Maximizing Wide-Bandgap Value: Smart Integration in Compact AC-DC Converters

Mike Matthews

Integration of WBG Semiconductors and Applications

Industry Session IS07.7

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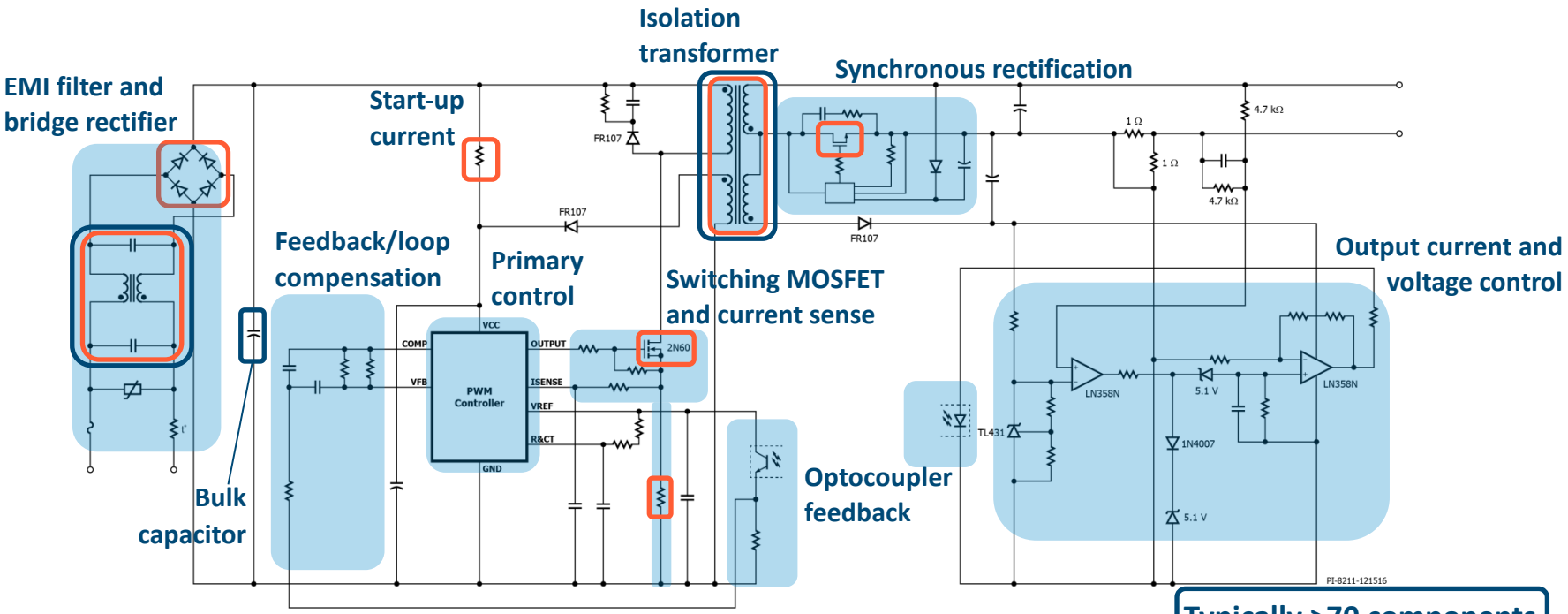
power integrations

Mr. Matthews joined Power Integrations in 1992, managing the company's European applications engineering group and then its European sales organization. Since 2000, he has led the company's product-definition team in San Jose, California; he was named vice president of product development in 2012. Prior to joining Power Integrations, Mr. Matthews worked at several electric motor-drive companies and then at Siliconix, where he served as a motor-control applications specialist.

WBG vs. Silicon Transistors in AC-DC Converters

- **Silicon has been the industry workhorse for many decades…**
  - …and still has a role to play
- **Wide bandgap (WBG) transistors offer huge advantages in power density and efficiency**
  - Manufacturers must ensure a seamless user experience to promote widespread adoption
  - Requires system optimization partnering WBG devices with advanced control features
- **The presentation compares silicon, GaN and silicon carbide (SiC) device applications in a variety of isolated AC-DC power converters**

