GaN Power Devices:
From Watt to Kilo-Watt Power Applications

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TI training – summary

GaN: Watt to KW Power Applications

TI's Portfolio of GaN FETs with integrated driver and protection are in mass production and are enabling designers to reach unprecedented levels of power density and efficiency in every power level and end-equipment. These cost-competitive solutions are found in applications such as robotics, solar converters, telecom, grid infrastructure, AI servers, networking, industrial power supplies, and personal electronics.

What you'll learn:

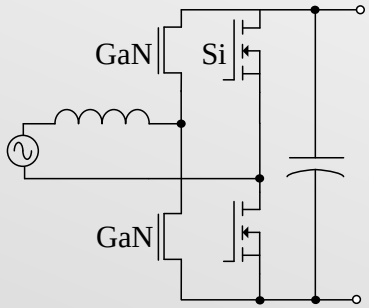
- Learn about how the LMG3410 can bring differentiation in a typical application
- Integration for system performance and reliability
- Overview of GaN applications: power supply, motor drive, wall adapter

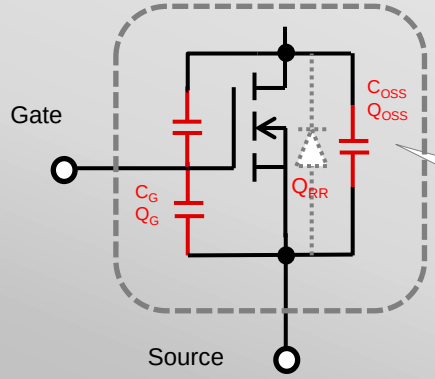
Detailed Agenda

- GaN Overview
- Why LMG3410x GaN?
- Half-bridge Solutions
- GaN Applications:
  - High Density Power Supply Designs
  - High Efficiency Motor Drives
  - Ultra-Small USB PD and AC-DC Solutions
- Summary

GaN Overview

GaN: Key Advantages Over Silicon FET





Low C_G,Q_G gate capacitance/charge (1 nC-Ω vs Si 4 nC-Ω)
- ✓ faster turn-on and turn-off, higher switching speed
- ✓ reduced gate drive losses

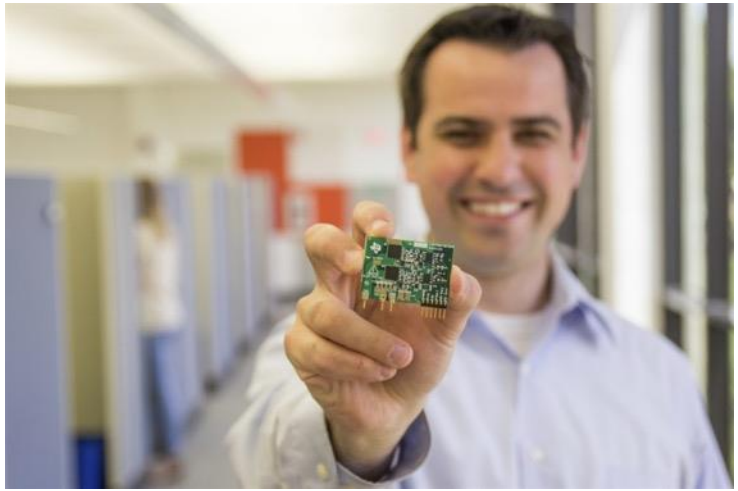
Low C_{OSS},Q_{OSS} output capacitance/charge (5 nC-Ω vs Si 25 nC-Ω)
- ✓ faster switching, high switching frequencies
- ✓ reduced switching losses

Low R_{DSON} (5 mΩ-cm^2 vs Si >10 mΩ-cm^2)
- ✓ lower conduction losses

Zero Q_{RR} No ‘body diode’
- ✓ No reverse recovery losses
- ✓ Reduces ringing on switch node and EMI

GaN: Ready to Take you Beyond Silicon Today

- GaN devices are enabling solutions with twice the power density of what is possible with best-in-class superjunction FETs
- TI LMG3410x GaN devices are now in production with our customers ramping to mass production now.
  - 3kW Telecom Rectifier
  - Class-D Audio Amplifier
  - 3D Printer
  - Factory Robotics Drive
  - OLED TV PSU



LMG3410x: GaN performance beyond Silicon

2x Higher Power Density

37 W/in³

1.6kW in ½ the space

70 W/in³

98.8% efficient 1MHz CrM PFC

[TIDA-00961]

Loose the fan

85% Smaller Heat Sink

No Fan!

99.2% efficient 1.2kW Servo Drive Inverter

[TIDA-00915]

Ultra small form factor

>60% Smaller Volume

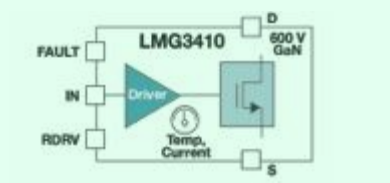
>30 W/in³

65W Pocket Sized USB Type-C Adapter

Why LMG3410x GaN?

LMG3410x GaN: Ready to Use Now

Integrated



- Complete GaN, driver and protection in single package
- Fast and easy system design

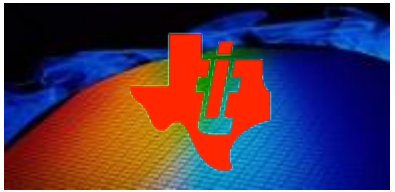
Robust

- 720V surge capability while switching
- 100ns short-circuit protection
- Thermal protection

Reliable

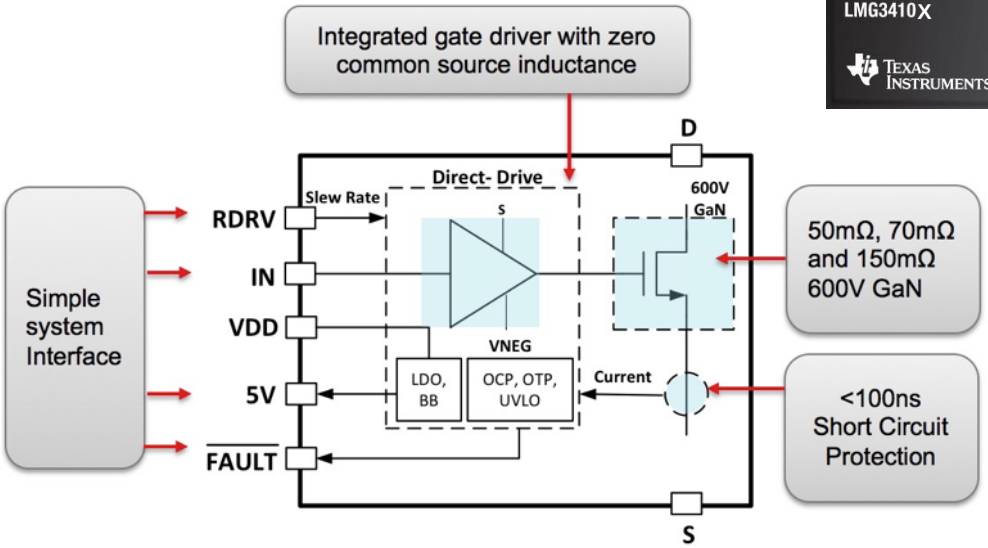
- > 20 million hours of reliability testing to date
- < 1 FIT rate for 10 year lifetime

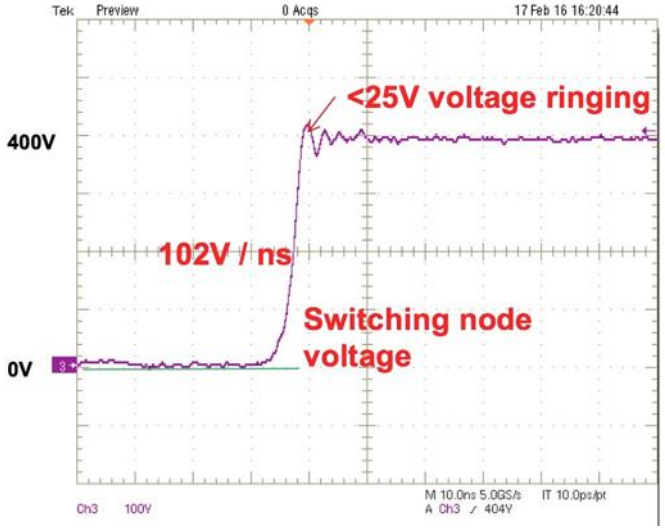
Ready



- Available in 50, 70, and 150mΩ
- 100% TI internal HV GaN process, fab, and assembly

