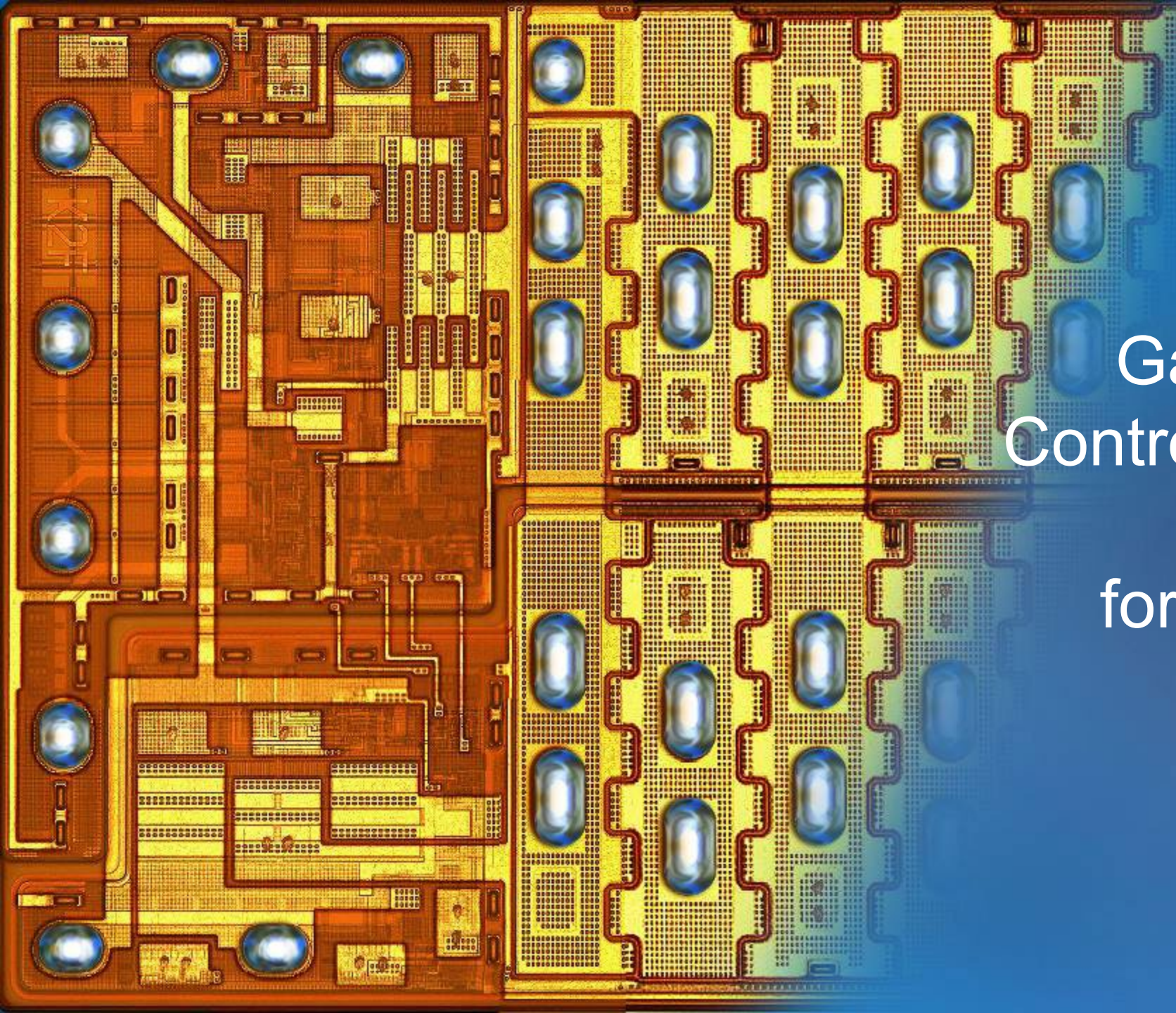


GaN First Time Right: Controllers, Gate Drivers, & PCB Layout Tips for DC-DC Converters

Brian Miller

EPC
EFFICIENT POWER CONVERSION

Agenda

- Review: EPC eGaN FETs & ICs
- GaN First Time Right
- Controllers
- Gate Drivers
- Layout Tips & Examples

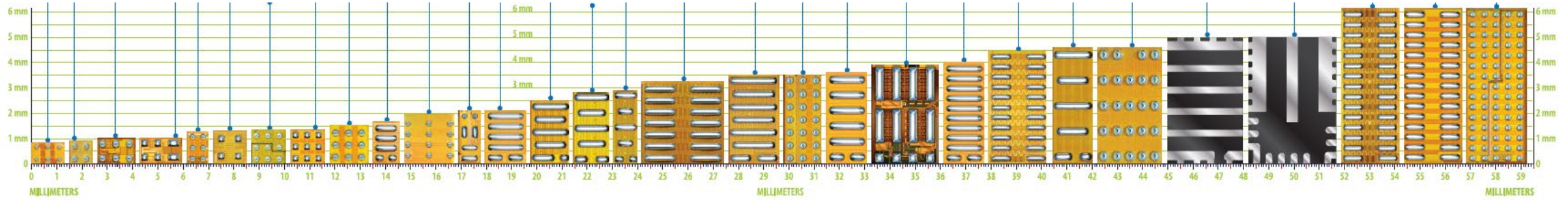
EPC Products

Overview:

- EPC makes:
  - power transistors (FETs) & power integrated circuits (ICs)
  - made from GaN (gallium nitride): a material superior to silicon

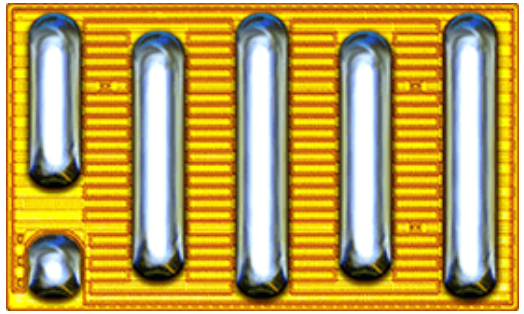
- Range: 40 to 350 Volts, 0.5 to 102 Amps

touchscreen version of this chart



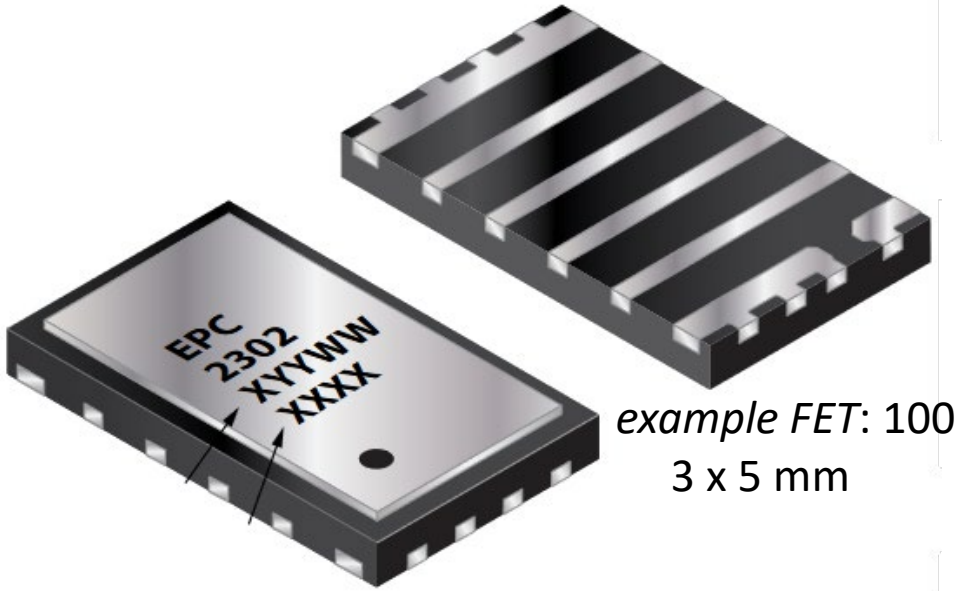
package types

- **Chip Scale**
  - 30 to 350 V
  - All sizes, except largest



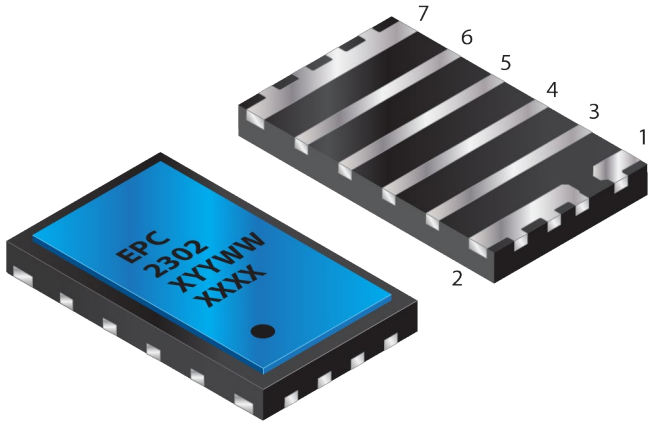
example FET:
100 V, 29 A, 2.5 x 1.5 mm

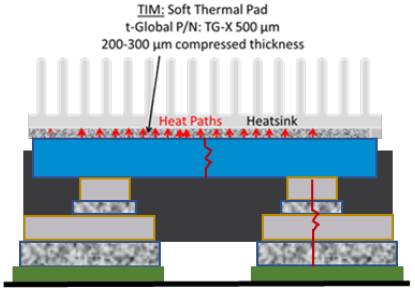
- **Packaged (QFN package)**
  - Medium & Large sizes
  - 100, 150, & 200 V
  - Packaged FETs are popular
  - Top of die is exposed for very good thermals



example FET: 100 V, 101 A
3 x 5 mm

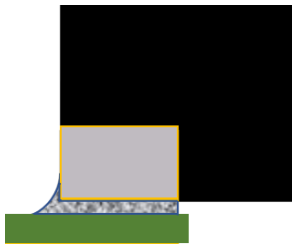
eGaN FETs in 3x5 mm QFN package





Rthjc (top) = 0.2 °C/W

Rthjb (bottom) = 1.5 °C/W

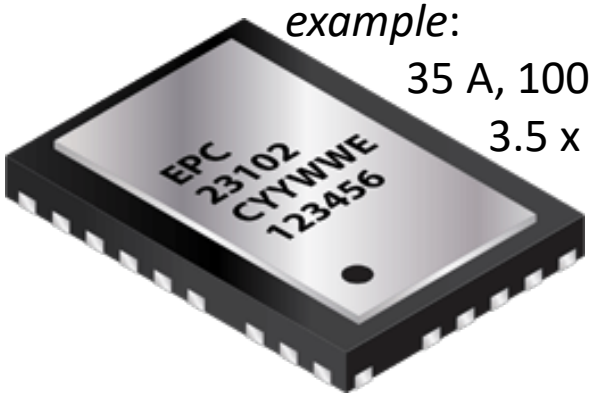


Wettable Flanks

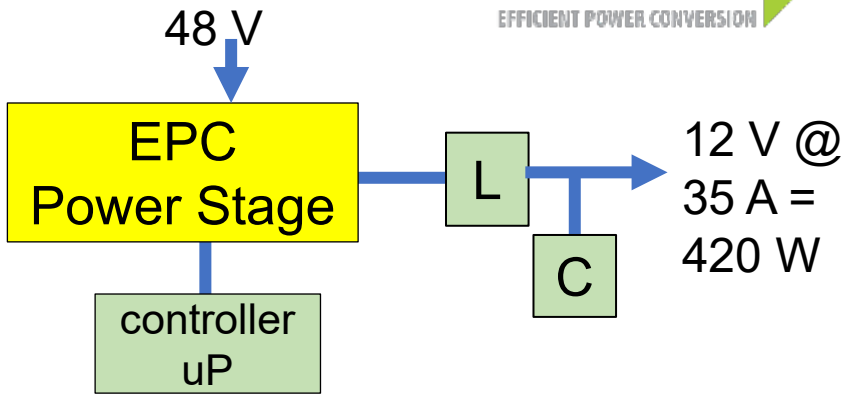
Parameter (5V V_{GS})	EPC2361	EPC2302	EPC2306	EPC2305	EPC2308	EPC2304	EPC2307
V_{DS}	100 V	100 V	100 V	150 V	150 V	200 V	200 V
$R_{DS(on)}$ max	1.3 mΩ	1.8 mΩ	3.8 mΩ	3 mΩ	6 mΩ	5 mΩ	10 mΩ
$R_{DS(on)}$ typ	1.0 mΩ	1.4 mΩ	3.2 mΩ	2.2 mΩ	4.9 mΩ	4.1 mΩ	8.2 mΩ
Q_G typ	27 nC	18 nC	11 nC	21 nC	9.8 nC	21 nC	10.6 nC
Q_{GD} typ	3.2 nC	3 nC	1.1 nC	2.6 nC	1.2 nC	2.6 nC	1.3 nC
Q_{OSS}typ	86 nC	82 nC	41 nC	105 nC	49 nC	115 nC	58 nC
Q_{RR}typ	0 nC	0 nC	0 nC	0 nC	0 nC	0 nC	0 nC
$R_{\Theta JC}$	0.2 °C/W	0.2 °C/W	0.5 °C/W	0.2 °C/W	0.5 °C/W	0.2 °C/W	0.5 °C/W
I_D	101 A	101 A	62 A	102 A	48 A	102 A	48 A