Conventional AC-DC Converter: 90-265 VAC Input



Typically >70 components

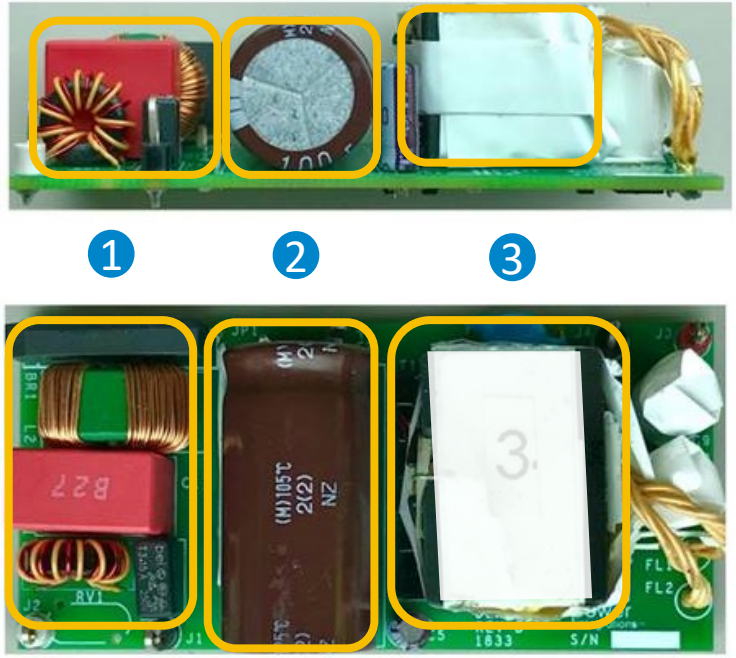
Key sources of loss

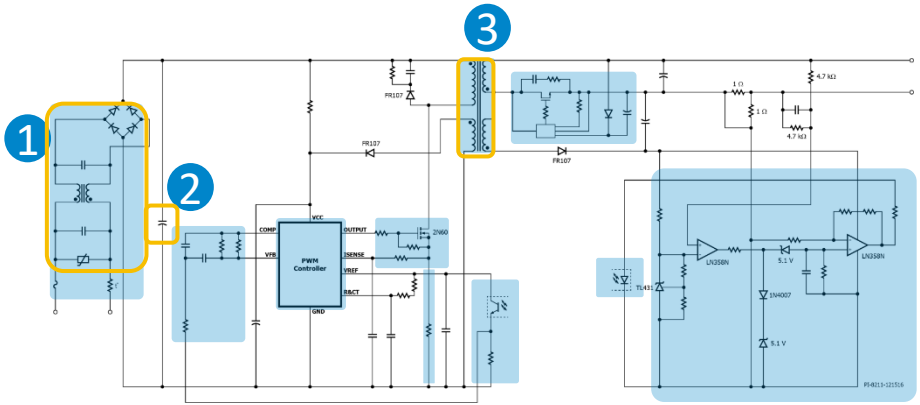
Key elements impacting converter volume

Careful adoption of WBG devices can impact both

Example: Key Elements Impacting Converter Volume

- 65 W AC-DC converter

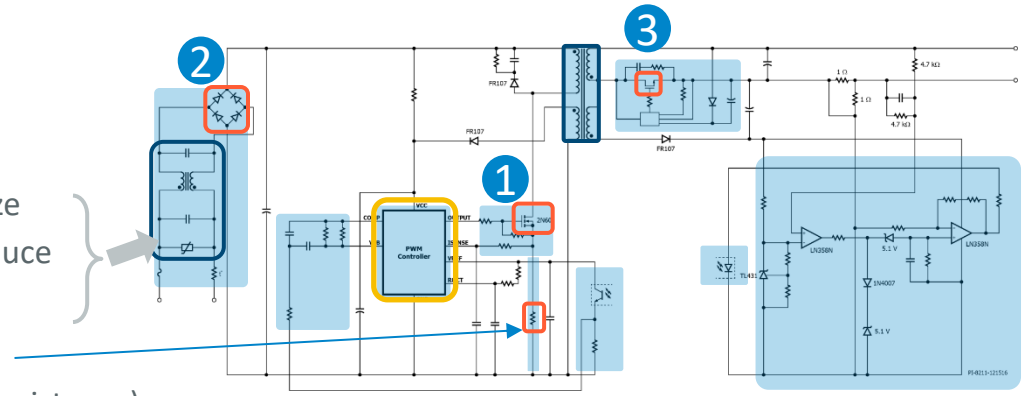




Adoption of WBG to Impact Key Loss Elements

❶ Low specific $R_{DS(ON)}$ reduces RMS losses, however:

- Switching characteristics can increase EMI filter size
- Temptation to increase switching frequency to reduce transformer size also impacts EMI filter size
- Current sense integration is essential to avoid resistor loss (comparable to main primary switch resistance)
- All require primary controller to be optimized for WBG interface and operation



Key sources of loss

Key elements impacting converter volume

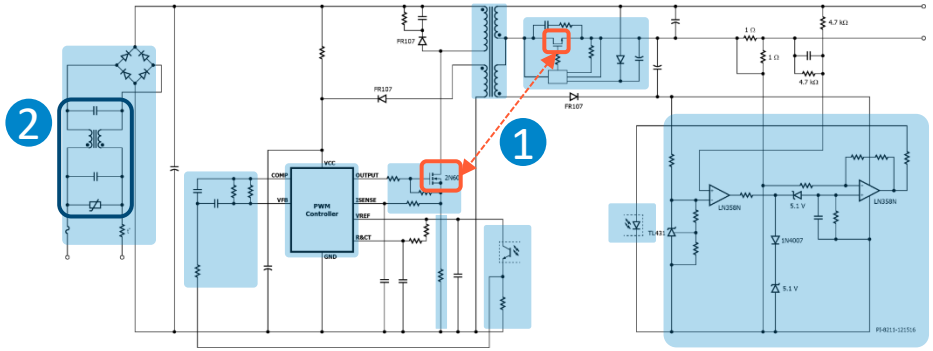
❷ & ❸ Low specific $R_{DS(ON)}$ again key to reducing RMS losses

- Switching characteristics have less impact on EMI filter and have no influence on converter switching frequency
- Choice is therefore primarily economic - based on funds available to optimize system efficiency and thermal specifications

Other Influences on Losses and Converter Volume

1 Synchronization of primary and SR switches

- Delays between primary and SR switch transition impacts efficiency and ability to operate in discontinuous/continuous mode (DCM/CCM) (important for USB PD applications)
- Impacted by switch speed and primary-secondary feedback path (optocoupler in example shown)

