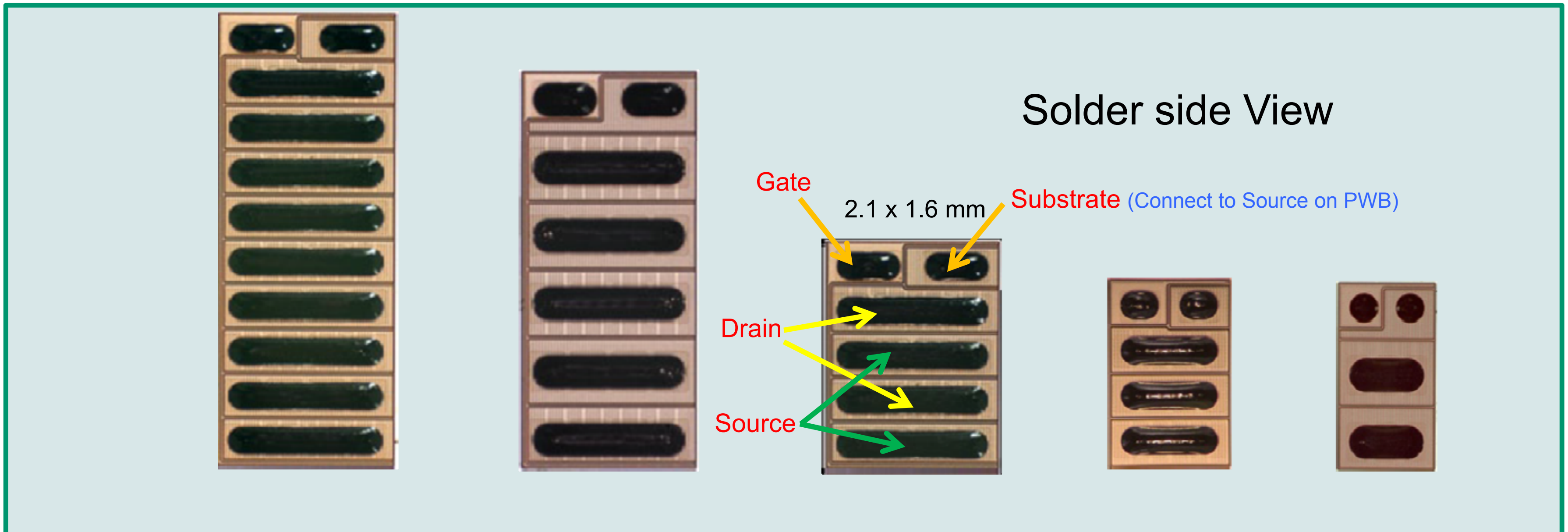

The eGaN® FET
Journey Continues
Enhancement Mode GaN FETs
Efficient Power Conversion Corporation

Agenda

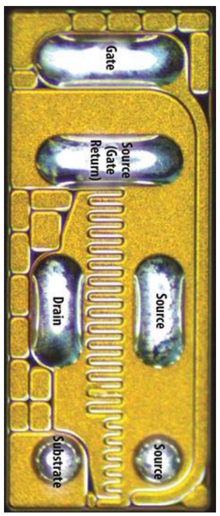
- Technology
- Packaging and Layout
- Driving and Deadtime
- Recent Applications Work
- Status

eGaN® FET Product Family



Part Number	Package (mm)	Vds (Volts)	Vgs (Volts)	Rdson @5V (mohm)	Qg @5V Typ. (nC)	Qgs Typ. (nC)	Qgd Typ. (nC)	Rg Typ. (Ohms)	Vth Typ. (Volts)	Qrr (nC)	Id (Amps)	TJ(MAX) (deg C)
EPC2015	LGA 4.1x1.6	40	6	4	10.5	3	2.2	0.6	1.4	0	33	150
EPC2014	LGA 1.7x1.1	40	6	16	2.5	0.67	0.48	0.6	1.4	0	10	150
EPC2001	LGA 4.1x1.6	100	6	7	8	2.3	2.2	0.6	1.4	0	25	125
EPC2016 *	LGA 2.1x1.6	100	6	16	4.1	0.93	0.75	0.6	1.4	0	11	125
EPC2007	LGA 1.7x1.1	100	6	30	2.1	0.5	0.6	0.6	1.4	0	6	125
EPC2010	LGA 3.6x1.6	200	6	25	5	1.3	1.7	0.6	1.4	0	12	125
EPC2012	LGA 1.7x0.9	200	6	100	1.5	0.33	0.57	0.6	1.4	0	3	125

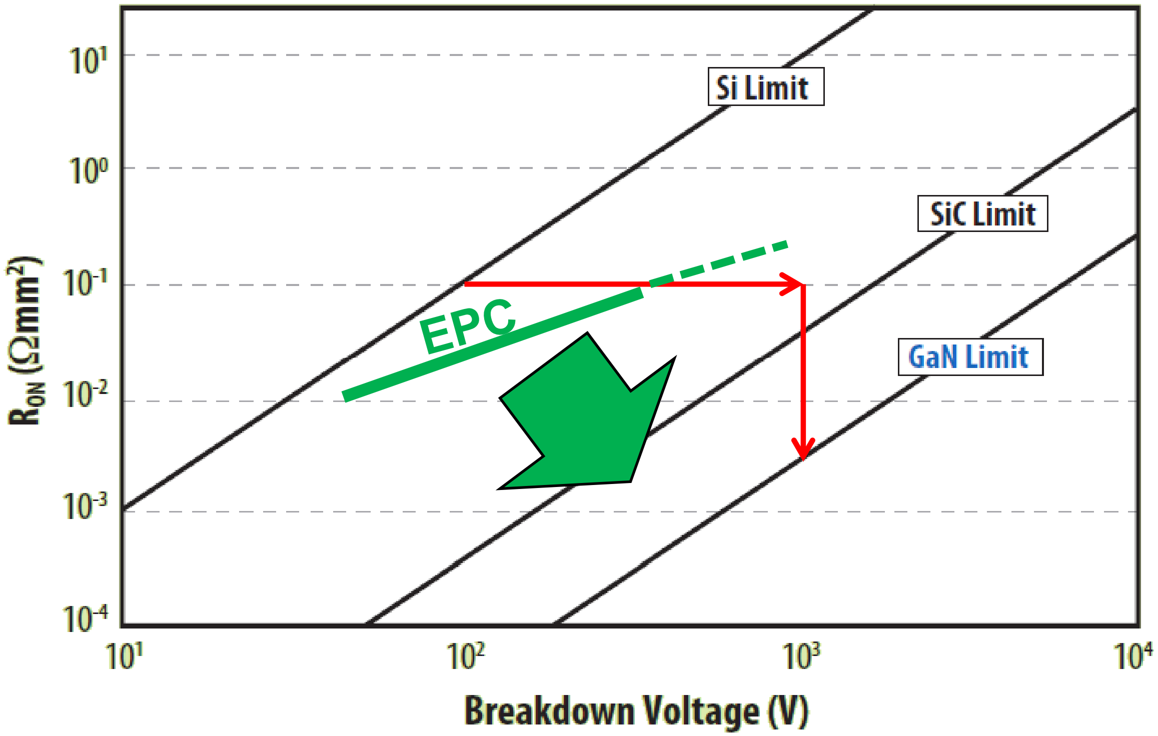
Ultra High Frequency eGaN FETs

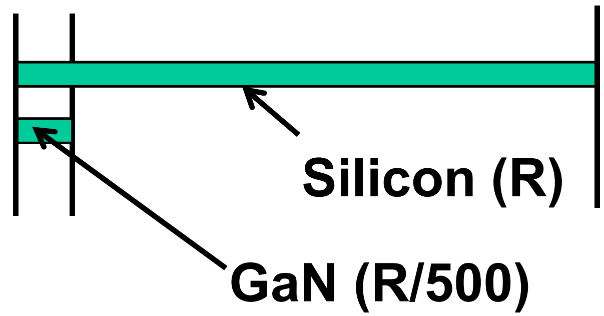


EPC Part No.	BV (V)	Max. $R_{DS(ON)}$ (mΩ) (V_{GS} = 5V, I_D = 0.5 A)	Min. Peak Id (A) (Pulsed, 25 °C, T_{pulse} = 300 µs)	Typical Charge (pC)					Typical Capacitance (pF) (V_{DS} = 20 V; V_{GS} = 0 V)		
				Q_G	Q_{GD}	Q_{GS}	Q_{OSS}	Q_{RR}	C_{ISS}	C_{OSS}	C_{RSS}
EPC8004	40	125	7.5	358	31	110	493	0	45	17	0.4
EPC8007	40	160	6	302	25	97	406	0	39	14	0.3
EPC8008	40	325	2.9	177	12	67	211	0	25	8	0.2
EPC8009	65	138	7.5	380	36	116	769	0	47	17	0.4
EPC8005	65	275	3.8	218	18	77	414	0	29	9.7	0.2
EPC8002	65	530	2	141	9.4	59	244	0	21	5.9	0.1
EPC8003	100	300	5	315	34	110	1100	0	38	18	0.2
EPC8010	100	160	7.5	354	32	109	1509	0	47	18	0.2

Technology

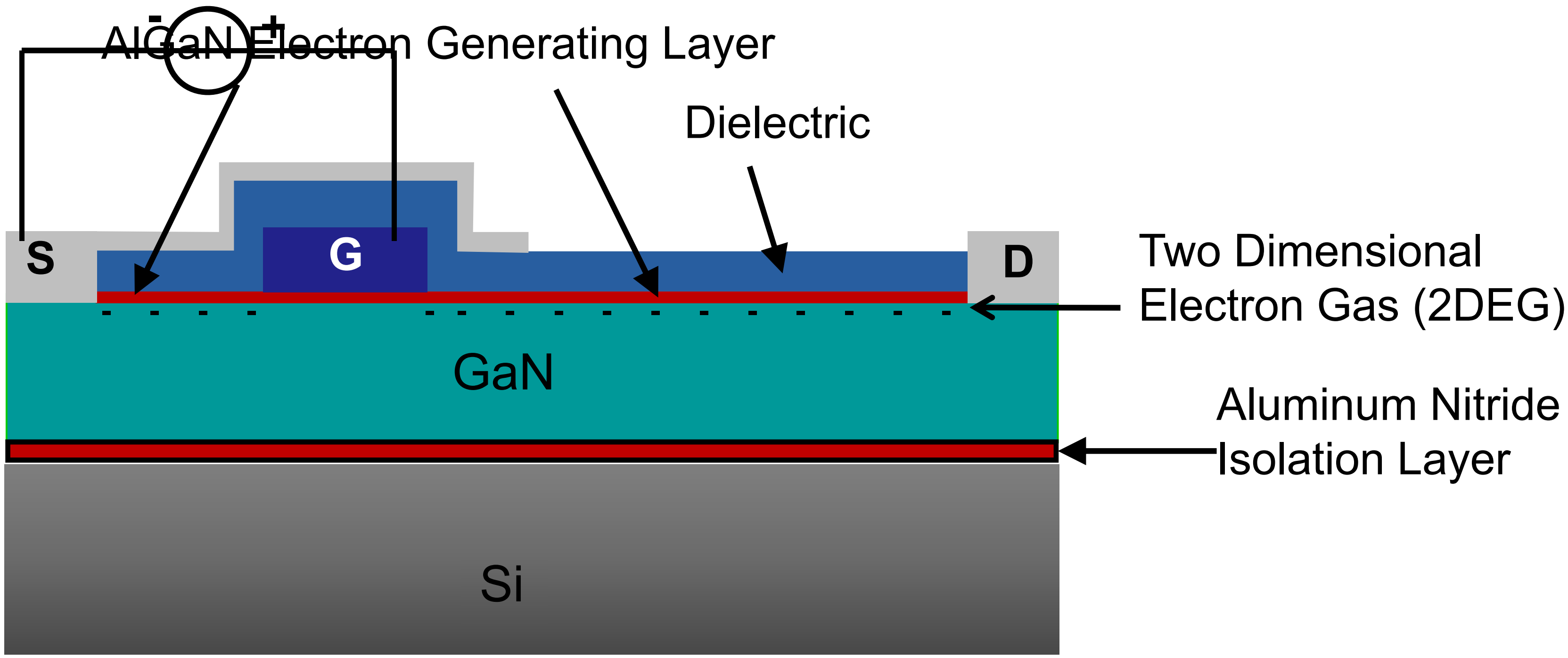
Fundamental Material Superiority





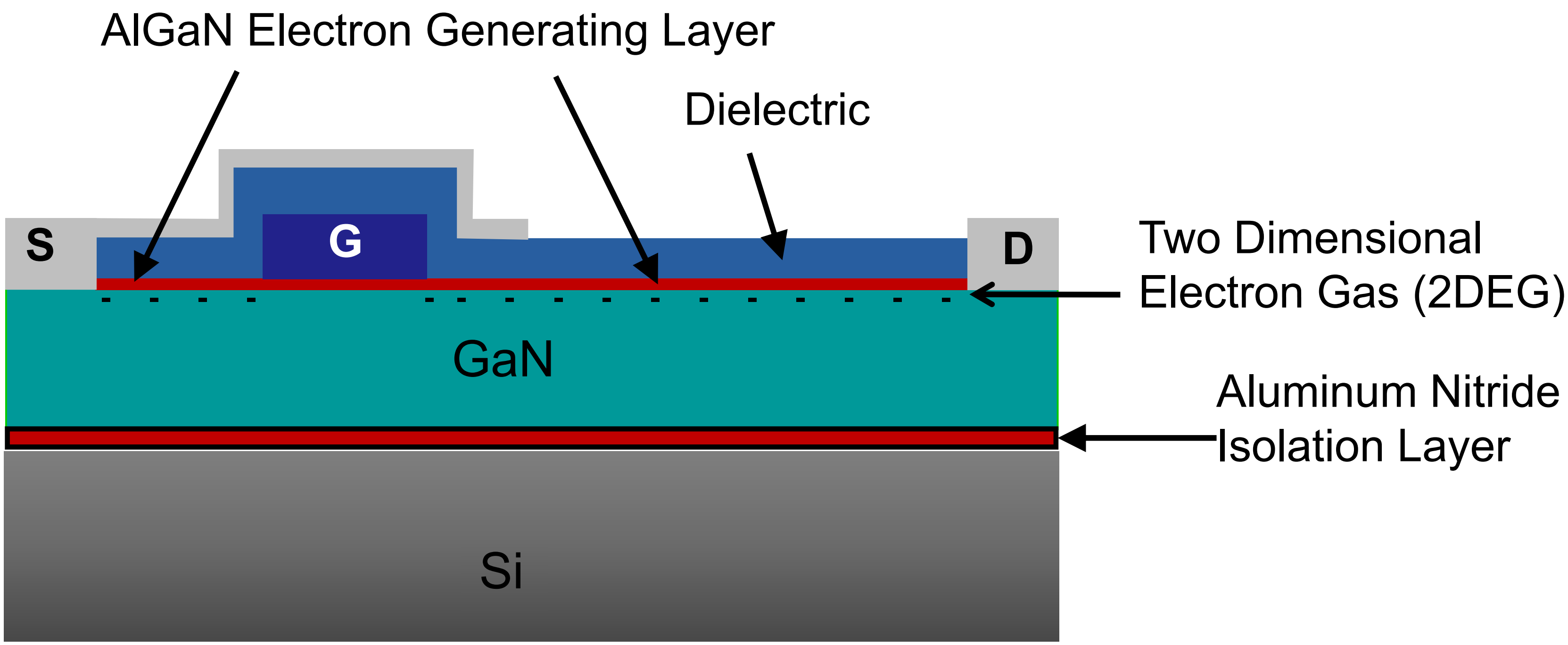
- GaN has a 10x advantage in critical electric field.
  - For a given breakdown voltage, GaN terminals can be one tenth the distance apart compared with Silicon
- GaN has a 50x advantage in resistivity
  - For a given geometry, GaN resistance will be one 50^{th} of that of Silicon
- GaN has a 500x theoretical material advantage over Silicon

eGaN FET Structure



- Works like a MOSFET
  - Positive Gate to Source Voltage turns on bidirectional channel
  - Gate shorted to Source blocks from Drain to Source

eGaN FET Structure



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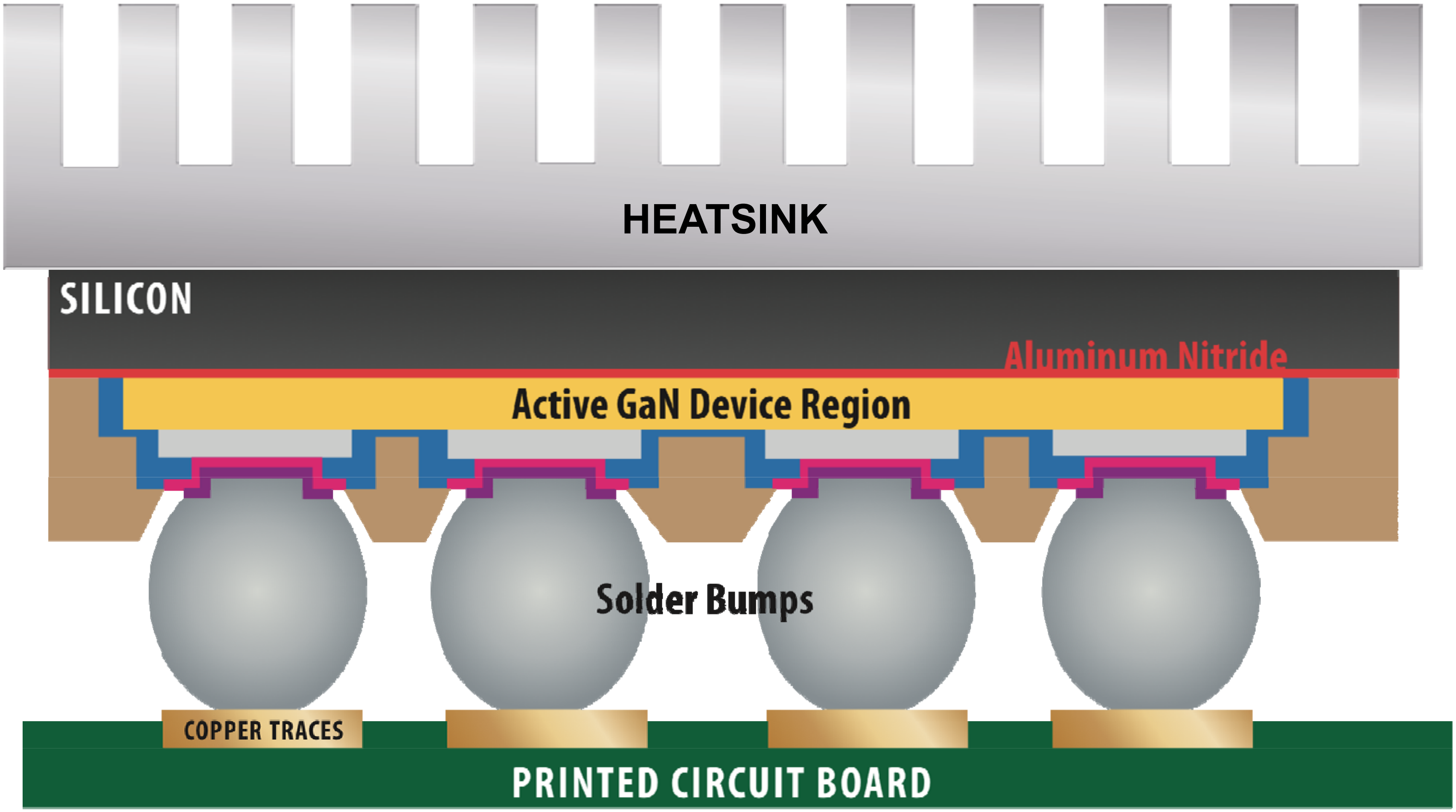
Flip Chip Assembly