Integrated Circuits – power ICs

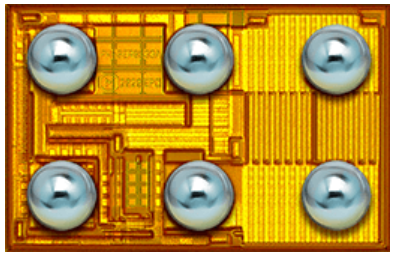
- **Power Stages**
  - Built-in gate drivers
  - Easy to use, efficient
  - Half Bridge
  - Up to 100 V, up to 35 A

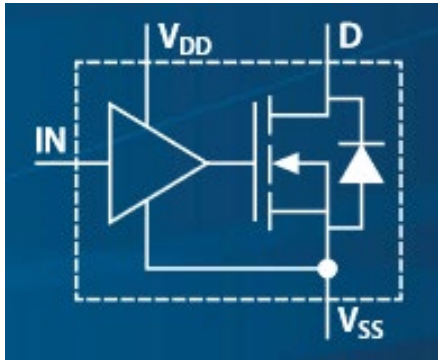


example:
35 A, 100 V
3.5 x 5 mm

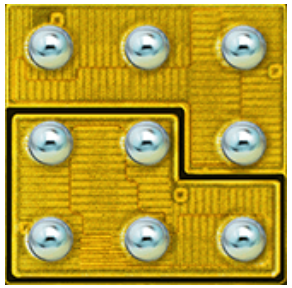


- **FET + Driver**
  - For pulsing lasers
  - Also for boost converters





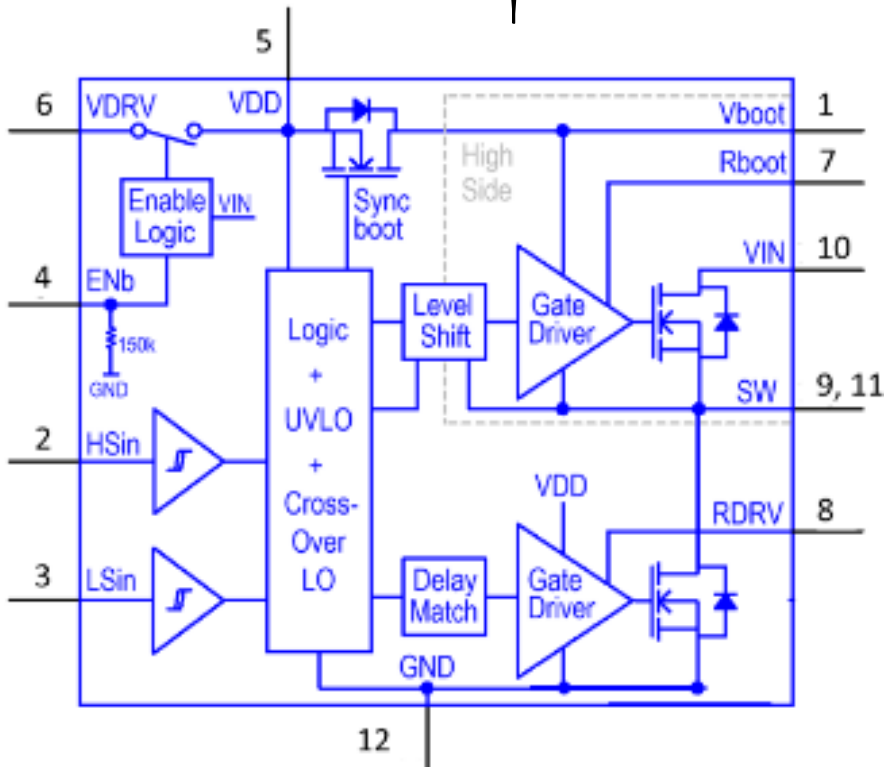
- **Half Bridges**
  - Without gate drivers
  - Up to 100 V

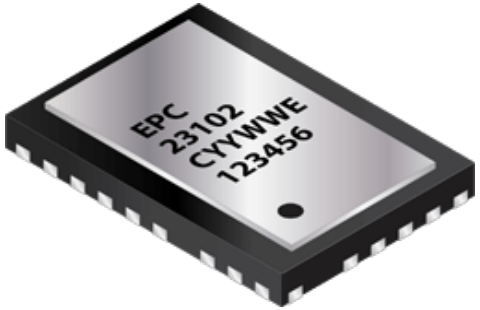


example: dual, 100 V,
1.35 x 1.35 mm

eGaN Power Stage

	EPC23102	EPC23103	EPC23104
V_{DS}	100 V	100 V	100 V
I_{DC}	30 A	20 A	15 A
Package	3.5mm x 5mm		





Applications

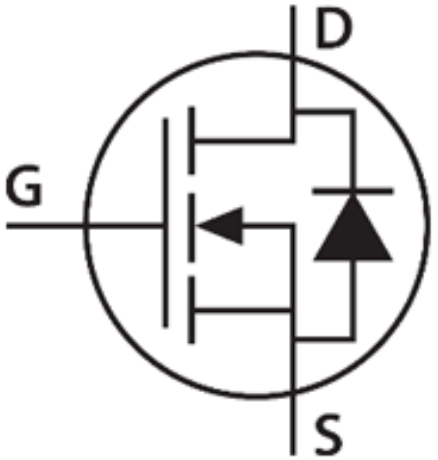
- Buck, Boost, Buck-Boost
- Half-Bridge, Full Bridge LLC
- Motor Drive Inverter
- Class D Audio Amplifier

1 chip Power Stage

Key GaN FET Performance Metrics

GaN FETs: like MOSFETs but…

- Smaller
- Switch faster
- Reverse voltage conduction
  - Main channel, not a parasitic element
- Zero reverse recovery (Q_{RR})
- Miller ratio < 1 (Q_{GD}/Q_{GS_Th})
  (dv/dt immunity)
- Exceptional reliability



EPC 200 V vs. Si Devices

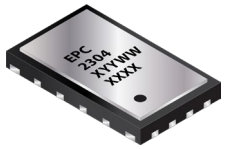
Si MOSFET Benchmark

9.9 x 11.7 mm

eGaN FET

4.6 x 1.6 mm

Sampling now



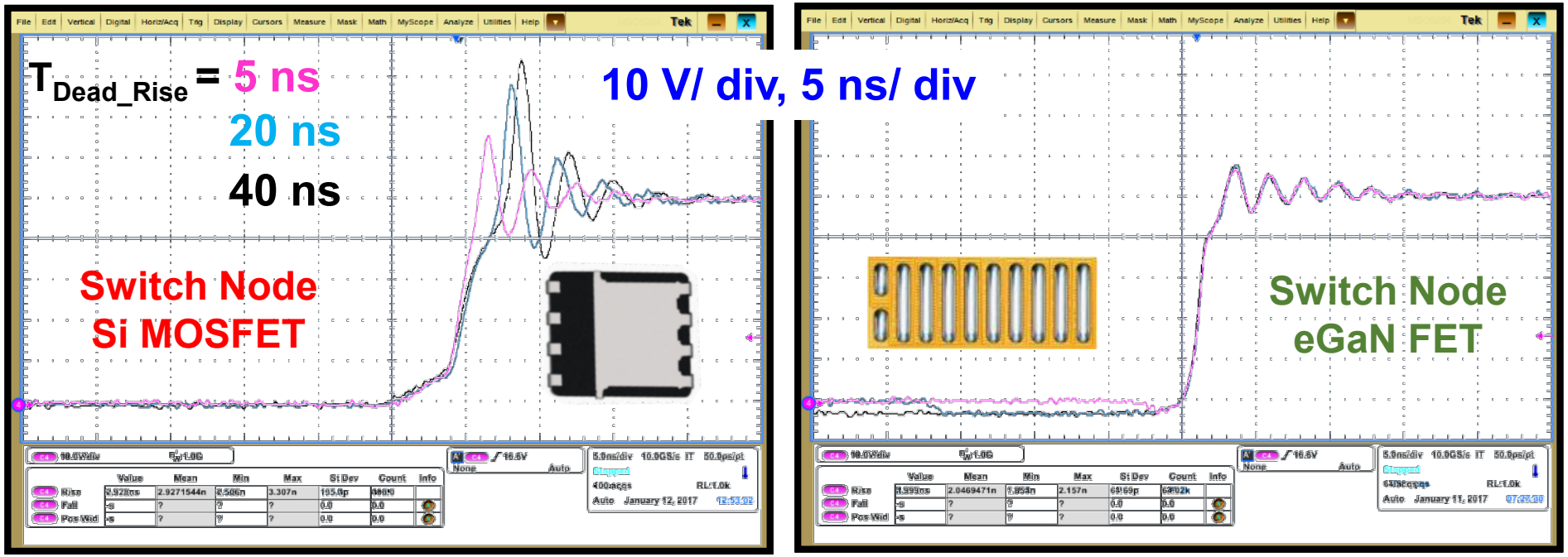
3 x 5 mm

Parameter	IPT111N20NFD (@ 10 V_{GS})	EPC2215 (@ 5 V_{GS})	EPC2304 (@ 5 V_{GS})
$R_{DS(on)}$ typ	9 mΩ	6 mΩ	3.4 mΩ
$R_{DS(on)}$ max	11.1 mΩ	8 mΩ	5 mΩ
Q_G typ	65 nC	10 nC	20 nC
Q_{GD} typ	8 nC	1.6 nC	3.2 nC
Q_{OSS} typ	162 nC	68 nC	68 nC
Q_{RR} typ	309 nC	0 nC	0 nC
Device Size	115.83 mm^2	7.36 mm^2	15 mm^2

15x smaller, less losses, no reverse recovery, higher f_{SW}

GaN FETs: Zero Reverse Recovery

- Higher hard-switching frequencies without penalty
- Lower switching distortion

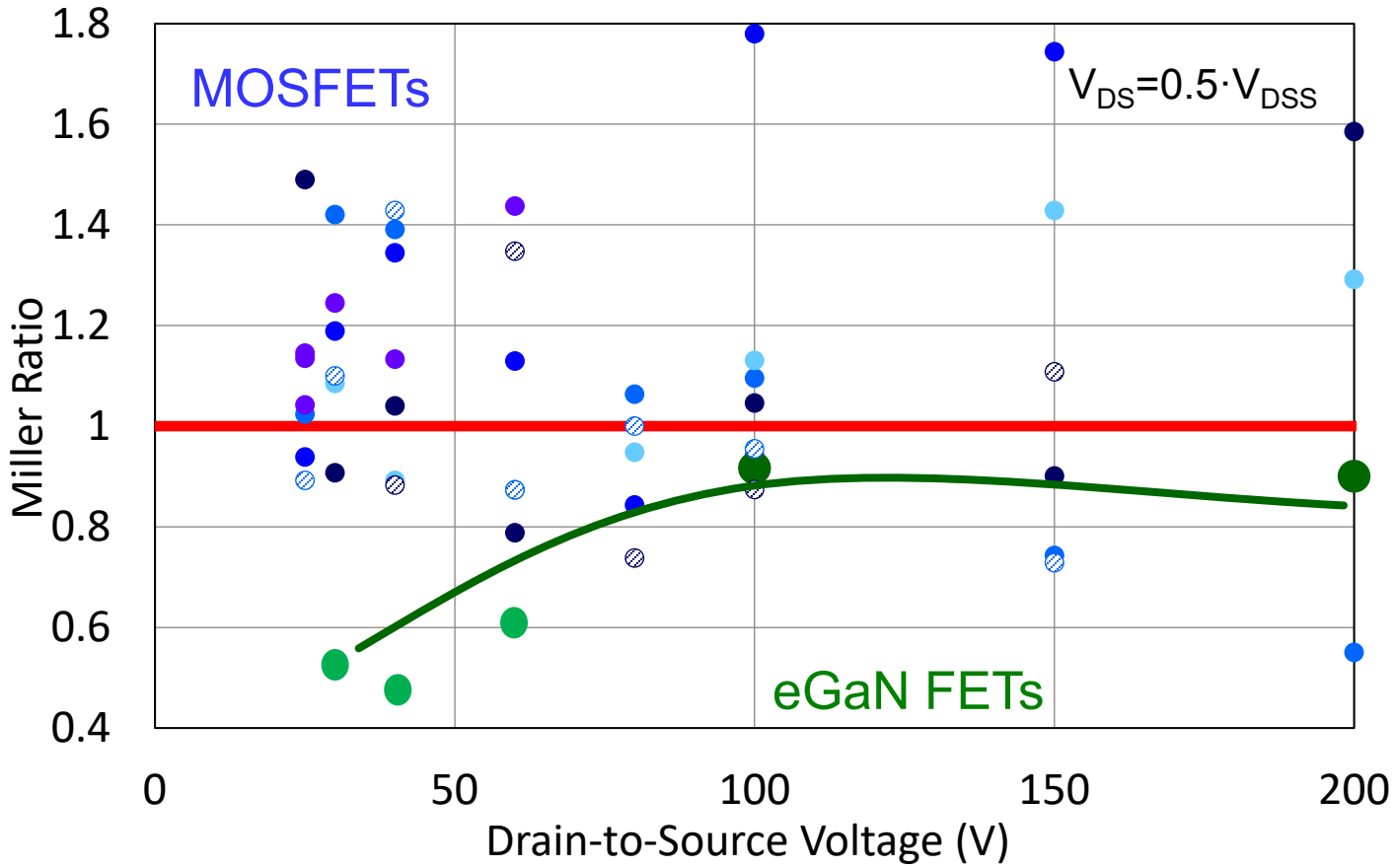


V_{IN} = 48 V, V_{OUT} =12 V, I_{OUT} = 20 A, f_{sw} = 500 kHz, L_{Buck}= 4.7µH

Miller Ratio

$$Ratio_{Miller} = \frac{Q_{GD}(V_{DS})}{Q_{GS\_Th}}$$

- Indicator of dv/dt immunity
  - Simplifies gate driver requirements
  - Reduces converter startup failures
- GaN FETs Miller ratio across full rated voltage



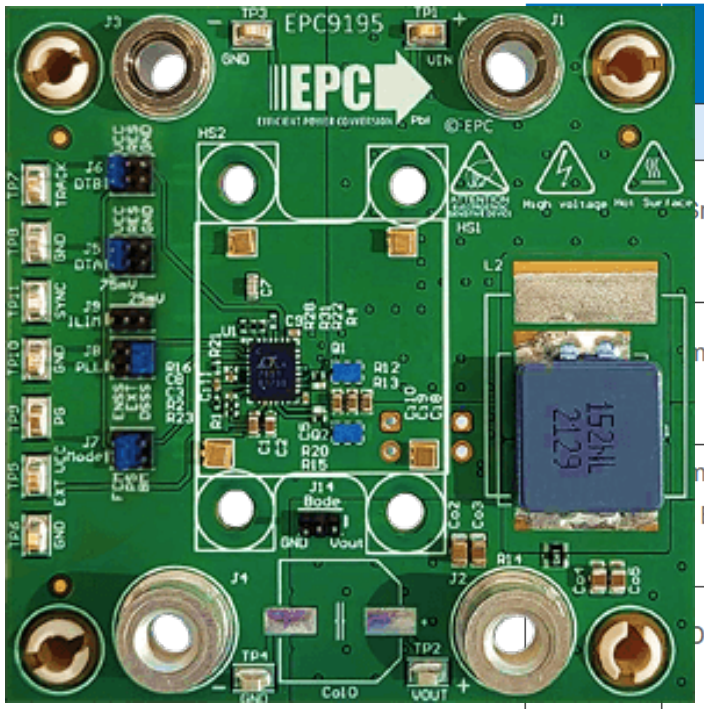
GaN First Time Right

What is GaN First Time Right?

