WBG Devices Enable Mainstream Adoption of Totem Pole PFC

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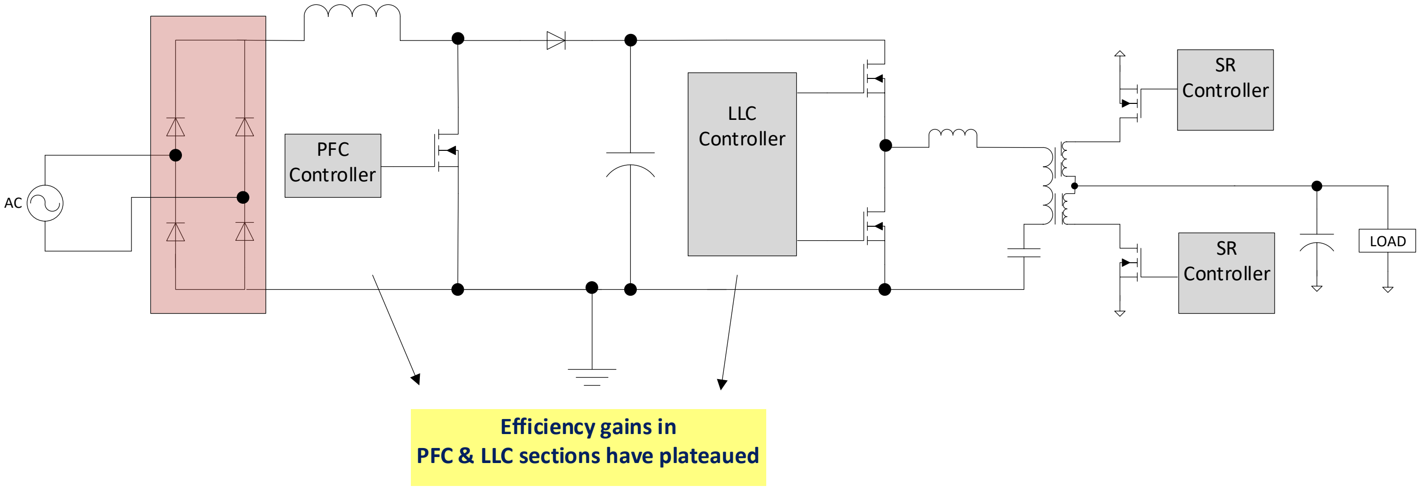
Agenda

- Introduction to Totem Pole Power Factor Correction (TPFC)
- Reasons for slow adoption of TPFC
- Compare and contrast key parameters: GaN vs SiC vs HV SJ FET
- Totem Pole PFC performance & Role of WBG devices

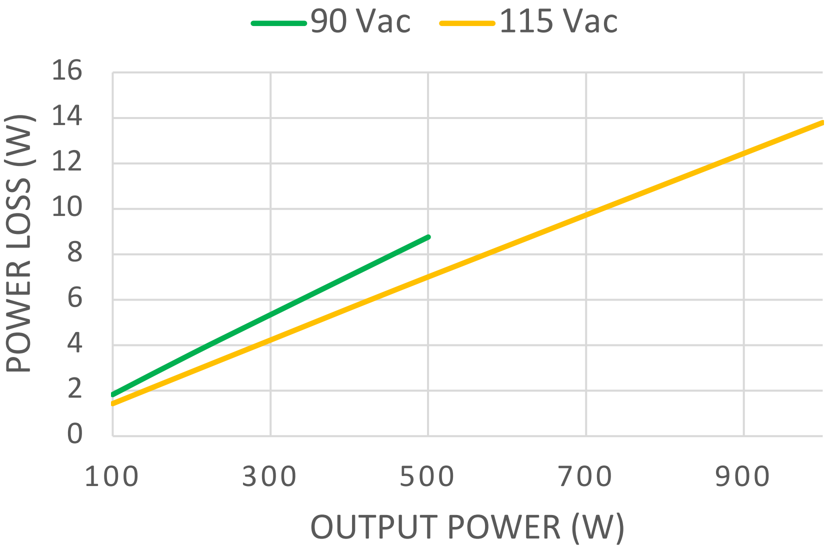
Why Totem Pole PFC?

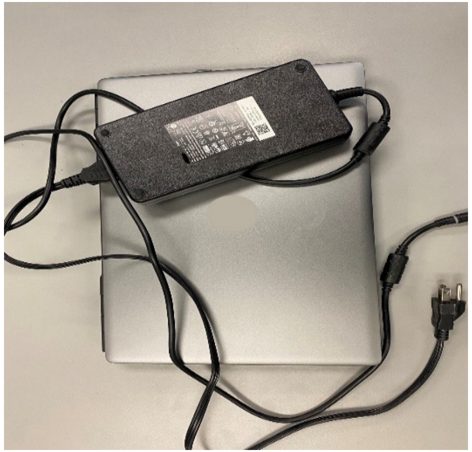


Modern power devices, topologies, and control techniques have tremendously improved the efficiency of the PFC and the Dc-Dc stage.

The bridge diode has remained the same and hasn’t utilized any of the latest advancements.

Estimated Bridge Diode Power Loss





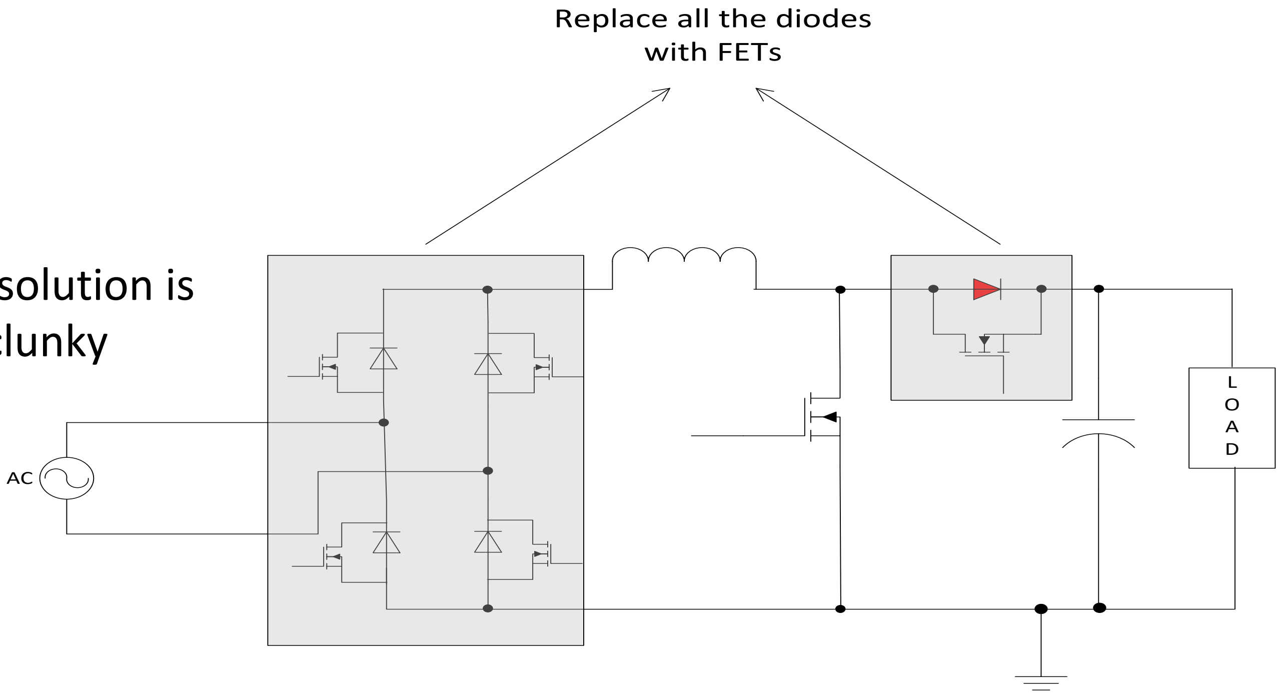
16'' laptop w. 240 W adapter

NCP1399AIOGEVB

Bridge diodes dissipate tremendous amount of power needing bulky heat sinks and are a major impediment to improve power density