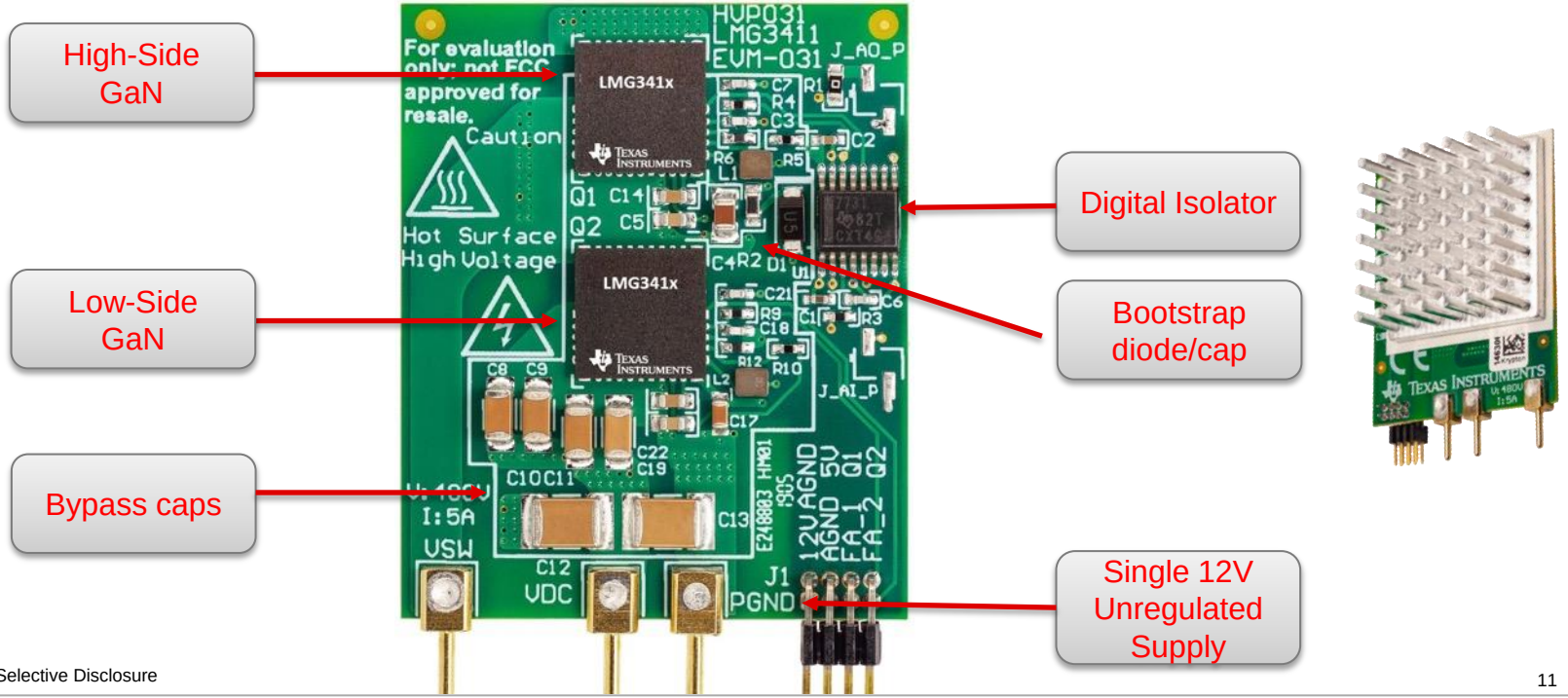
LMG3410x: Integrated Driver
Ease of Design & Higher Efficiency





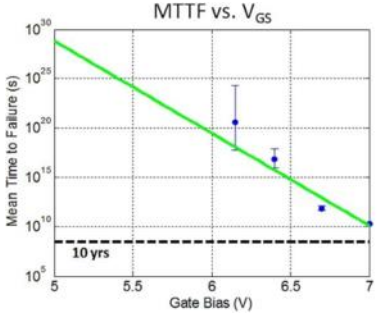
LMG3410x: Integrated Driver
Design Simplicity & Smaller HB BOM

Complete Half-Bridge Design for any Power Level



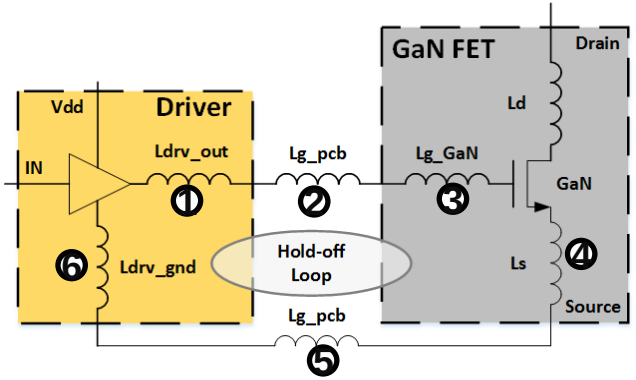
Challenges of GaN Designs with External Driver and Protection

- Driver Bias Voltage: GaN gate bias is critical to its performance and long-term device reliability



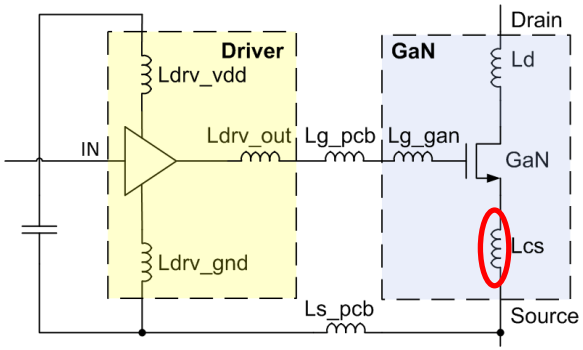
- Protection: Designing a robust overcurrent protection circuit at high slew rate is difficult and costly.

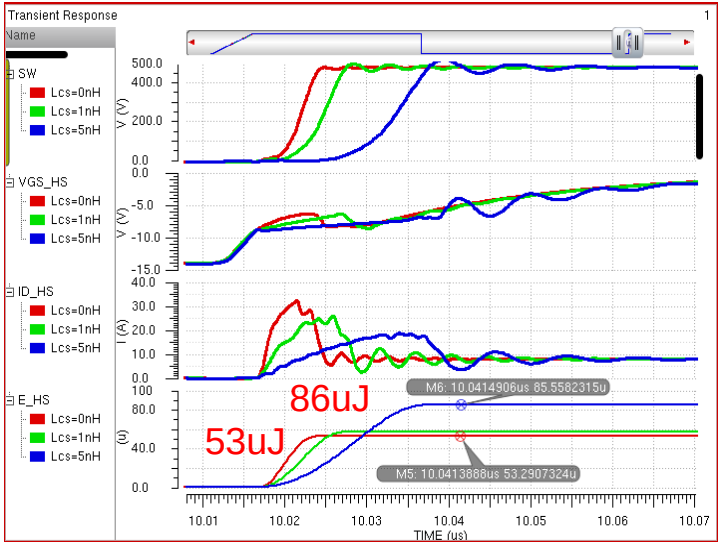
- Parasitic Inductance: causes switching loss, ringing and reliability issues, especially at high GaN frequencies



Parasitic Effect:
Common Source Inductance

- Common Source inductance reduces the di/dt during turn-on and turn-off.
  - Increases power dissipated during the di/dt ramp
- 5nH common source inductance increases turn-on loss by 60%

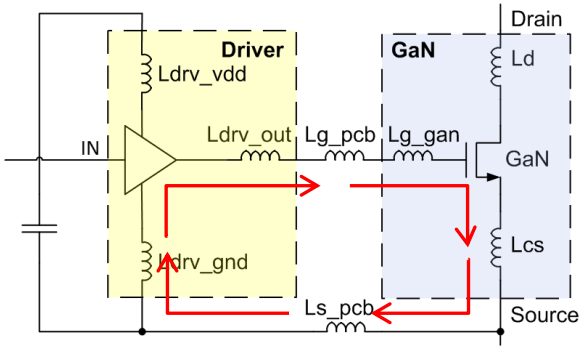


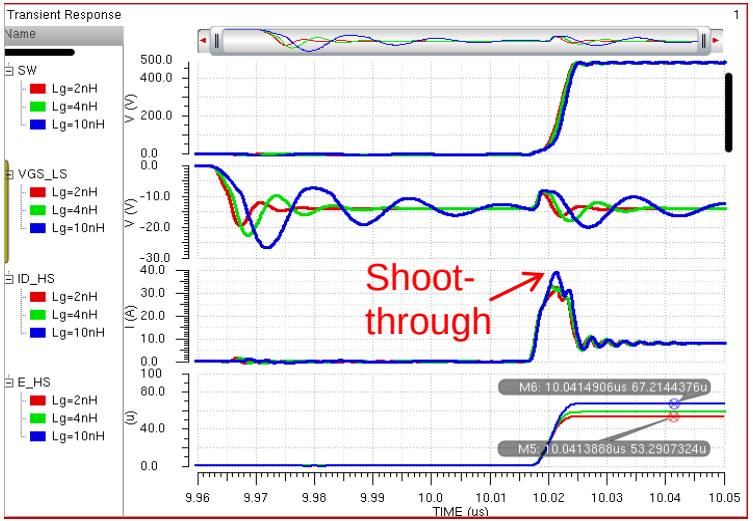


High-side turn on versus common-source inductance: red = 0 nH, green = 1 nH, blue = 5 nH

Parasitic Effect:
Gate Loop Inductance

- Gate loop inductance increases the impedance between the gate and the driver.
  - Limits the ability to hold off the GaN device during the Vds ramp
  - Shoot through increases the power dissipated in the high-side device and can cause it to fail due to SOA.
- Gate loop inductance increases ringing
  - Higher stress on gate
  - Ringing can cause the device to turn-on/off
  - Loop resistance is required to dampen ringing