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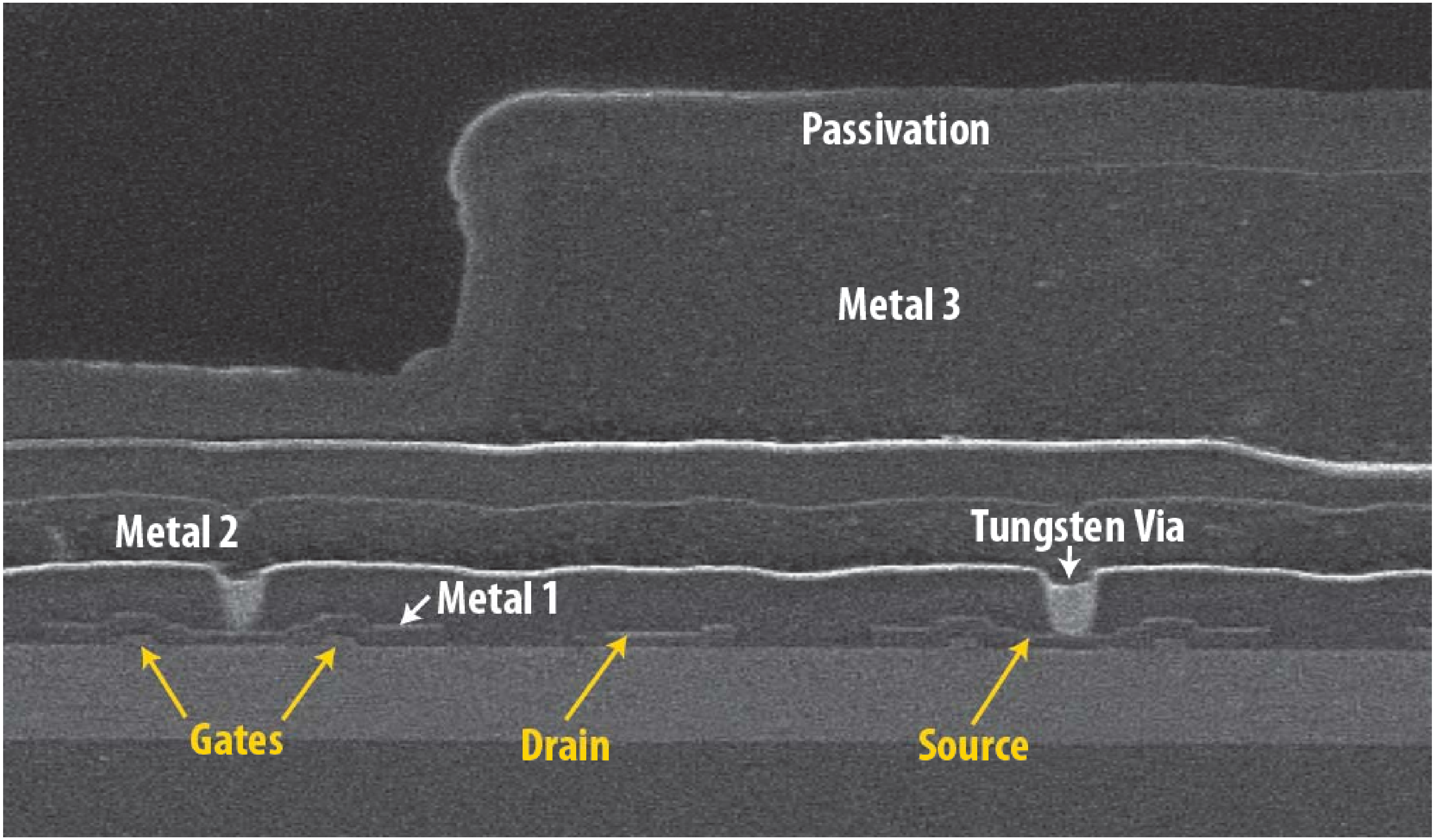
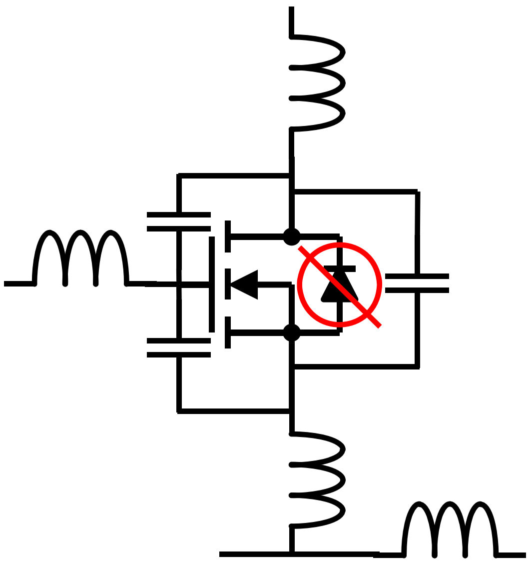
Cross Section of an eGaN FET



GaN is …

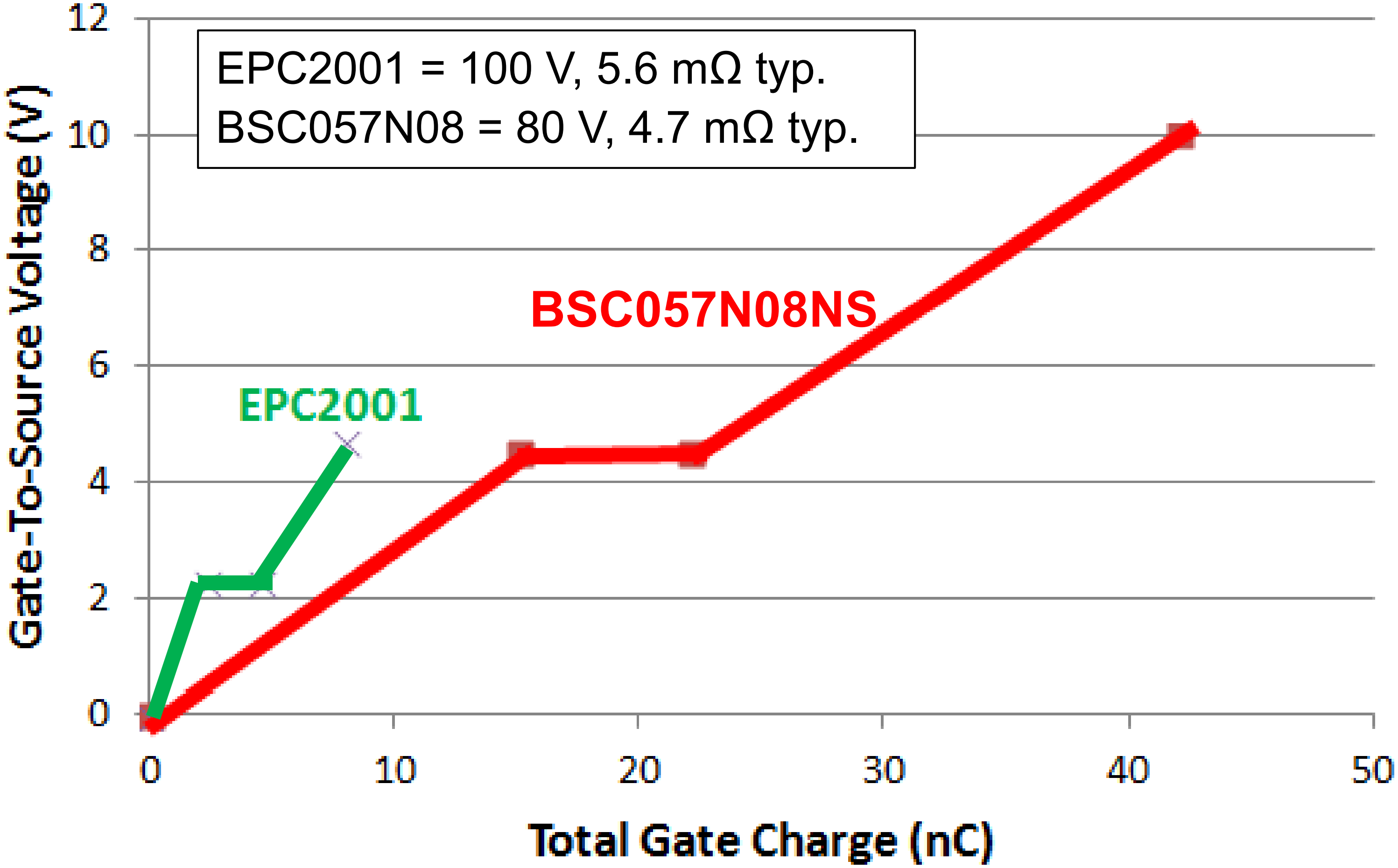


- For a given $R_{DS(on)}$
  - 1/5 the Q_{GS}
  - 1/10 the Q_{GD}
  - 1/2 the Q_{OSS}
  - 1/20 the L_{CS}
  - 1/5 the L
  - Zero Q_{RR}
- GaN Enables Higher Frequency
  - Smaller, lighter, cheaper energy storage elements
  - Faster Transient Response
  - Increased bus voltages
  - Reduced motor size and weight

Switching Performance

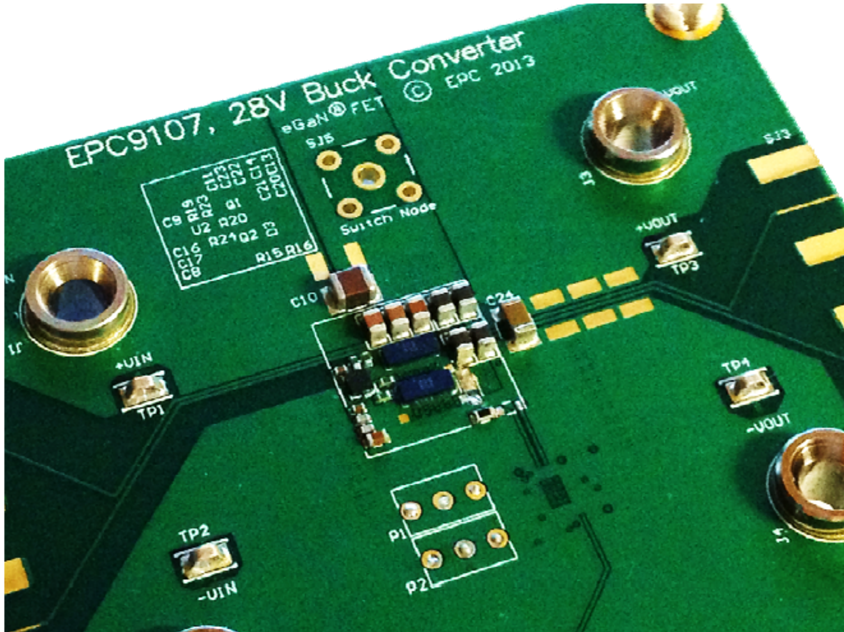
- Superior conduction characteristics allow a much smaller chip for the same $R_{DS(ON)}$
- The smaller device and lateral structure give much lower capacitances and charges for the same $R_{DS(ON)}$
  - Q_{GD} – determines classic switching loss - 1/5 to 1/10 of a MOSFET with similar $R_{DS(ON)}$
  - Q_{OSS} - < ½ of that of MOSFET with similar $R_{DS(ON)}$
    - Hard switched – losses proportional to Q_{OSS}
    - Soft switched – switching time proportional to Q_{OSS}
    - Q_{OSS} x $R_{DS(ON)}$ will be improved with Gen 3.
  - Q_{RR} – There are no minority carriers, no stored charge and zero Q_{RR}
- The small, wide package gives very low inductance
  - Inductance has become a dominating contributor to switching performance

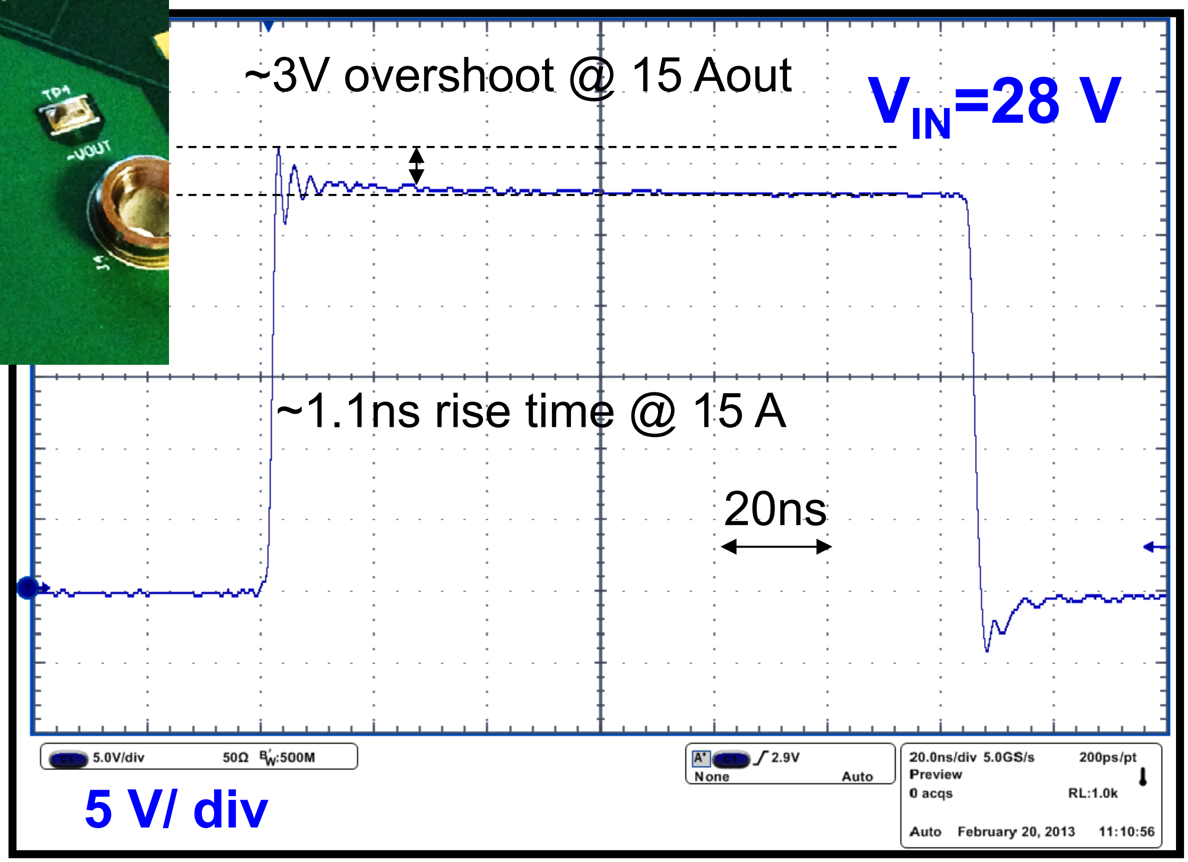
Total Gate Charge



EPC9107 Demonstration Board

V_{IN}=12-28 V V_{OUT}=3.3 V
I_{OUT}=15 A F_S=1 MHz
2 x EPC2015





Switching Node Voltage

V_{IN}=28 V I_{OUT}=15 A

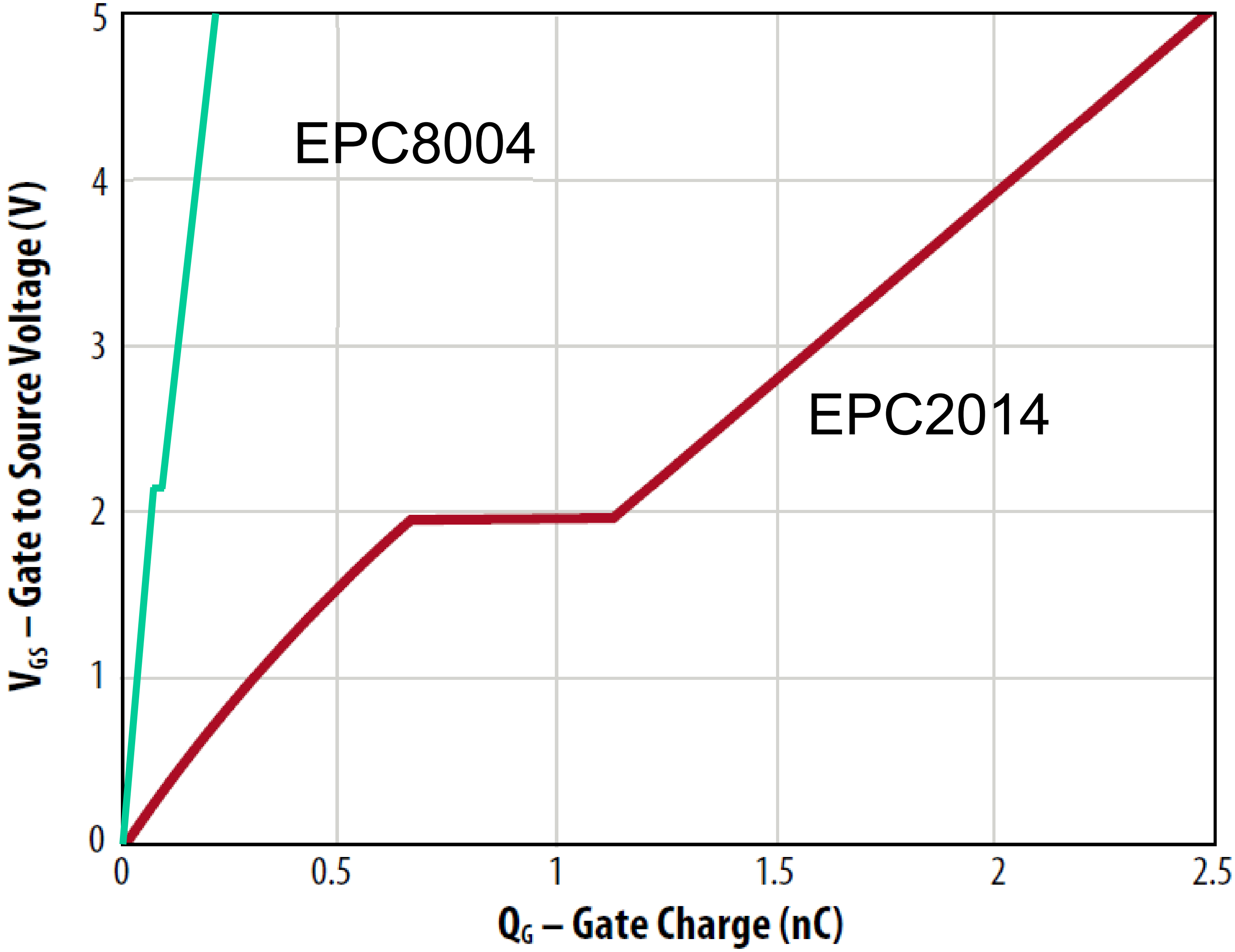
Silicon Vs eGaN Wafer Costs

	2010	2015
Starting Material	same	same
Epi Growth	higher	~ same
Wafer Fab	same	lower
Test	same	same
Assembly	lower	lower
OVERALL	**higher**	**lower!**