How to make a Boost PFC more efficient

Active bridge solution is costly & clunky

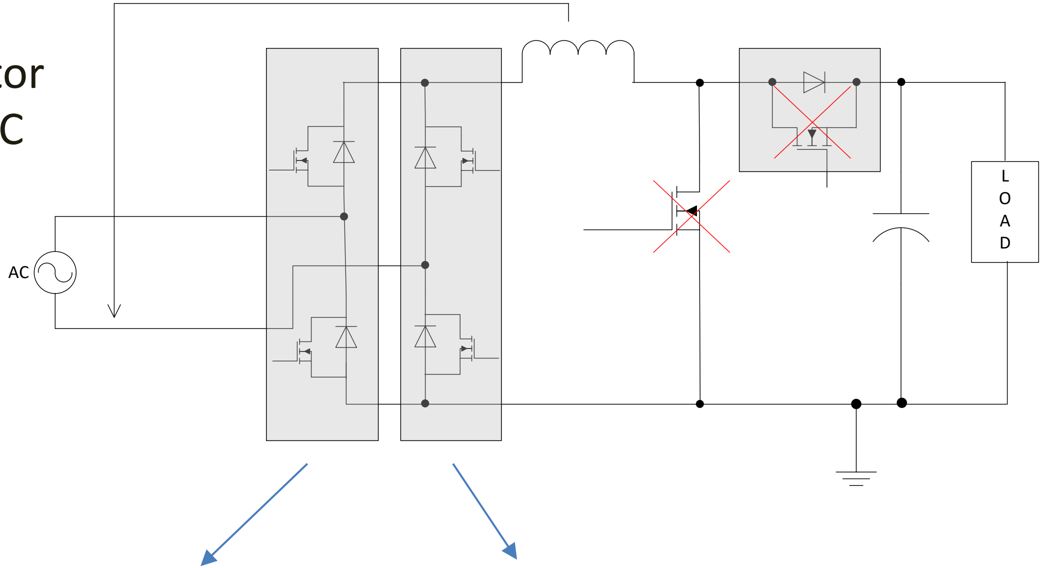


Replace all the diodes with FETs. Active Bridge + Synchronous Boost

2 switches in the 'bridge' and 1 FET in the boost stage are always conducting.

Rearranging Classical Boost Converter

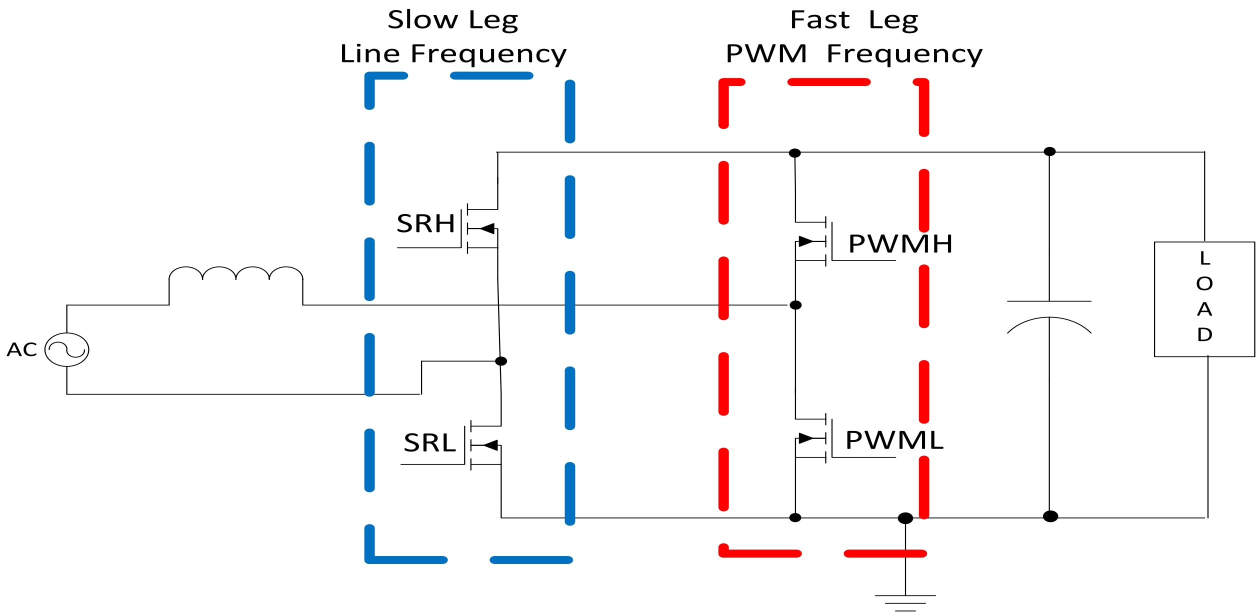
Move the inductor in series with AC



Low Frequency Leg

High Frequency Leg

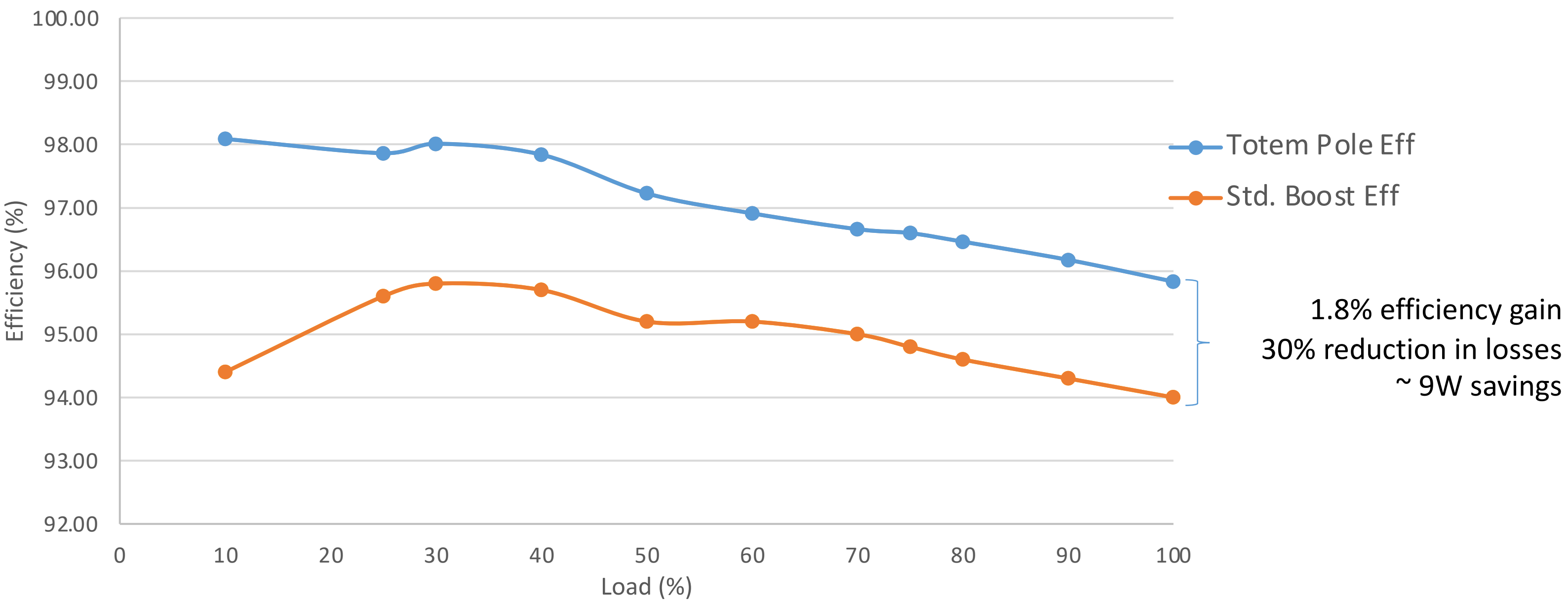
Totem Pole PFC



Totem Pole is an elegant 4 switch boost solution that reduces number of components in the current path.

