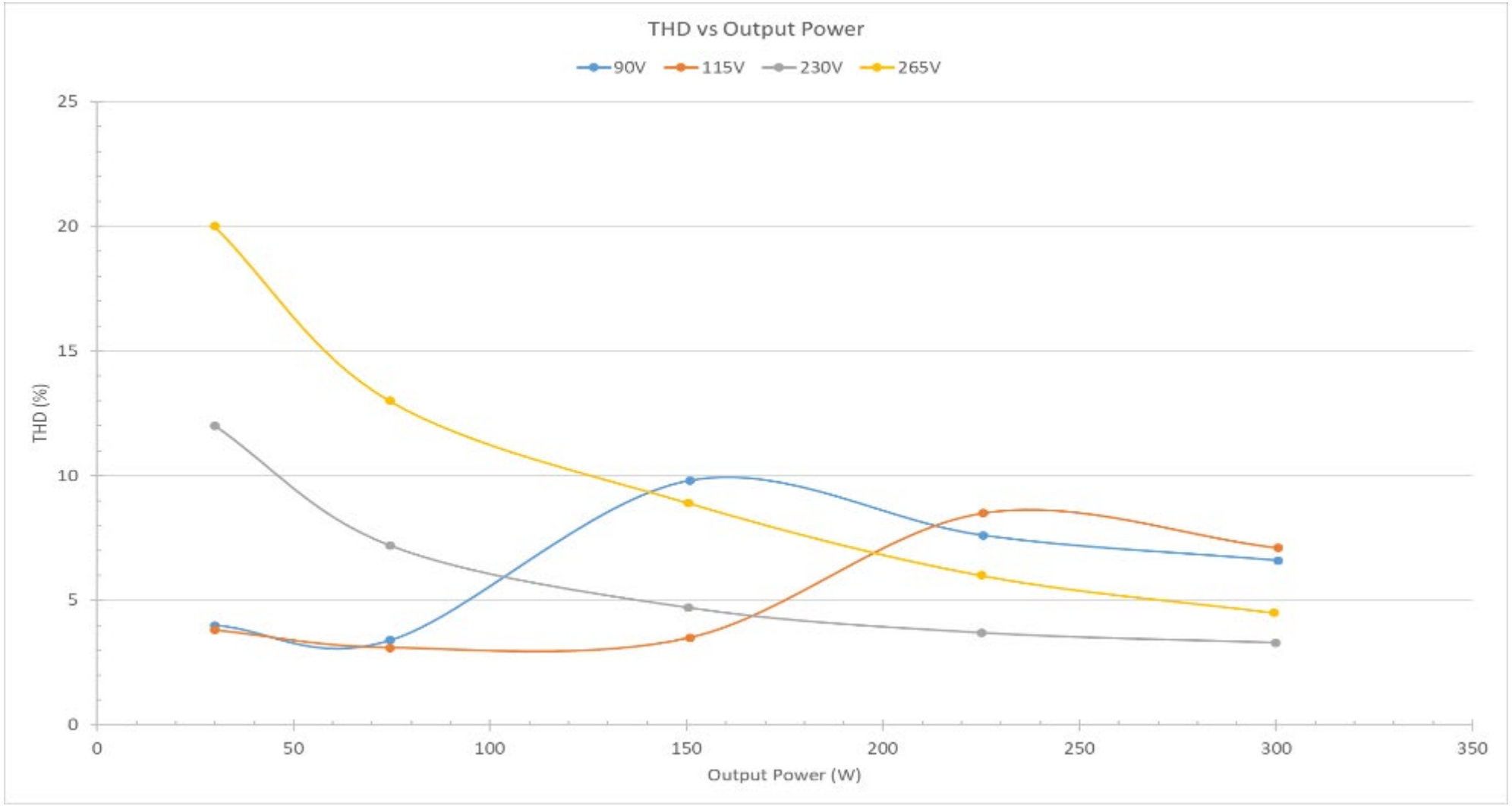
NCP1680 Evaluation Board

Description	Value	Units
Input Voltage Range	90 - 265	VAC
Line Frequency Range	47 - 63	Hz
Output Voltage	395	V
Output Power	300	W
Bulk Capacitors	200	µF
Fast Leg Switch	NCP51820+GS66508B	
Slow Leg Switch	FCPF067N65	
ZCD Resistor	125	mΩ
CAP CER, NPO,	22, 50V	pF
Inductor, Differential,, 5.4A_42mOhm	150	µH
PFC Inductor, AUX, uH, 3 A, Np:Naux = 10:1	150	µH
Common Mode Choke, 2x, 2x 80mOhm, 3.5A	2x35	mH
Common Mode Choke, 2x 20mOhm, 7A	2x7	mH