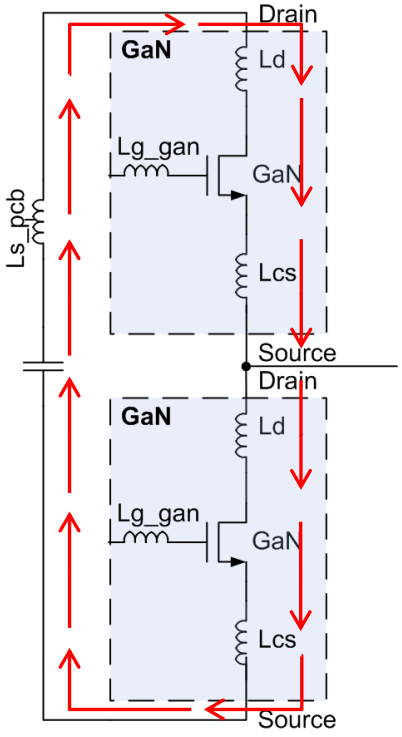


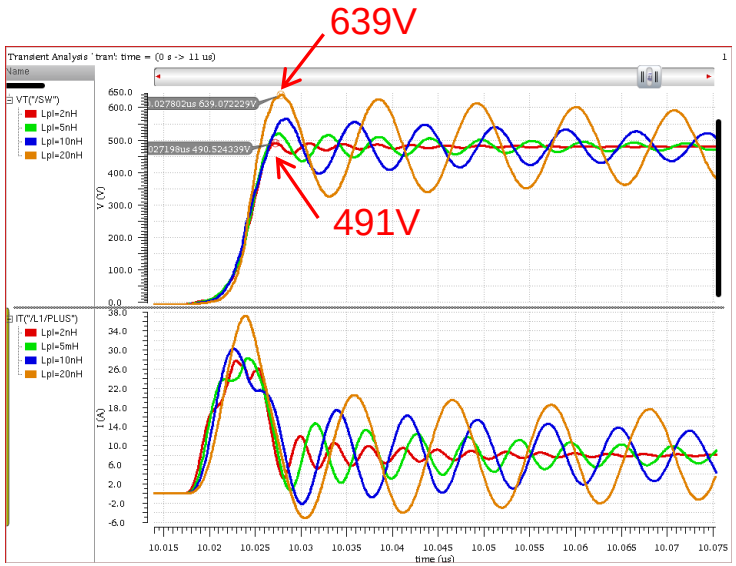


Low-side hold-off versus gate-loop inductance
red = 2 nH, green = 4 nH, blue = 10 nH

Parasitic Effect:
Power Loop Inductance

- Power loop inductance
  - Increases Ringing and EMI
  - Increases V_{ds} voltage stress
  - Increase switching losses
- Package must be designed to enables low power loop inductance PCB layout
- GaN must be switched without snubber to have high efficiency

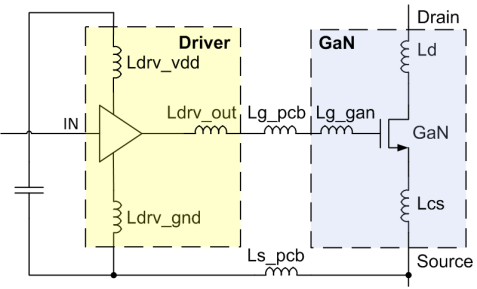




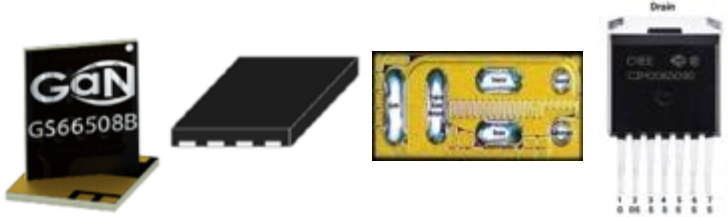
V_{sw} ringing versus power loop inductance
red = 2nH, green = 5nH, blue = 10nH, orange = 20nH

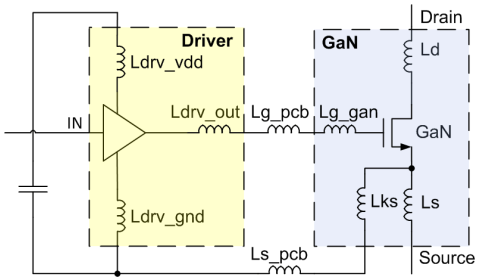
Common Source & Gate Loop: Comparison

Standard Packages

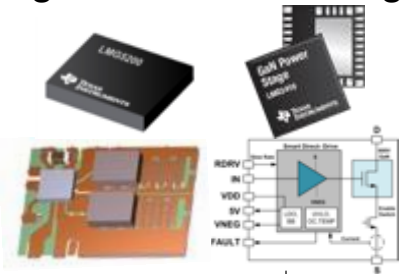


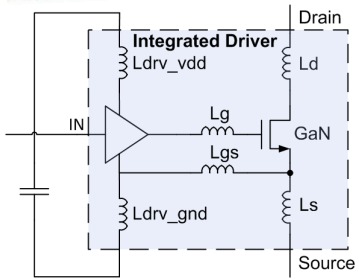
Kelvin Source Packages





Integrated Driver Packages



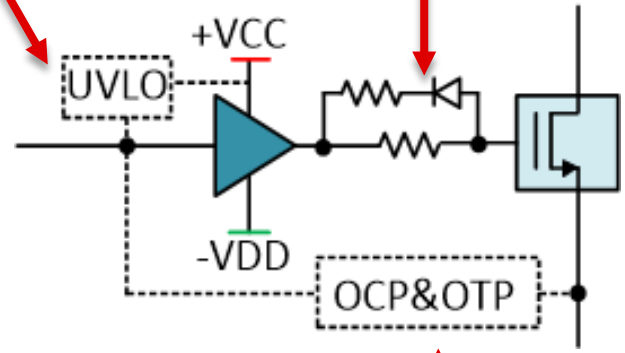


	Standard Power Package	Kelvin Source Power Package	Integrated Driver Power Package
Common Source	2nH -10nH	<1nH	<1nH
Gate Loop	5nH – 20nH	5nH – 20nH	1nH – 4nH

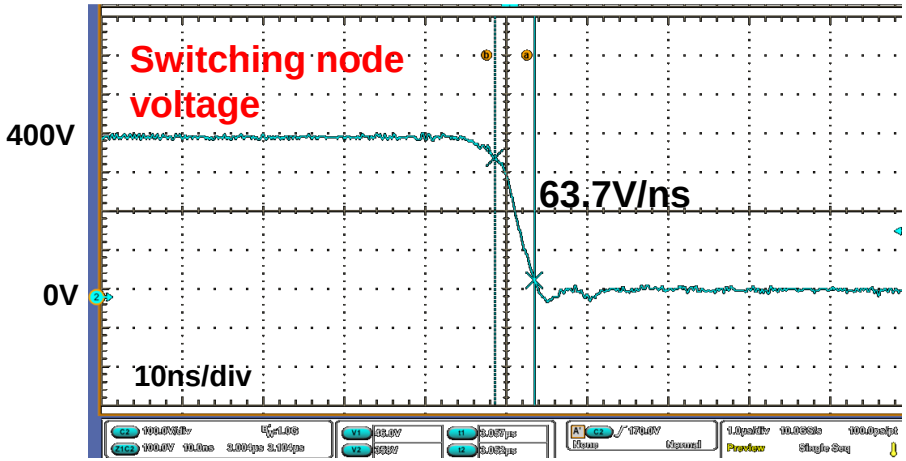
Discrete GaN: Limited Switching Performance

Expensive bias supply
With negative voltage

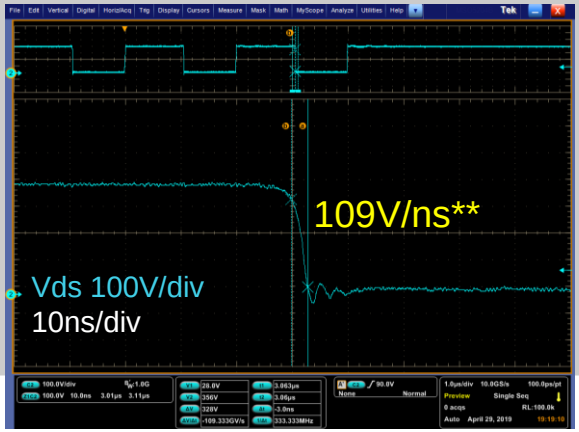
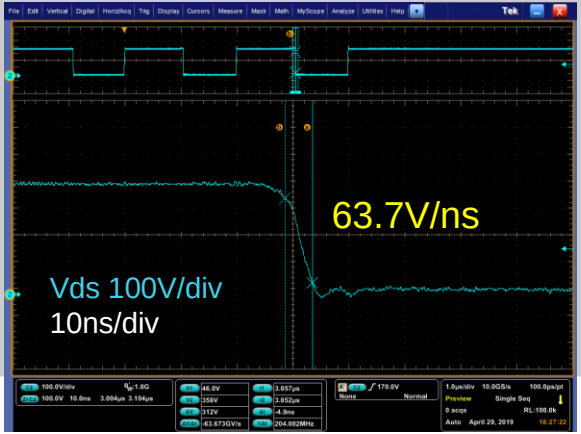
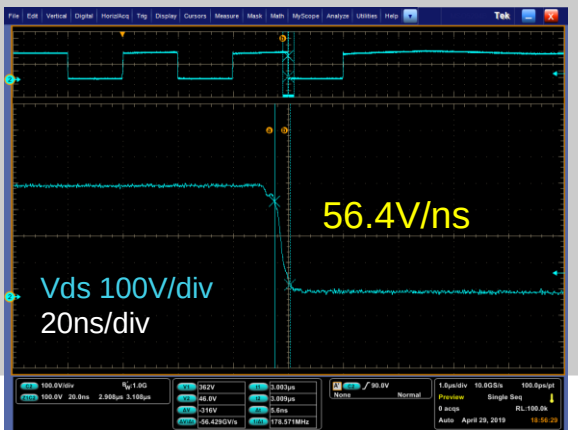
>10nH gate
inductance



> 250 mm^2 extra area
> 6 extra active comp.