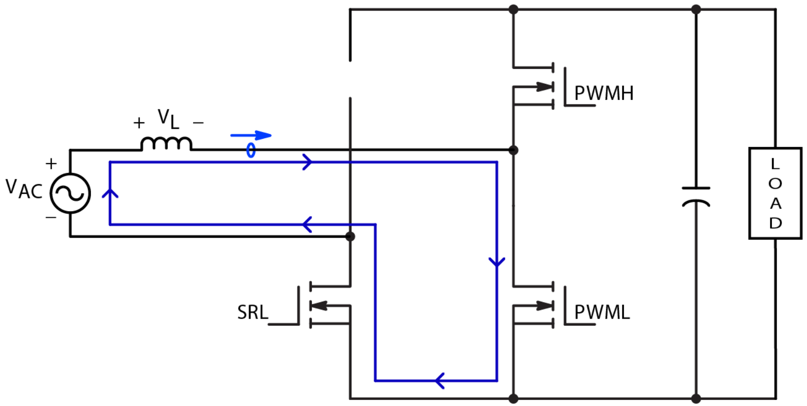
1 FET in the “diode” section (Low Freq leg) and 1 FET in the boost section conducting.

Totem Pole PFC Efficiency Gain

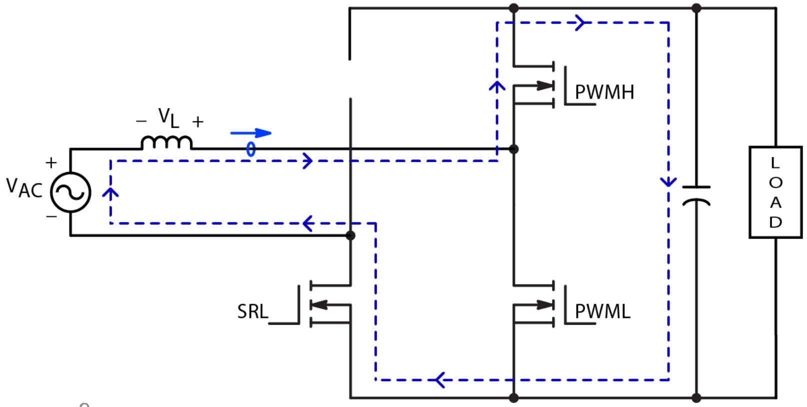


Totem Pole PFC can result in up to 9 W savings or 30% reduction in losses
Data captured on a 500 W PFC at 90 Vac. Std Boost utilized SiC diode

Positive Half Cycle Operation

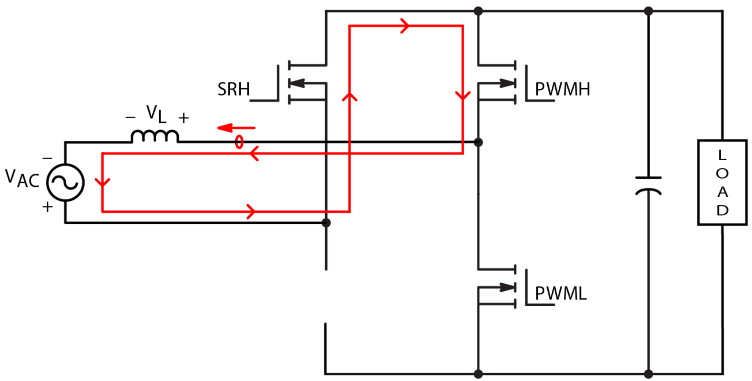


- PWML is responsible for Pulse Width Modulation or duty cycle control aka “D”
- Inductor current ramps up during this phase
- SRL is kept on through out the positive half line cycle

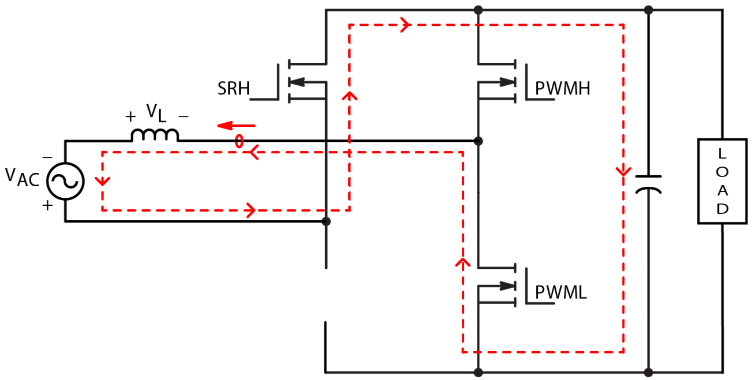


- PWMH is the synchronous boost FET and is responsible for the “1-D” operation.
- Inductor current ramps down during this phase
- **<u>Notice the direction of current flow</u>**

Negative Half Cycle Operation



- PWMH is responsible for Pulse Width Modulation or duty cycle control aka "D"
- Inductor current ramps up during this phase
- SRH is kept on during the entire cycle

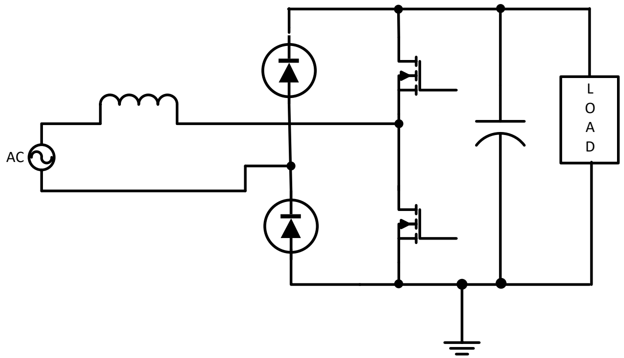


- PWML is the synchronous boost FET and is responsible for the "1-D" operation.
- Inductor current ramps down during this phase
- **Notice the role reversal of the fast leg switches i.e., PWMH and PWML.**

Reasons for Slow Adoption

Cost & Complexity

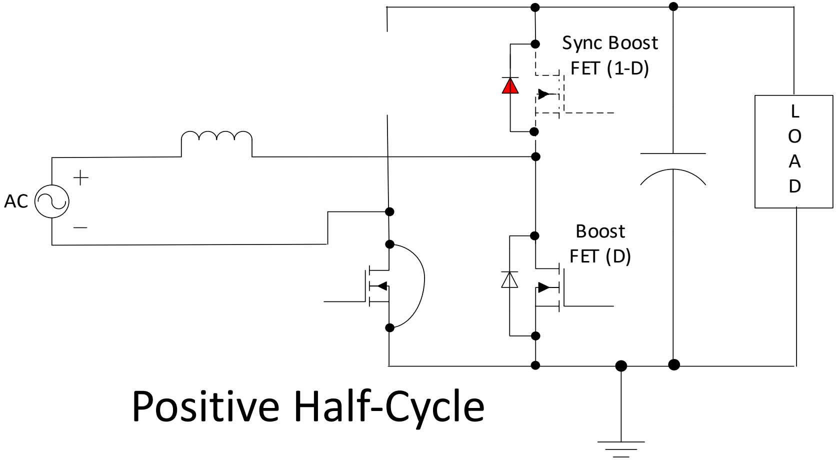
- 4 Switch topology
  -2 switch implementation w. slow leg diodes possible
- 2 Gate Drivers
- Bidirectional nature of inductor current