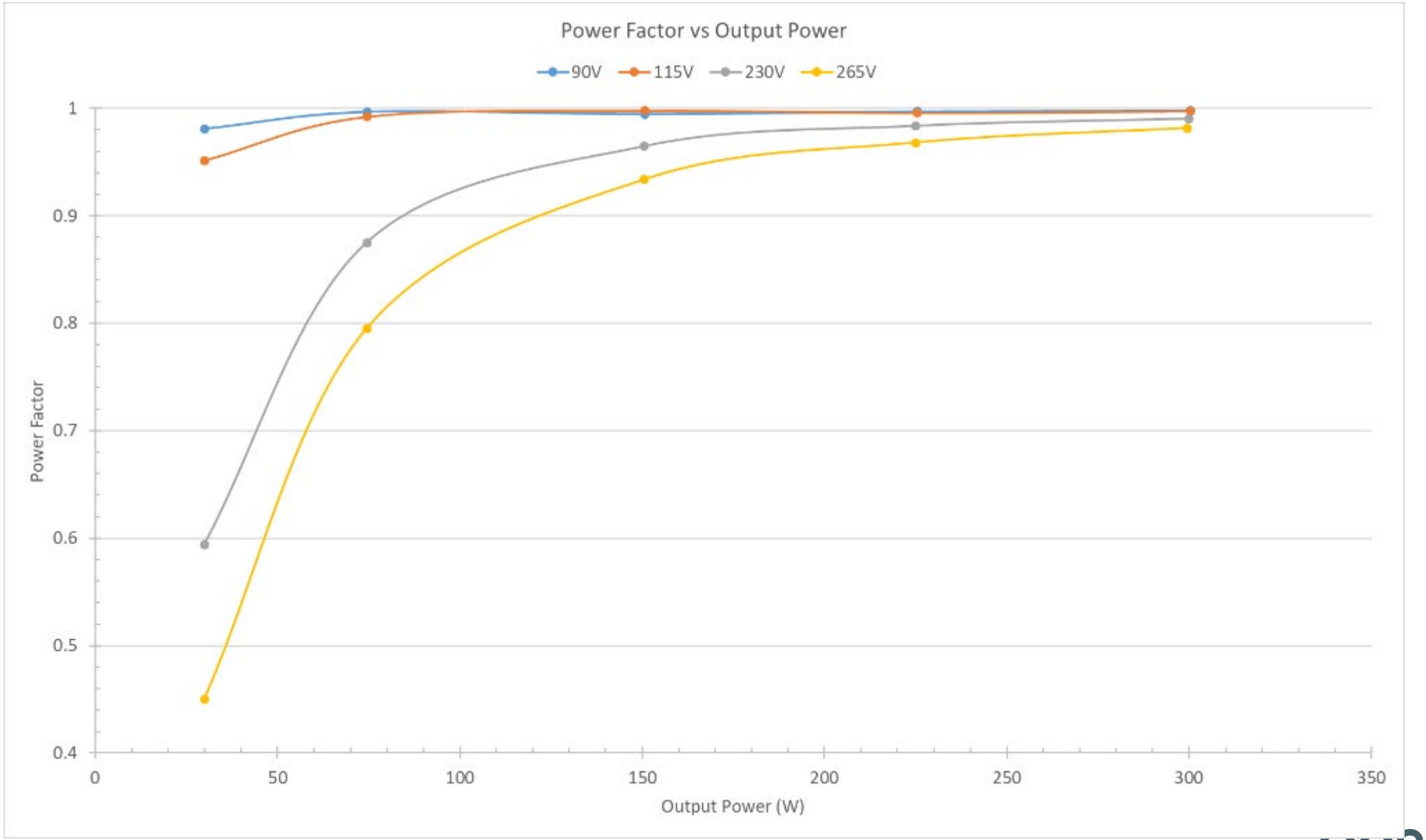
Efficiency



THD

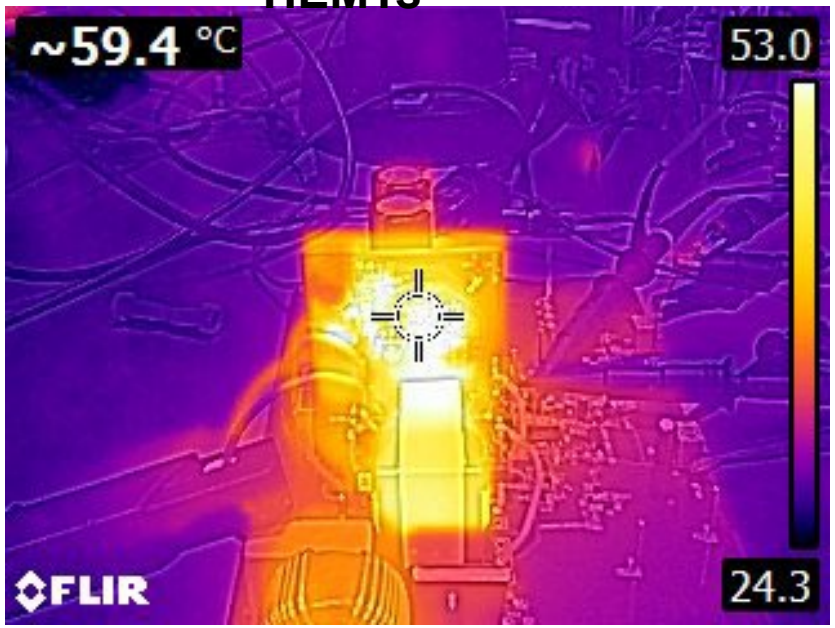


Power Factor

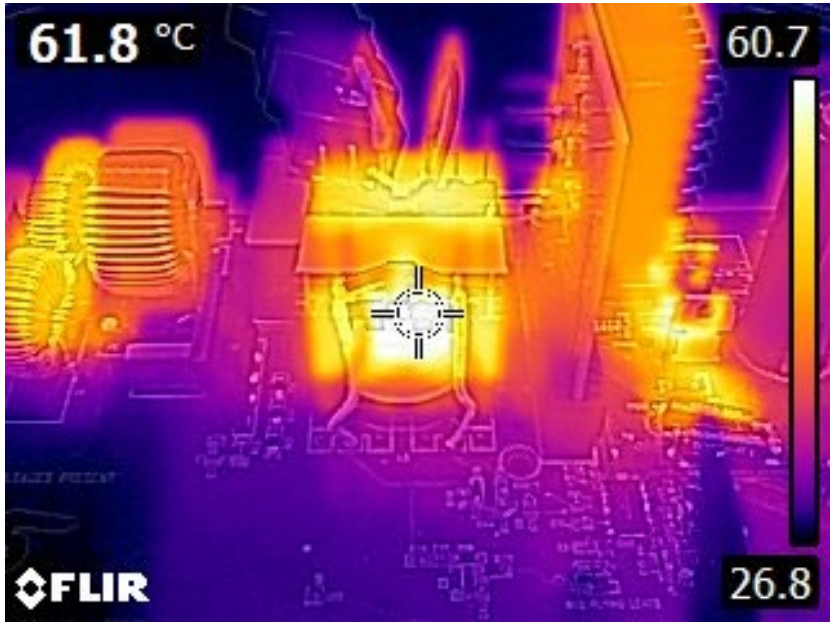


Thermal scan

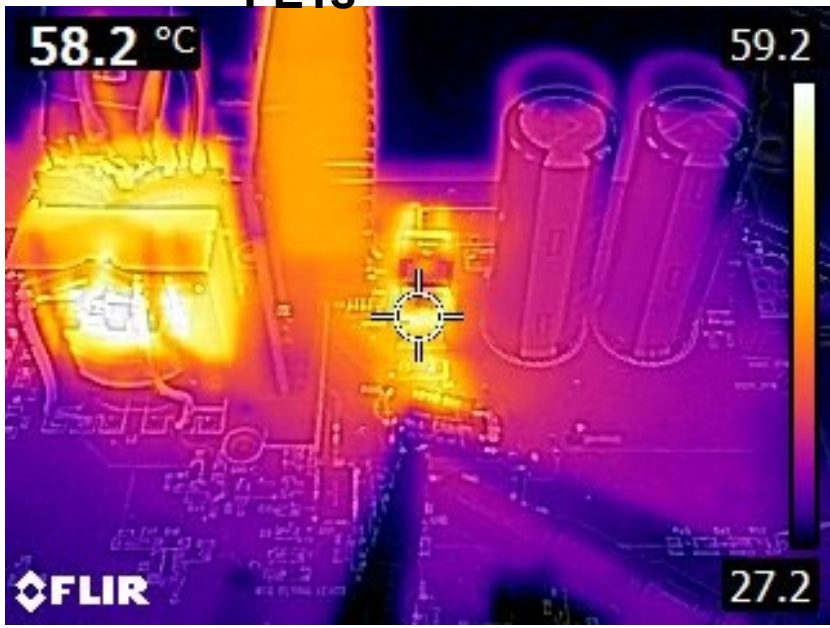
GaN HEMTs



Boost Inductor



Slow leg Si FETs



- Thermal scans showing the temperature of the 50 mΩ GaN HEMTs, boost inductor, and slow leg Si devices captured 90 Vac, 300 W, room temp ambient.

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