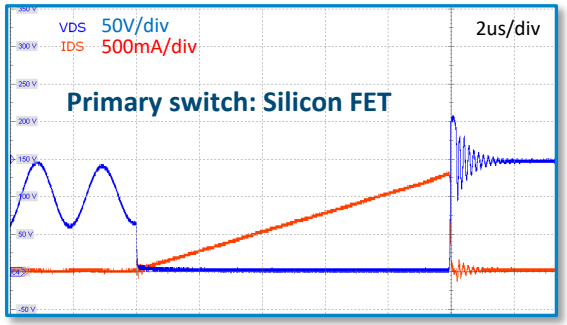


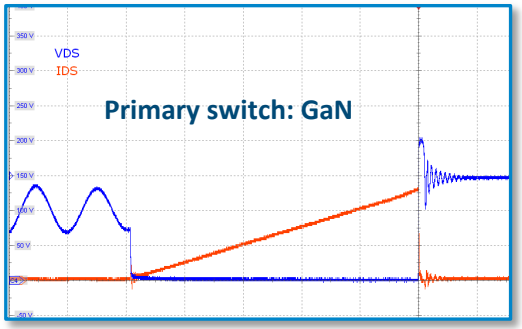
Key sources of loss

Key elements impacting converter volume

2 EMI filter optimized with WBG switching characteristics

- WBG or silicon MOSFET - transparent to user:





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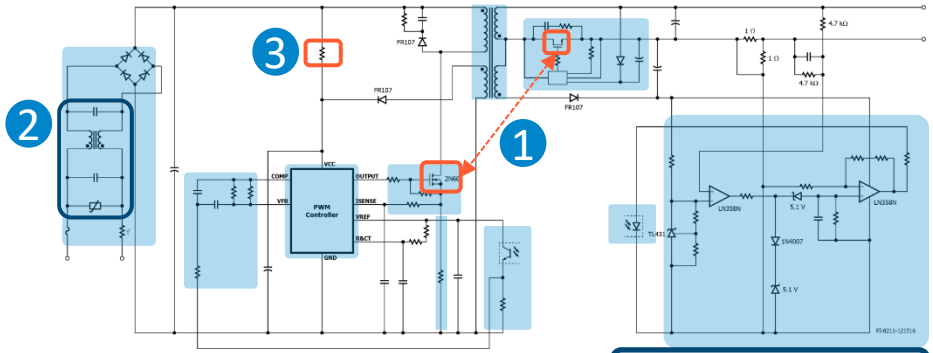


Key sources of loss

Typically >70 components

4

Key elements impacting converter volume

2 EMI filter optimized with WBG switching characteristics

- WBG or silicon MOSFET - transparent to user

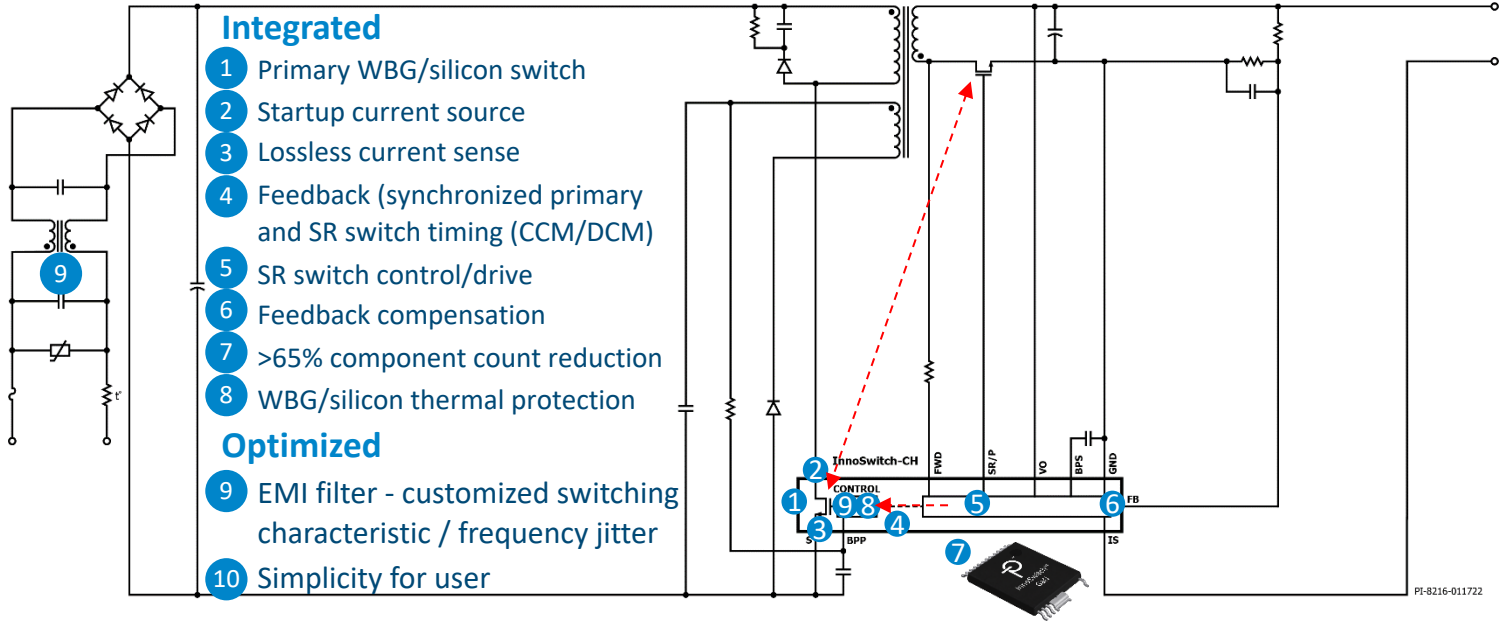
3 Start-up resistor loss (standby/no-load impact)

- Can be eliminated through integration of primary WBG/silicon switch with main PWM controller