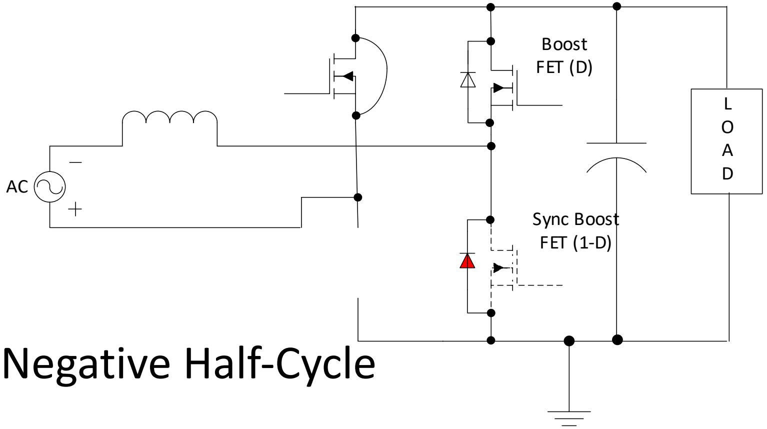
Technical challenges

- Poor Qrr & High Coss of HV SJ FETs
- Lack of specific PFC controllers.

Reverse Recovery in TPFC



Positive Half-Cycle



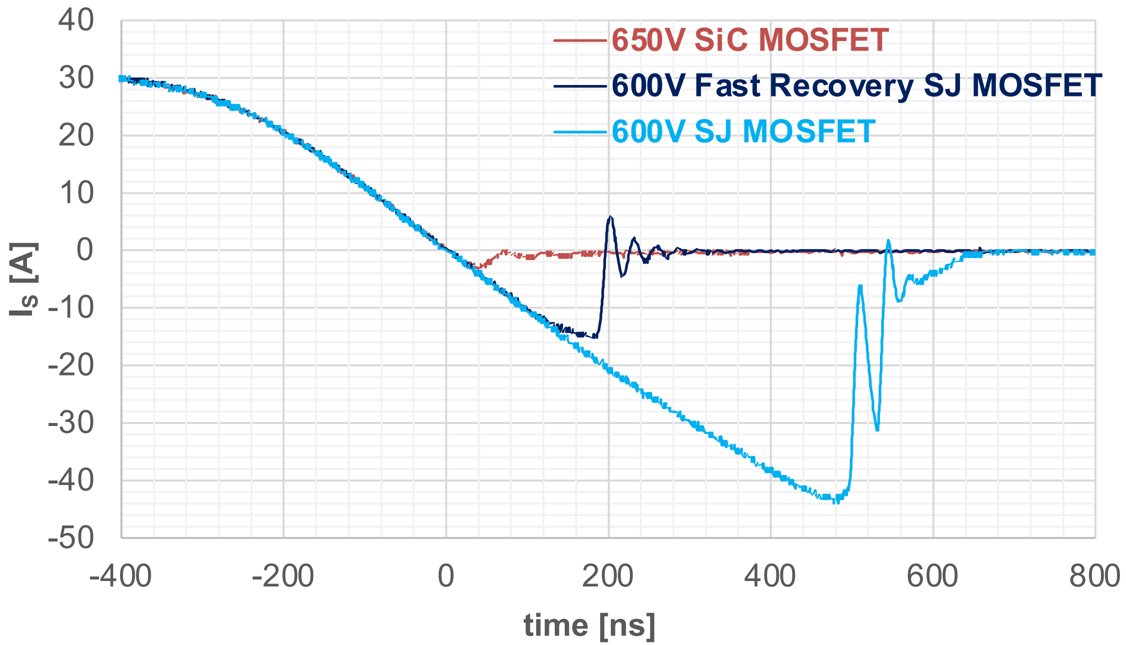
Negative Half-Cycle

Totem Pole PFC is a synchronous boost topology; reverse recovery performance of the switch is very important in CCM.

SJ FETs have poor reverse recovery characteristics compared to SiC diodes used in classical boost PFC operating in CCM

On paper, reverse recovery of SJ FETs shouldn't cause any challenges in CrM

Reverse Recovery Performance



Test Conditions

V_{dd}= 400 V

I_s=30 A

di/dt= 100 A/µs

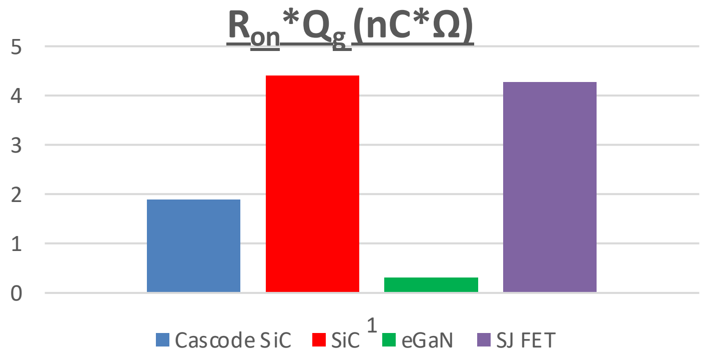
Even the fast recovery type SJ FETs have poor reverse recovery performance preventing CCM operation

Comparison of HV Switch Technologies

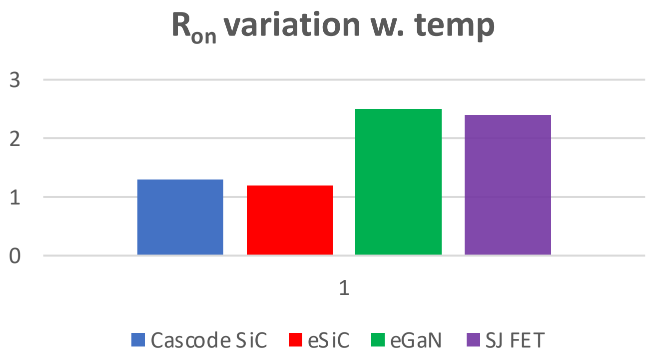
Quite a few competing switch technologies challenging industry standard Si SJ FET such as:

1. *Cascode GaN (Si FET + GaN D Mode)*
2. Cascode SiC (Si FET + SiC JFET)
3. eGaN HEMT (enhancement mode GaN)
4. Enhancement mode SiC

Key Parameters	System impact
R_{on}*Qg	Efficiency, trade-off b/n conduction and switching loss
R_{on} temp Variation	Applicability in high temp & high-power environment