With superior $R_{DS(ON)}$ x Area, eGaN FETs have many more devices per wafer

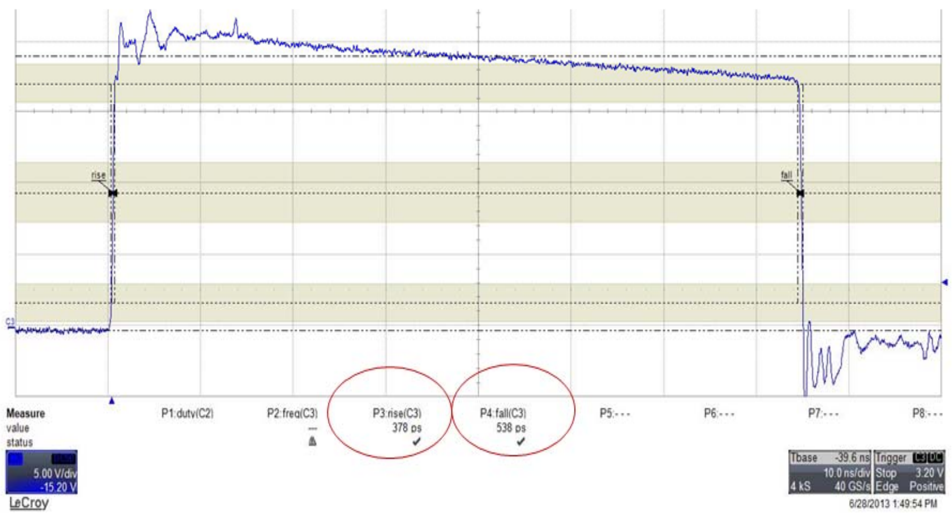
Gen 3 eGaN FETs

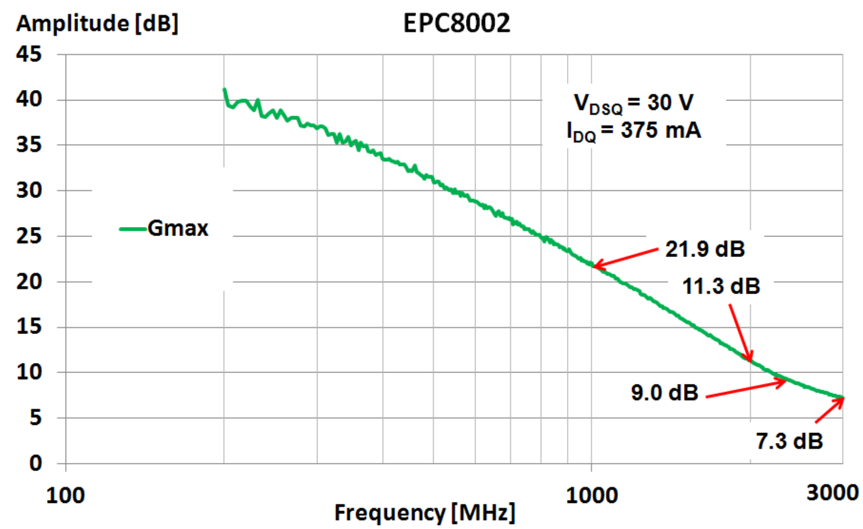
Fast Gets Faster



How Fast is Faster?

- **20 V**
- 4 A load, 1 MHz
- 380 ps rise, 540 ps fall

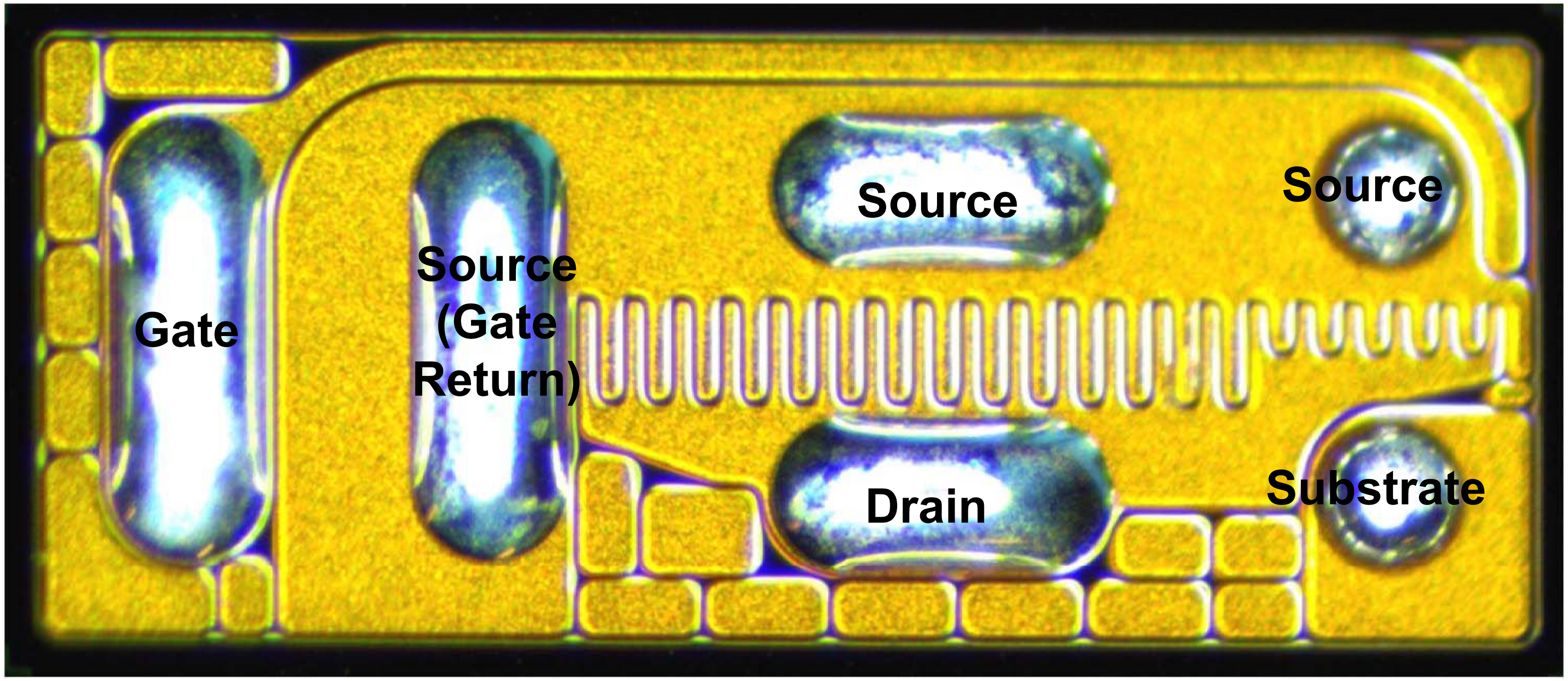




EPC8007 driven by LM5113

Small signal Performance

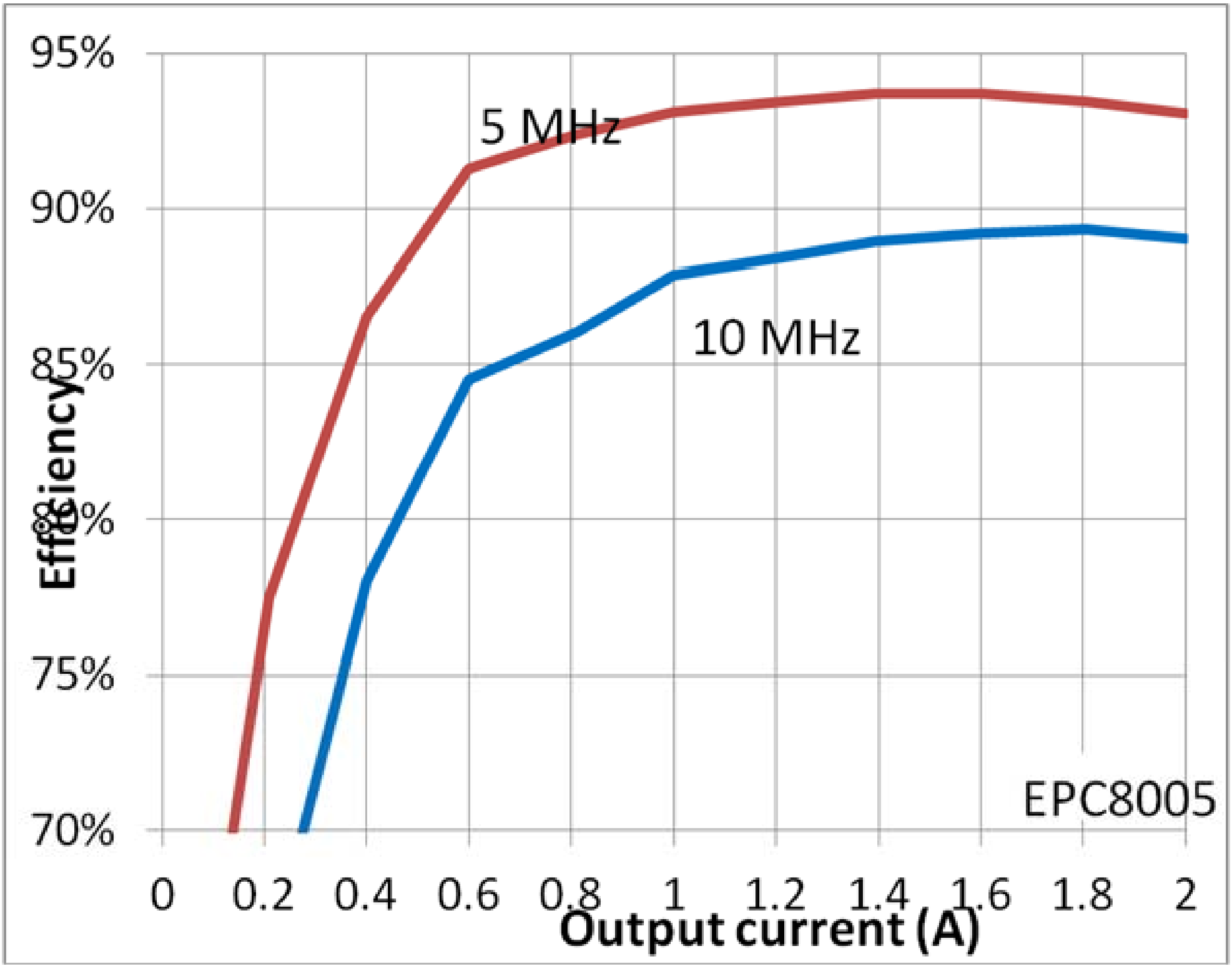
High Frequency Packaging



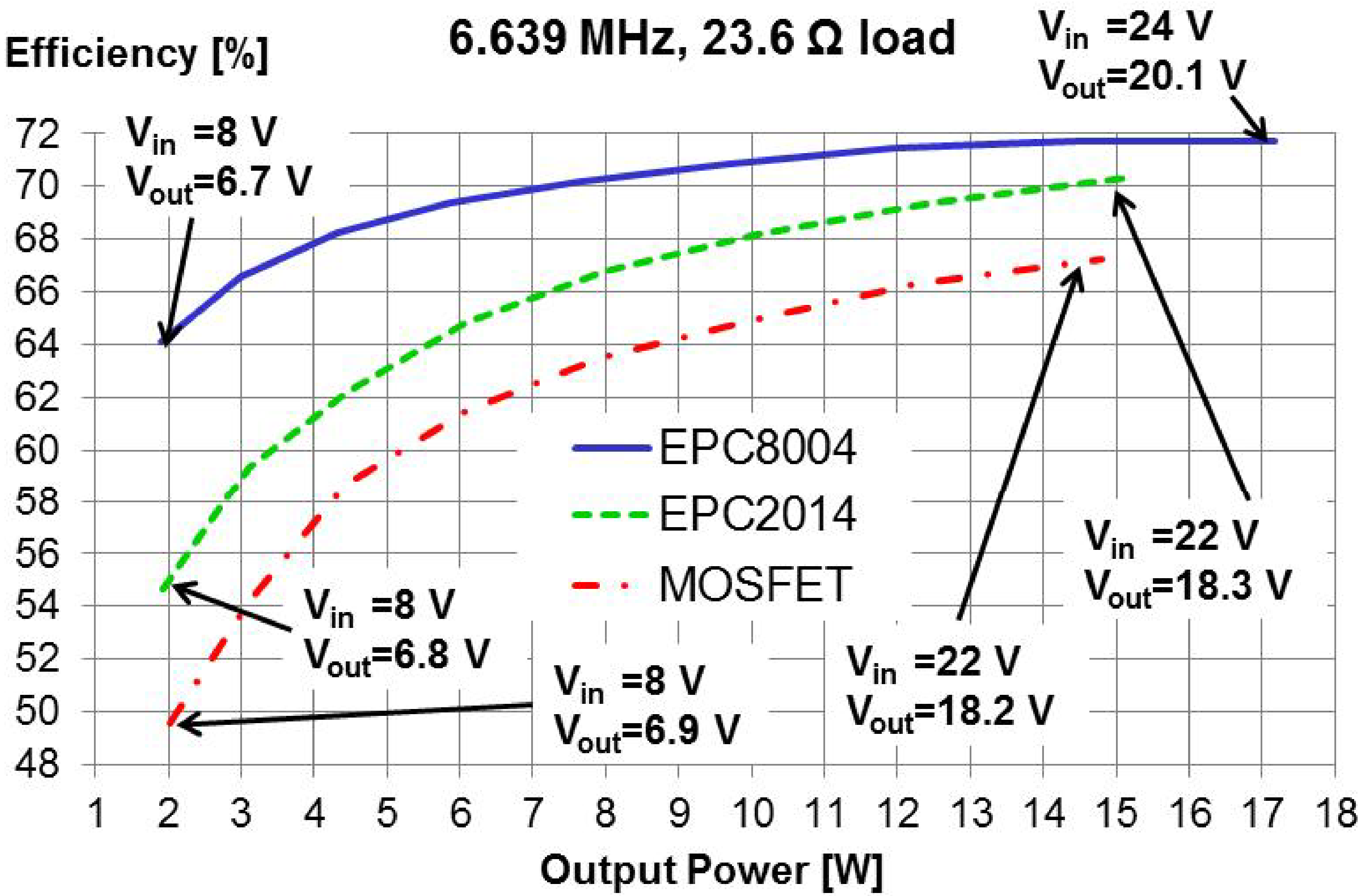
- Separate gate return (source)
- Low inductance gate
- Orthogonal gate and drain circuit layout
- Low internal parasitic inductances

Envelope Tracking

V_{IN} = 42 V, V_{OUT} = 20 V



Wireless Power Transfer



Generation 3 eGaN® FETs

EPC Part No.	BV (V)	Max. $R_{DS(ON)}$ (mΩ) (V_{GS} = 5V, I_D = 0.5 A)	Min. Peak Id (A) (Pulsed, 25 °C, T_{pulse} = 300 µs)	Typical Charge (pC)					Typical Capacitance (pF) (V_{DS} = 20 V; V_{GS} = 0 V)		
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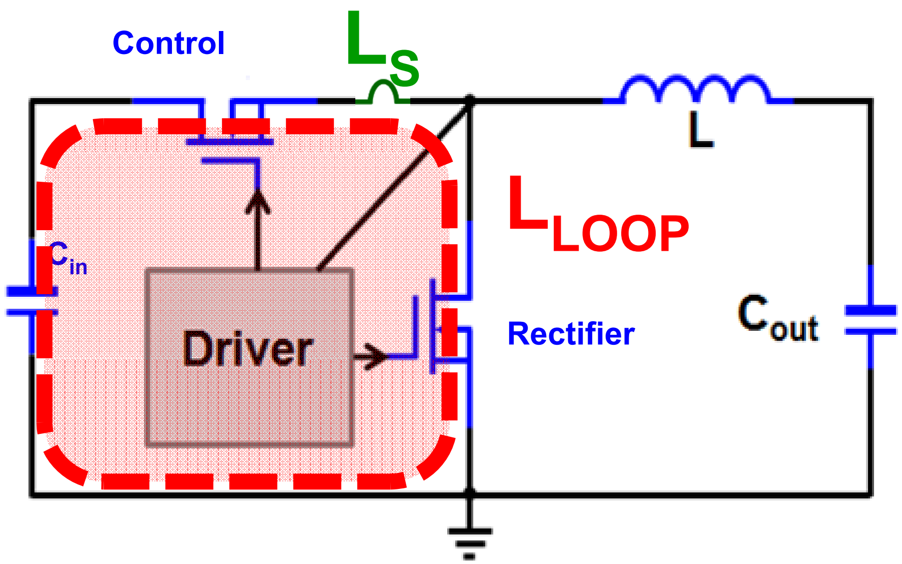
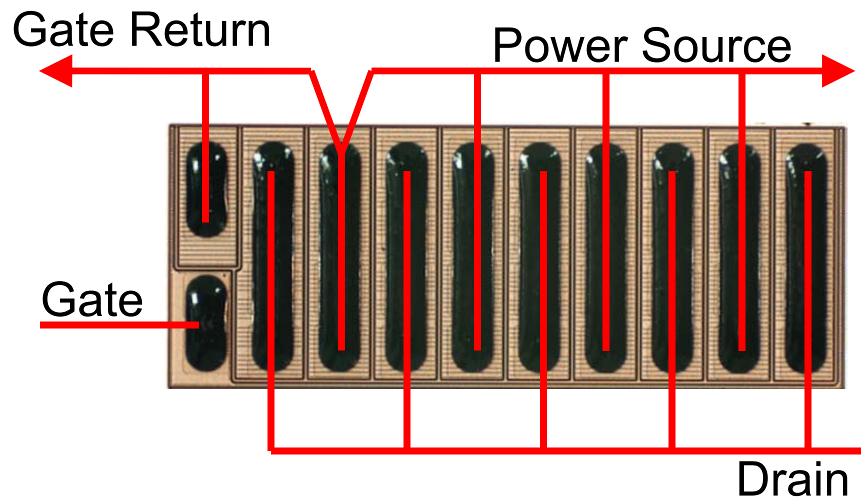
* Preliminary Data – Subject to Change without Notice