Integrated Driver Allows Faster Switching

LMG3410R070	IGOT60R070D1	GS66508T
		

$$P_{sw} \sim (I_{RMS} \times V_{DC} \times t_R \times f_{PWM})/2 + (V_{DC} \times Q_{oss} \times f_{PWM}) + (V_{DC} \times Q_{rr} \times f_{PWM})$$

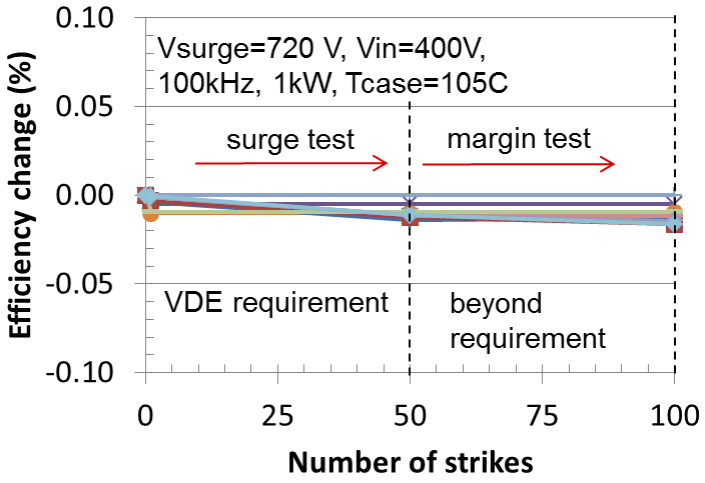
Switching Loss
100kHz,1kW
TP CCM PFC

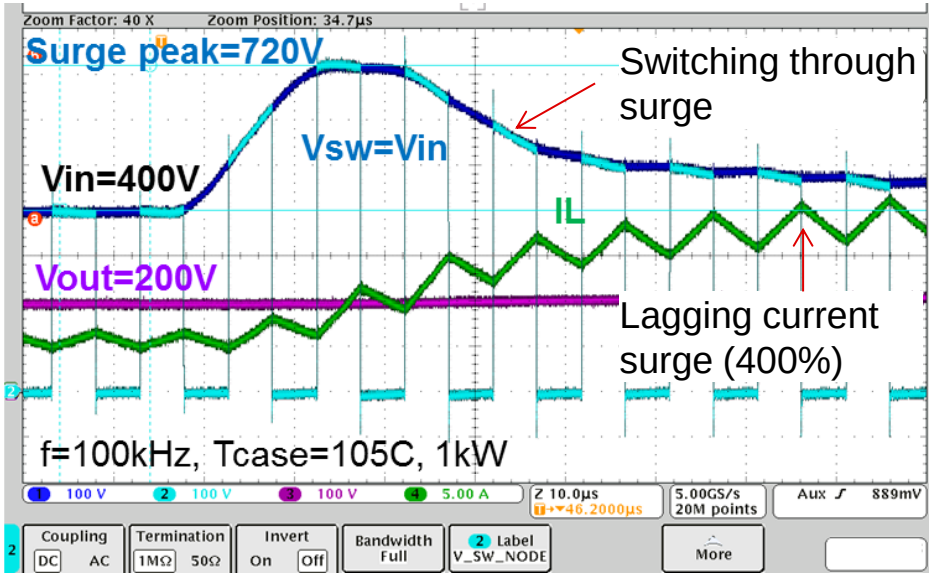
TI GaN:100V/ns → 0.95W	2.3W at 387V	0W
Discrete: 50V/ns → 1.9W	1.6W at 387V	0W

* @turn-on at 400V V_{bus} 10A with default driving configuration on EVM
** dv/dt measured within 10%-90% V_{bus}

LMG341x: Robust to Surge

- The IEC 61000-4-5 standard specifies the surge waveform.
- The VDE 0884-11 standard specifies the application of 50 strikes.
- The TI test consists of an additional 50 strikes, to assure margin.

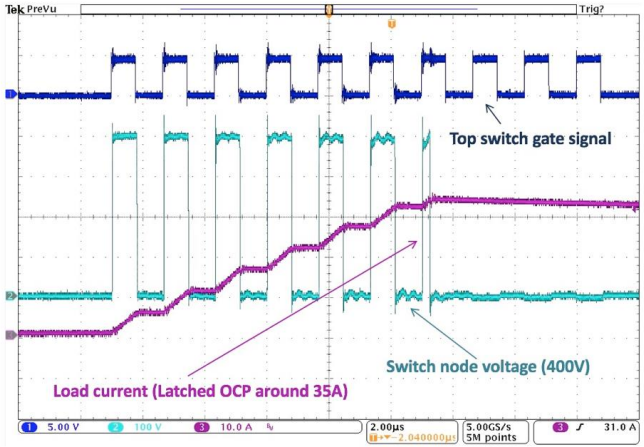




LMG341x: Robust 100ns Overcurrent Protection

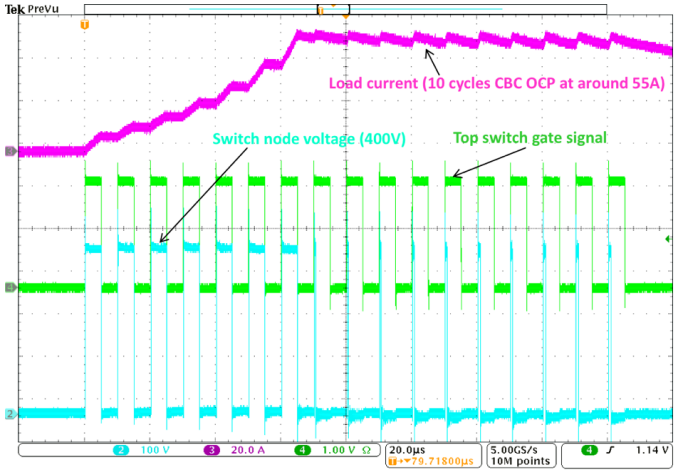
- Latched (LMG3410Rxxx)

  In an OCP event, the device is turned off in less than 100ns and held off until the fault is reset by either holding the IN pin low for >350µs



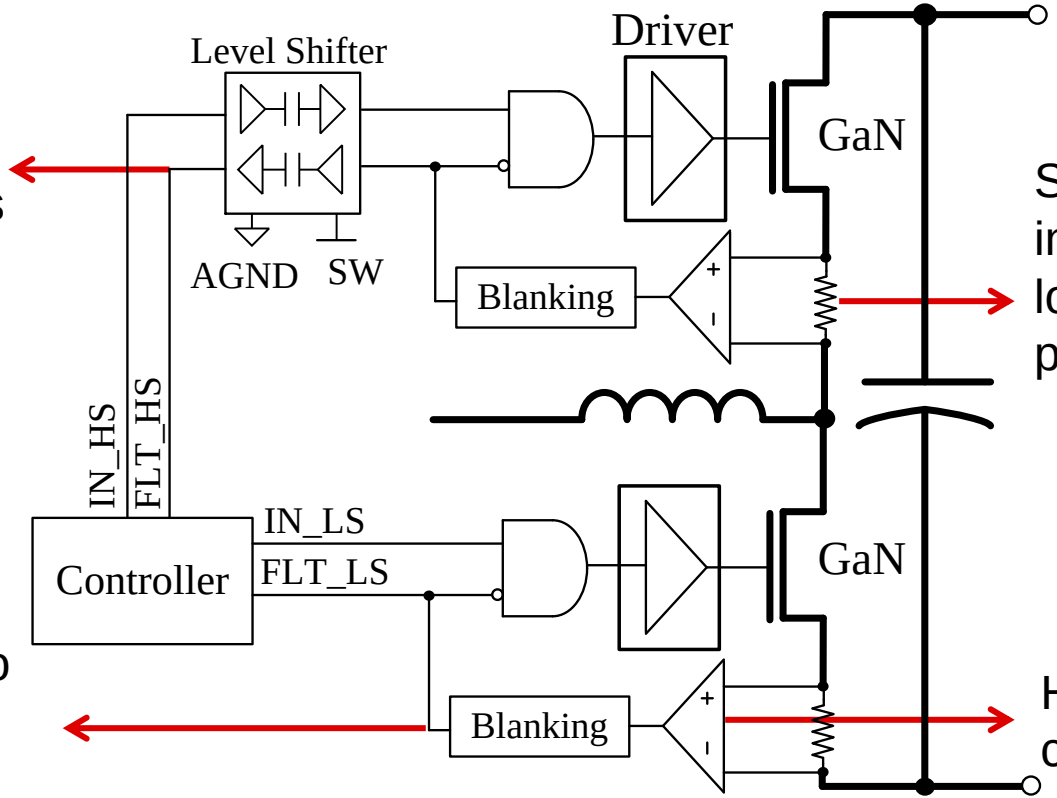
- Cycle-by-Cycle (LMG3411Rxxx)