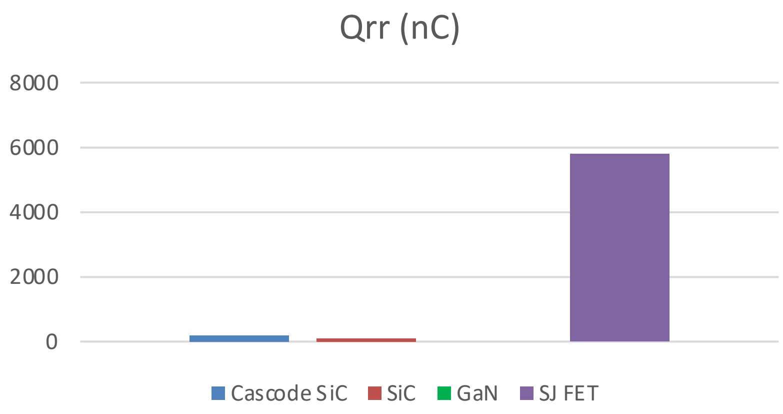


eGaN is a superior device for medium to high freq

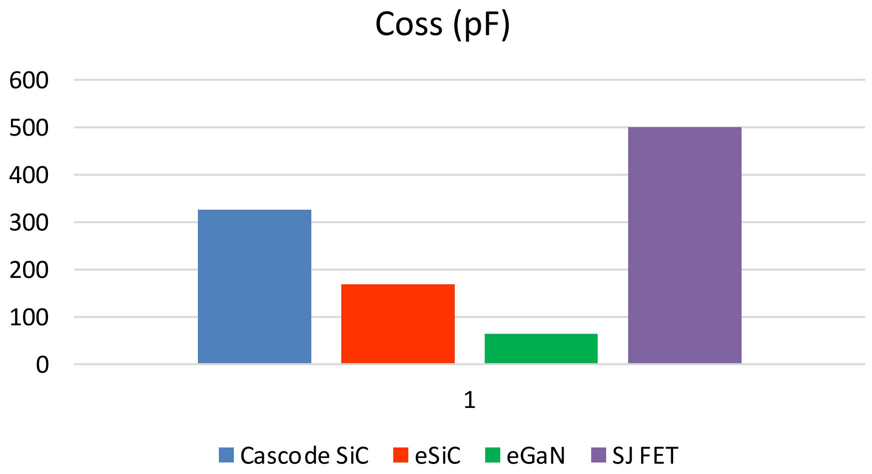


SiC is a superior device for high temp apps

Comparison of HV Switch Technologies



GaN with its Zero Qrr is a superior device for hard-switching apps. SiC is not too far behind

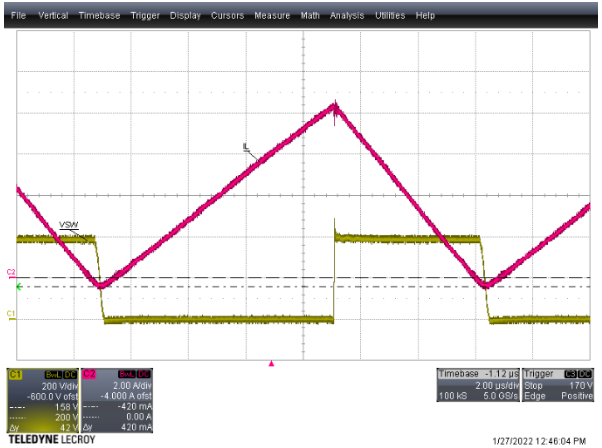


Lower the Coss, lower the circulation currents
GaN is better for AC Flyback

Qrr of SJ FET is an order of magnitude higher than Qrr of WBG devices resulting in slow adoption of hard switching topologies such as TPFC in CCM.

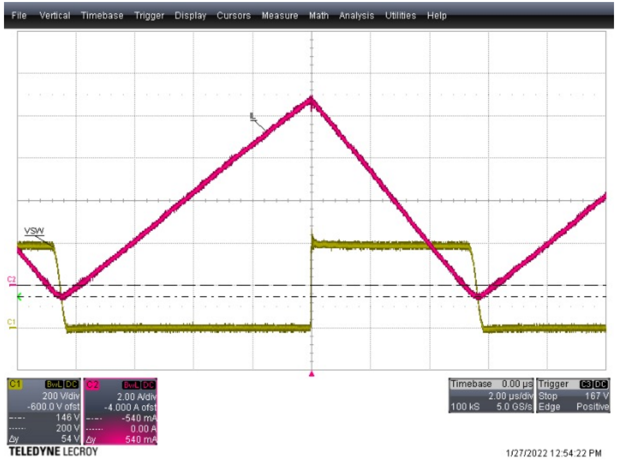
TPFC CrM Inductor Current Waveforms

115 Vac, 300 W CrM



50 mΩ GaN

420 mA Neg. Current



45 mΩ SiC

540 mA Neg. Current

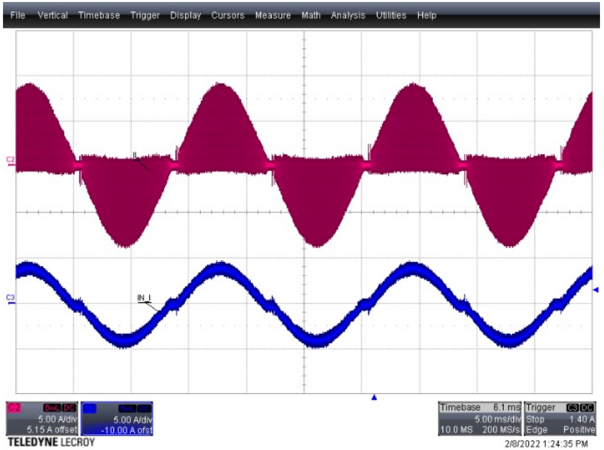
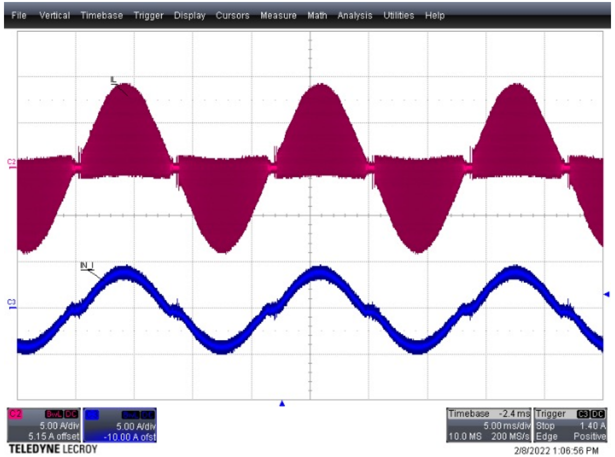
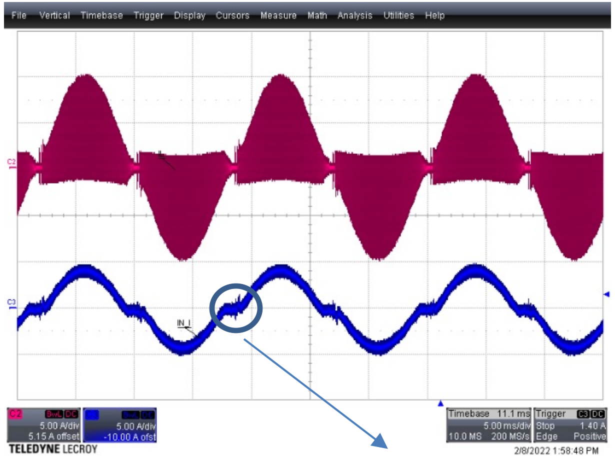
80 mΩ SJFET

1060 mA Neg. Current

Amount of negative current is a function of Coss and Qrr.