4 Component count

- Can be minimized through integration of primary/secondary controller circuitry and all feedback components

Integration Optimizes WBG Benefits

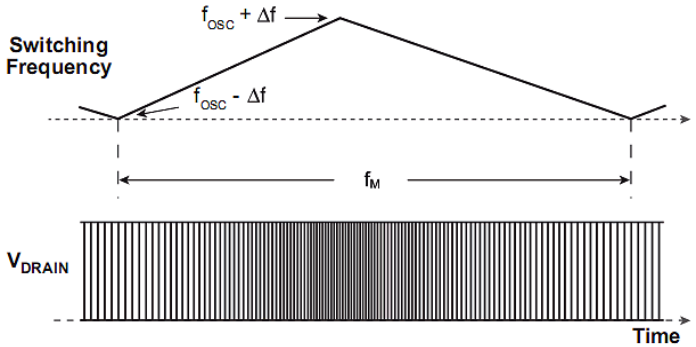


7 **24 components (reduced from >70 components)**

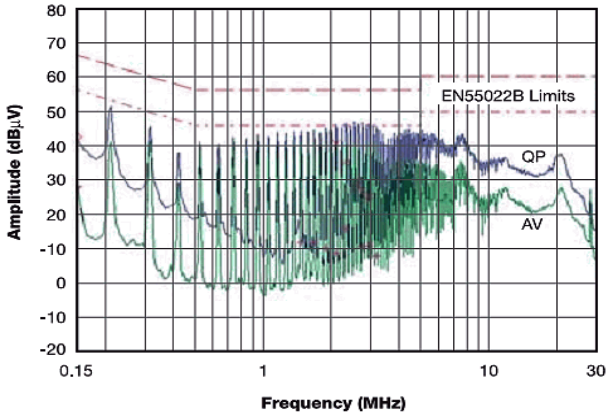
10 **Silicon / GaN / SiC primary switch transparent to user**

Frequency Jitter

- Modulation range (typically) 250 to 1100 Hz
- No external timing capacitors
- Results in smaller / lower cost EMI components



Conducted EMI without Jitter



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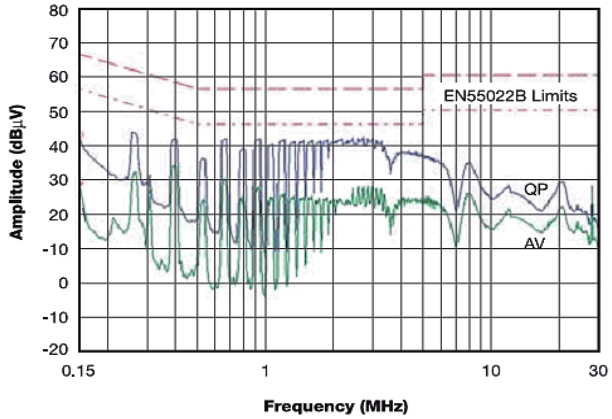
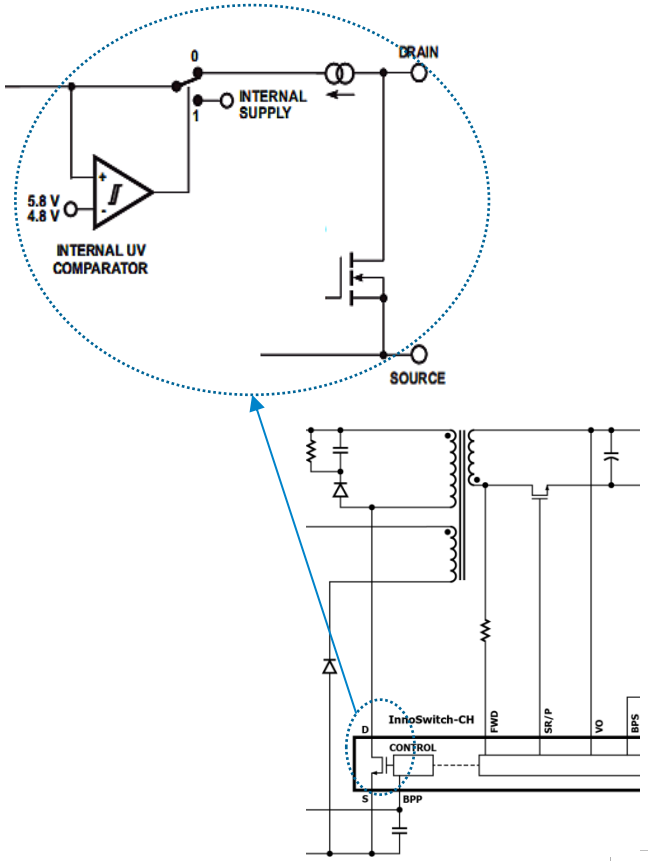