Packaging and Layout

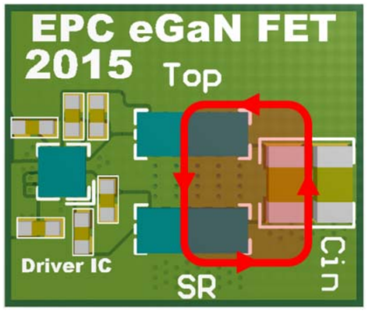
LGA has very low inductance

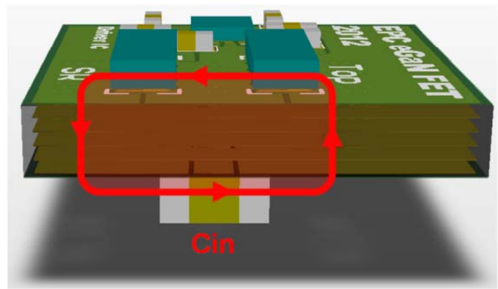




- Source Inductance common to the gate drive and control loops, L_S, slows current commutation by reducing effective gate drive during di/dt
- High Frequency Loop Inductance causes increased losses, high peak voltage and increased ringing
- LGA Package has low common source inductance and enables low high frequency loop inductance

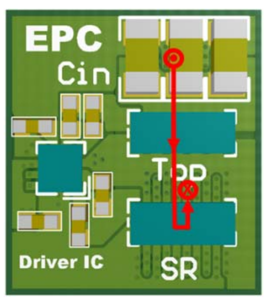
Half Bridge Layout Options

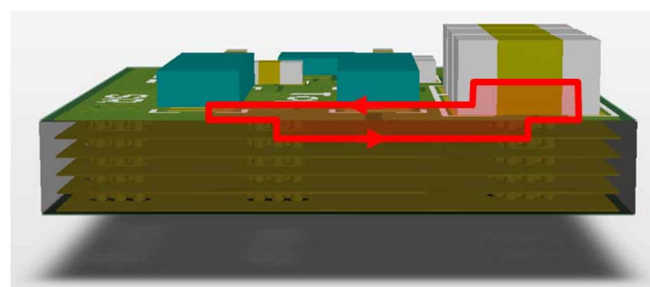




Horizontal

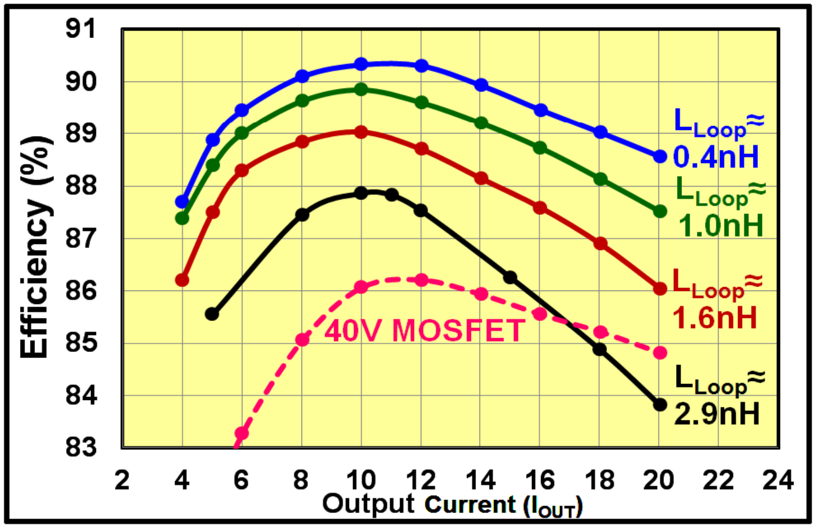
Vertical



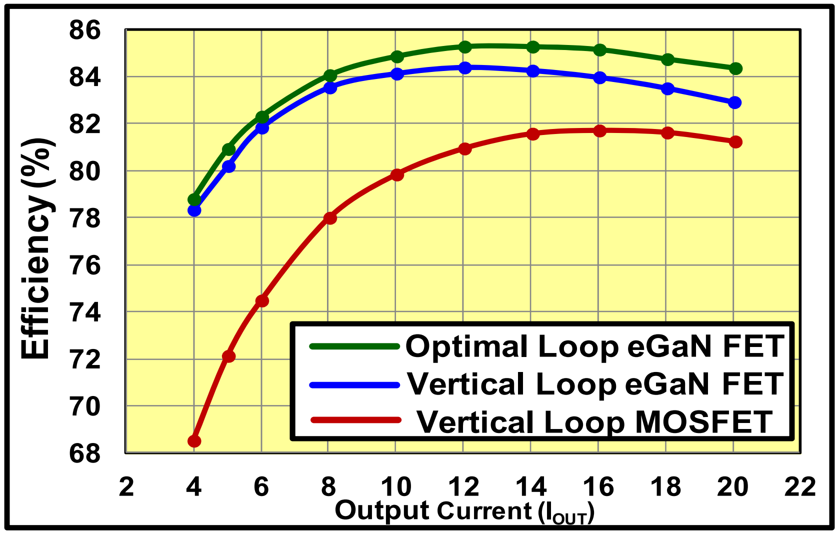


Optimal

Layout Comparison Efficiency Results



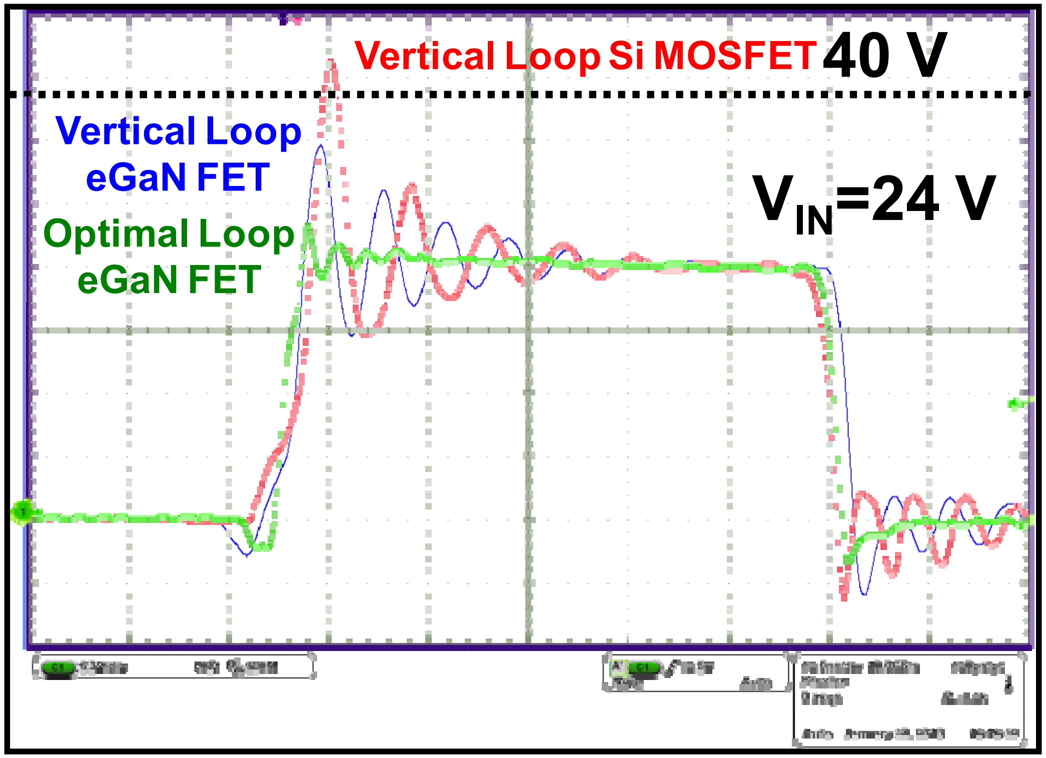
12 V to 1.2 V, 1 MHz



24 V to 1.2 V, 1 MHz

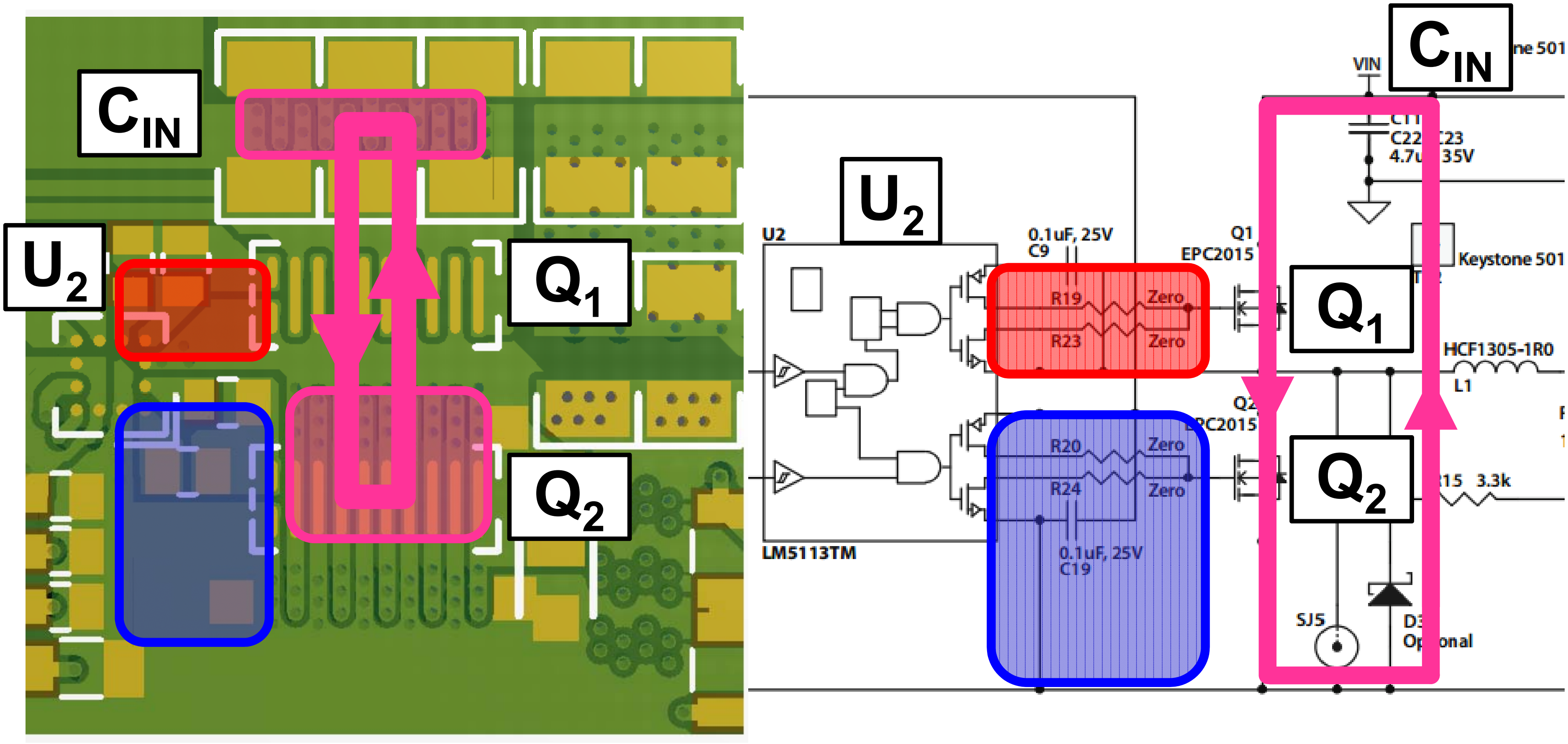
- Package inductance of MOSFETs dominates both common source inductance and high frequency loop inductance losses
- eGaN FET wafer level LGA packages have ultra-low inductance and allow ultra-low high frequency loop inductance

Switchnode Peak and Ringing

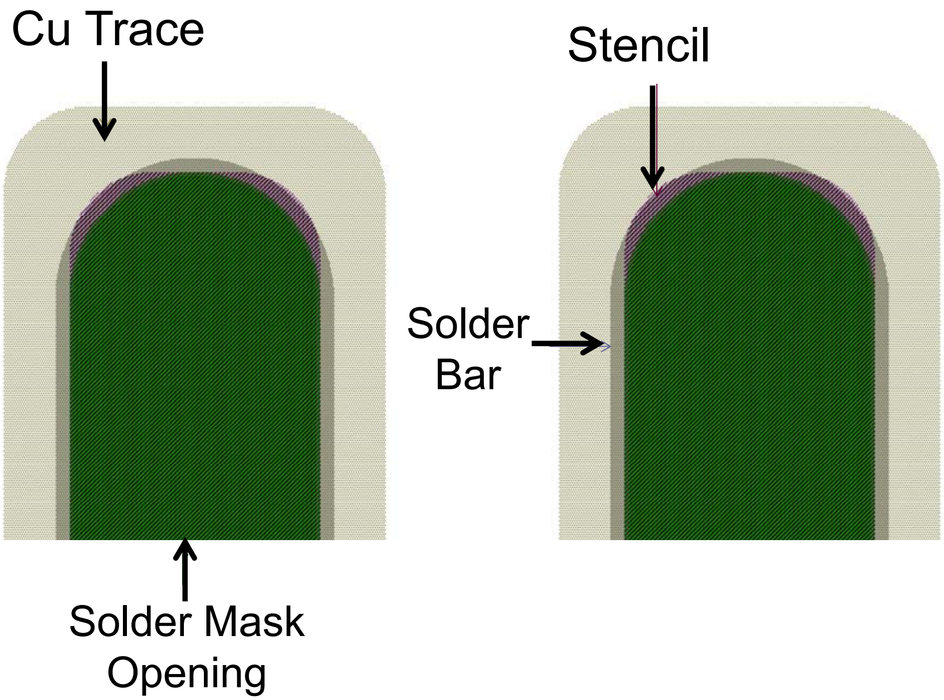


- Low inductance high frequency loop reduces peak voltage and ringing
  - Lower voltage device for same application can further increase efficiency
- Reduced ringing eases design for EMI

Optimal Layout Implementation



Footprint



- Fine pitched LGA requires careful footprint and solder mask design.
  - Please see detail in:
  - http://epc-co.com/epc/documents/product-training/Appnote_GaNassembly.pdf

Gate Drive and Reverse Conduction time

Gate Drive Considerations

- 4.5 V is sufficient for full enhancement
- $V_{GS(Max)}$ = 6 V
  - Limited overheat requires low inductance gate loop.
- V_{SD} is high compared with MOSFETs
  - Must be considered with high current applications
  - Also causes distortion with class D amplifiers