Inductor Current Waveforms

115 Vac, 300 W CrM

Increased zero cross distortion

50 mΩ GaN

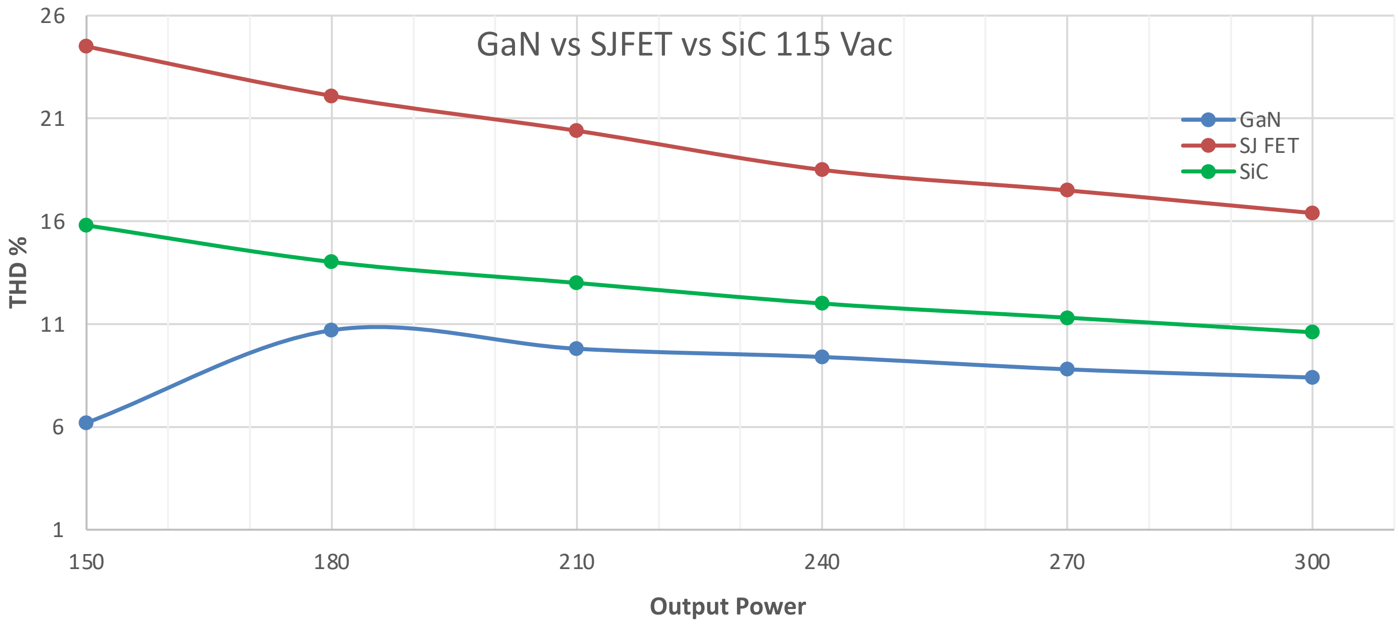
45 mΩ SiC

80 mΩ SJFET

Visually, we can notice that SJ FET w. same controller has more distortion

Constant on-time control in conjunction w. negative current increases zero cross distortion

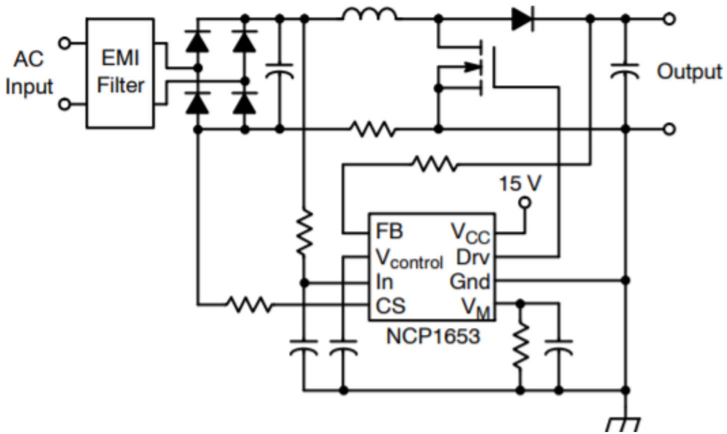
TPFC CrM THD



Wide Bandgap switches result in better THD in CrM due to lower negative inductor current

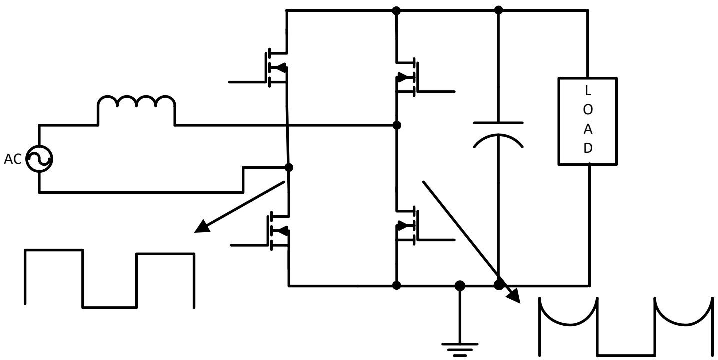
SJ FETs do work in CrM but its performance is inferior.

Lack of easy-to-use controllers



Standard analog PFC ICs don't include:

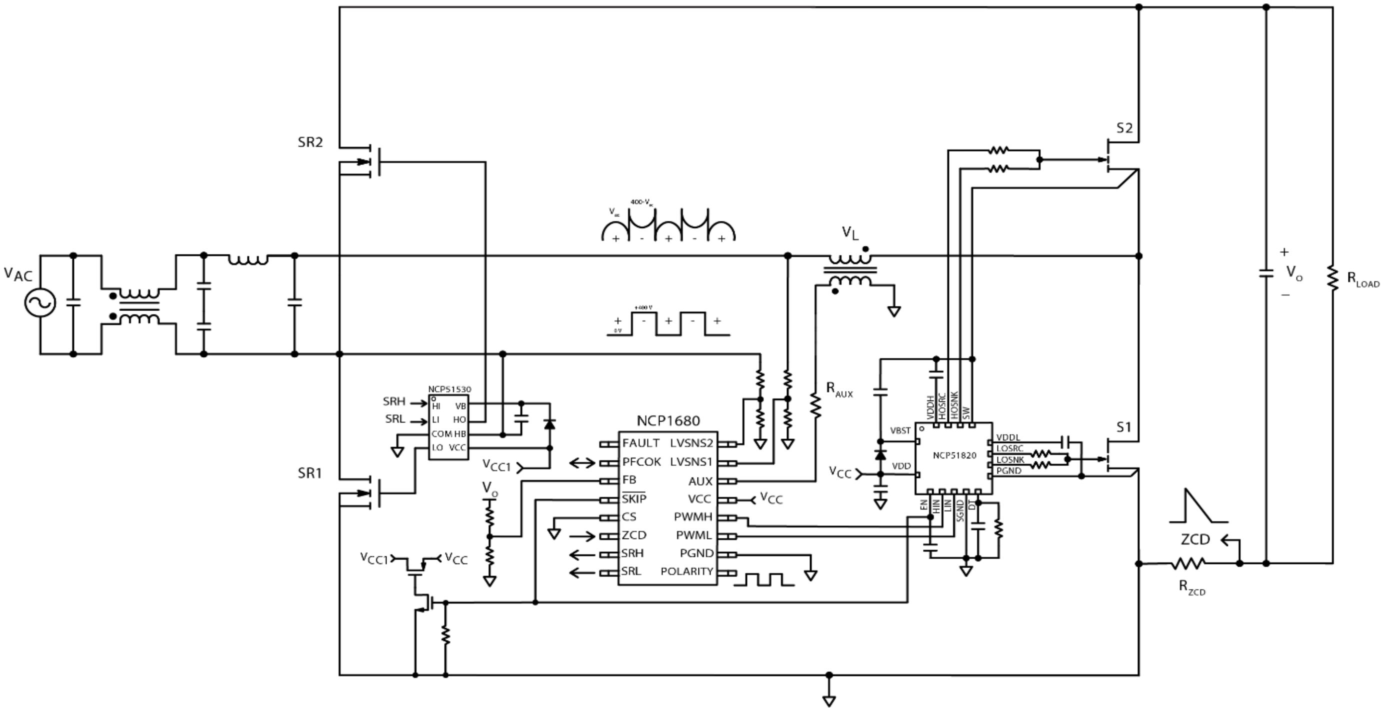
- Polarity detection
- Fast leg switch's role reversal circuit
- Reconstructed haversine
- Zero current detection for sync FET