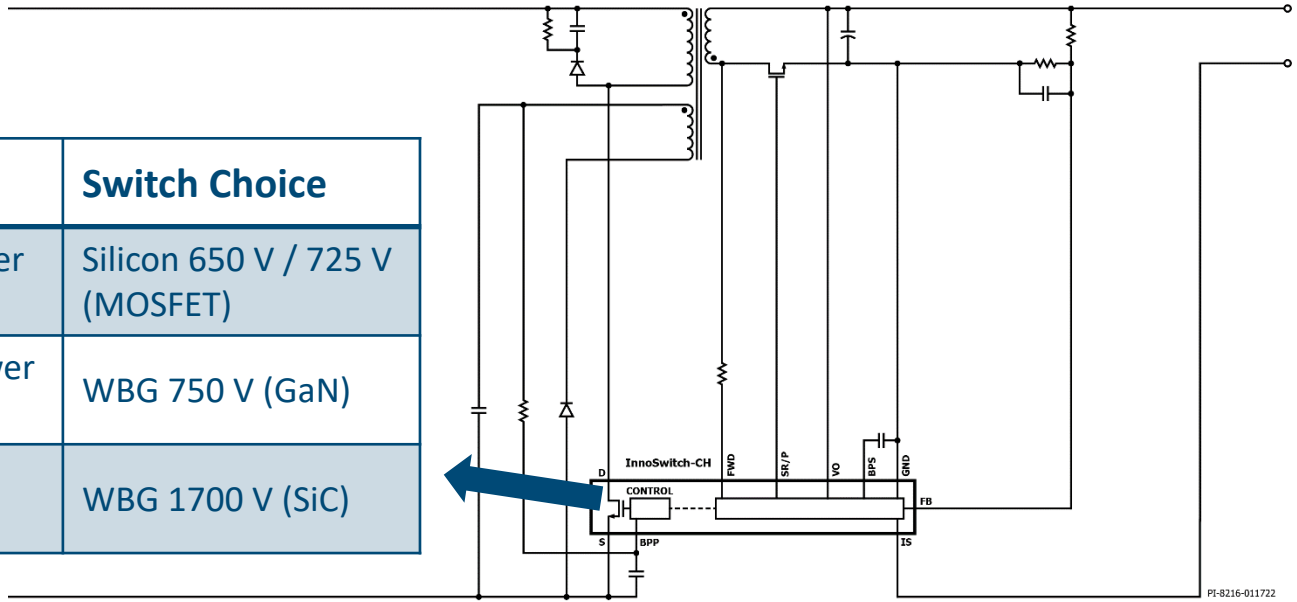
High-Voltage Startup Current Built Into WBG/Silicon Structure

- **Startup via internal HV current source**
  - Turned off after startup - reduces power dissipation
- **Combined startup and drain pin**
  - Saves pin
  - Simplifies package creepage considerations
  - Better ESD withstand
- **Provides fast power supply startup time**
  - Discrete solution needs two-stage startup circuit to meet startup-time specification



Primary Switch Choice by Application

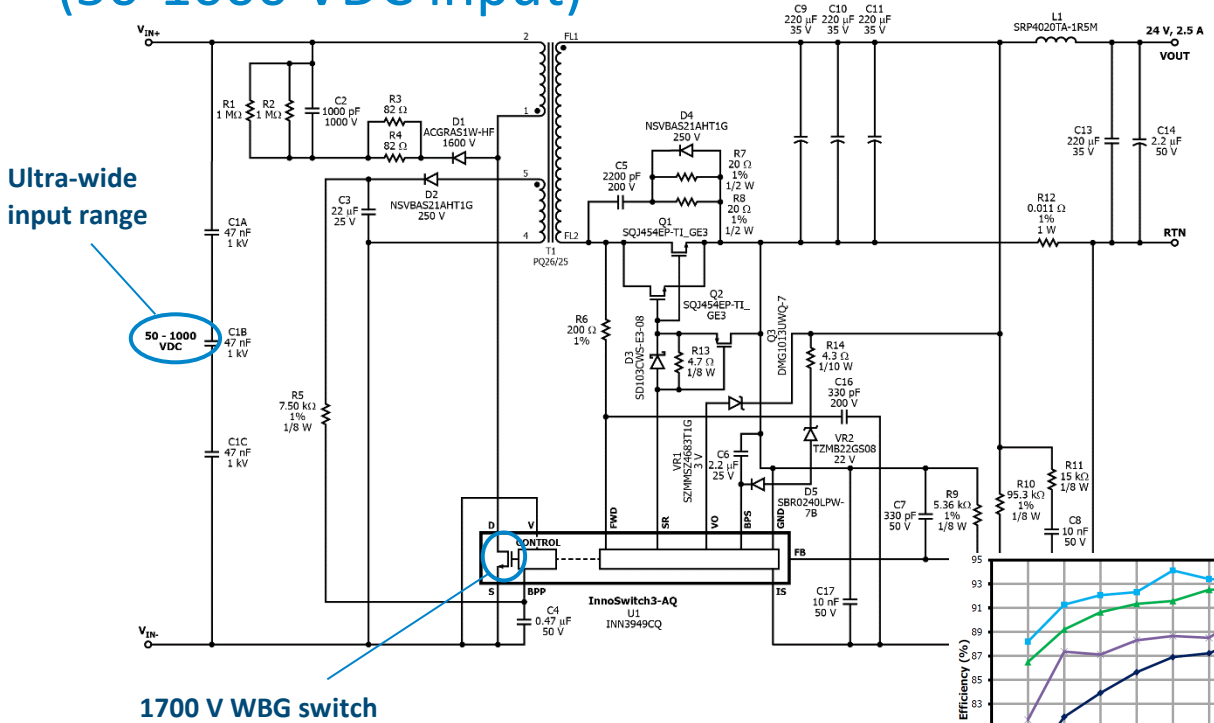
Application	Switch Choice
90-265 VAC low power (typically <25 W)	Silicon 650 V / 725 V (MOSFET)
90-265 VAC high power (typically >25 W)	WBG 750 V (GaN)
>400 - 1000 VDC (EVs and industrial)	WBG 1700 V (SiC)

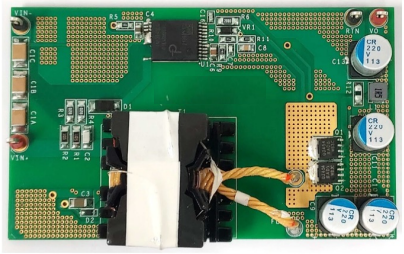


Integration enables WBG / silicon switch choice transparent to user
All other controller features unchanged