- Helps with the design process
  - Using application notes, design examples, calculators, etc.
- Goal: a smooth product development, with excellent performance

Design Examples

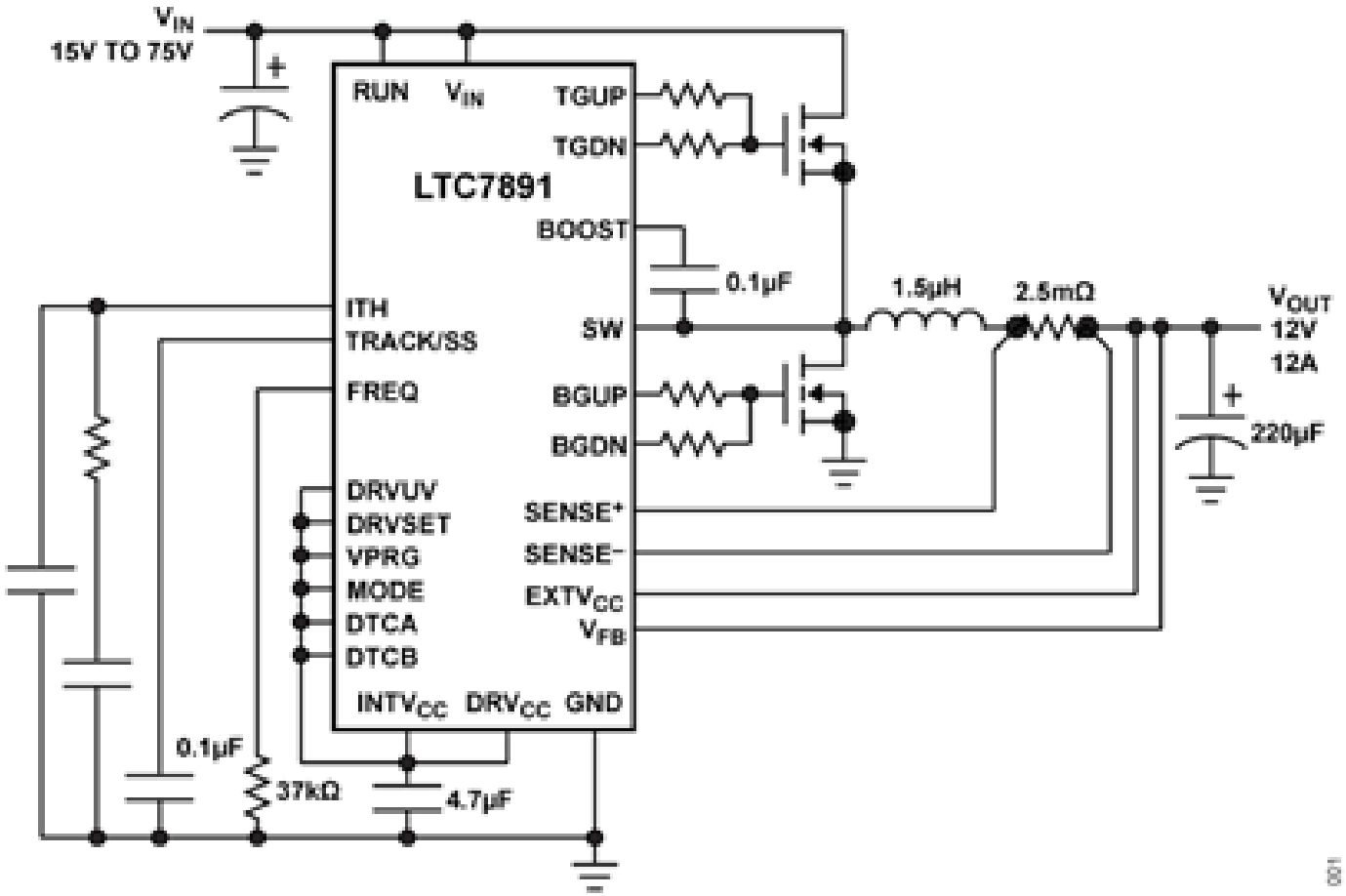
- Eval boards – with documentation
  - Link to chart EPC evaluation boards, for DC-DC
  - Partner reference designs: from TI, ADI, Renesas, Microchip, Richtek, etc.
  - Buck, boost, buck/boost, LLC, etc.



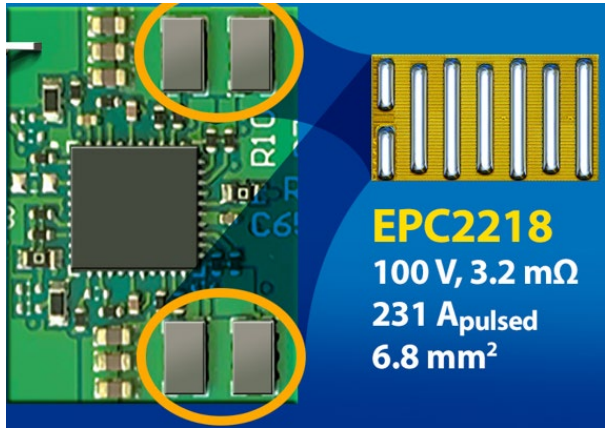
Description	Power (W)	Topology	GaN Product	Controller	Gate Driver	V_{IN} (V)	V_{OUT} (V)	I_{OUT} (A)
Buck Converters								
mall, 94%+ efficient, 740 kHz, analog controller	200+ W	buck, 1-phase	EPC2619	ADI/LT EVAL-LTC7891-AZ (analog controller)	(in controller)	36 - 60 V	13 V	16 A
nall, Synchronous Buck, analog controller	600 W	buck, 2-phase	EPC2218	ADI/LT EVAL-LTC7890-AZ (analog controller)	(in controller)	14 - 54 V	12 V	50 A
nall (1/16th Brick), Synchronous Buck, analog controller, with motherboard	300 W	buck, 2-phase	EPC2218	Renesas ISL81806 (analog controller)	(in controller)	18 - 60 V	12 V	25 A
Dual Output, analog controller, Synchronous, Buck	125 W	buck, dual output	EPC2055	ADI/LT EVAL-LTC7890-AZ (analog controller)	(inside controller)	9 - 24 V	Dual Output: 5 V / 3.3 V	15 A

Example #1: Single Buck

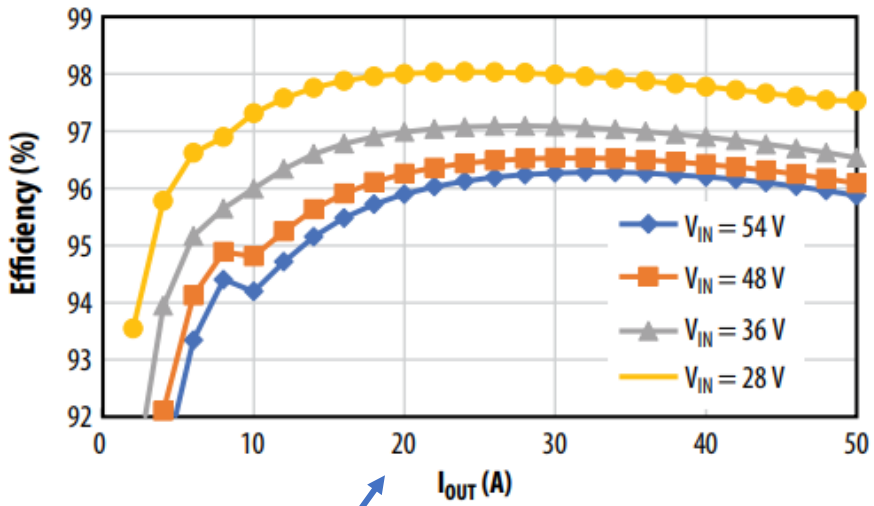
- ADI / LTC7891
  - Made-for-GaN buck controller
  - 5-100 V input
  - 0.1 to 3 MHz

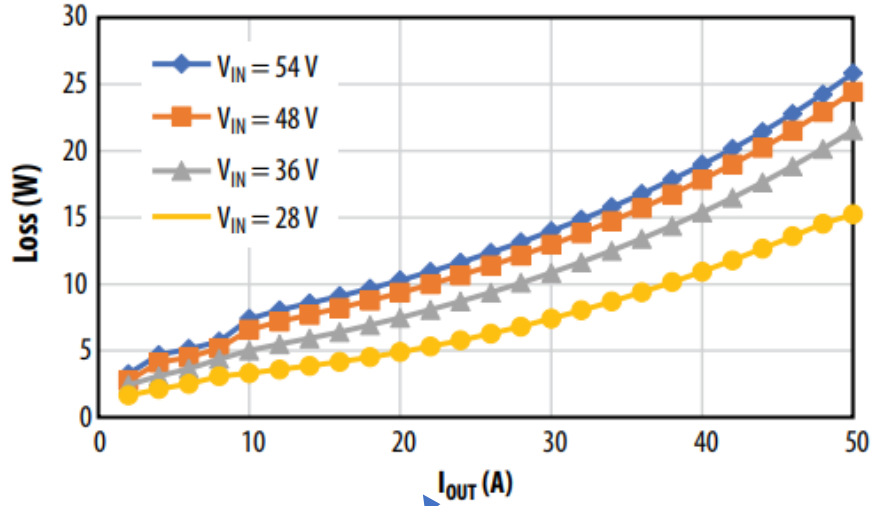


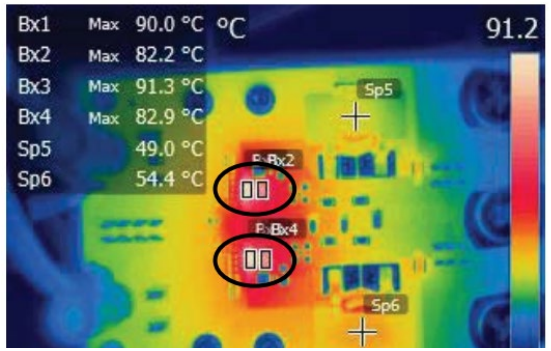
EPC9158 Demo board with LTC789x



Efficiency and Power Losses, 12 Vout

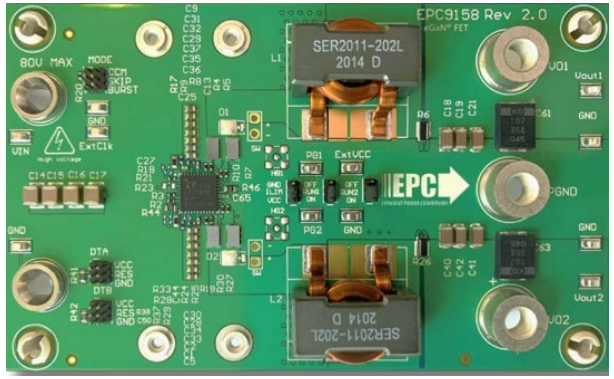






V_{IN} = 48 V, V_{OUT} = 12 V, I_{OUT} = 50 A, 400 LFM air flow

Note:
2 phases

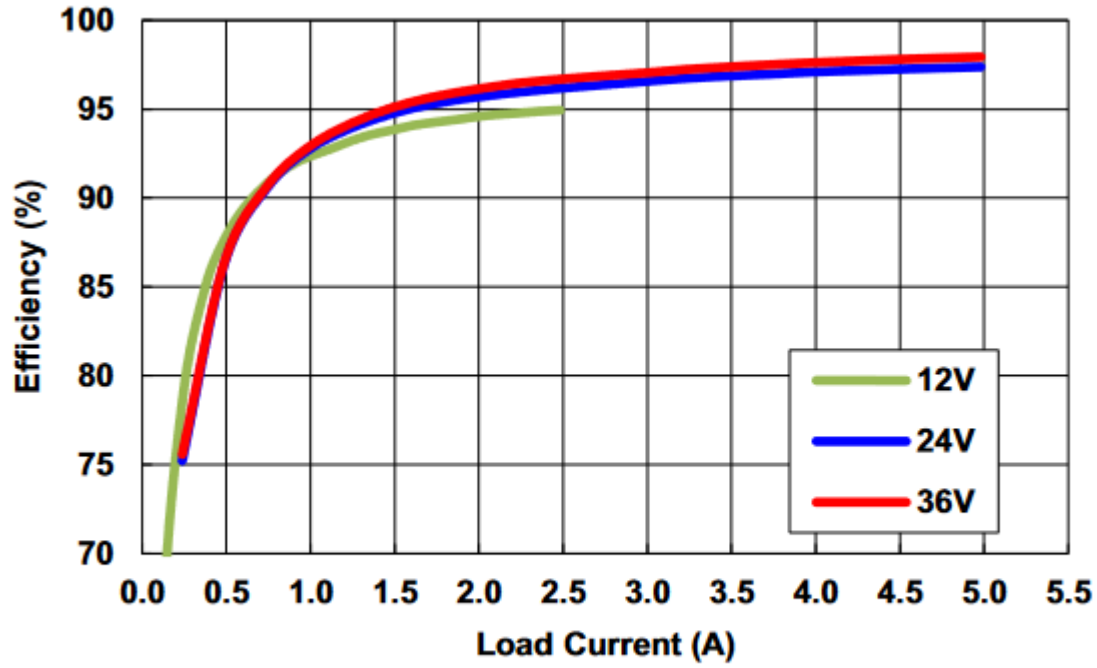


Note:
2 phases

Example #2: Boost

- Renesas ISL81807 boost
  - Made-for-GaN
  - 2-phase boost controller
  - 5-80 V output & input
  - 0.1 to 2 MHz