Figure 4: $R_{DS(on)}$ vs V_{GS} for Various Temperature

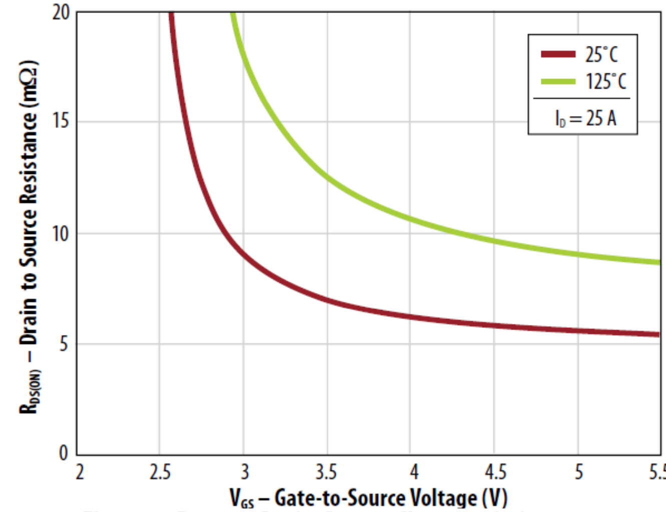
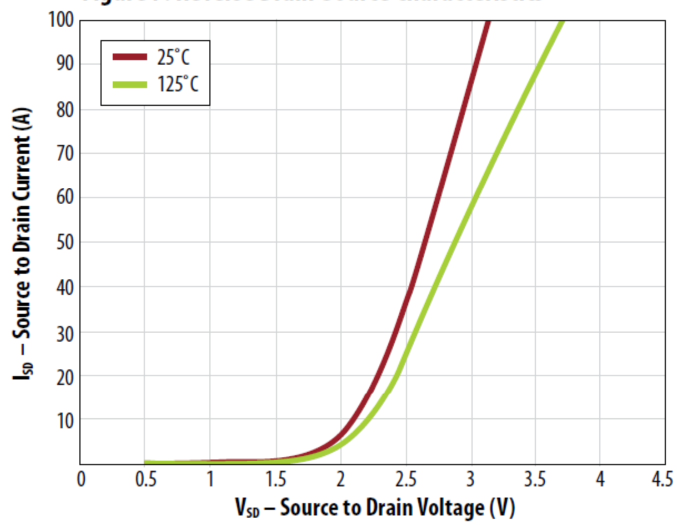
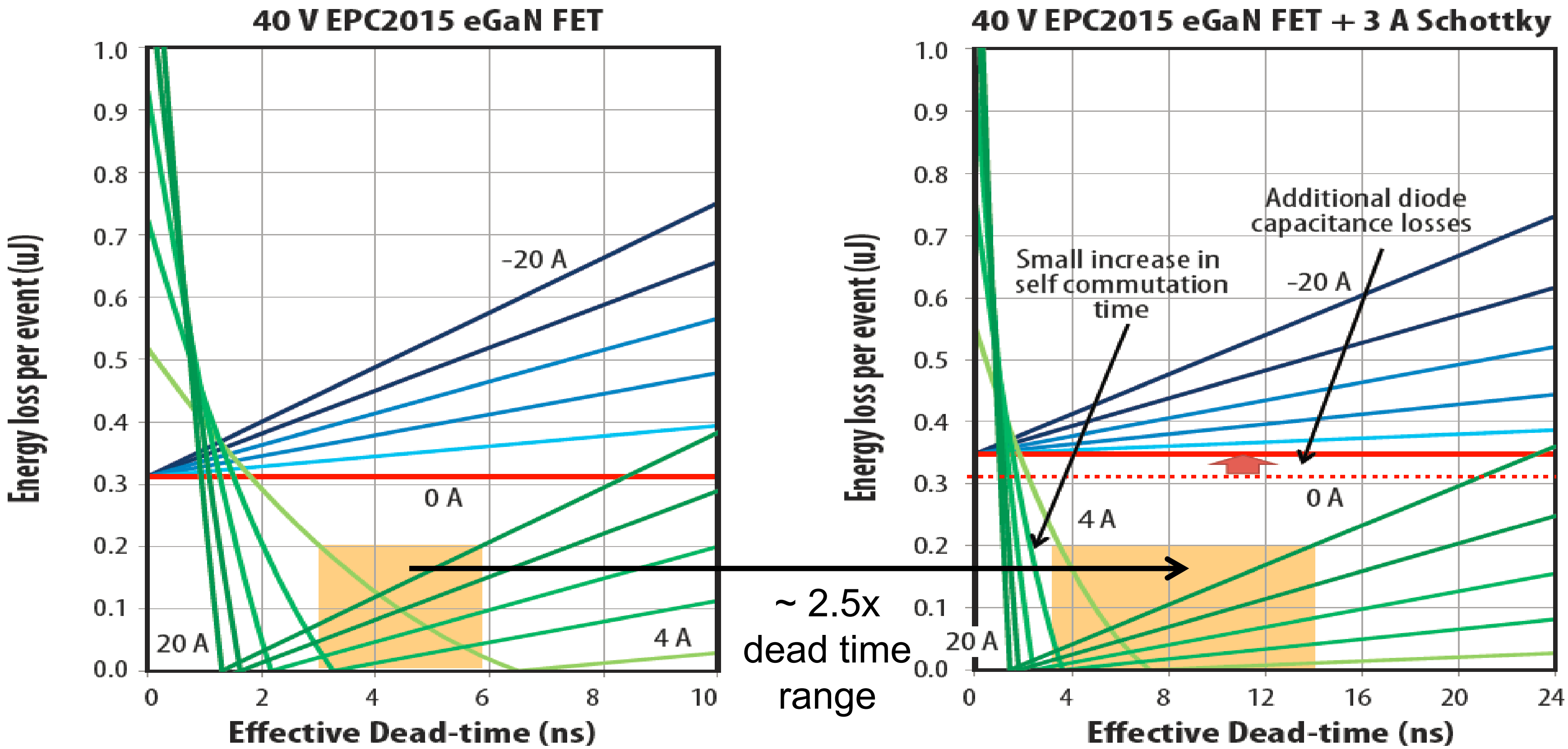


Figure 7: Reverse Drain-Source Characteristics

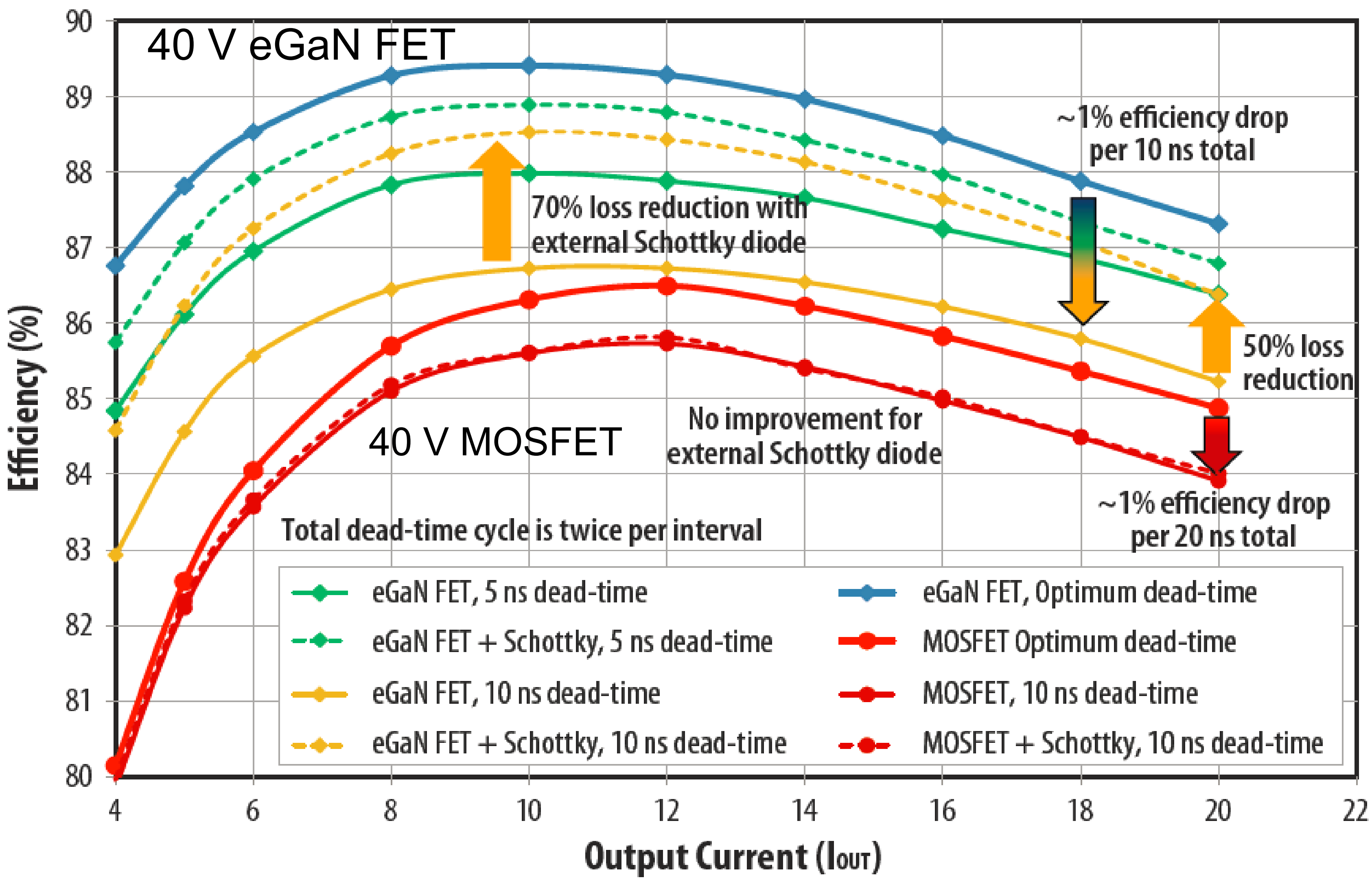


Deadtime
Optimize with External Schottky



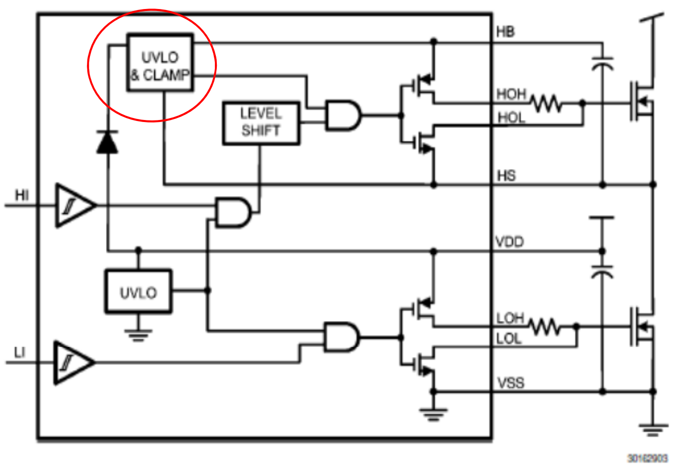
- Low Inductance Packaging and high V_{SD} enable effective transfer from FET to Diode
- Low Inductance Schottky is required

12 VBUS Efficiency Measurements



eGaN® FET Drivers

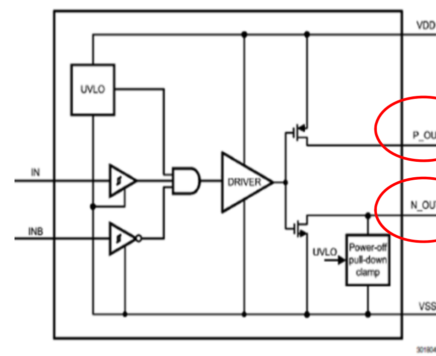
- LM5113: Dual driver for HB and FB
  - Pushpull, HB/FB, Sync Buck, two switch forward, active clamp
  - Split outputs for adjustable turn-on/turn-off currents (common to all drivers)
  - Internal bootstrap supply voltage clamping at 5V for HS driver
  - 107V max at HS (LX) Pin
  - 5A sink & 1.2A Source



- Single Driver : Boost, Flyback, Forward, Sync. Rect, solar & motor control.

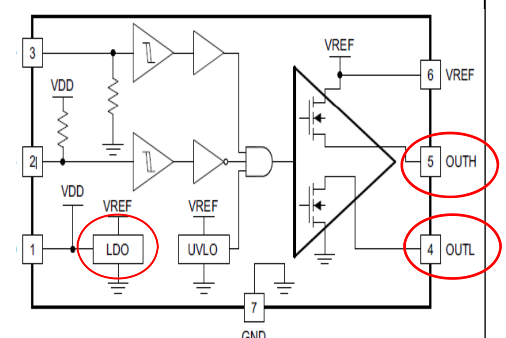
•LM5114 :

- Sink 7.6A & Source 1.3A
- 4 to 12.6V supply
- LLP-6 and SOT23
- Inverting gate drive
- UVLO only
- 12ns propagation delay



•UCC27611:

- Sink 6A & Source 4A
- 4-18V supply
- 2x2mm package
  - •With thermal pad
  - Works as high side & low side drivers
- 14ns propagation delay

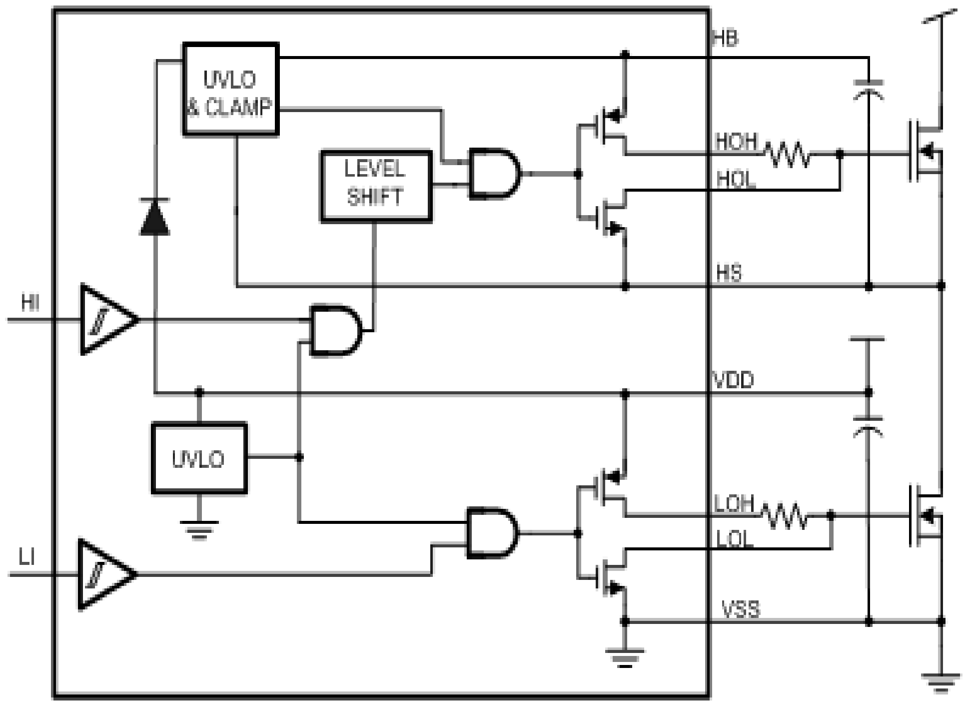


LM5113
eGaN FET Half Bridge Gate Driver

EFFICIENT POWER CONVERSION

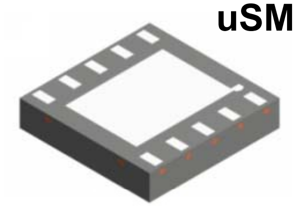
Key Features

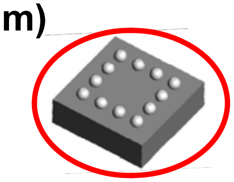
- 0.5 Ohm Sink and 2 Ohm Source Capability
- Independent Source and Sink Outputs
- Bootstrap Voltage Clamp
- Vcc UVLO optimized for eGaN FETs (3.5V)
- 100V V_{HS} Rating
- >50V/ns dv/dt Immunity at V_{HS}
- Independent TTL Inputs
- Short Propagation Delays (25ns)
- 4ns Delay Matching Between Channels
- Low Power Consumption (2mA @ 0.5MHz)



Availability

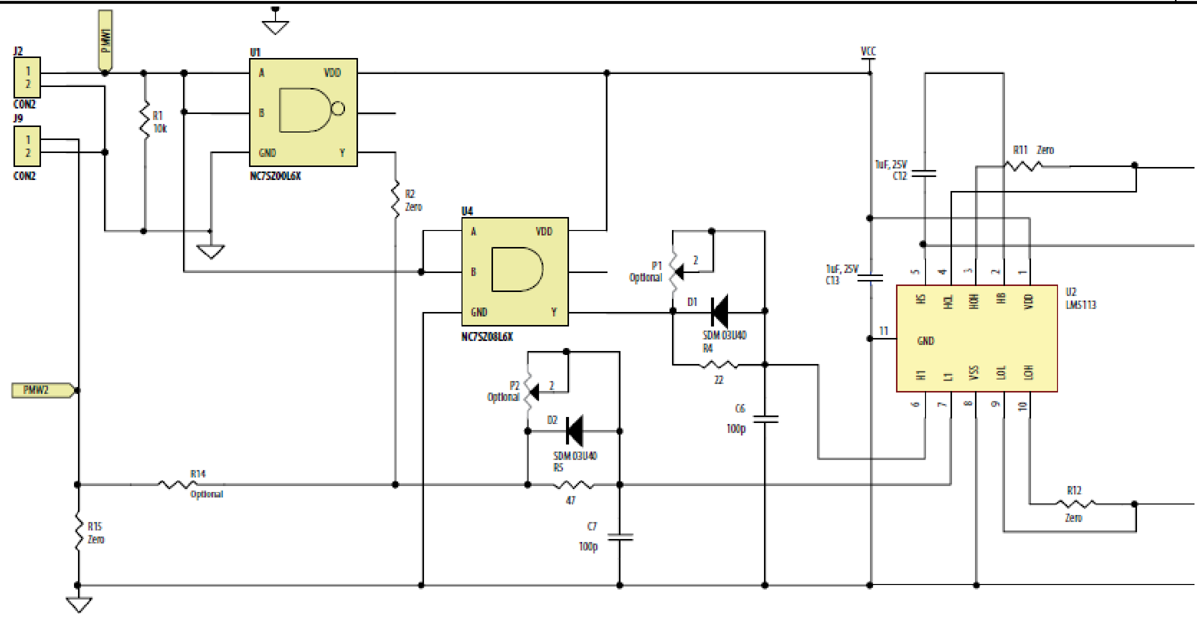
- Packages: **LLP-10 (4mm x 4mm),**
  uSMD12 (2mm x 2mm)