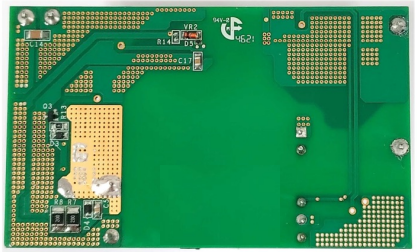
1700 V WBG (SiC) in EV Auxiliary 60W Power Supply

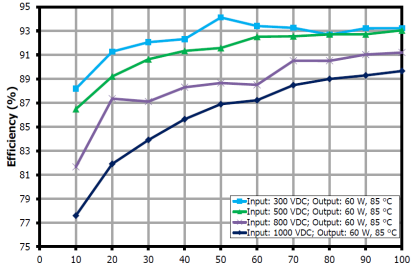
(50-1000 VDC input)





Simple layout, low component count



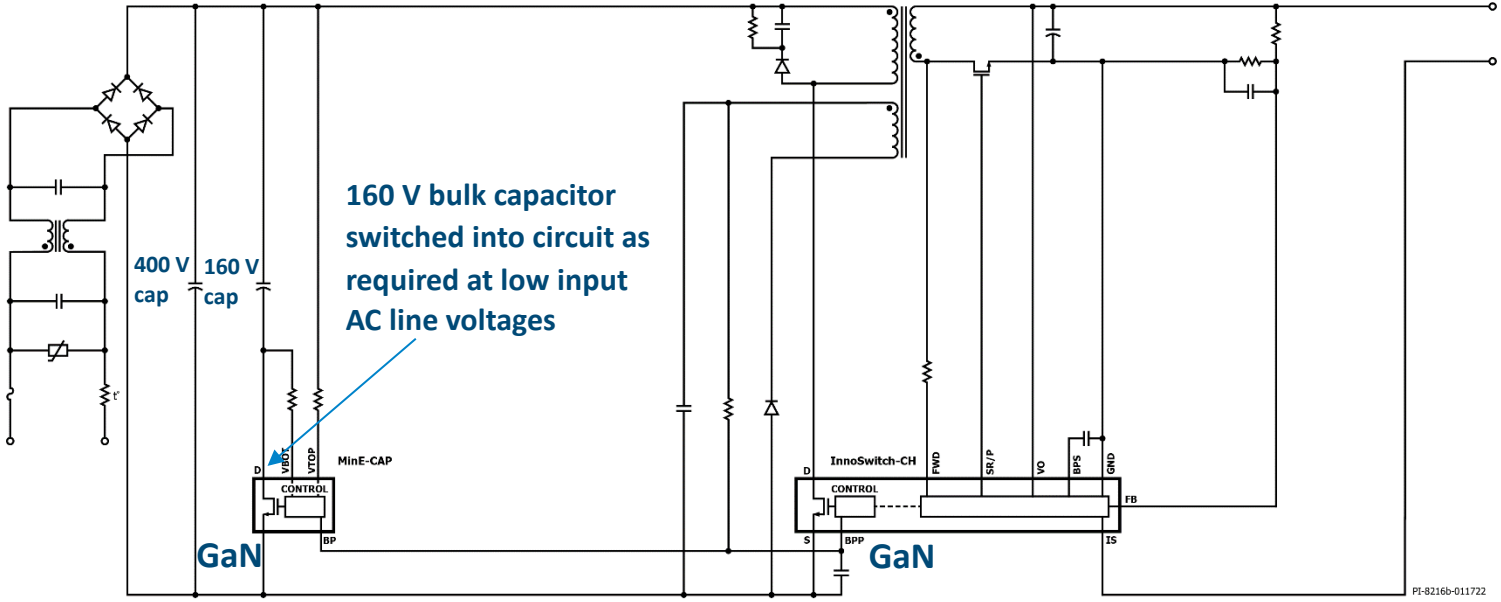


Efficiency vs. Load (85 °C ambient)

V_{IN} DC	Max. Output Power Derating
50-100 V	4 W
100-200 V	35 W
200-300 V	45 W
300 -1000 V	60 W

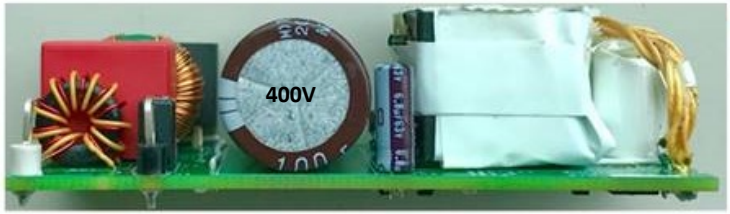
Other WBG Applications in High-Voltage Power Converters

Bulk Capacitor Volume Reduction



- Approximately 40% reduction in bulk capacitor volume
- WBG GaN employed at 50/60 Hz switching frequency - not just a high frequency technology!