  - EPC reference design
    - Board EPC9166



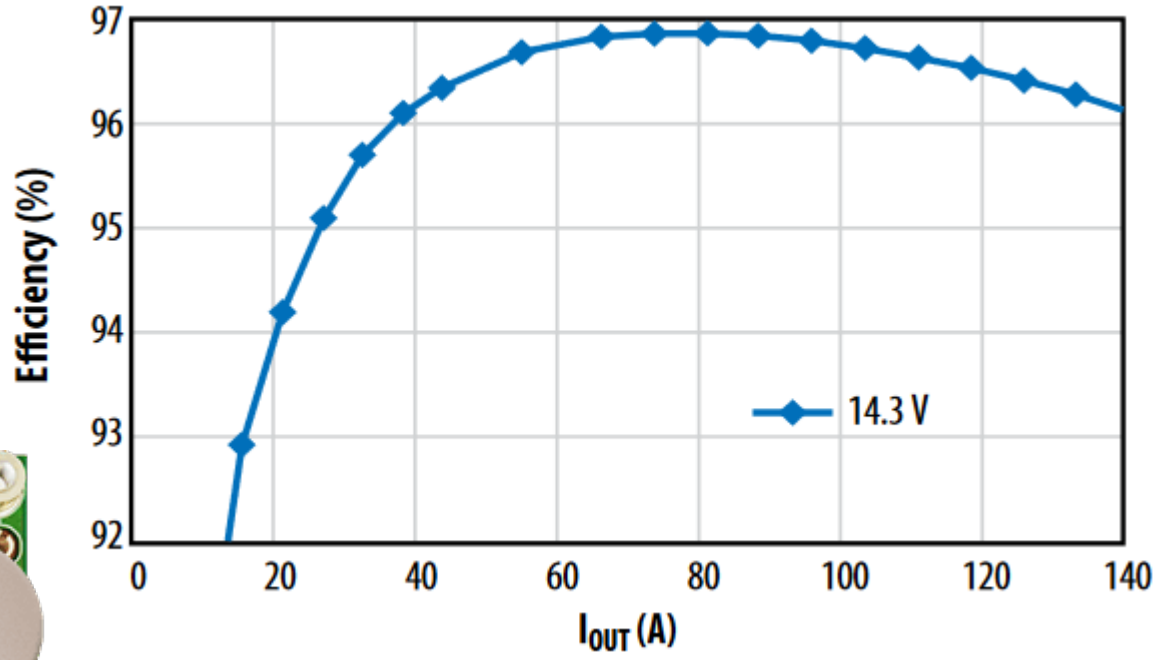
2. Efficiency (V_{OUT} = 48V, L = 4.7µH, f_{SW} = 500kHz, PWM Mode)

from ISL81807 data sheet

Example #3: high-power, buck or boost

- High Power Evaluation Boards
  - 1 kW per phase
    - 48 to/from 12 V
  - Digital control
  - 2-phases per board
  - 500 kHz

  - EPC reference design
    - Board EPC9165
    - Graph: buck mode



Select the Right Device

- Optimize performance & cost
- New GaN Devices: often best performance *and* cost
- Tools:
  - Buck Converter GaN FET Selector Tool
    - Boost version coming soon
  - Cross Reference: enter a MOSFET, get a GaN FET upgrade suggestion. With thermal, cost, etc. info.
  - Thermal Calculator: Graphical representation/choices of construction, and other details, result is junction temp

Controllers
& Gate Drivers

Controllers for GaN

- Many controllers available now designed for GaN FETs
- Analog Controllers:
  - Buck: single and dual
  - Boost: single and dual
  - Buck/boost, including for USB-PD
  - Synchronous Rectifier
- Digital Controllers
  - Using external gate driver (or GaN IC)

GaN Compatible Controllers

Single Buck Controller

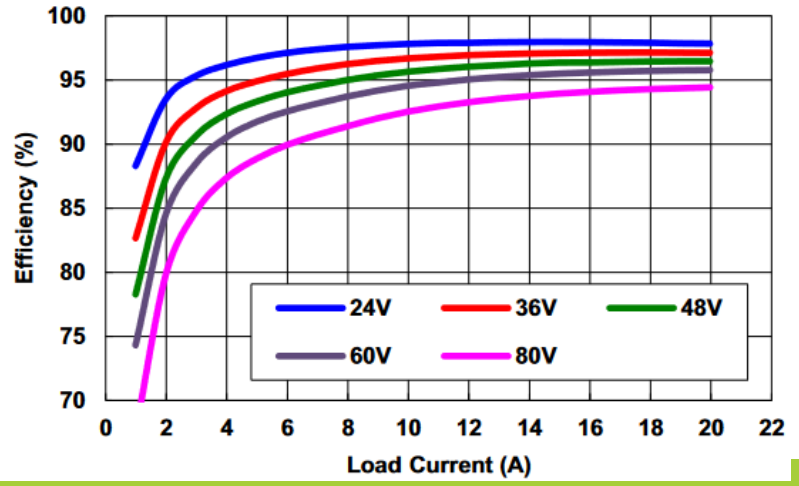
- LTC7891 input 5-100 V, 0.1-3 MHz
  - Example design at 2 MHz

Dual (or 2-phase) Boost Controller

- ISL81807 output up to 80 V, 0.1-2 MHz
  - Example Design: EPC9166

Dual (or 2-phase) Buck Controller

- ISL81806 input 5-80 V, 0.1-2 MHz
  - Example Design: EPC9157



Synchronous Rectifier Controller

- Several available, see list

Additional GaN Controllers in development

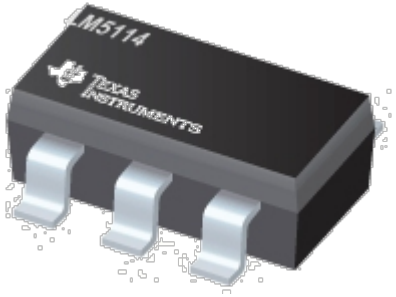
GaN Compatible Gate Drivers

rev. 3/2024

EPC
EFFICIENT POWER CONVERSION

Single Drivers

- LMG1020 & -25[a] : ultra fast
- UCC27611 – with LDO
- LM5114
- 1EDB7275F* – isolated



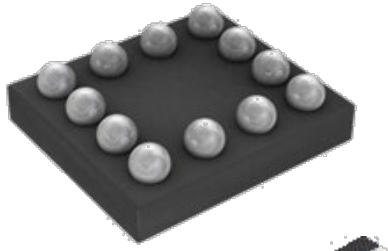
Half Bridge Drivers

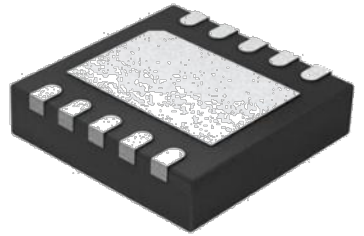
- uP1966E‡ (80 V)
- LMG1205‡ (90 V)
- MP8699B ‡ (100 V)
- LT8418 ‡ (100 V)

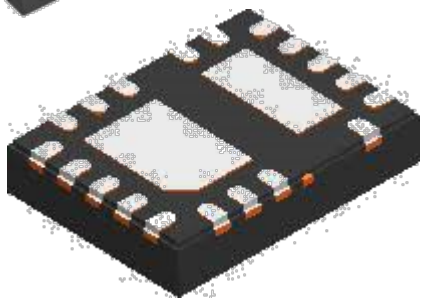
- LM5113-Q1[a] (100 V)
- MPQ1918[a] (100 V)

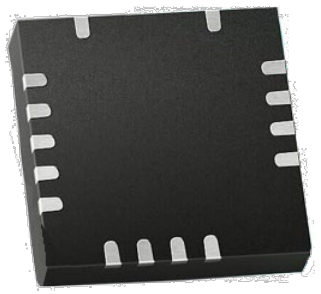
- LMG1210 (200 V)
- 1EDN71x6U (200 V)
- NCP51820 & -10 (650, 150 V)
- STDRIVEG600 (600 V)

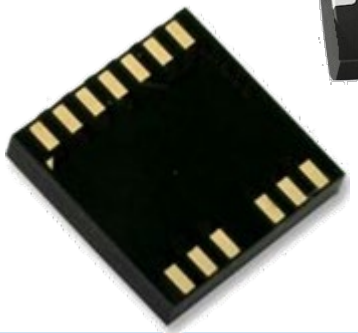
- Si827xGB1-IM*[a] (650 V)
- ADuM4221A* (>600 V)
- 2EDB7259Y* (>600 V)











*isolated ‡ Footprint compatible
[a] automotive

Gate Drivers – Interesting Features

- ***PWM input*** (single-line input, built-in dead time)
  - LMG1210, NCP518x0, etc.
- ***Current Sense Resistor (series with Source) compatible***
  - NCP518x0, STDRIVEG600, etc.
- ***Built-in 5V LDOs***
  - LMG1210, NCP518x0, etc.
- ***High Speed***
  - Half-bridge: LMG1210: up to 50 MHz
  - Single: LMG1020: as fast as 400 ps Rise & Fall Times
- ***Other features***: isolation, split top/bottom drivers, short propagation time, etc.

Layout Tips

PCB Design

- Advantages of Good Layout
  - Efficiency
  - Thermal
  - Ringing and EMI
- Optimal design
  - Variations
- Thermal