  In an OCP event, the device is turned off in less than 100ns and held off until the next PWM cycle



Discrete OCP Implementation: External Components

High side fault reporting requires level shifting

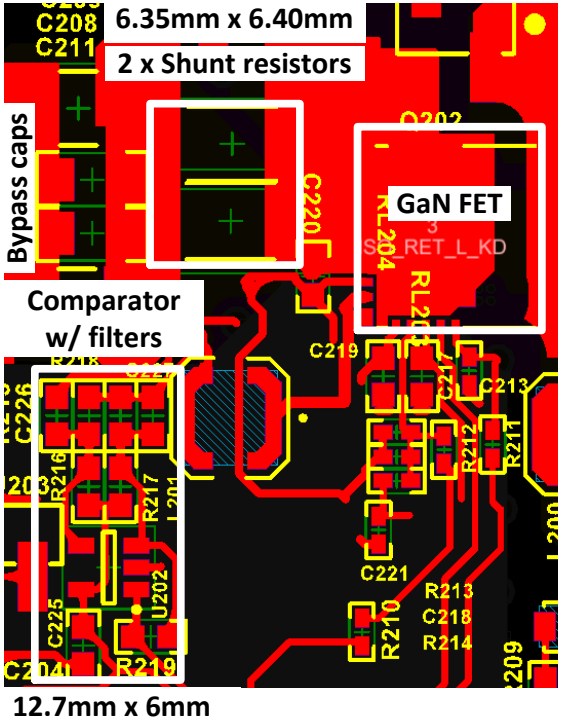


Shunt resistor increases the power loop inductance and power losses

~20ns blanking time is required to prevent false trigger

High-speed comparator

Discrete OCP Implementation: Performance

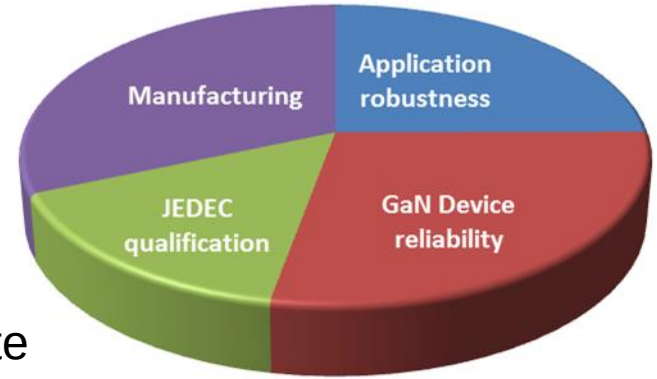


Parameter	Resistive Shunt 2X 12mΩ (25mΩ /2)
Added PCB Area	233 mm^2
Added Power Loop Inductance	1.2nH
dv/dt	80V/ns
Additional Power Loss at Po=1.2kW	0.9W

LMG341x: Reliable and In Mass Production

- ✓ Over 20 million hours of reliability testing to date
- ✓ < 1 FIT rate for 10 year lifetime
- ✓ JEDEC JESD47 qualification complete
- ✓ Hard-switching reliability complete
- ✓ Dynamic Rds-on testing complete
- ✓ Long term in-application testing complete
- ✓ Extreme Short-circuit and surge testing complete
- ✓ In mass production with 100% TI owned fab

Device Reliability Hours:
>20,000,000



LMG3410x GaN: Ready for Watts to 10kW

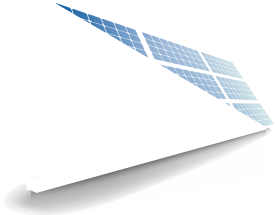
ACF

PFC

LLC

Inverter

Multi-Level



<65W

10kW

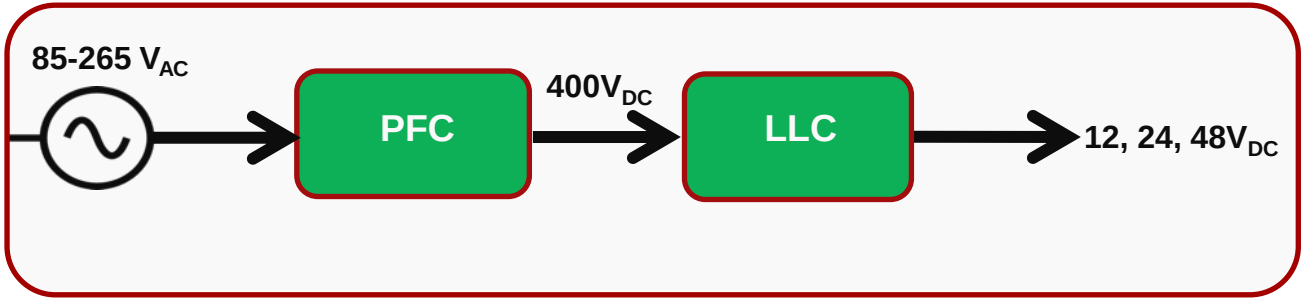
150mΩ
LMG341XR150

70mΩ
LMG341XR070

50mΩ
LMG341XR050

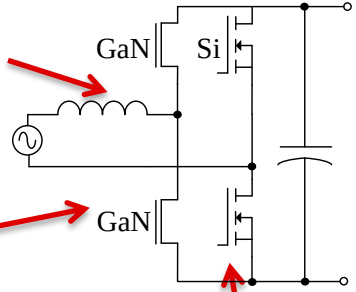
High Density Power Supply Designs

Power Supply Architecture: PFC and LLC



Typical AC/DC PSU for industrial, medical, telecomm and server applications.

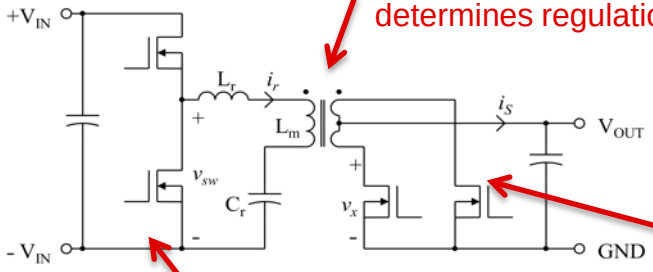
PFC inductor is used to regulate input current in phase with the input voltage



600V GaN

Line frequency Silicon MOSFET active rectifier

Resonance set up with Lr, Cr (& Lm), this network determines regulation characteristics



600VGaN

Low-voltage Si or GaN synchronous rectifier

LMG3410x GaN: Maximize Power Density

Silicon PFC @ 1.6kW

- 2x higher density
- 50% reduction in magnetics
- 2 GaN replaces 2 SJ and 2 SiC diodes
- 2-3% Higher Efficiency

GaN PFC @1.6kW

TIDA-00961

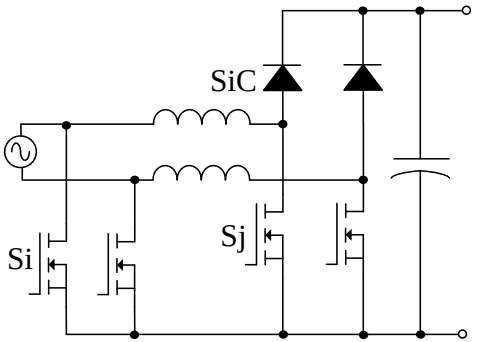
Power Density: 37 W/in^3

Power Density: 70 W/in^3

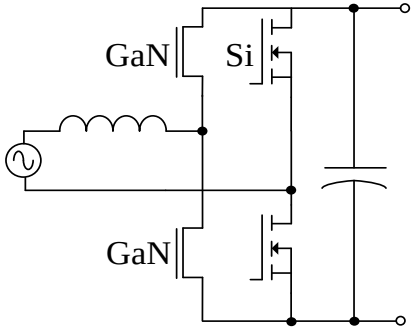
GaN PFC Solution: Superior Power Supply Design

- **Higher efficiency**
  - Reduced power loss by 36%
- **Higher power density**
  - 2X power density in Totem-pole PFC versus Silicon
- **Solution cost parity**
  - Reduced magnetics and external components bring total solution cost down

Dual boost PFC



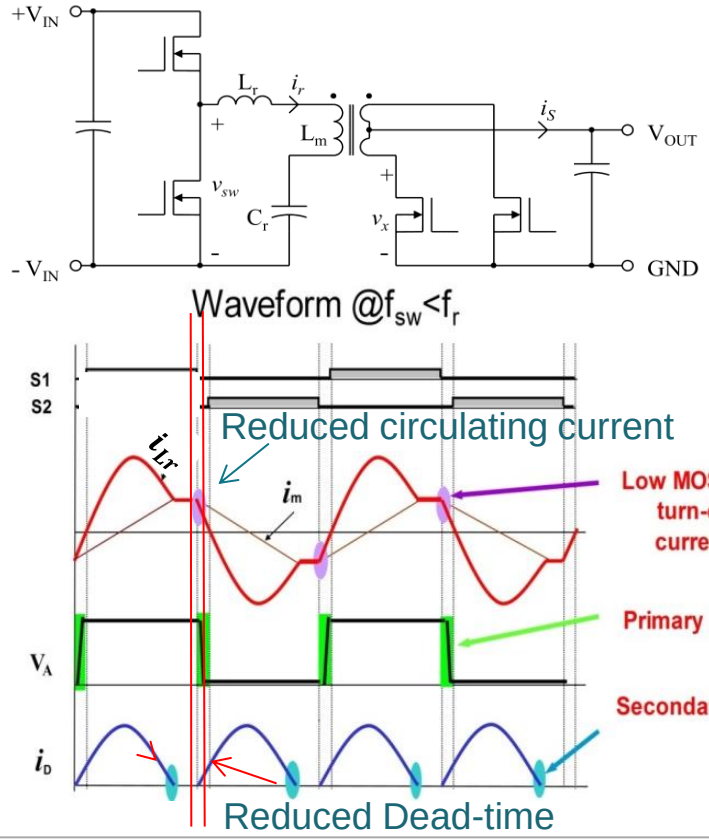
Totem-pole PFC



Loss Mechanism	Dual Boost PFC with Silicon	Totem-pole PFC with GaN
Switching FET Cond.	0.6 W	2.06 W
SiC Diode Cond.	2.75W	-
FET E_{oss} / SiC Diode Q_{oss}	3.9 W	2.4W
I-V Overlap	1.47 W	0.95W
Rect. Diodes / FETs	0.45 W (FET)	0.45 W (FET)
Total Power Losses	9.17W	5.86W