TEXAS INSTRUMENTS

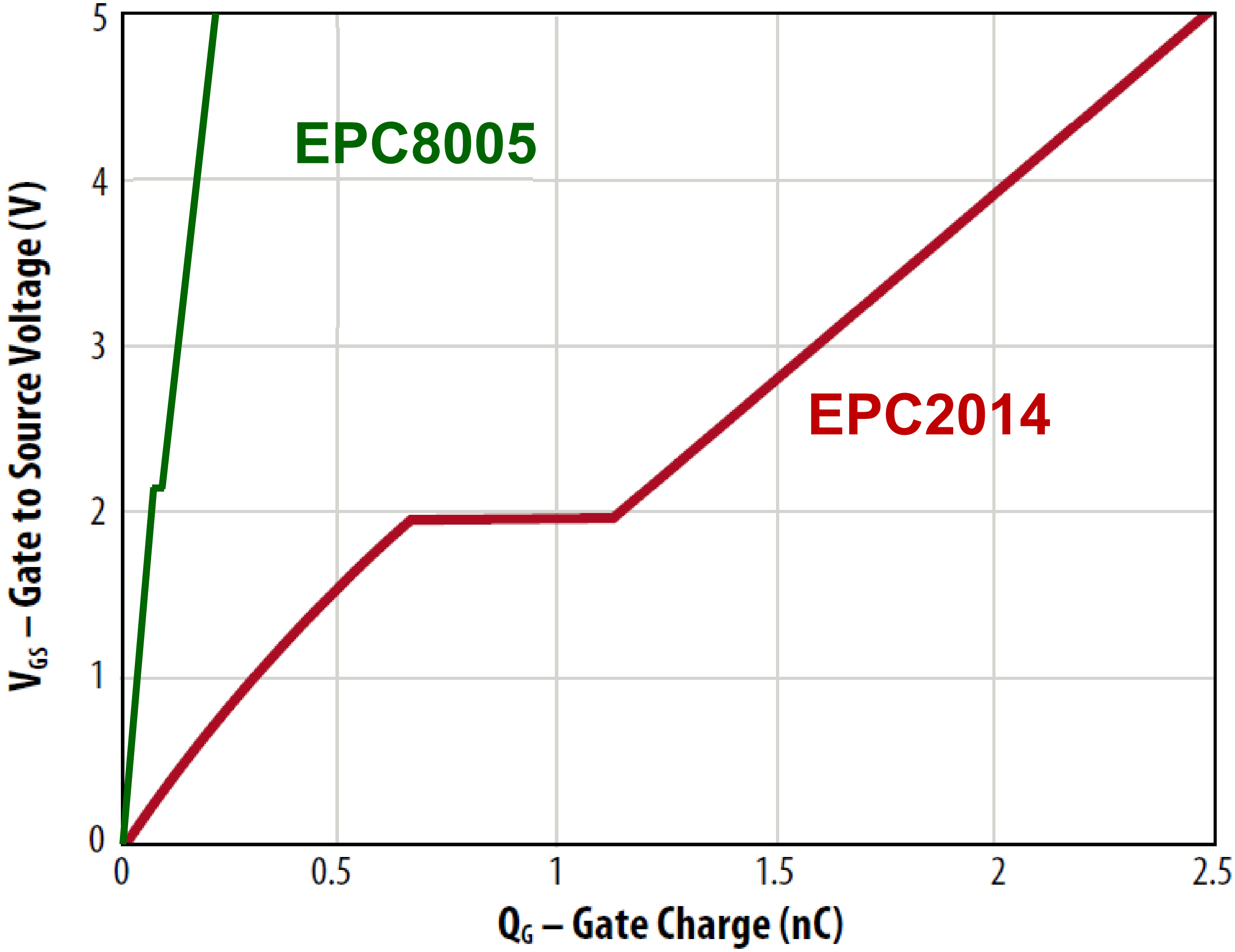
Advanced Driver



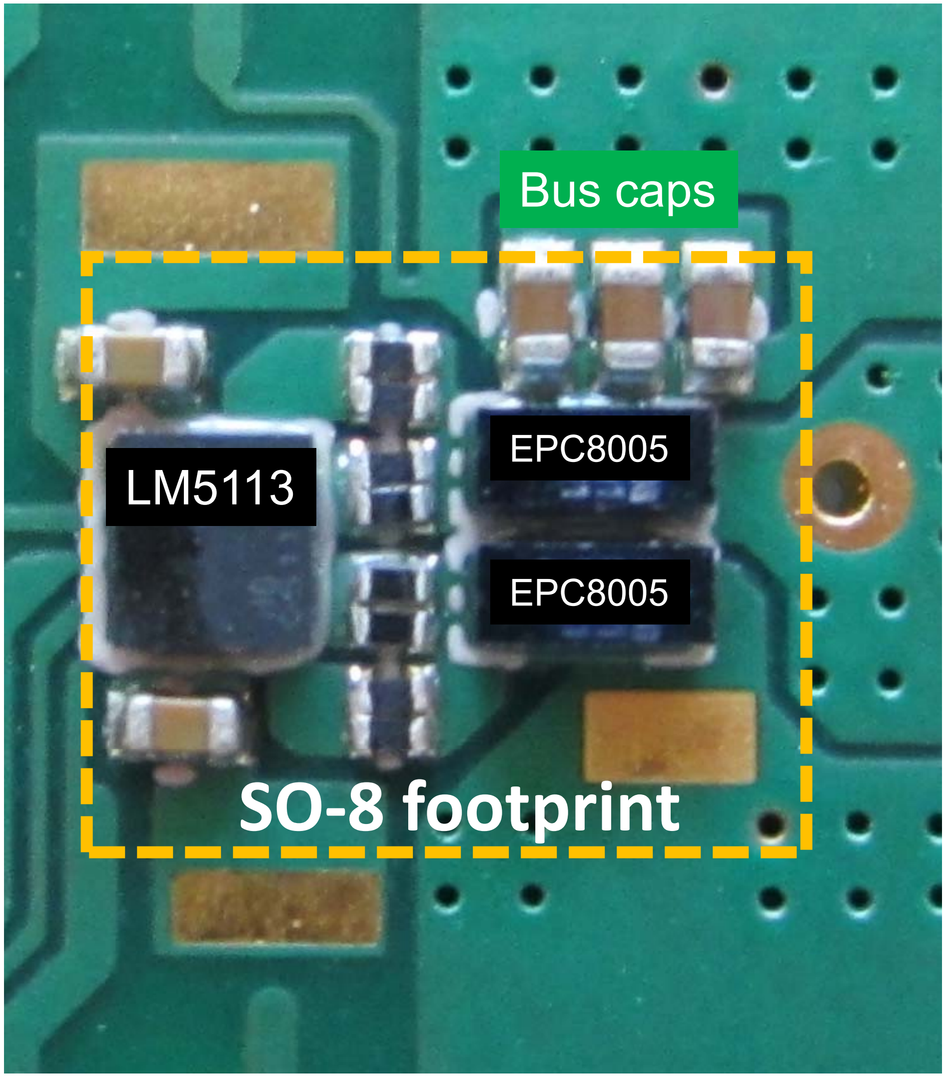
- Existing technology can be used to manage reverse conduction time to within 5 ns in a production line
- Needed – Driver with single input with simple, bidirectional deadtime set
- Can the speed of GaN FETs be taken advantage of as part of the driver integrated in the power device to achieve?
  - Toolbox includes Depletion Mode devices
- Ideas for sub nanosecond diode conduction time at critical conditions?

Applications

High Frequency Conversion



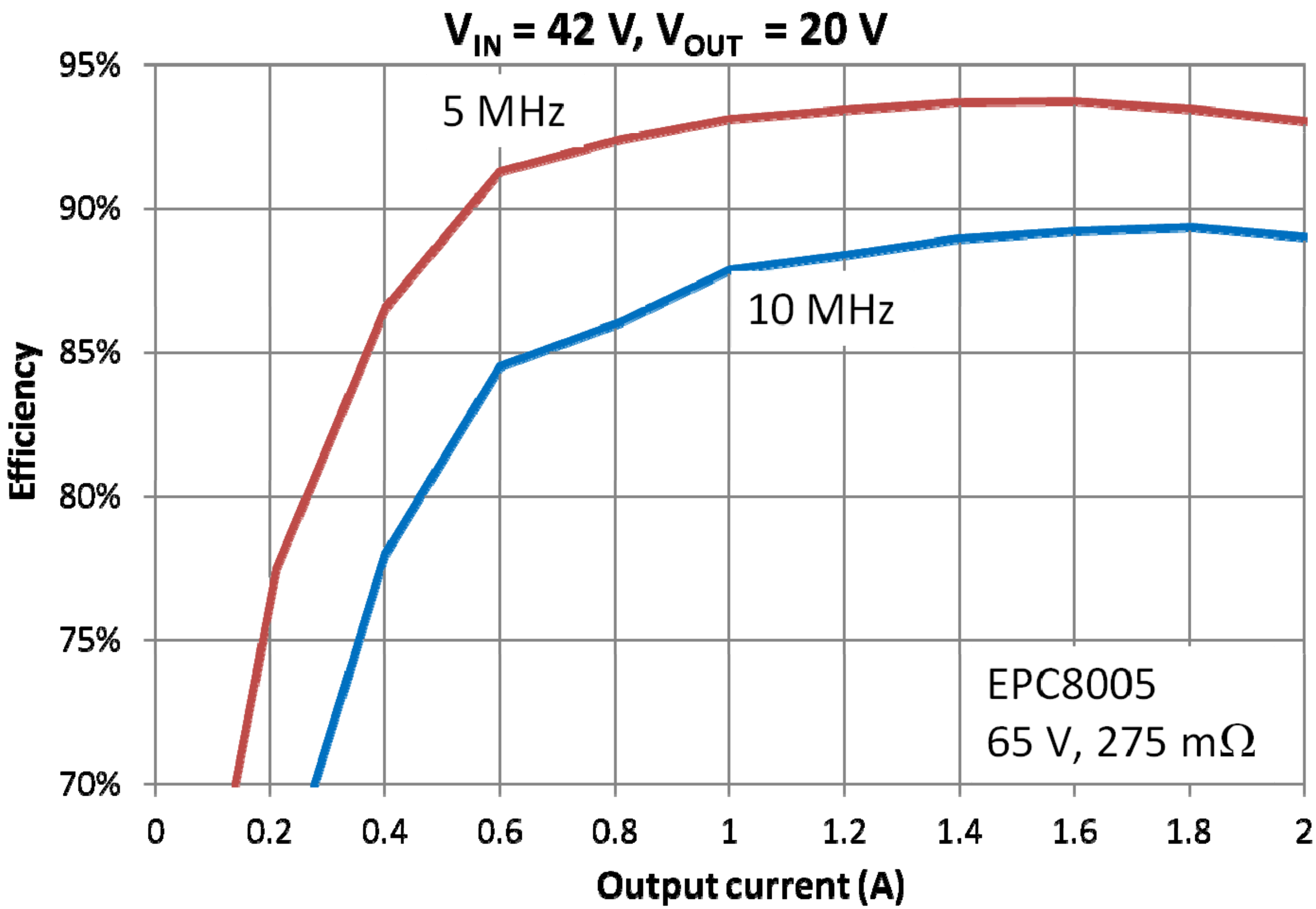
High Frequency Evaluation



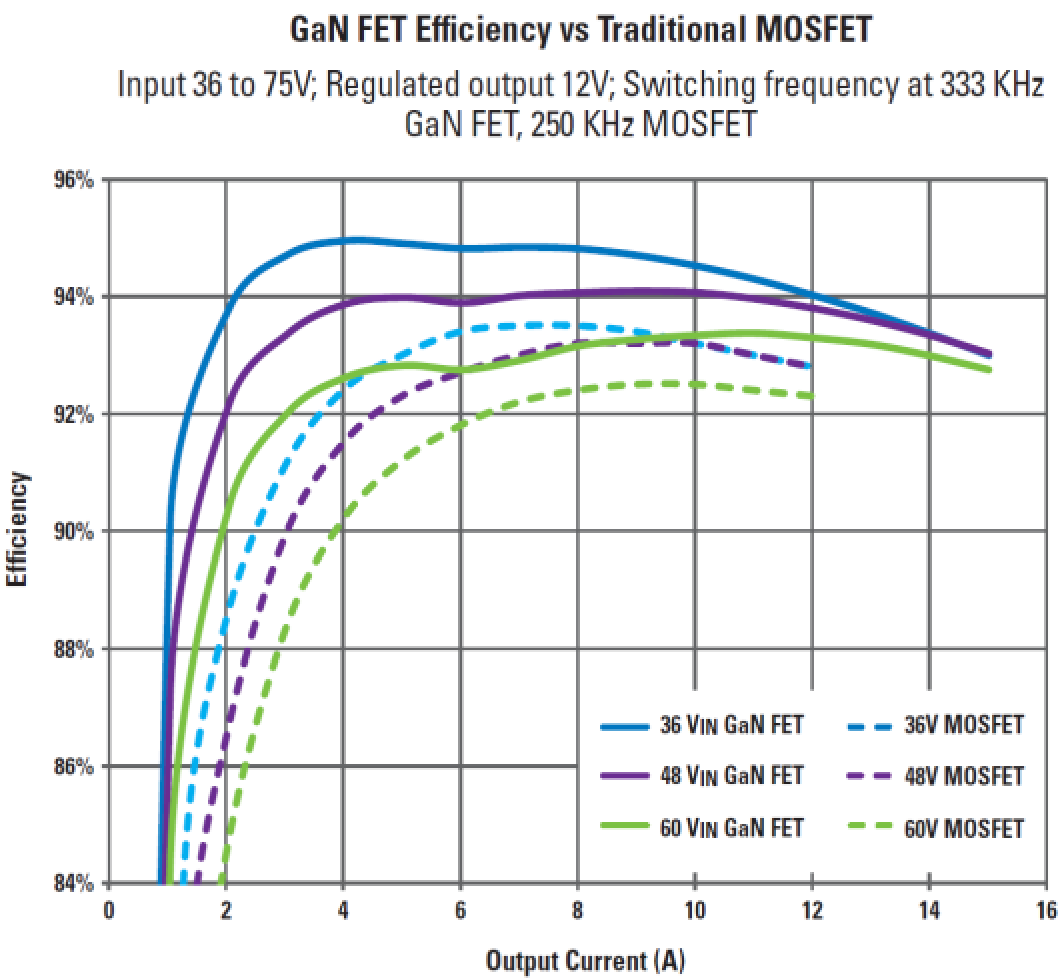
- LM5113 BGA driver
- 2x 0201 resistors in parallel to minimize gate inductance
- Optimum gate and power loops

42 V to 20 V / 2 A buck

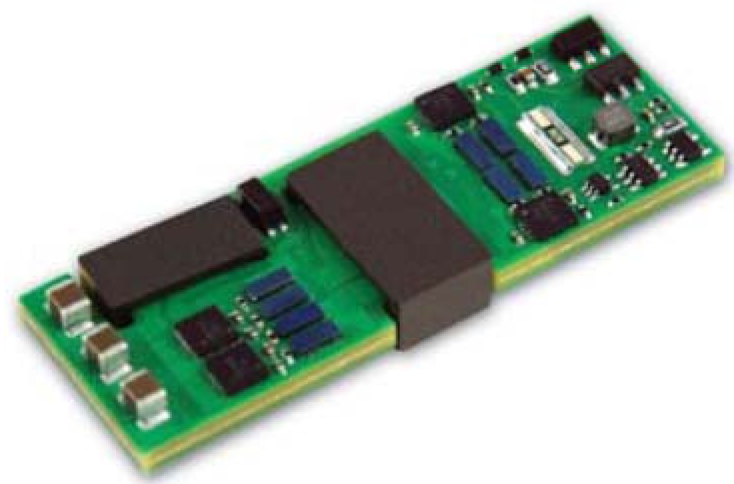
High Frequency Efficiency



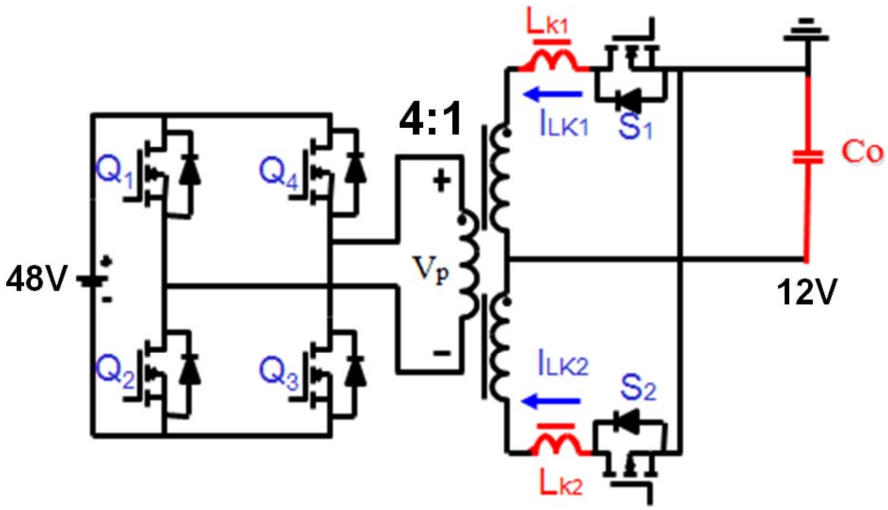
Regulated, Isolated 48 V to 12 V

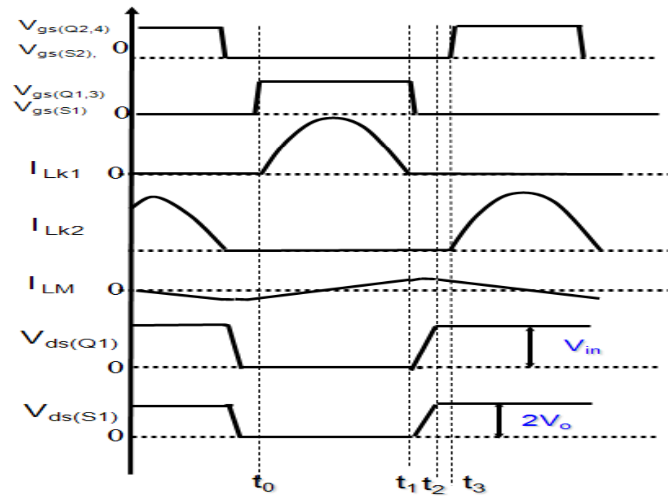


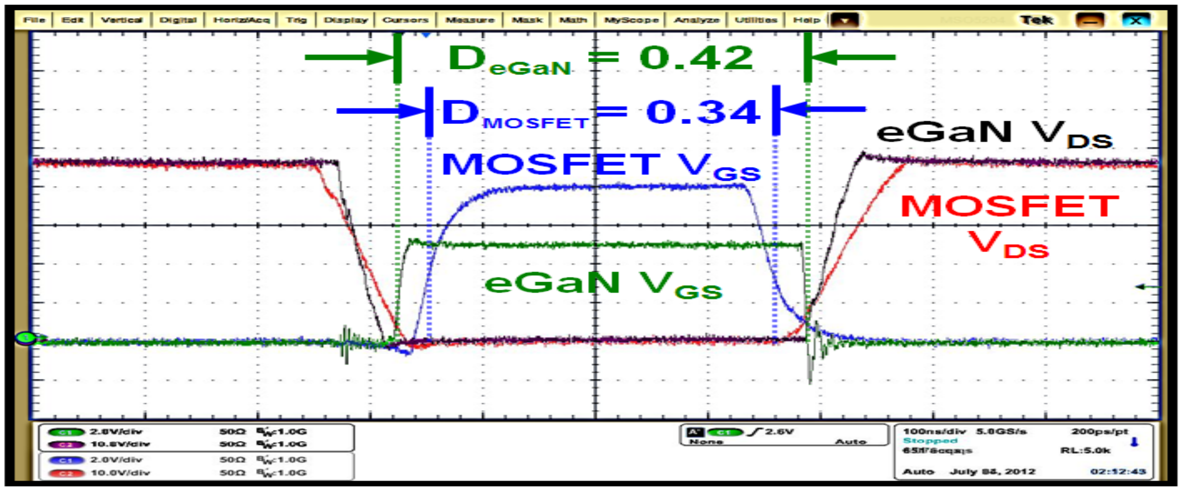
180W 1/8 Power Brick



1/8 power brick featuring the EPC2001 eGaN FET and LM5113 GaN FET driver.