Volume Savings Employing WBG for Bulk Capacitor Reduction



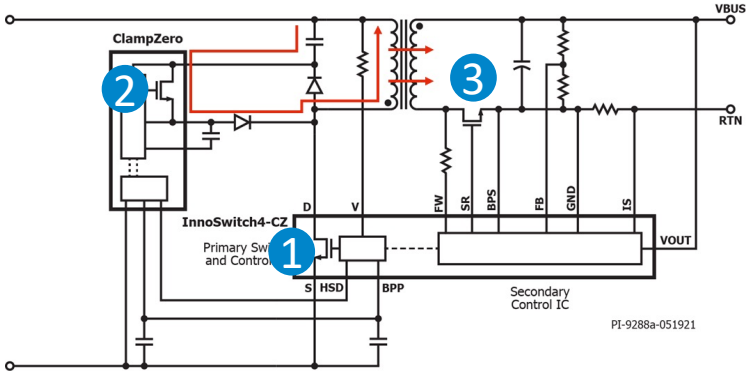
Original board

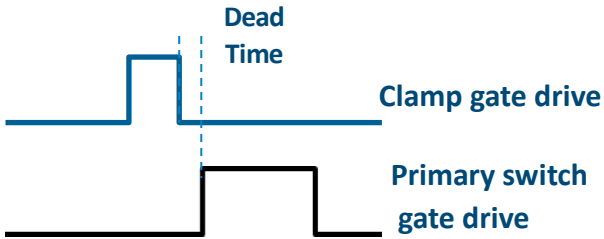
Total 100 µF bulk capacitance

65 W 90-265 VAC Power Converter Example

GaN Active Clamping Ensures Most Cost-Effective Use of Clamp Energy

- **Precisely synchronizes switches ❶, ❷ & ❸**
  - Reliable - prevents cross conduction
  - Highly integrated drive makes design simple
  - Seamless implementation across DCM and CCM
    - Vital for widely varying load/line combinations (USB PD)

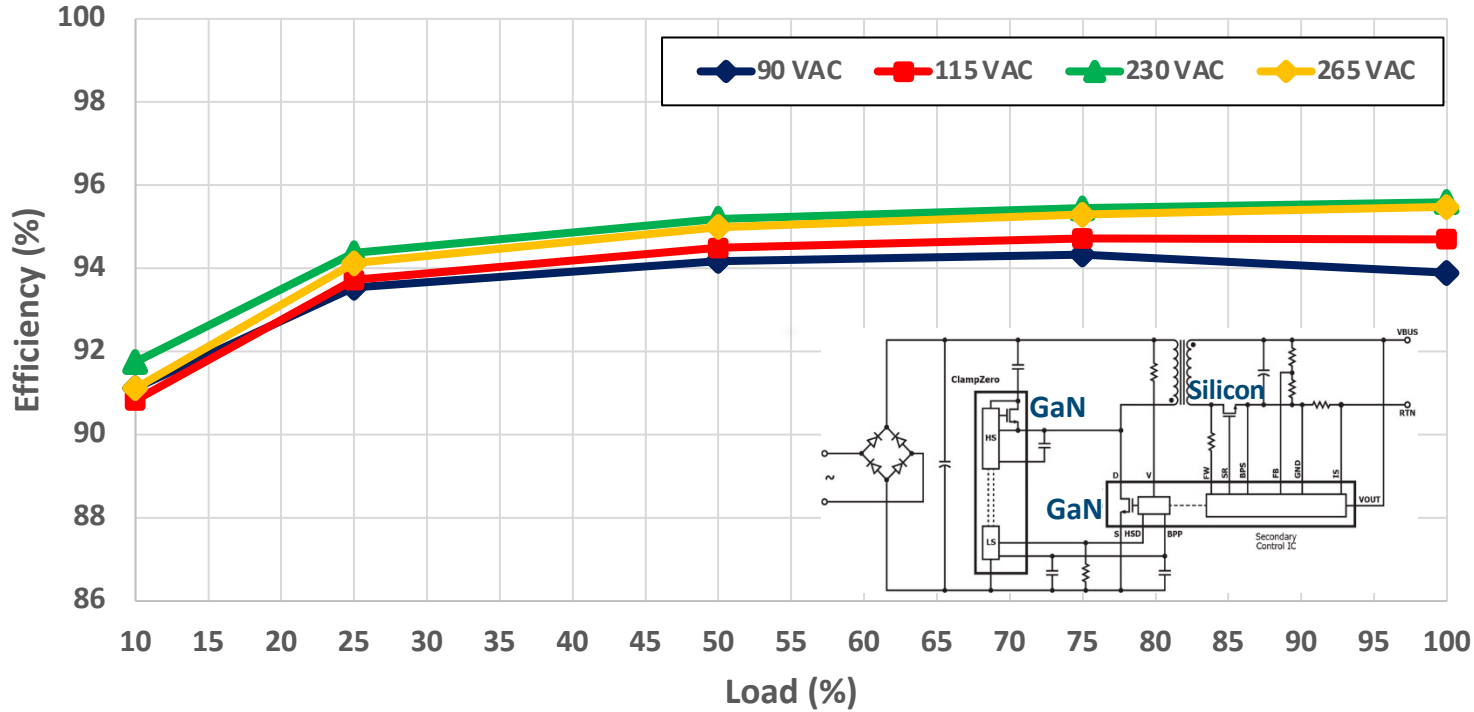




Non-complementary mode switching – active clamp is cycled just before primary switch

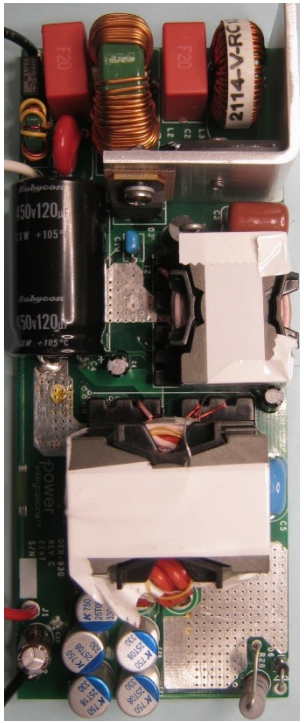
>95% Full Load Efficiency: 2 x WBG Active Clamp Flyback