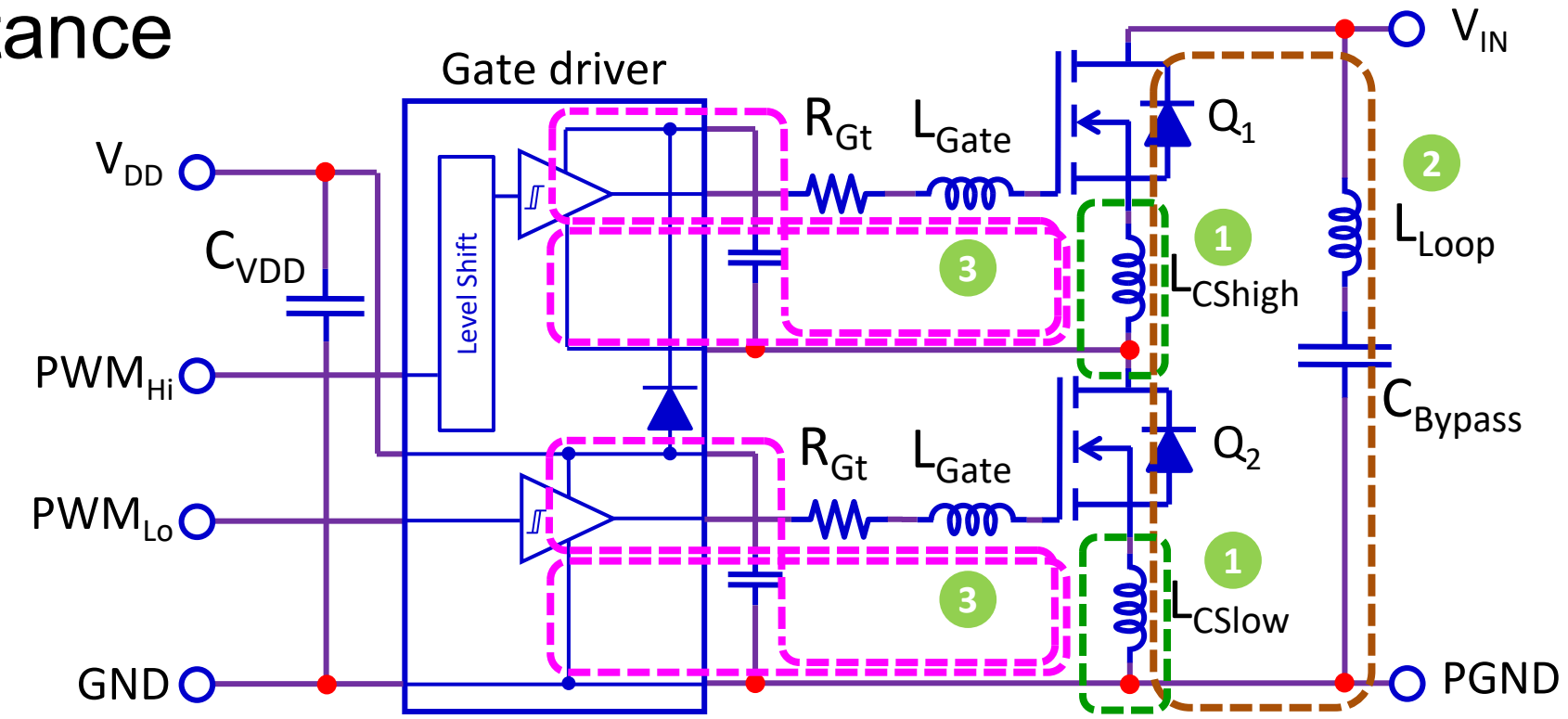
Parasitic inductances

1. Common source inductance
2. Power loop inductance
3. Gate loop inductance
   - Turn-on
   - Turn-off

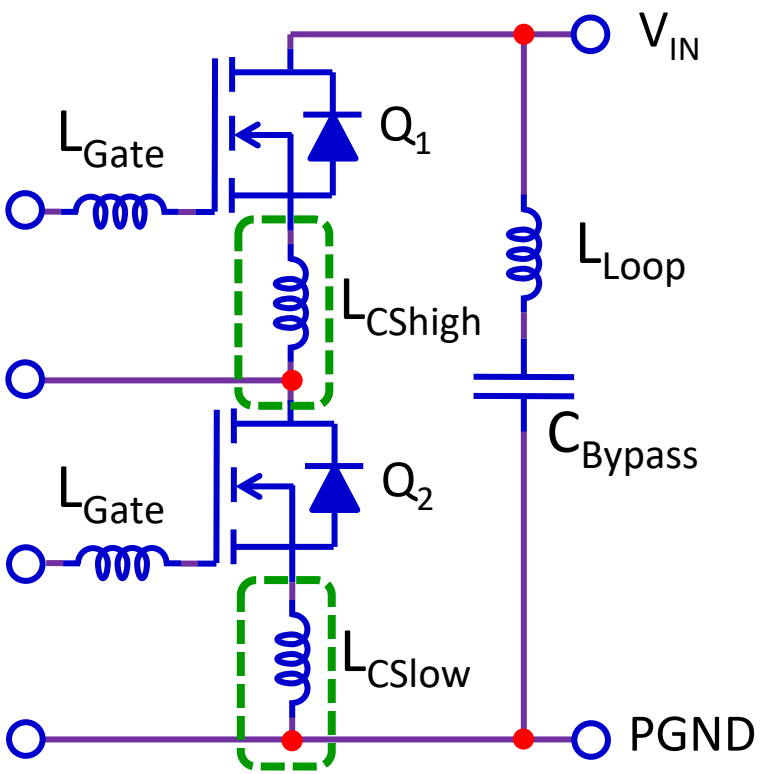
[WP010: Optimizing PCB Layout](#)

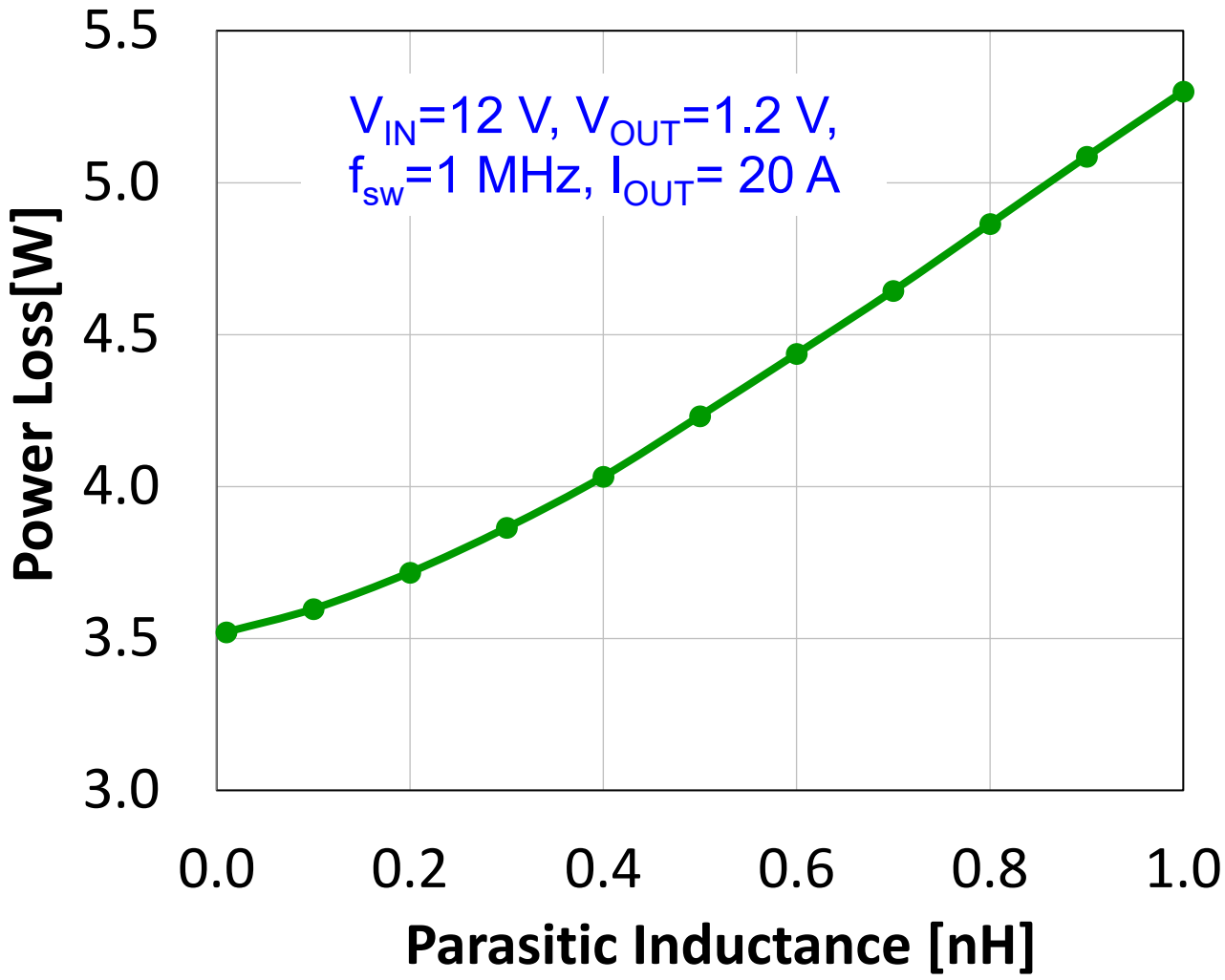
[How to GaN 05](#)

[How to GaN 05a](#)