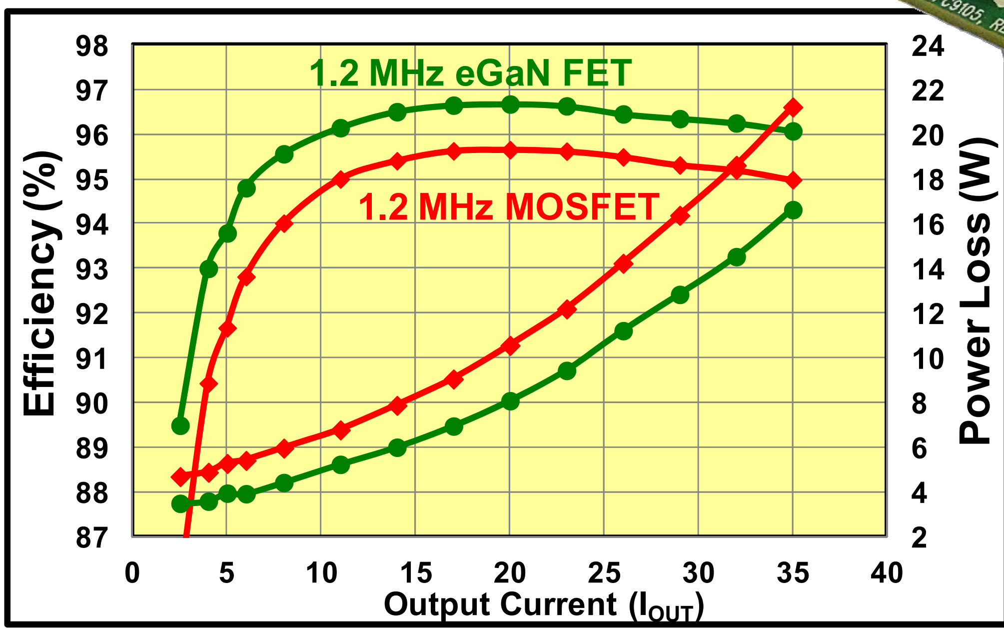


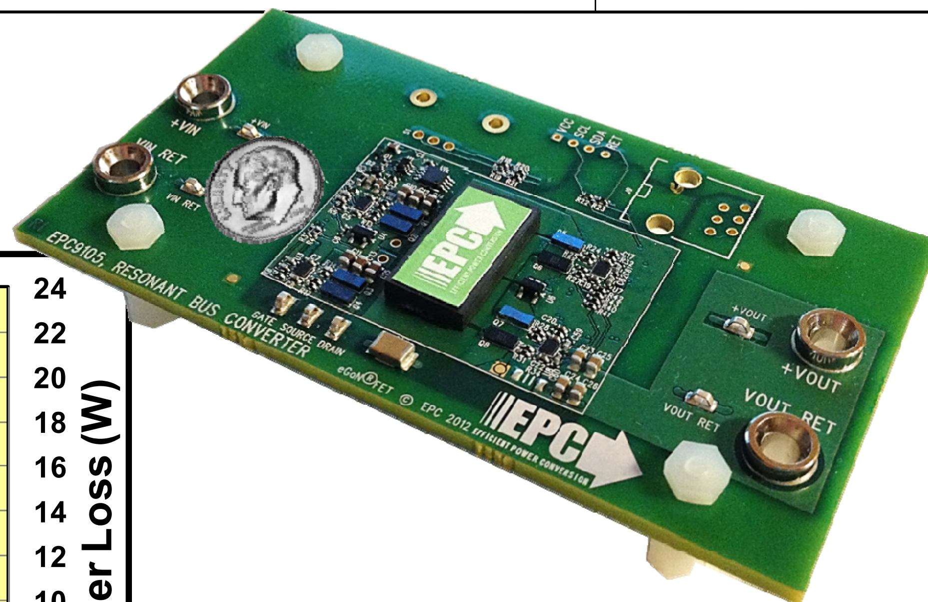




F_S = 1.2 MHz, V_{IN} = 48 V, and I_{OUT} = 26 A

eGaN FET Efficiency is Superior

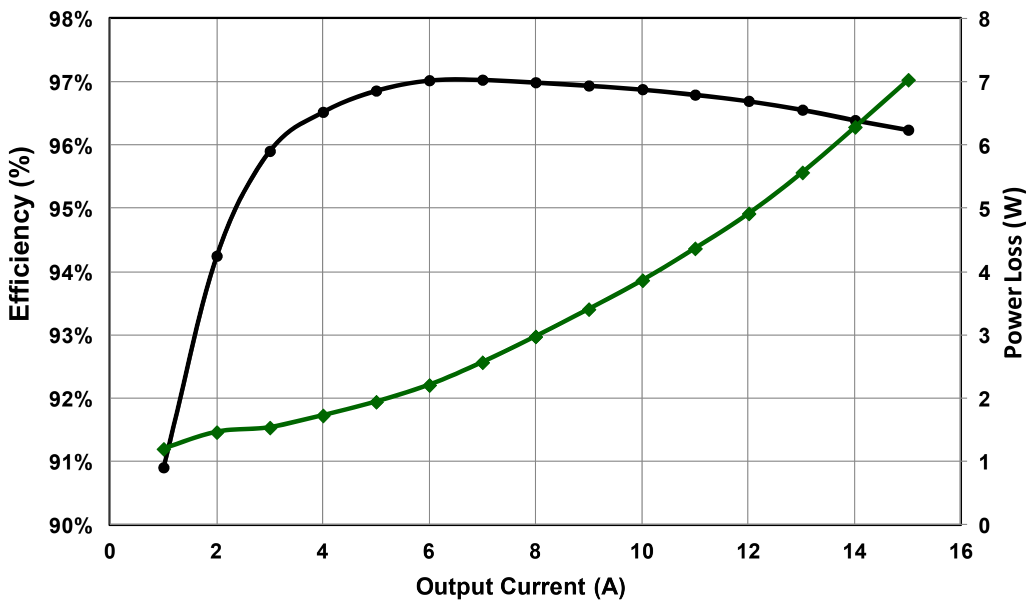


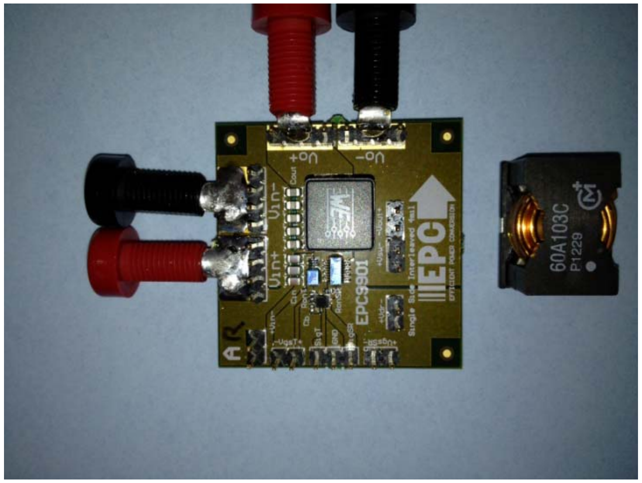


V_{IN} = 48 V, V_{OUT} = 12 V, F_S = 1.2 MHz

For a board's limited by power dissipation, eGaN FETs allow higher output power for same power dissipation

48 V to 12 V Buck, 400 kHz

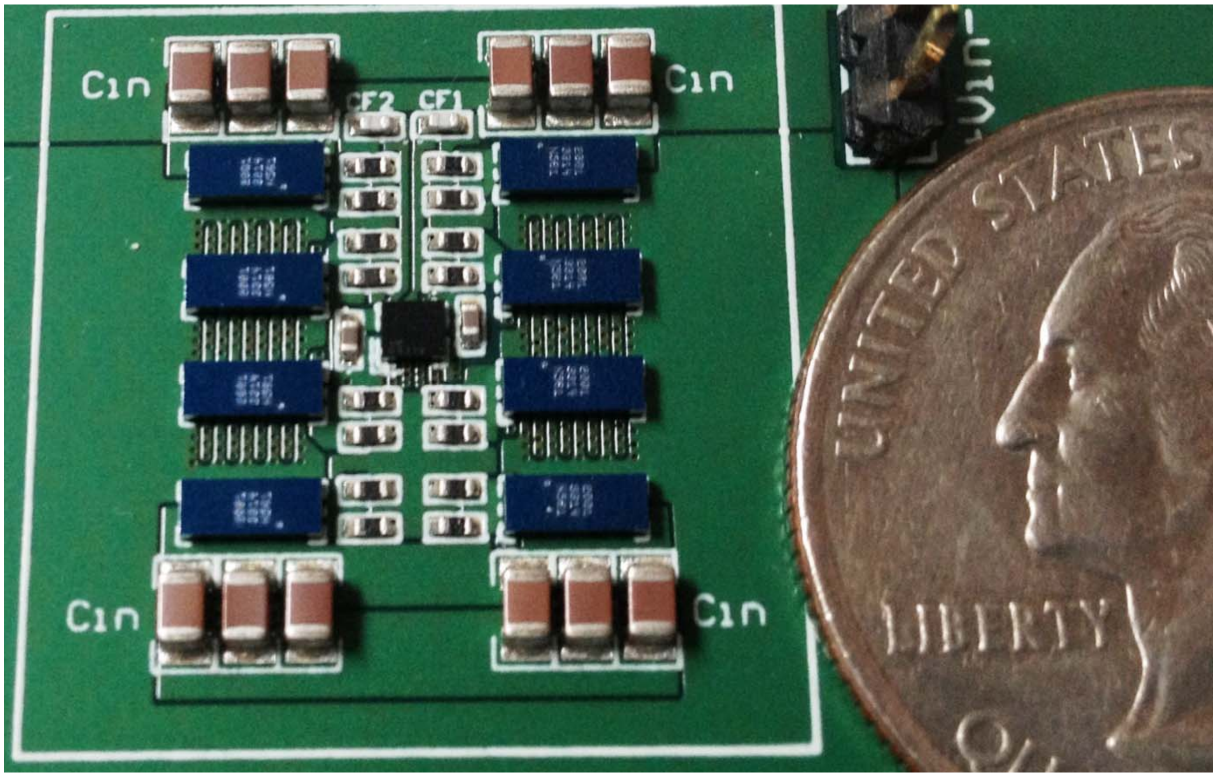




48 V Buck Power Stage

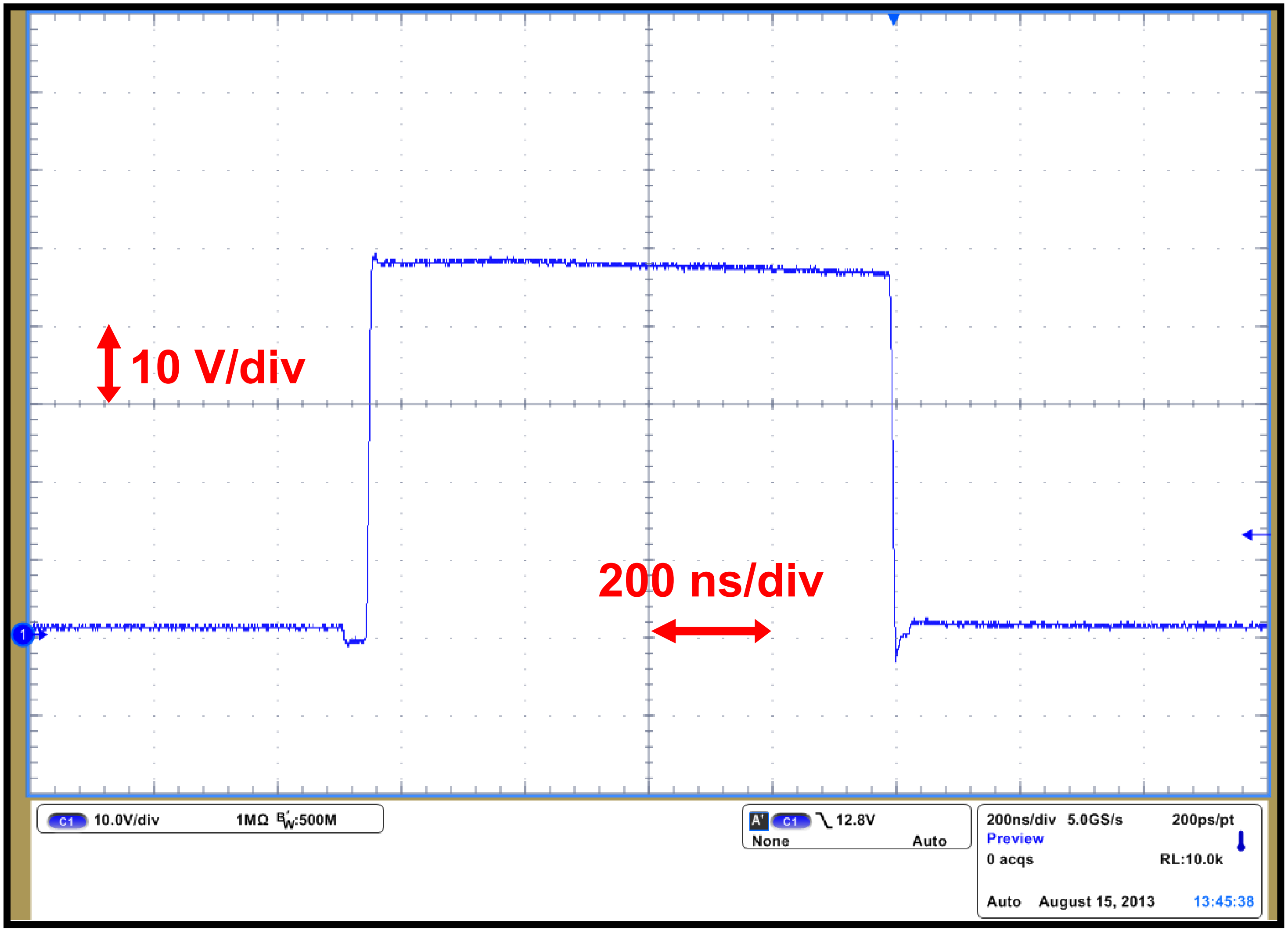
22.8mm
1/8th Brick Width

22.8mm
40% of 1/8th Brick Length



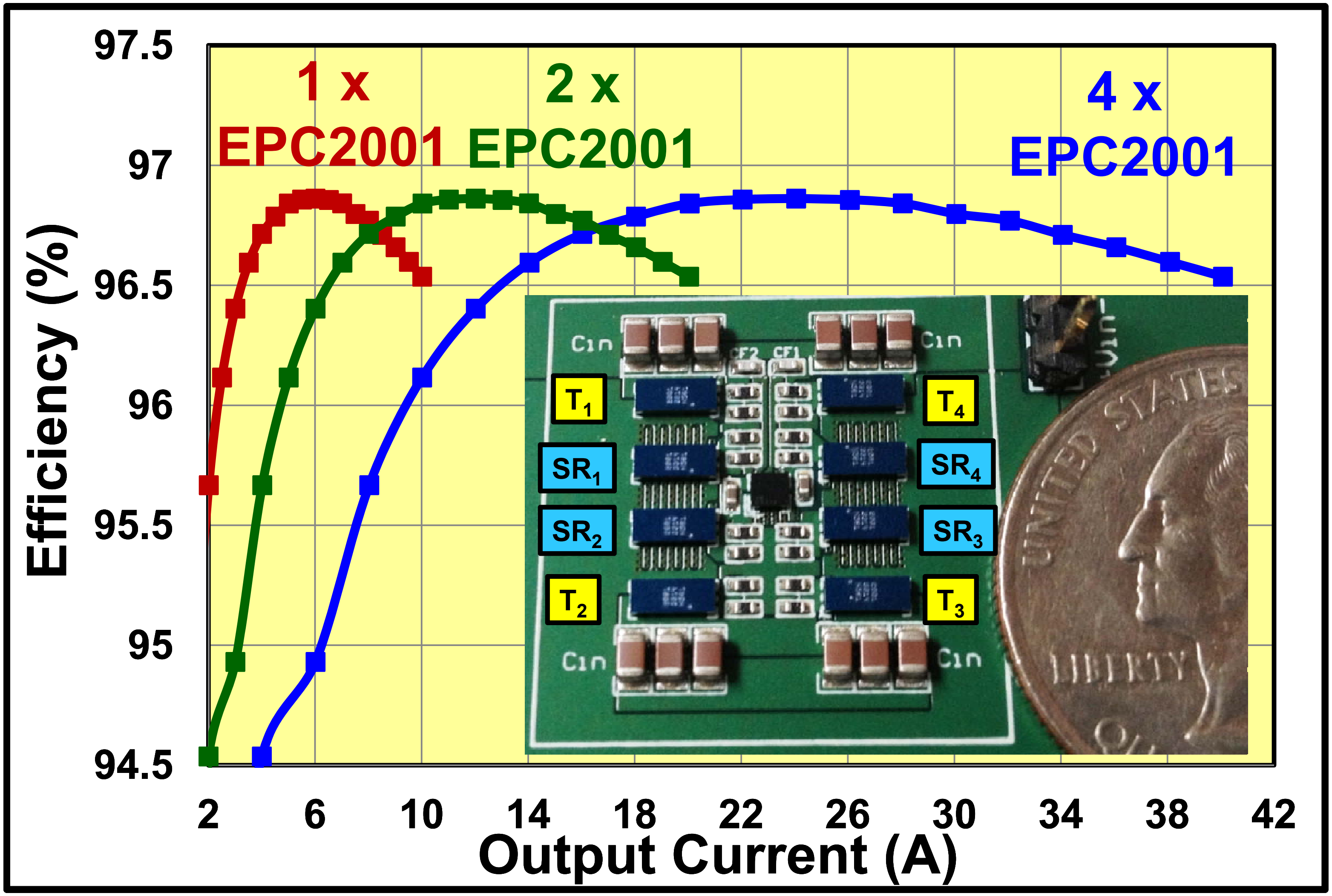
8 x EPC2001
4 Top Devices and 4 SR in parallel