Cost & Complexity is a challenge:

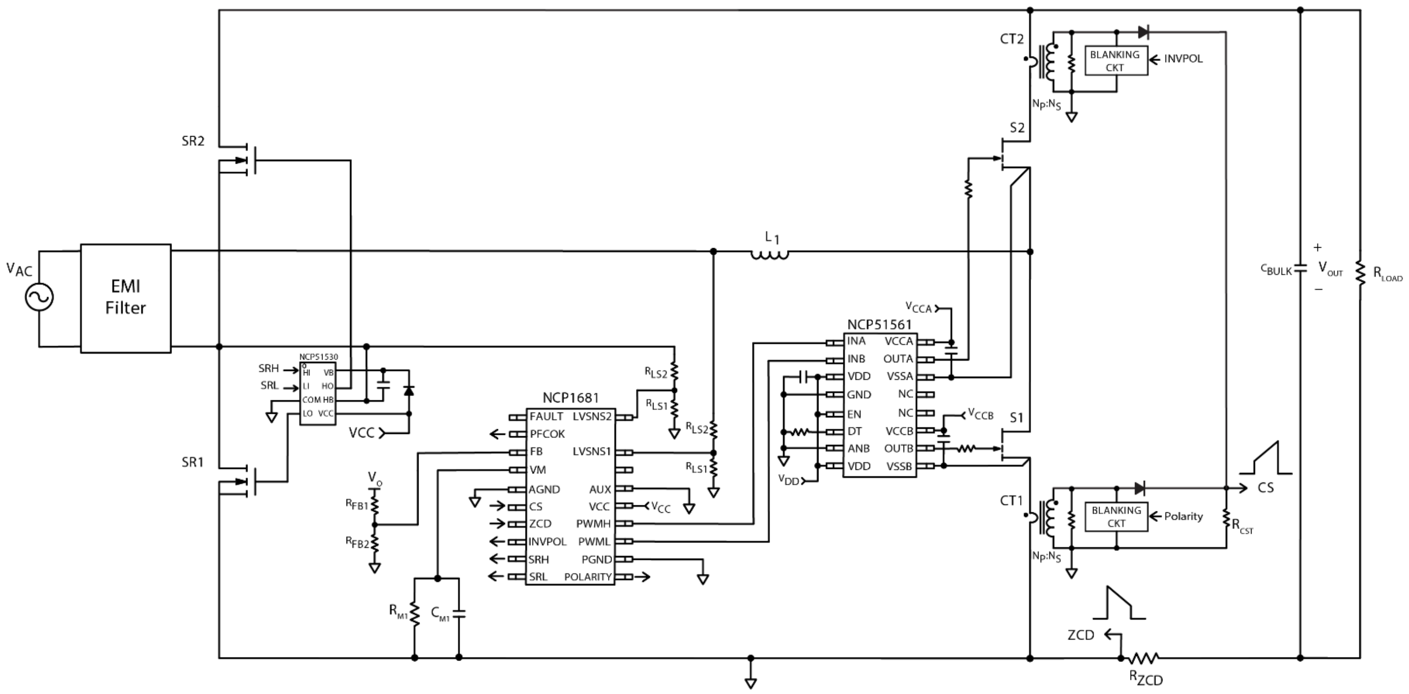
- Bidirectional current sensor
- Complex SW node valley detectors
- Use of synchronous FET & half-bridge drivers

New Generation of Easy-to-use ICs



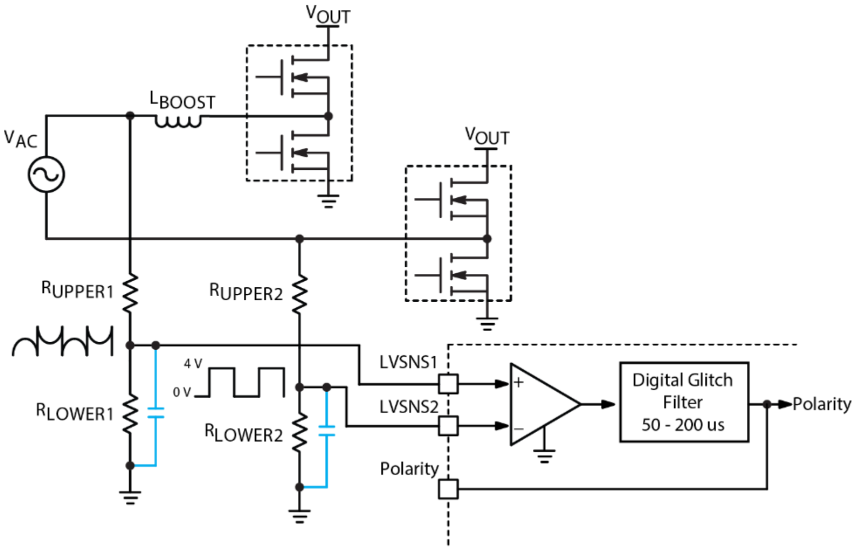
A family of Totem Pole PFC controllers that can operate in CrM and CCM suitable for power ranges from 90 W to multi kW range

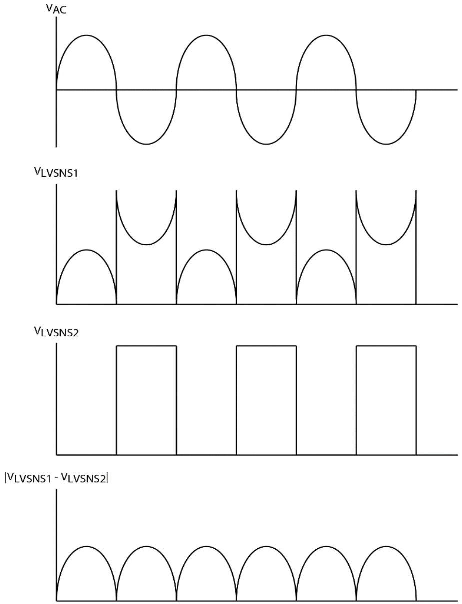
Typical Application Schematic NCP1681 CCM



A simple current sensing scheme eliminates the need for hall-effect sensors.

Polarity and Reconstructing Sinewave

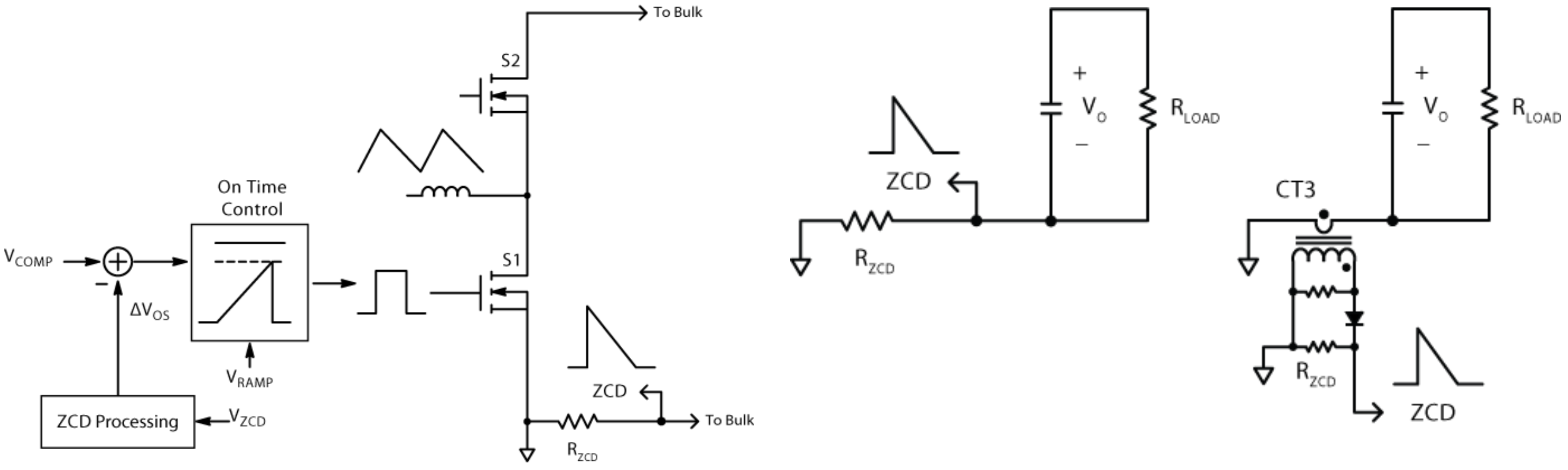




- Polarity detection
- AC Line Frequency Monitoring
- Brownout protection feature
- Line level detection
- AC zero crossing drive management