GaN in LLC: Superior Power Supply Design

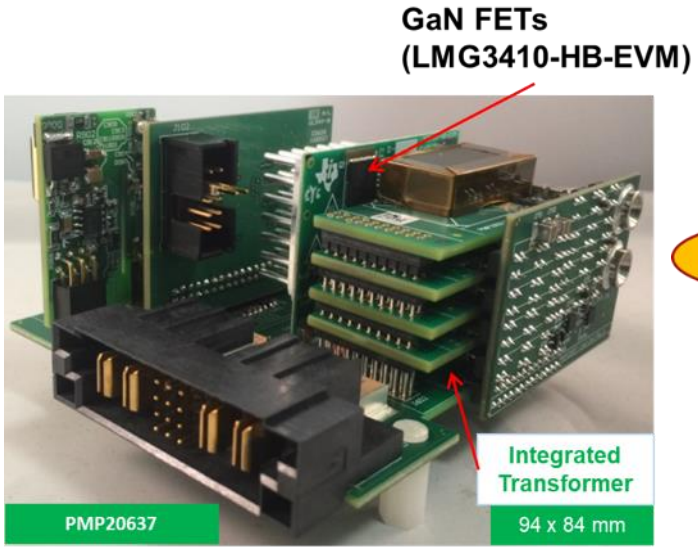
- **Reduced Output Capacitance C_{OSS}**
  - Reduces dead-time, increasing the time when current delivered to the output
  - Allows larger magnetizing inductance and lower circulating current losses as well as transformer fringe-field losses
- **Reduced Gate Driver Losses**
- **System Optimization**
  - GaN enables higher switching frequency to reduce magnetic components significantly
  - GaN enables LLC converter with higher efficiency and higher power density



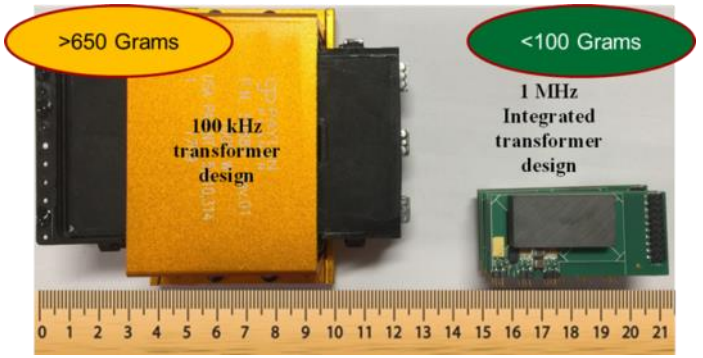
PMP20637: 1MHz Isolated LLC DCDC Converter

Parameter	Value
Input Voltage	380 – 400V
Input Frequency	≤ 1MHz
Output Voltage	48V
Output Power	1 kW
Switching Frequency	≤ 1MHz
Efficiency	97%

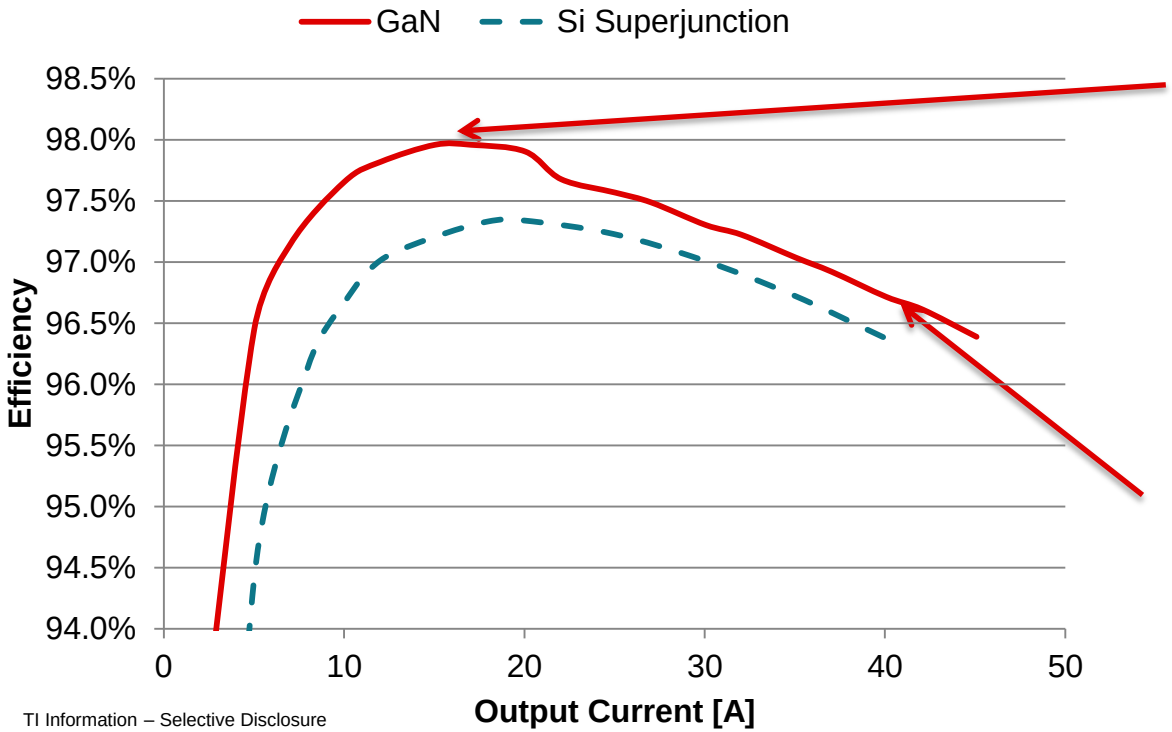
Power Density: 140 W/in3



Power Density Improvement & Weight Reduction



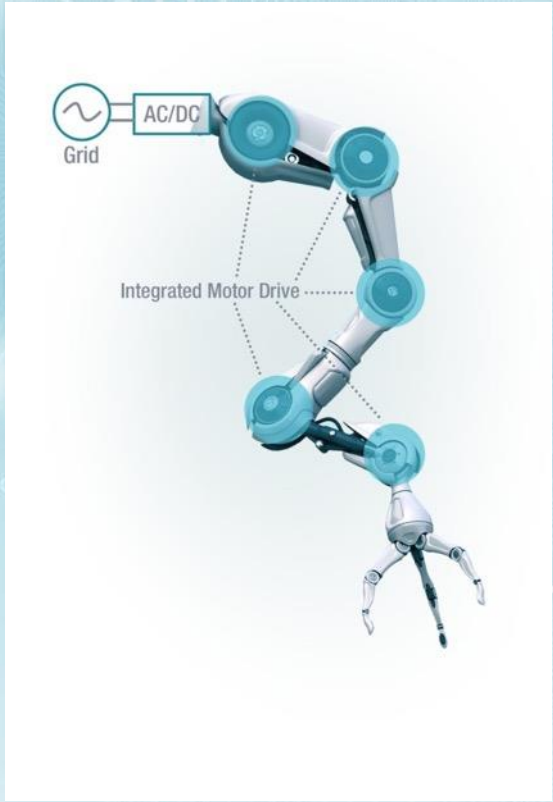
4x Density and 98% Efficiency
Comparison with MOSFET