USB PD 20 V Output - Flat Efficiency Across the Load Range



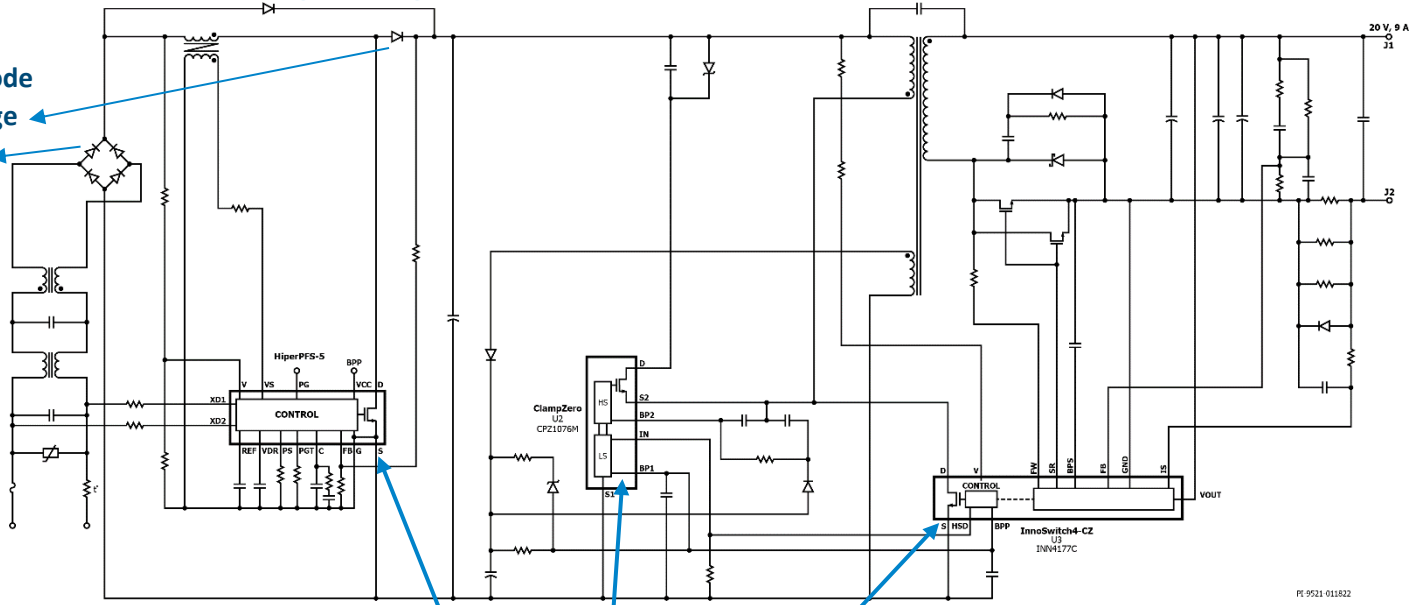
DER-943 60 W high efficiency design

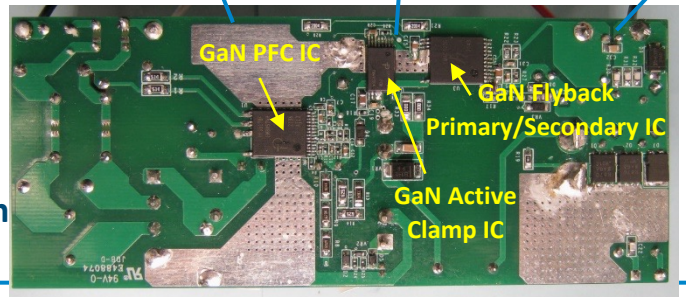
180 W PFC Active Clamp Flyback with Three WBG Devices



Boost diode and bridge rectifier require heatsink

PCB top view





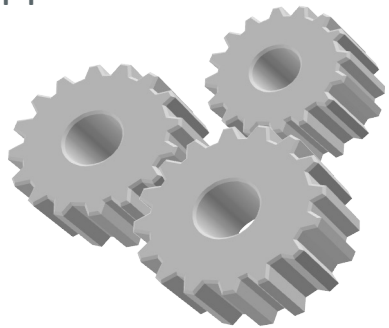
PCB bottom view

GaN-based PFC, active clamp and flyback ICs eliminate heatsinks at 180 W!!

Summary

WBG Set for Broad Adoption in Isolated Converters

- **WBG technologies complement existing silicon FETs**
  - Silicon MOSFETs remain optimum in low-power/lowest cost converters
  - GaN enhances power density with new levels of system efficiency
  - SiC provides highly efficient solutions for emerging high-voltage applications (e.g., 800 V EVs)
- **Integration offers users a seamless choice of technology**
  - MOSFET, GaN and SiC solutions all now commercially available
  - Optimized integrated control and protection features provide simplified and reliable solutions for a range of end applications



Thank you for your interest.

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Backup

Variable Frequency DCM PFC

- **WBG GaN switch**
  - Reduced conduction loss
    - Enables use of DCM up to 220 W
  - 750 V rating allows 305 VAC
    - Supports 410 VAC abnormal testing
  - Low turn-off loss
- **Frequency sliding with load**
  - Lower frequency at light load
    - Reduces switching loss
  - Frequency range 22 to 145 kHz
- **Spread-spectrum switching – PFC switching frequency varies across AC cycle**
  - Reduces EMI
  - Reduces Size of boost inductor