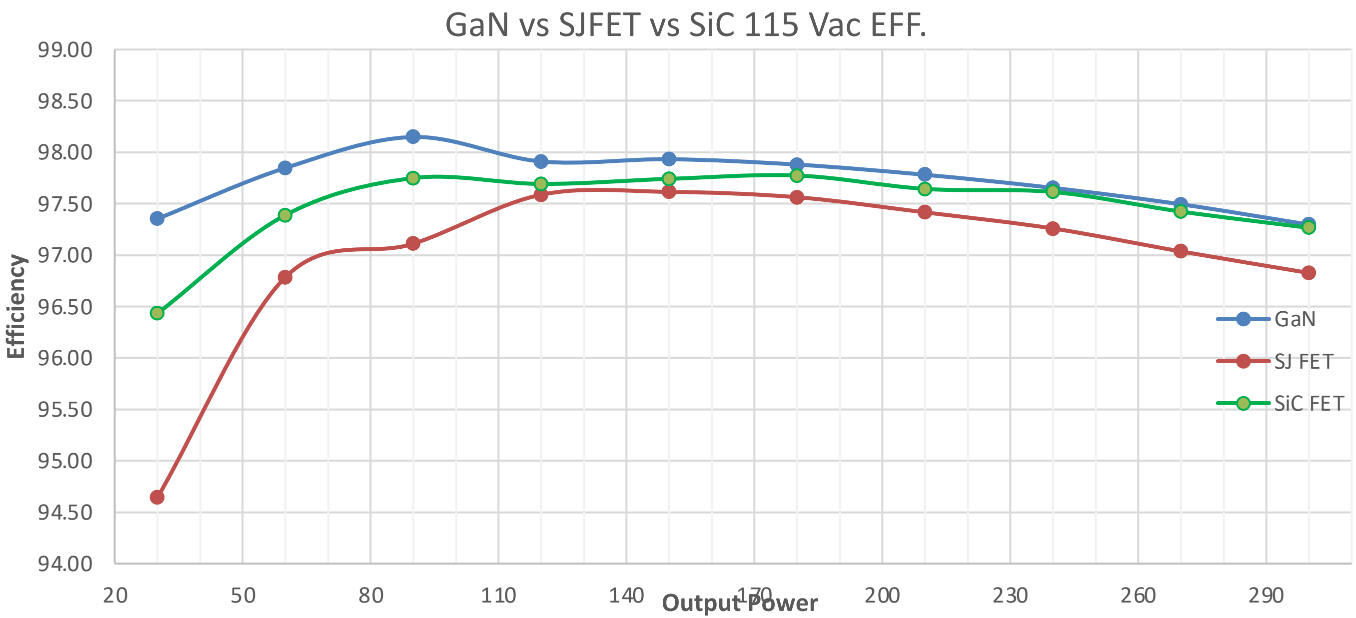
- Classical rectified sinewave is reconstructed inside the IC.

Simple Current Sensor



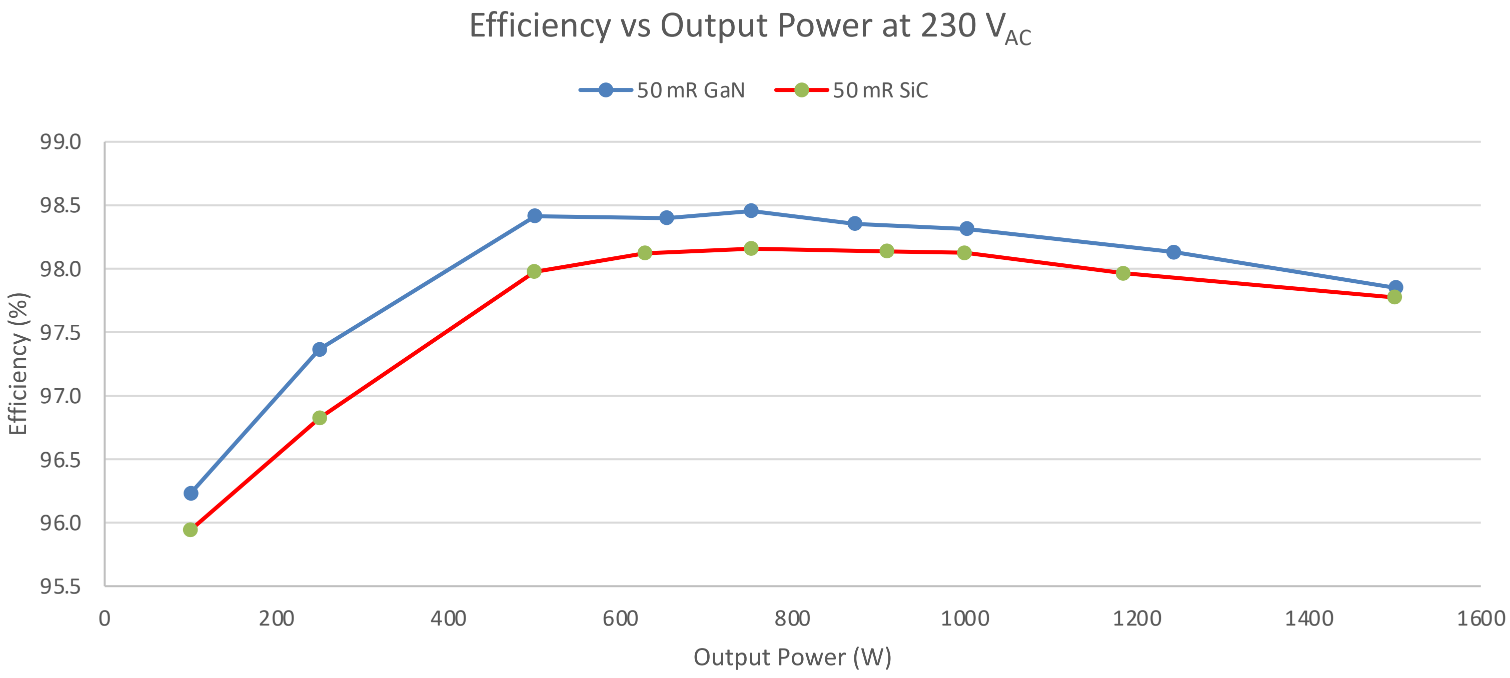
A simple current limit scheme with a resistor for both ZCD and current limit removes complexity and reduces cost

NCP1680 - CrM Efficiency Comparison



GaN outperforms in light load due to its low capacitance

NCP1681 - CCM Efficiency Comparison



GaN's efficiency is higher at lower power due to lower capacitance, however, SiC is a better device for higher power due to lower variation of Ron vs. temperature

Conclusion

Wide Bandgap devices will drive the mainstream adoption of TPFC.

New generation of TPFC controllers are easy to use and allow a lower cost BoM

Will the bridge diodes be relegated to history?

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