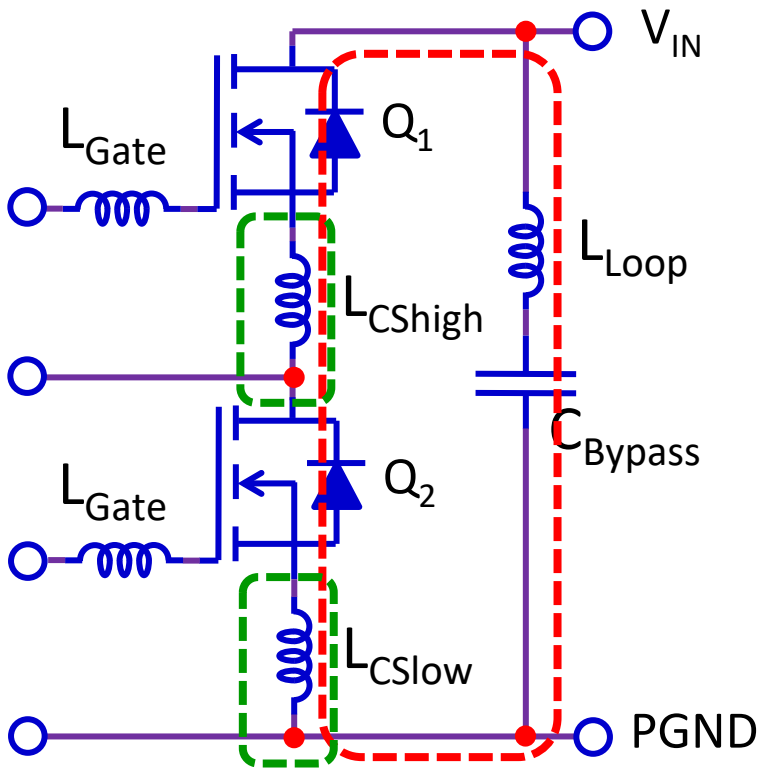


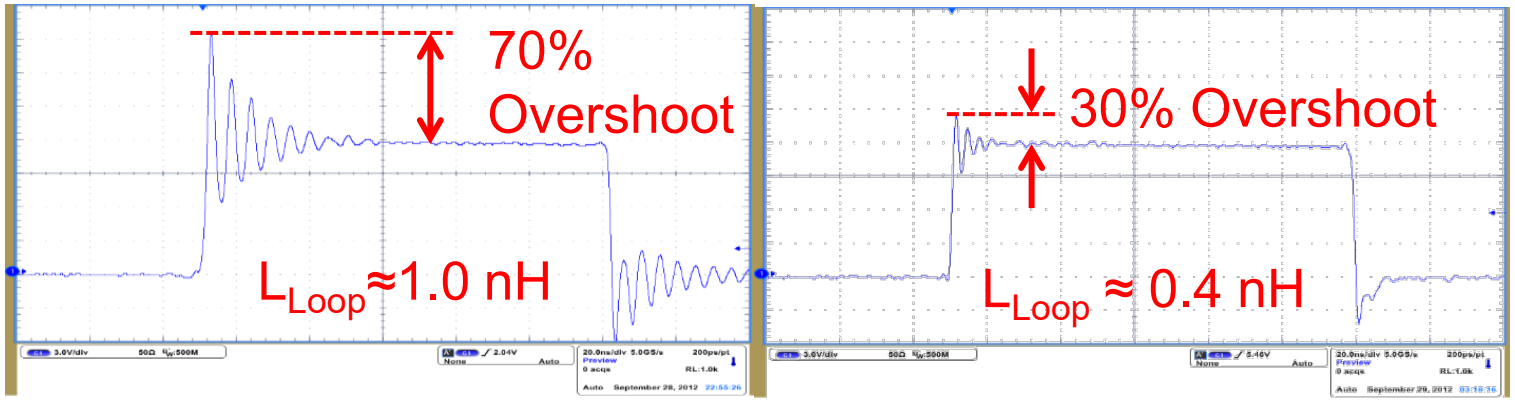
Impact of Common Source Inductance

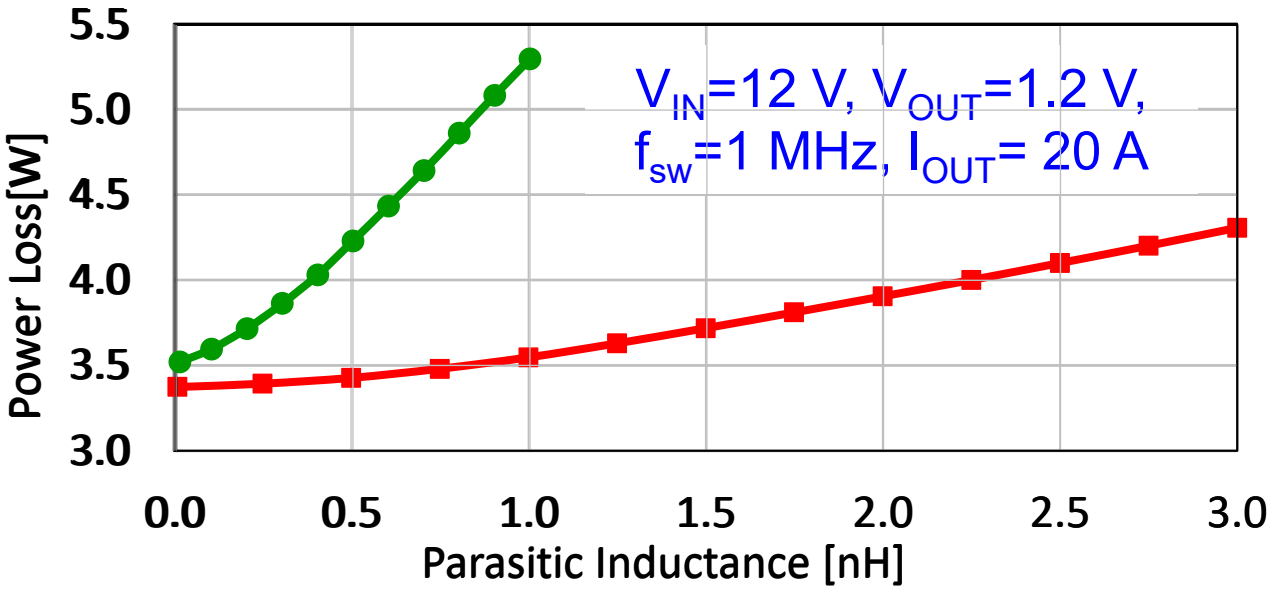




Impact of Power Loop Inductance

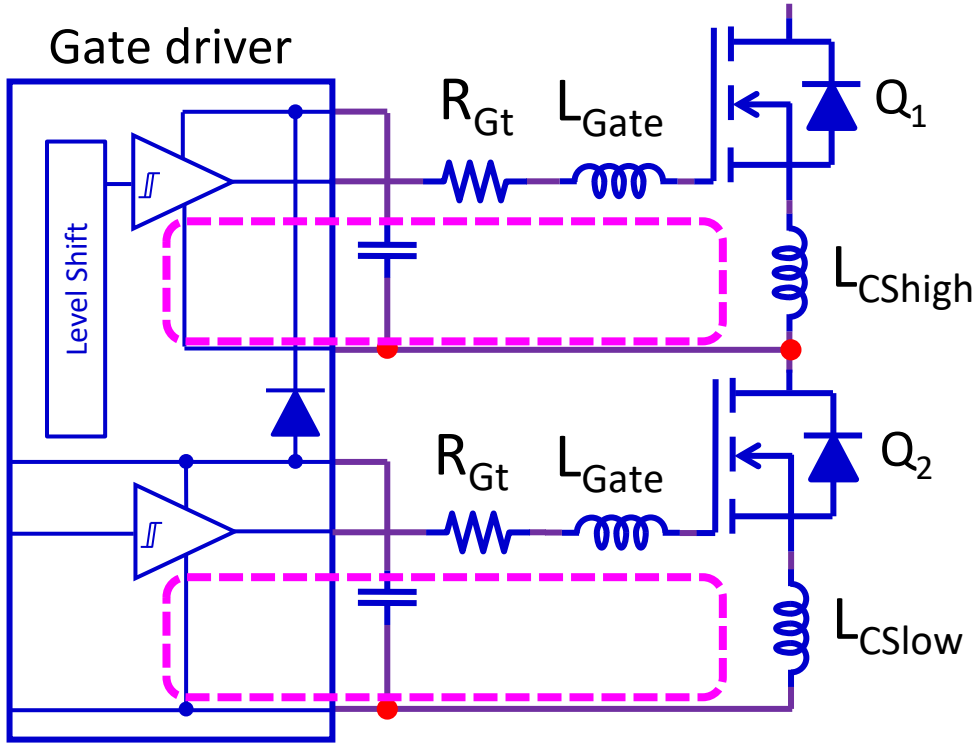




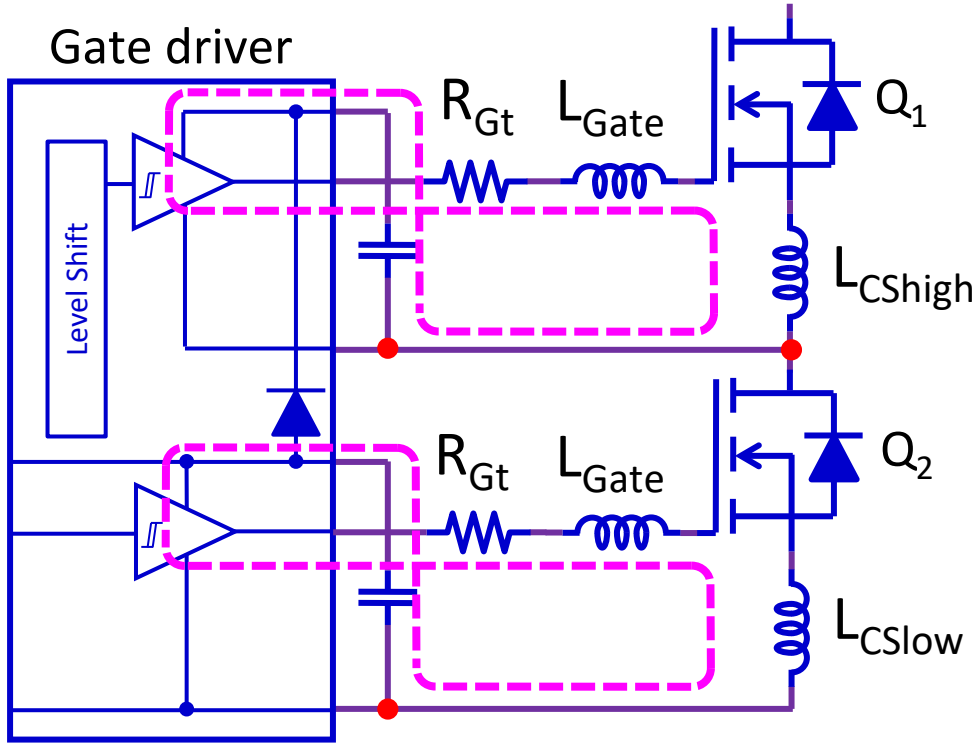


Impact of Gate Loop Inductance

- Two loops to consider: Turn-on & Turn-off
- L_{Gate} requires R_{Gt} to damp ringing overshoot
  - slows transition

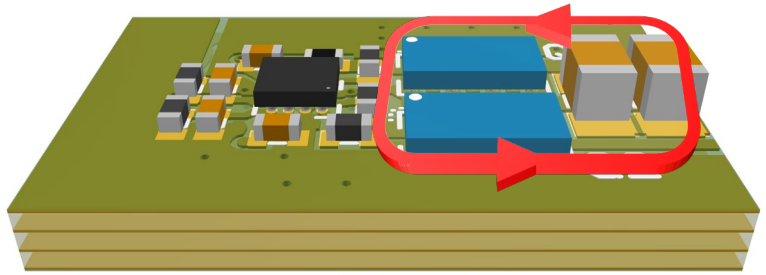


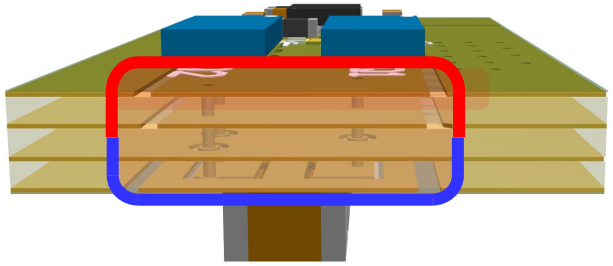
Turn Off

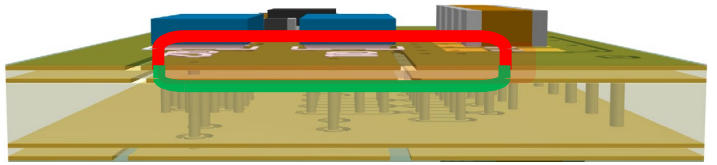


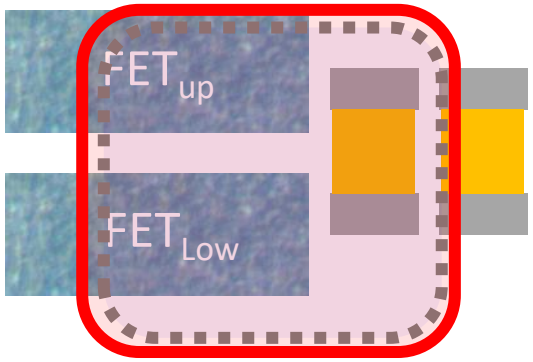
Turn On

Layout Comparisons

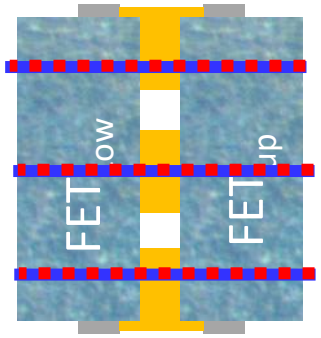






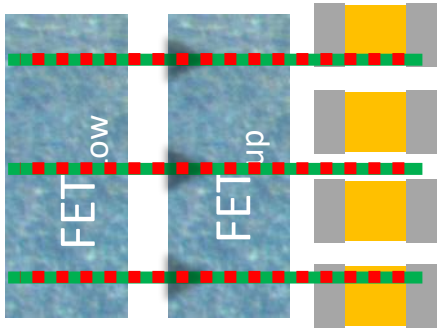


Top Layer
Mirror (Inner Layer 1)