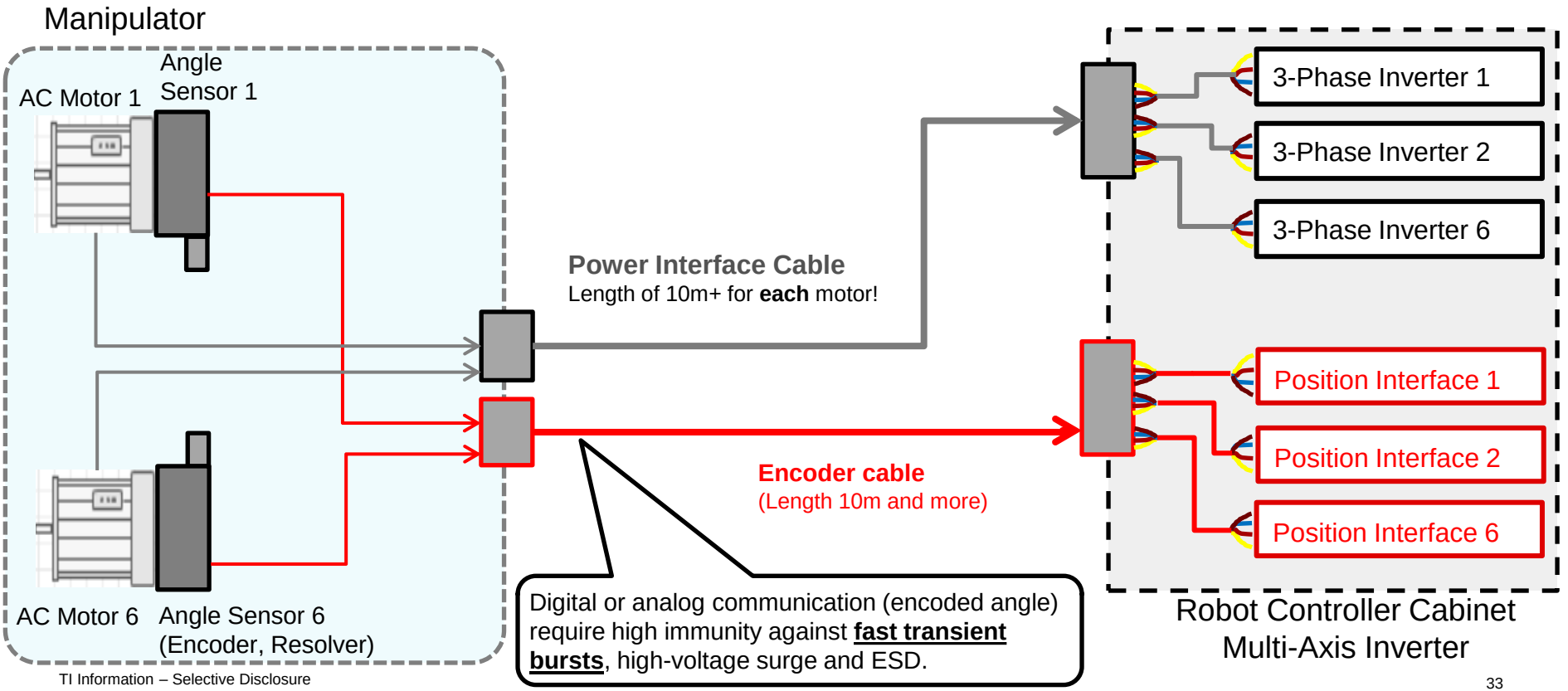
Reduced capacitance & circulating currents dramatically improve light-load efficiency

Resistance Limited (slight improvement)

High Efficiency Motor Drives



Factory Automation & Robotics System Diagram

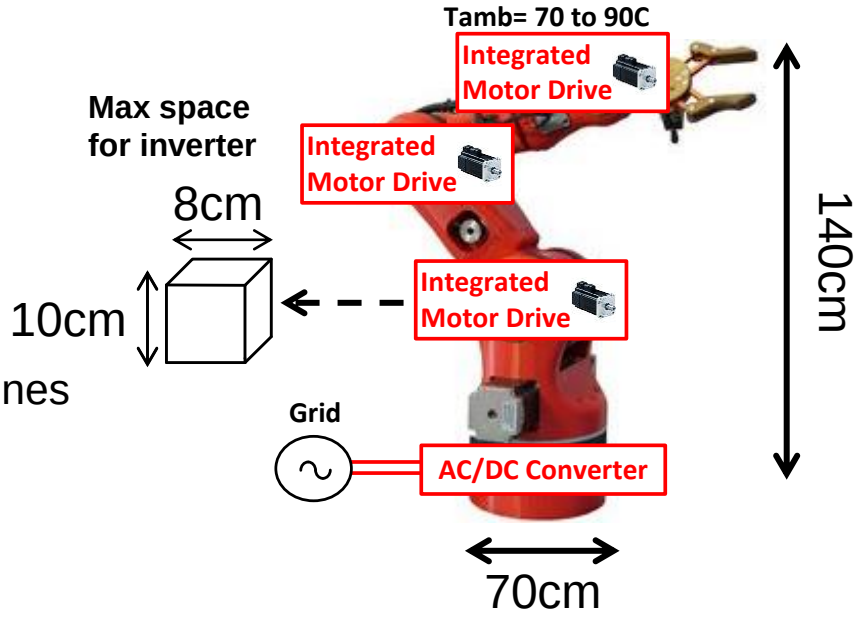


New Trend: Integrated Motor Drives

Integrated Drives with GaN

- ✓ Compact form factor
- ✓ Fan-less operation
  - No fan failures, higher reliability
- ✓ Integrated design
  - High dv/dt operation
  - DC distribution saves cabling cost
  - Noise immunity on comm and encoder lines
  - Factory floor savings

6-axis 4.5kW robotic arm



LMG3410R150: Enabling Integrated Motor Drive

Silicon Servo Drive @1.5kW

Cooling Area: ***Fan*** + 145 x 82 x 42 mm

- **75% reduction Factory Floor Cabinets**
- **90% less power and communication cabling**
- **85% smaller heatsink and NO-FAN**

- **in 6 axis robotic system*

TIDA-00915

Integrated GaN based Motor Drive

Cooling Area: ***No Fan:*** 80 x 46 x 20 mm

TIDA-00915: 1.2kW 3Φ Integrated Drive

Solution Features

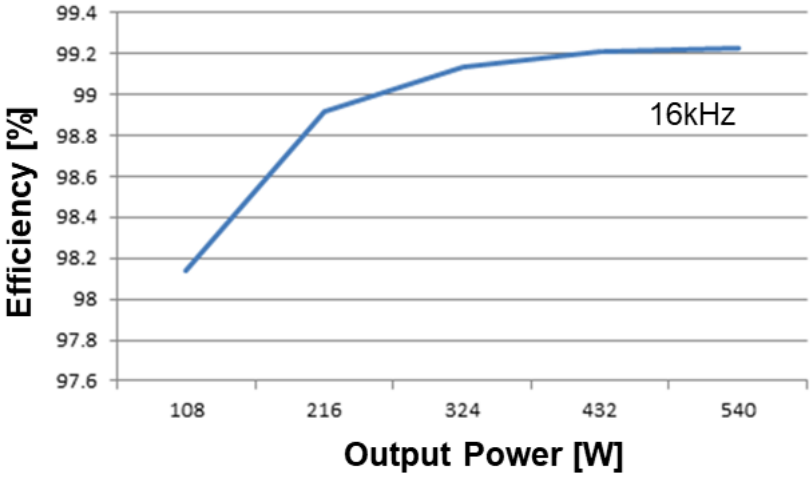
- Ultra-small form factor with power density of 150W/in3
  - 50ºC ambient conditions up to 1.25kW
  - 85ºC ambient conditions up to 550W
- Peak efficiency > 99%
- Natural convection cooling with 10mm heatsink
- Built-in short-circuit and over temperature protection
- 450V Max DC Operation

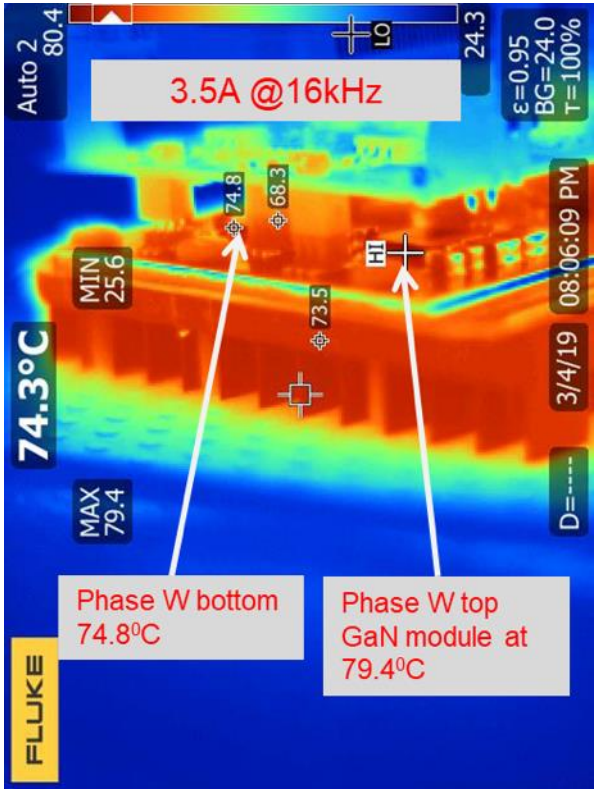
Applications

- Integrated motor drives
- Robotics
- Servo drivers

TIDA-00915: Natural Convection Cooling

Heatsink: 10mm fin height
Peak efficiency > 99.2%





GaN: Enabling Smart Motor Drive

- GaN reduces or eliminates heatsink
- GaN increases PWM frequency and reduces switching losses
  - Drive very low inductance PM synchronous motors or BLDC motors
  - High-speed motors (e.g. drone) achieves sinusoidal voltage above 1-2kHz frequency
  - Precise positioning in servo drives/steppers through minimum torque ripple
- GaN eliminates dead-time distortions of phase voltage
  - Better light load and THD performance
- GaN reduces or eliminates switch node oscillations
  - Lower radiated EMI, no additional snubber network (space, losses) required