Top Layer

Bottom Layer



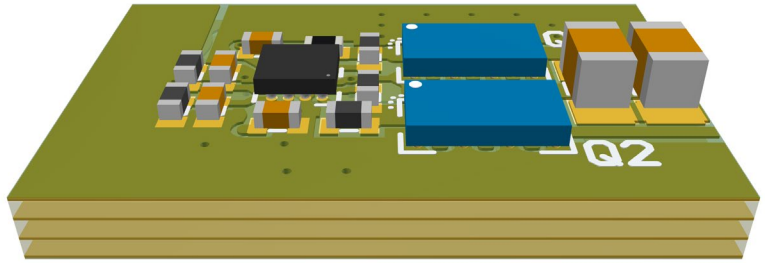
Top Layer
Inner Layer 1

Lateral

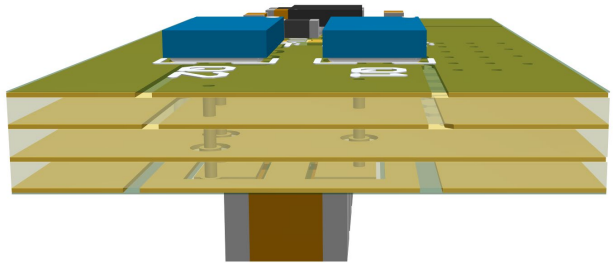
External Vertical

Internal Vertical

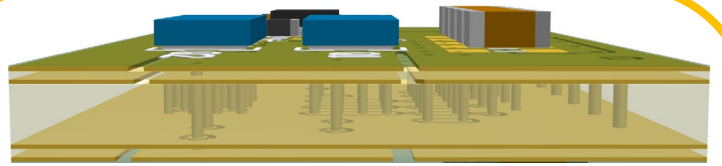
Layout Inductance Comparison



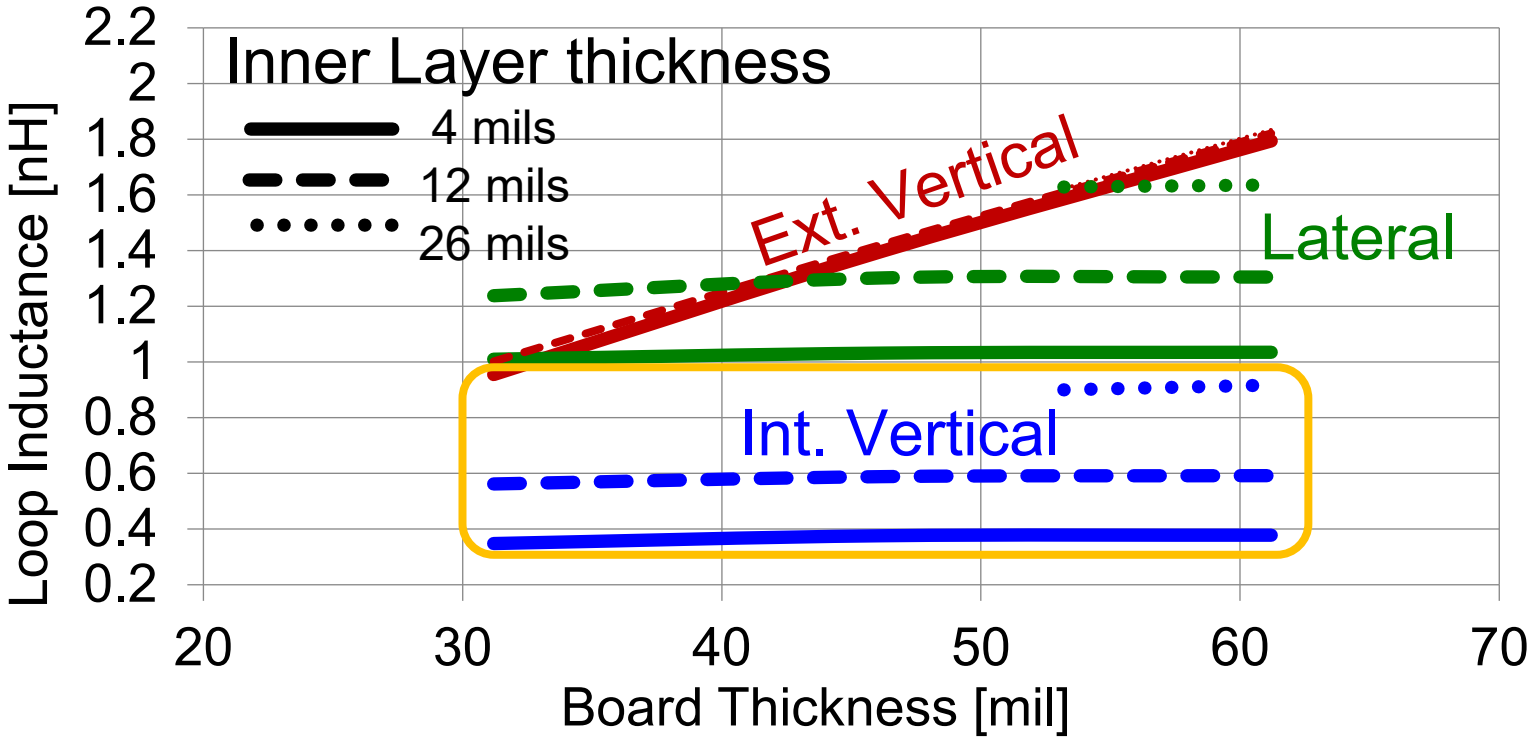
Lateral

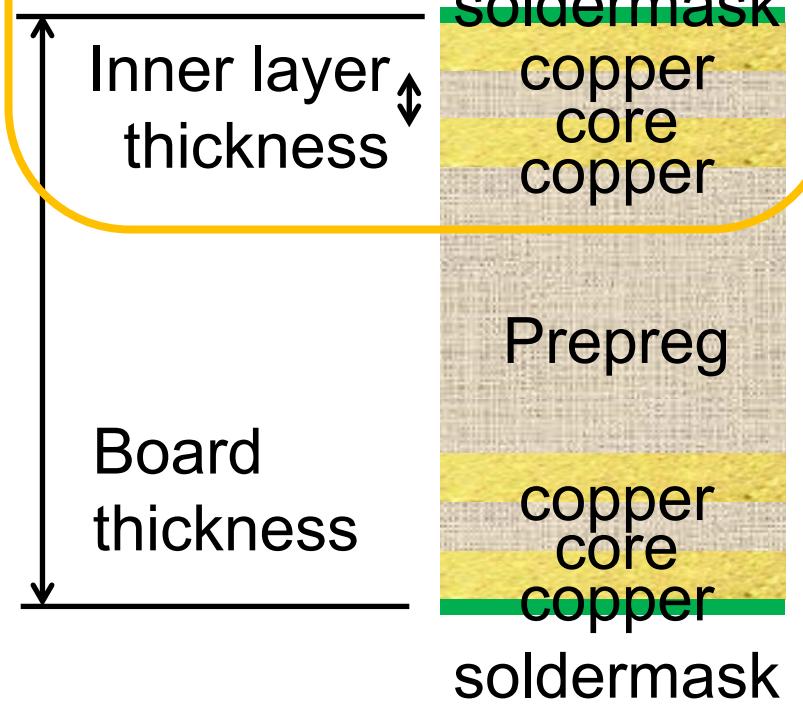


Ext. Vertical



Int. Vertical
Best Choice

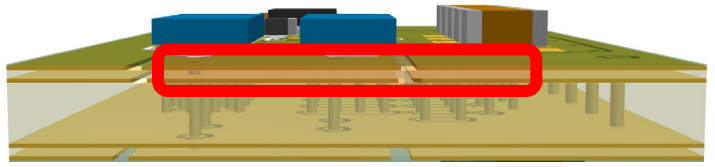




Designing a Low Inductance Layout

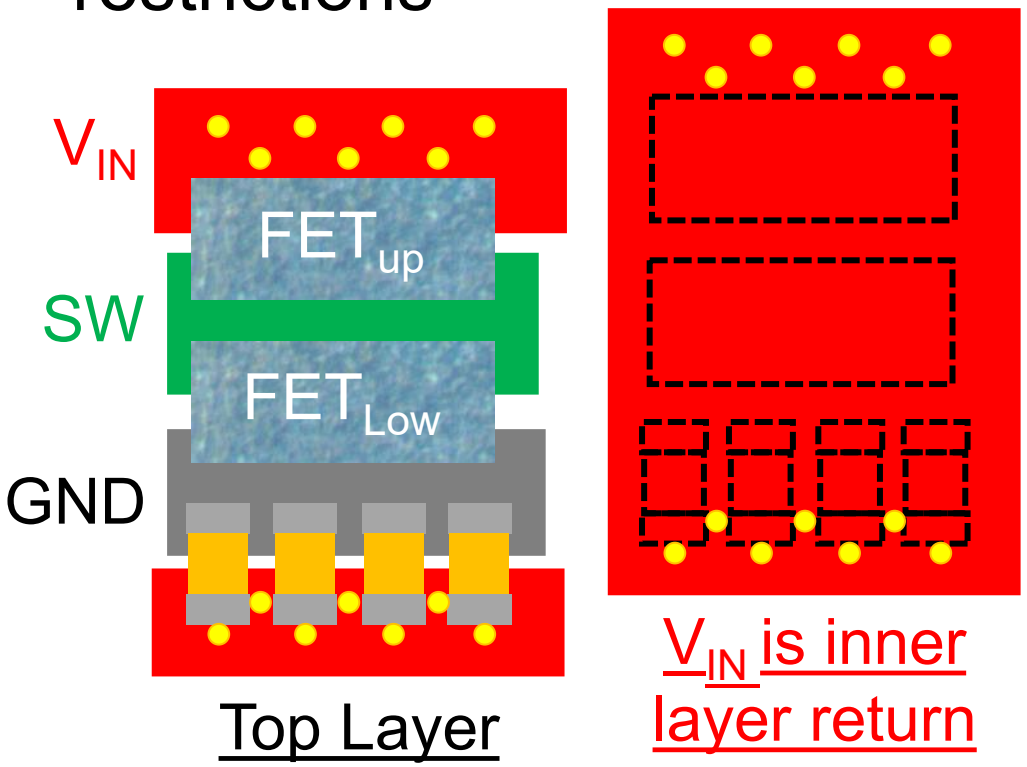
Internal vertical (optimal) power loop:

1. Pace components as close as possible
2. Place (many) vias as close to the innermost electrical connection
3. Thinnest permissible substrate thickness between outer and first inner layer
4. Spread out via connections at innermost connect
5. GND return does **not** need to carry the full current



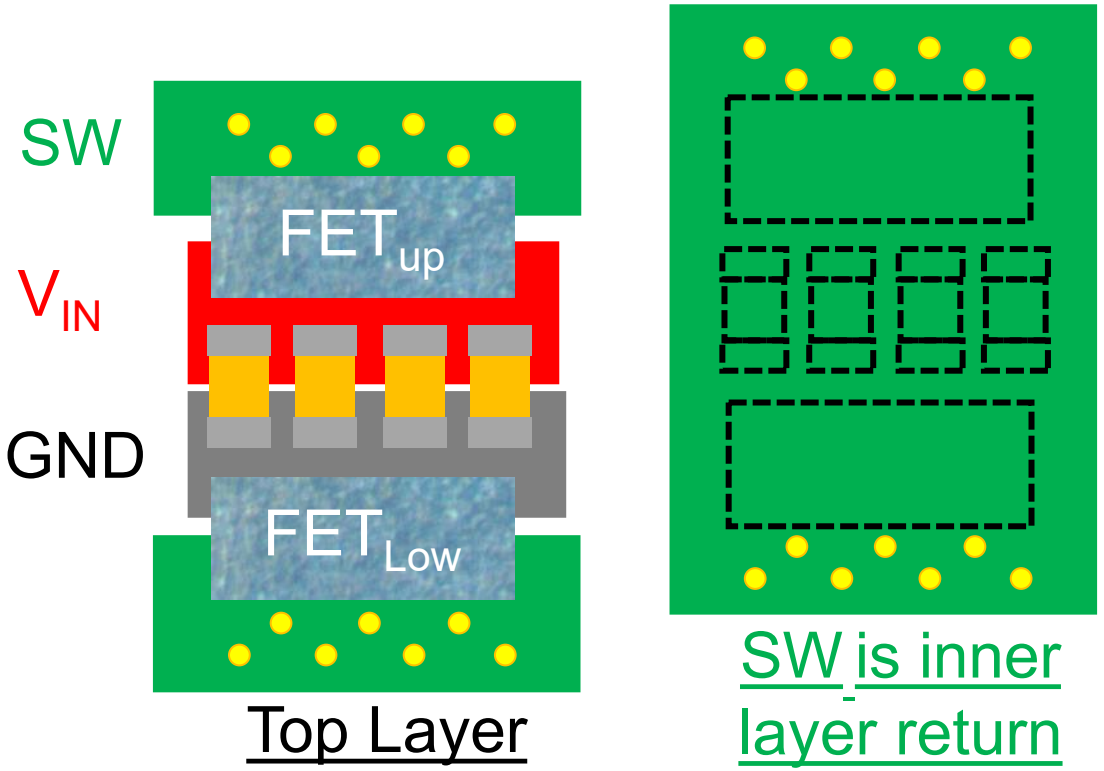
Alternative Layout Configurations

- Improves cooling for upper FET
- Useful for specific layout restrictions



Bus capacitors beside lower FET

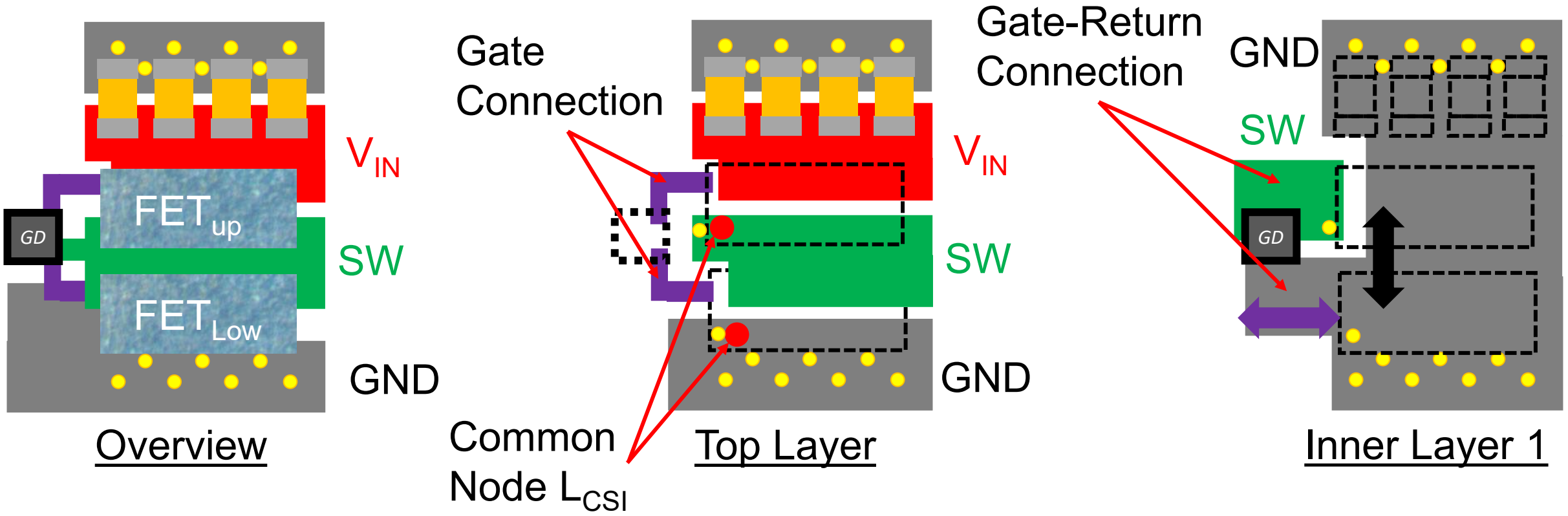
- Buries SW-node inside the board
  - Reduces E-field EMI



Bus capacitors between the FETs

What About the Gate Connection

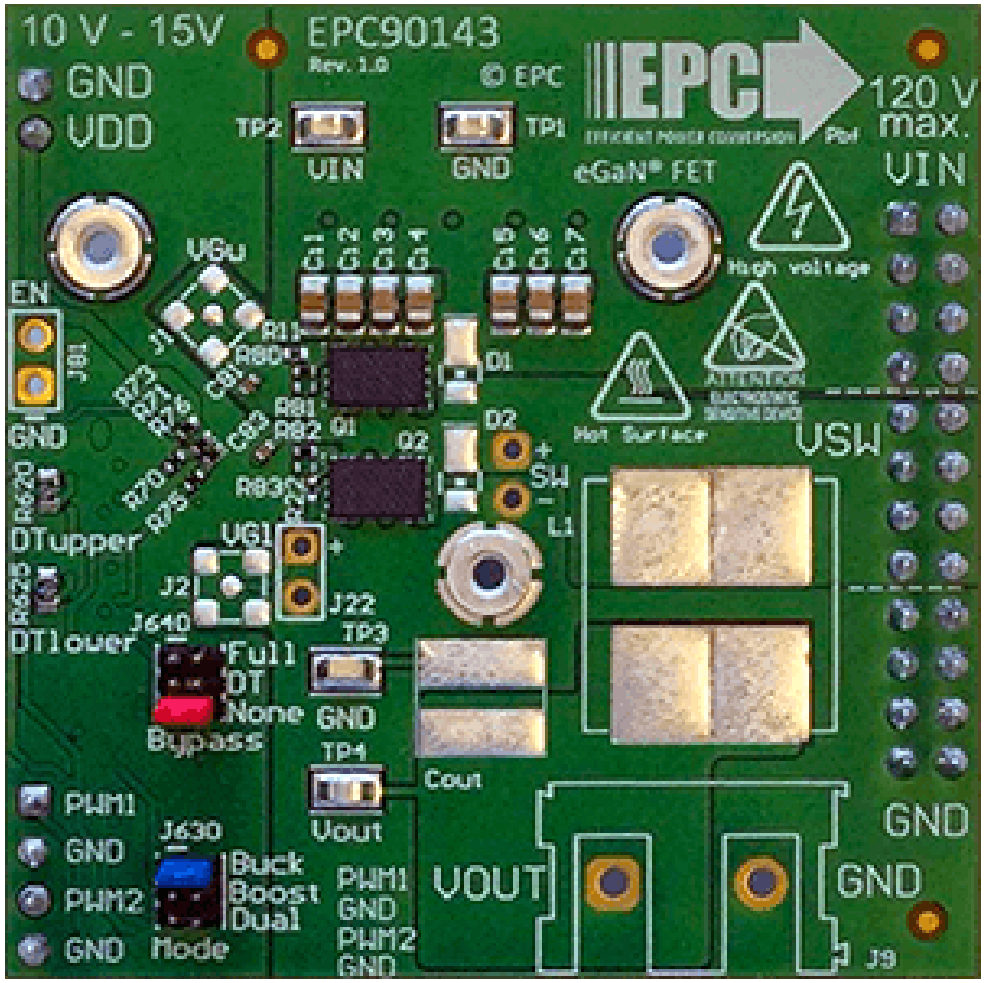
- Gate drive track with return polygon (its source!) on next layer
- Orthogonal gate to power connection reduces coupling between them



Simplifying GaN Layout

Example Layouts

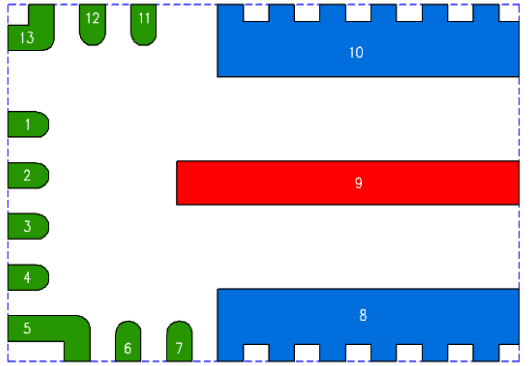
- EPC's half-bridge evaluation boards
  - Available for almost every FET
  - Gerbers, PCB design files available

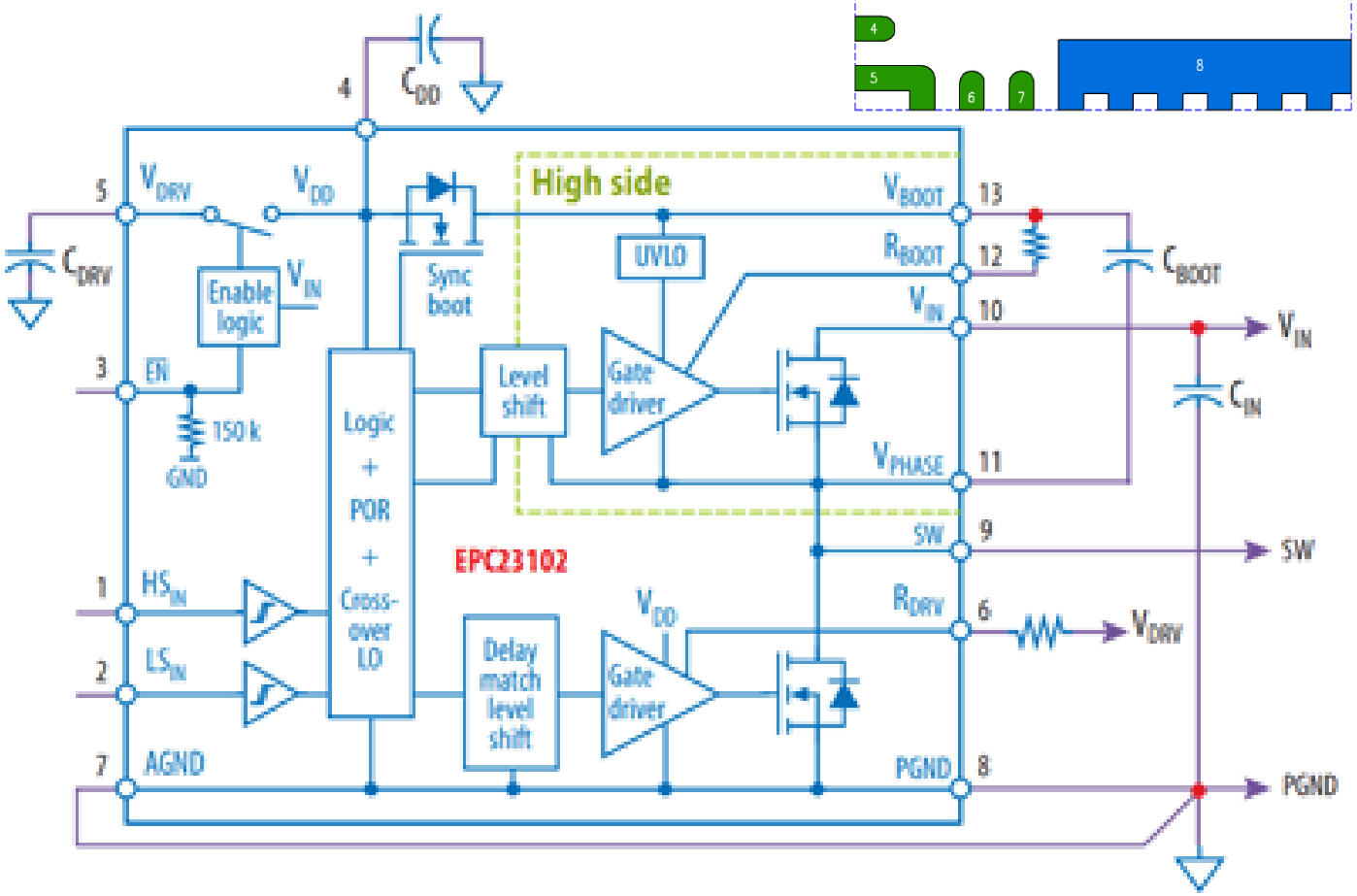


- *shown: half-bridge board for the packaged, 150 V FET EPC2305*

Simple Layout – ePower™ Stage IC

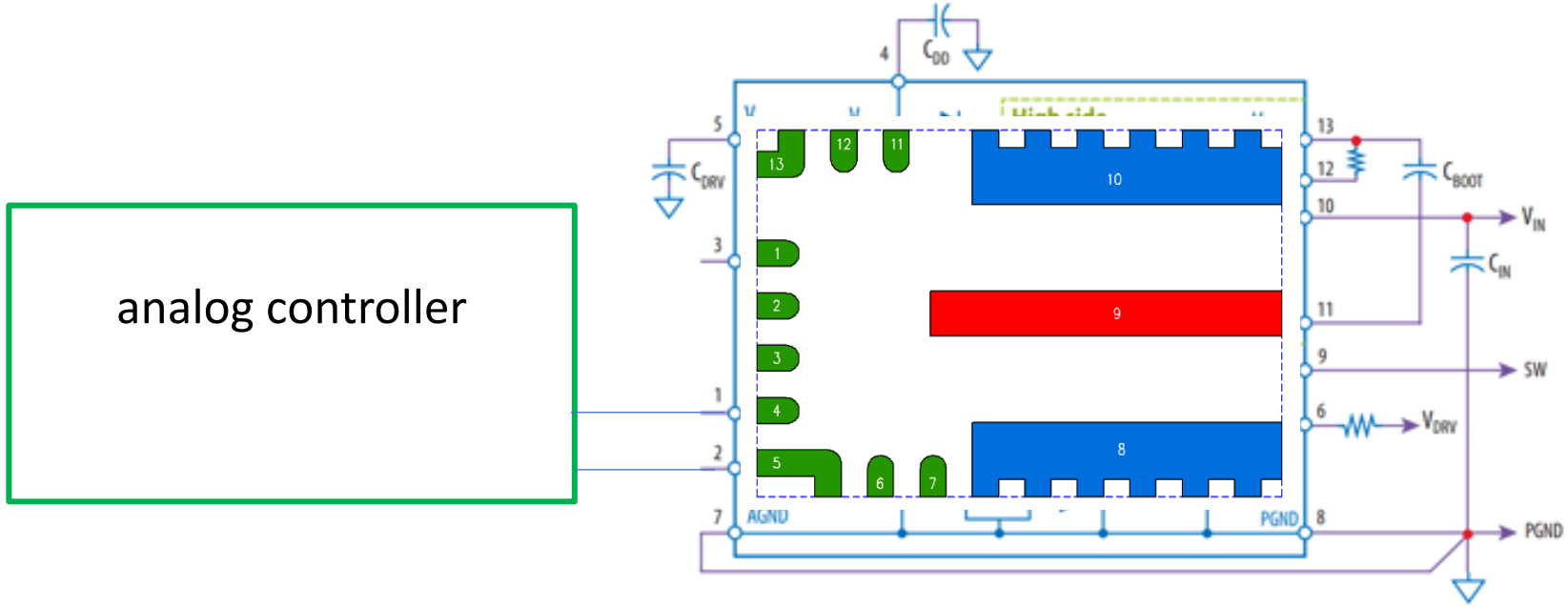
- Would you rather have the layout be internal to an IC?
- EPC2310x series
  - 100 V, 15A to 65A
  - Internal GaN gate driver
- Layout Tips
  - C_{IN} placement
  - Ground on first inner layer
- Example designs:
  - Buck: EPC9177
  - Half Bridge: EPC90147





ePower™ Stage IC + analog controller?

- What about an analog controller + Powerstage?
- Some have used a GaN controller + EPC2310x series
  - Example: LTC7891
- Benefits:
  - Fast, efficient, small DC-DC
  - Small # of parts
  - Simpler layout



What to Look Out For

For an engineer coming from a Silicon MOSFET design legacy, what things should we be on the lookout for when starting to design with GaN?

1. Layout
2. Thermal Design
3. Manufacturing chipscale parts in high volume

- EPC Has expertise to help with these issues

EPC team is here to help!

- **EPC technical expert contact**
  - https://epc-co.com/epc/contact/ask-a-gan-expert
- **EPC technical forum**
  - https://forum.epc-co.com/
- **Cross reference**
  - https://epc-co.com/epc/design-support/part-cross-reference-search

Summer of GaN Webinars

August 21, 2024, 10:00 AM PDT

GaN First Time Right: Web-based Design Tools to Accelerate Your Time-to-Market

Register at: https://epc-co.com/epc/about-epc/events-and-news/events/webinars/how-to-gan-webinar-series

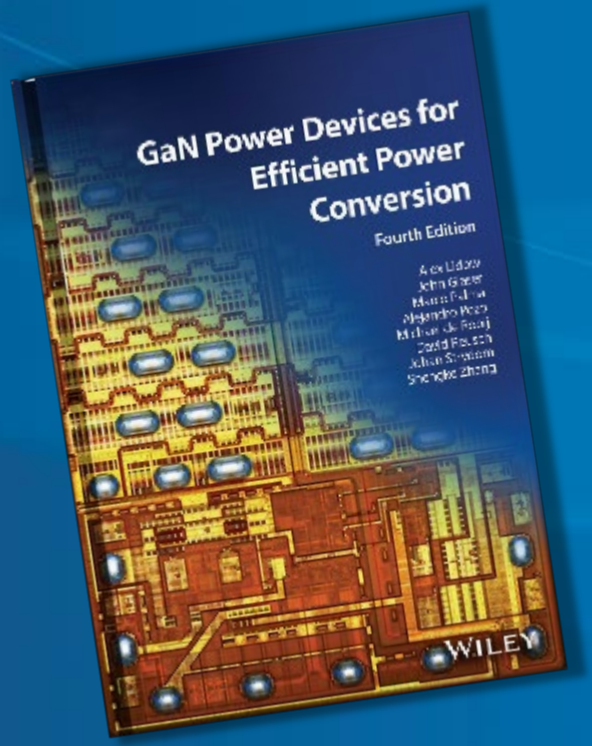
Previous Installments Available On Demand:

- **Unlocking Efficiency and Precision: Leveraging GaN FETs and ICs in 48 V Motor Drives**
- **Achieving Benchmark Power Density of 5130 W/in^3 with GaN FETs and Digital Control**
- **Next Generation Audio Amplifiers with EPC GaN FETs: Compact and High Fidelity**
- **GaN First Time Right: Controllers, Gate Drivers, and PCB Layout Tips for DC-DC Converters and Motor Drives**

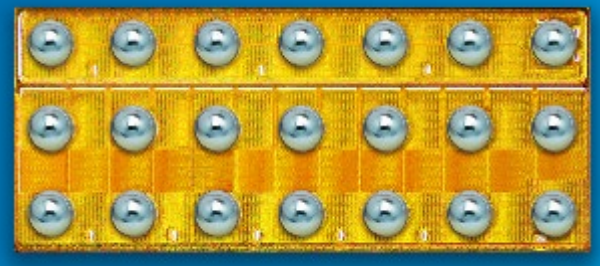
EFFICIENT POWER CONVERSION

Click on images to learn more

How To GaN Video Series

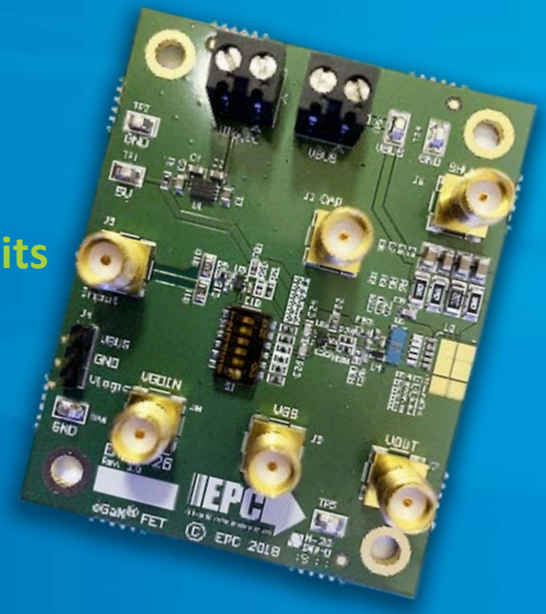


4th Edition Textbook



eGaN® FETs and ICs

Evaluation Kits



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