Ultra-Small USB PD and ACDC Solutions

LMG3410x GaN: Achieve Ultra-Small Solutions

Silicon <100kHz → **GaN >500kHz**

- QR flyback
- Size: 72 x 72 x 28 mm

70%
Smaller
Volume

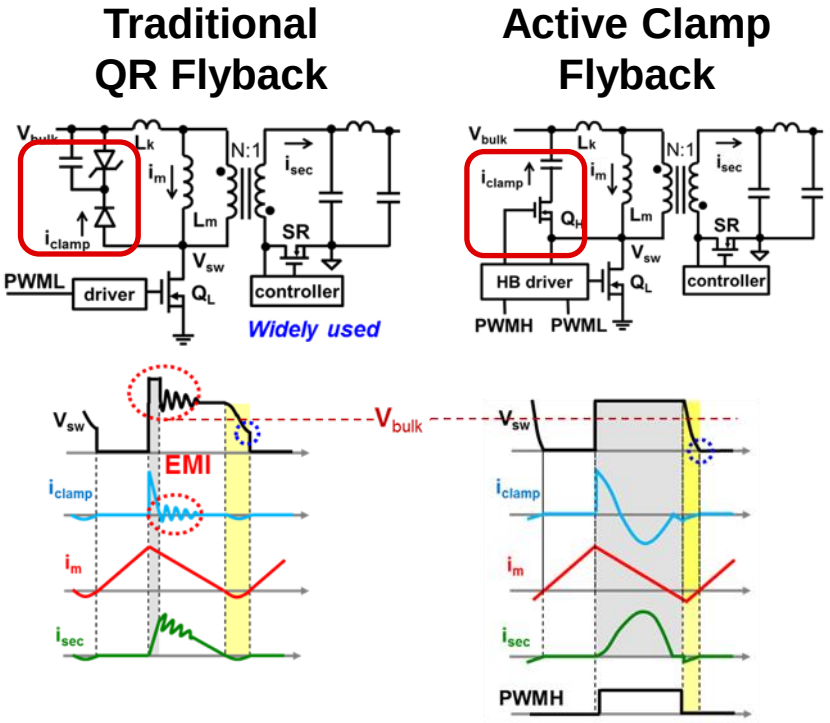
- Active clamp flyback
- Size: 65 x 30 x 22 mm

Active Clamp Flyback

Eliminates switching losses and reduces EMI with proper control of the clamp which allows **zero voltage switching (ZVS) to be achieved**

Improves efficiency over traditional Flyback converters by recirculating the leakage energy and delivering it to the output instead of dissipating it

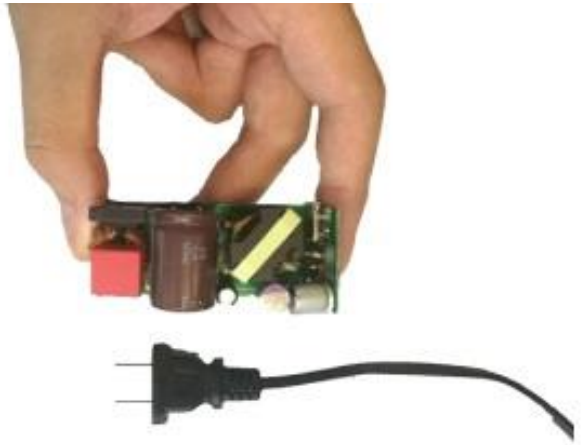
Enables greater power density Lower switching losses and corresponding temperature rise enables higher switching frequencies, which allows for smaller passive components and tighter packaging



PMP21639: 65-W USB Type-C PD AC/DC Adapter Reference Design

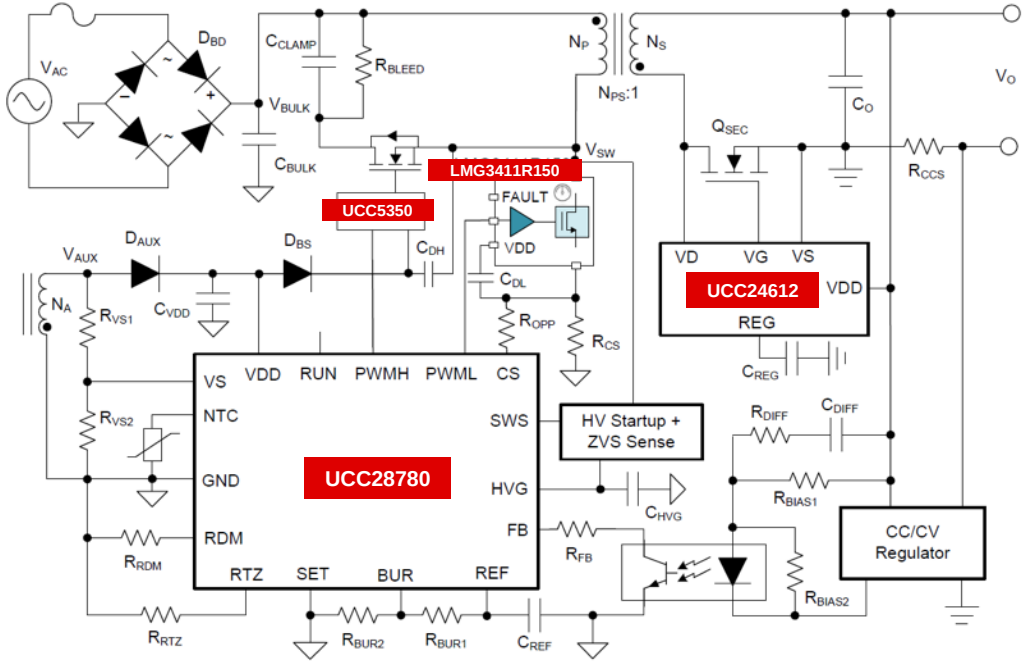
Features

- 100% TI GaN solution, ACF, and SR controllers
- Requires only ONE GaN Device
- High efficiency (94% Peak)
- High power density (>30W/in³)
- Low light-load input power (0.5W), @20Vout/0.25W output
- Fully compatible with USB PD 2.0 standard, with 5V/3A, 9V/3A, 15V/3A, 20V/3.25A output
- Small size (62mm*28.6mm*18.4mm)



TI-GaN Active Clamp Flyback Solution

More power in less space



LMG3411R150 GaN Power Stage

- 600V 150mΩ single-chip GaN with driver and protection
- 100ns cycle by cycle short-circuit protection

UCC28780 Active Clamp Flyback

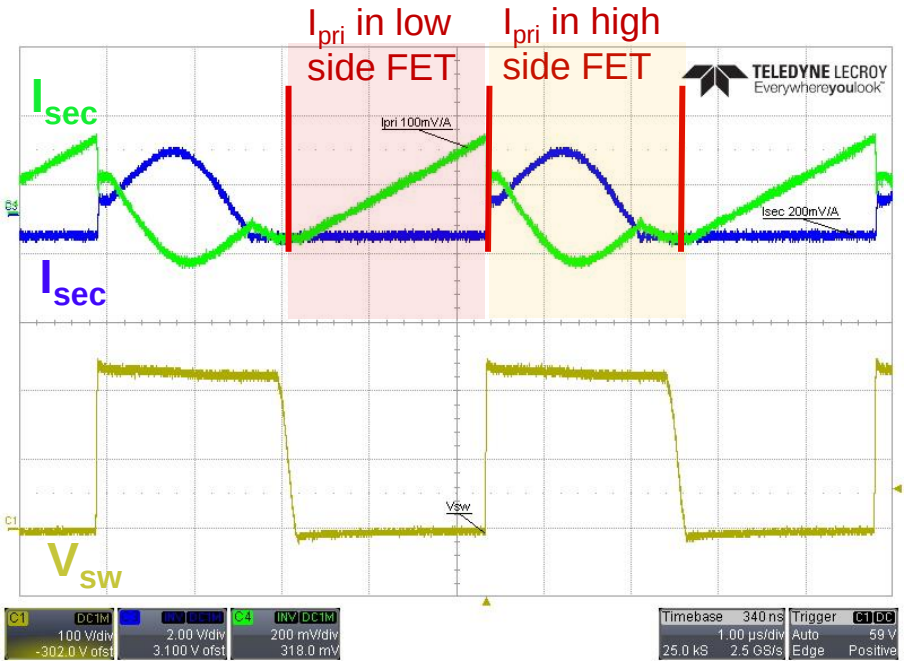
- Best in class efficiency and innovative ZVS algorithm
- Advanced protection features

UCC24612 Advanced Sync Rectifier

- Wide voltage range operation
- Intelligent control provides near ideal diode emulation

PMP21639: Why Si on the High-Side?

- 65W TM flyback high-side
  - High side I_{rms} << low side I_{rms}
  - can tolerate R_{dson} > 1Ω
  - C_{sw} dominated by C_{oss} of low side FET
- Trade offs of Si FET on high side:
  - \+ Significant cost savings
  - \+ Simplified drive for high side FET
  - \+ Avoid any boot-strap issues at no load
  - – Minor impact on efficiency



Key Takeaways

- TI GaN portfolio supports applications from Watts to 10kWs, enabling a new generation of power conversion designs with high power density and efficiency
- GaN enables 2X power density improvement on a PFC stage at system level cost parity
- 1MHz isolated LLC design delivers 6x reduction in size and weight of the solution
- GaN decreases USB PD Charger volume by 60%
- GaN based integrated motor drive eliminates cooling, and saves factory space and cabling costs
- For products, designs, and training material, visit **Ti.com/GaN**

Thank You