eGaN FET Parallel Waveforms



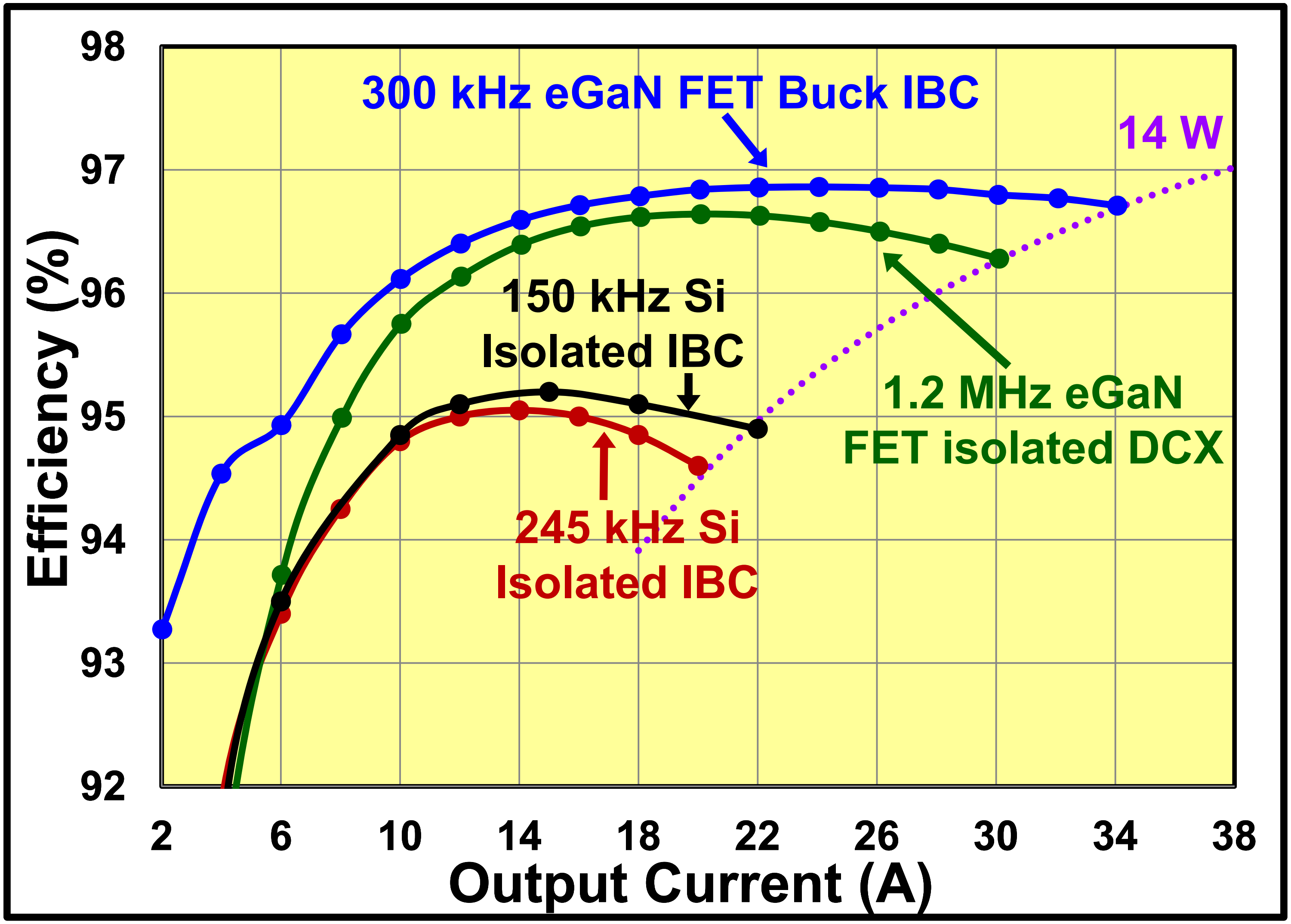
F_S = 300 kHz, V_{IN} = 48 V, V_{OUT} = 12 V, and I_{OUT}=30 A

Higher Current?...Parallel



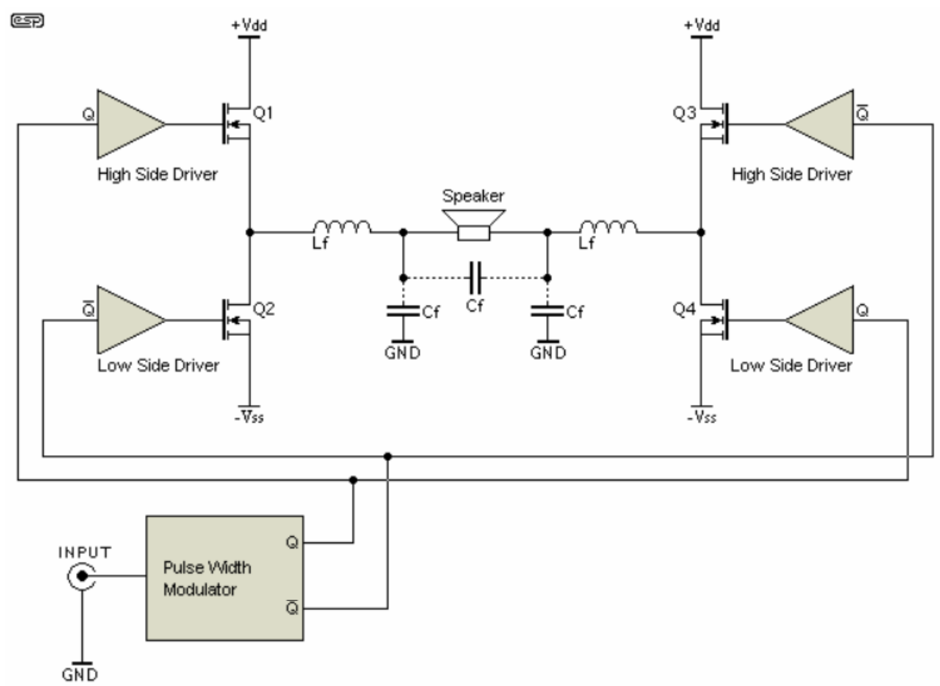
V_{IN}=48 V, V_{OUT}=12 V, F_S=300 kHz

Intermediate Bus Improvements

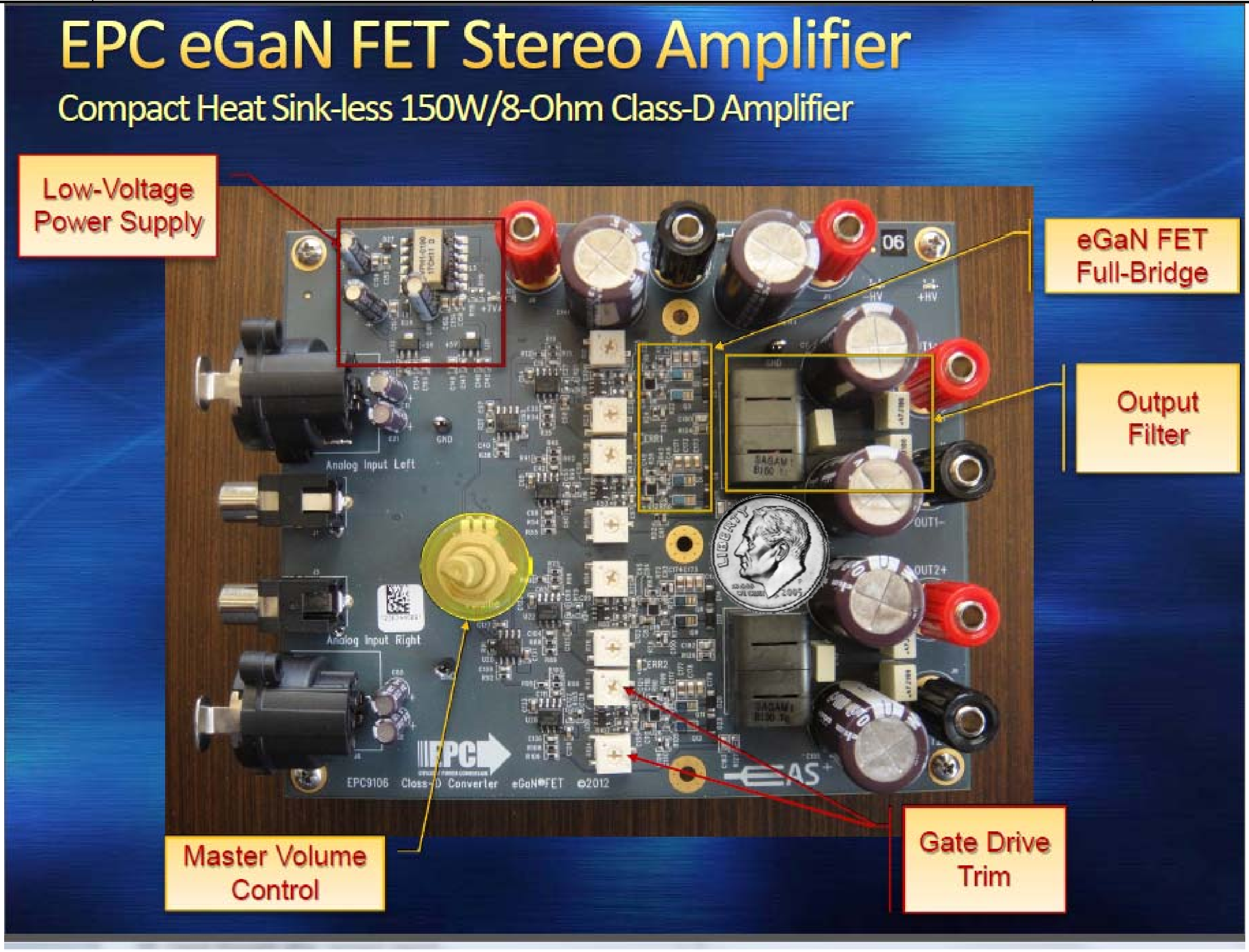


V_{IN}=48 V V_{OUT}=12 V

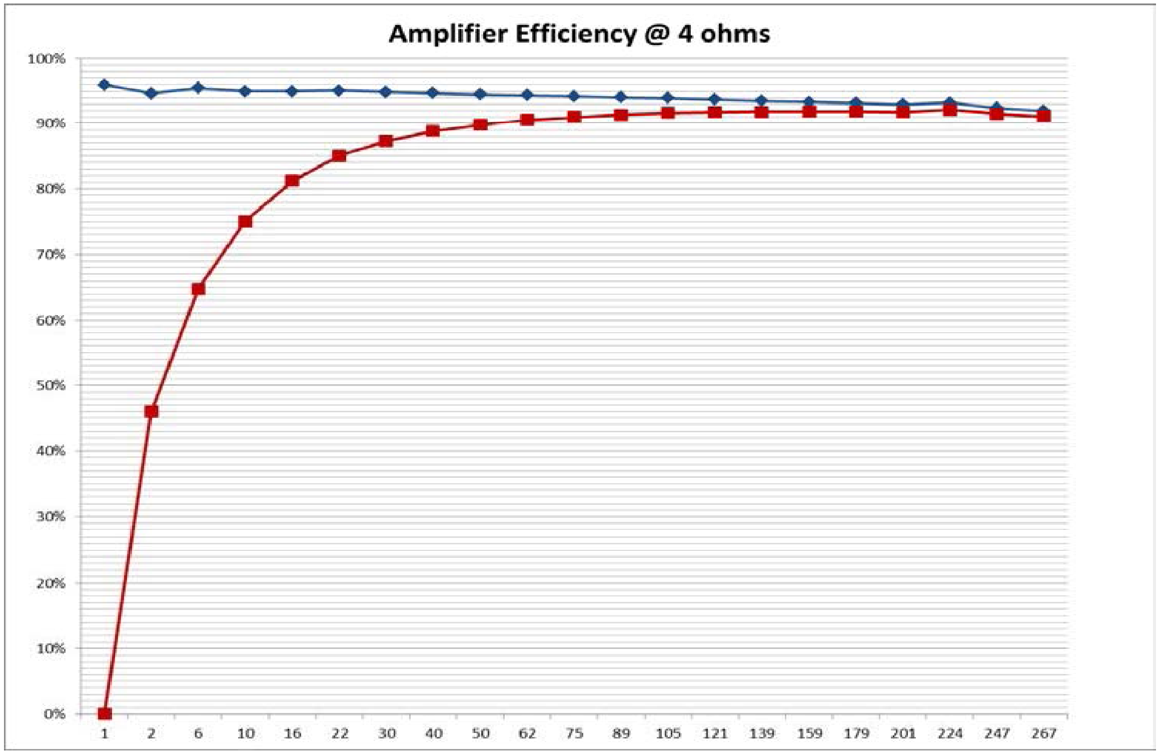
- FETs for Class D audio amplifiers balance the low $R_{DS(ON)}$ necessary for precise loudspeaker control and high sound quality against the low loss switching necessary for high frequency and high efficiency operation.

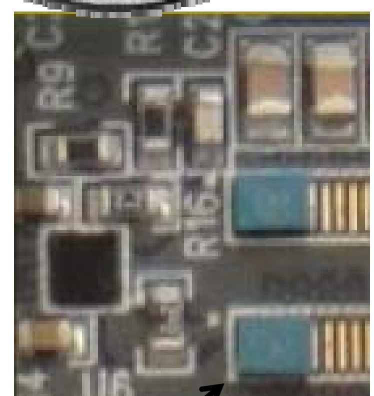


Class D Audio
250 W into 4 Ω



EPC Class D Audio Demo Board



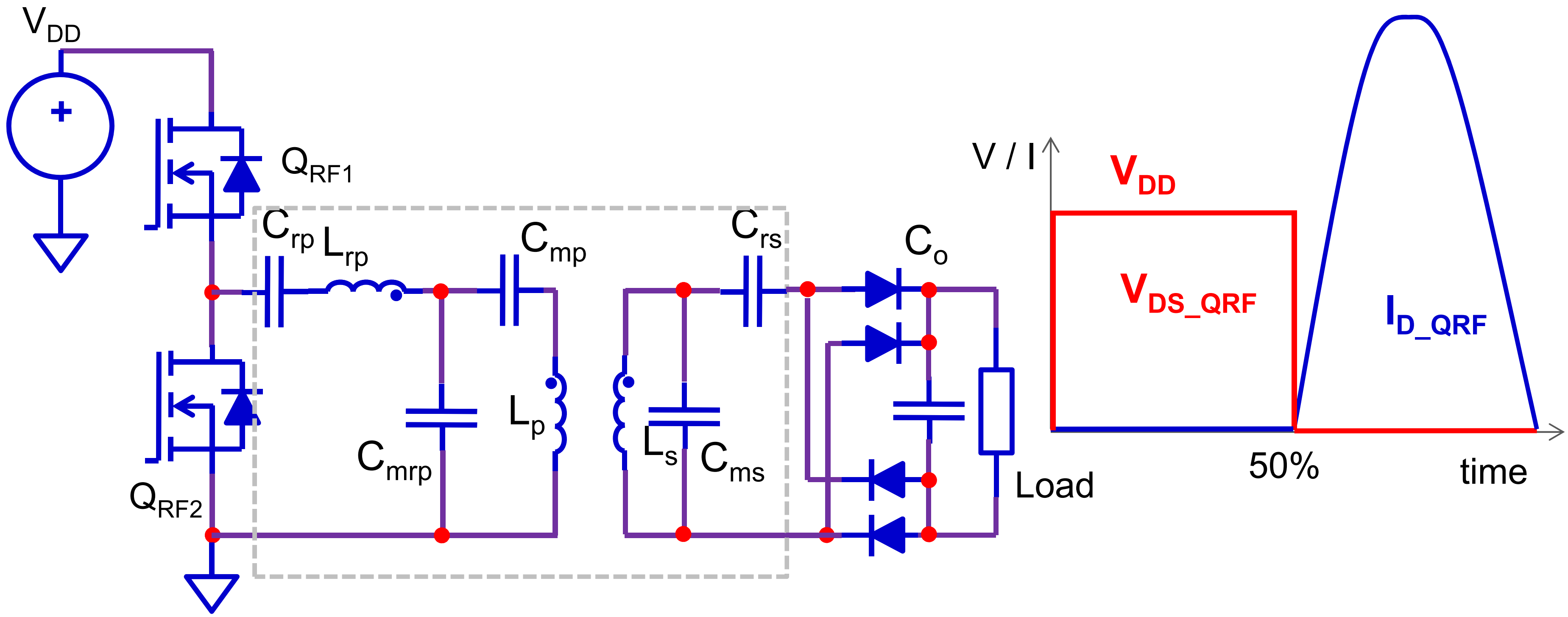


Power Block, **No Heatsink**, eGaN FETs 2.1 mm x 1.6 mm

EPC Class D Audio Demo Board

- THD+N vs. Level @ 1kHz, 8Ω
  - @ 5W Power 0.003%**
  - @ 15W Power 0.005%**
  - @ 50W Power 0.006%
  - @ Full Power 0.03%
- THD vs. Freq < 0.03% (20Hz to 20kHz)
- SNR/DNR 107.8dB Unweighted
  110dB (A-Wtd)
- PWM Freq 440 kHz

Wireless Power Transfer
Class D

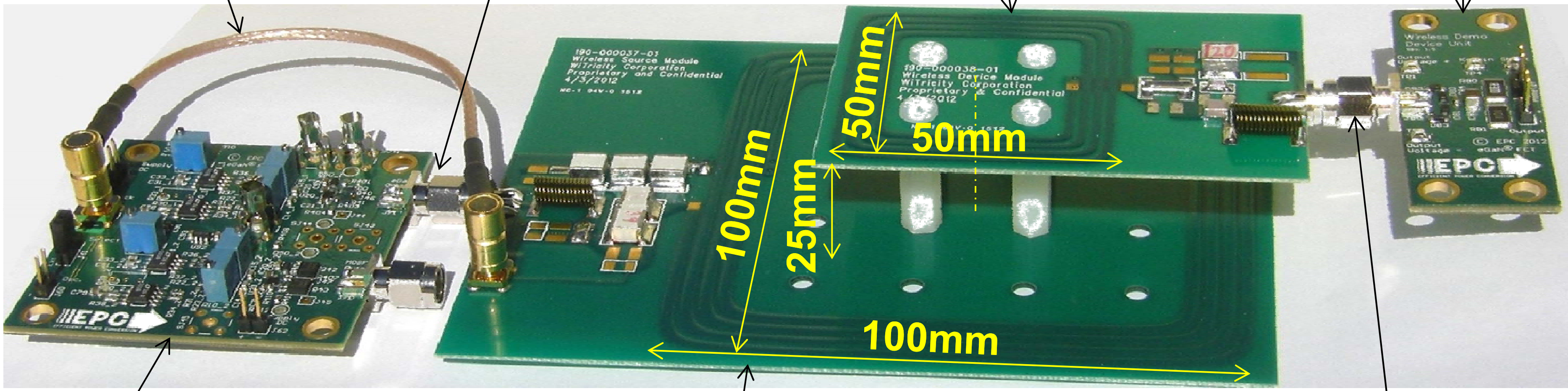


Coil Feedback

eGaN FETs RF connection

Device Coil

Device Board

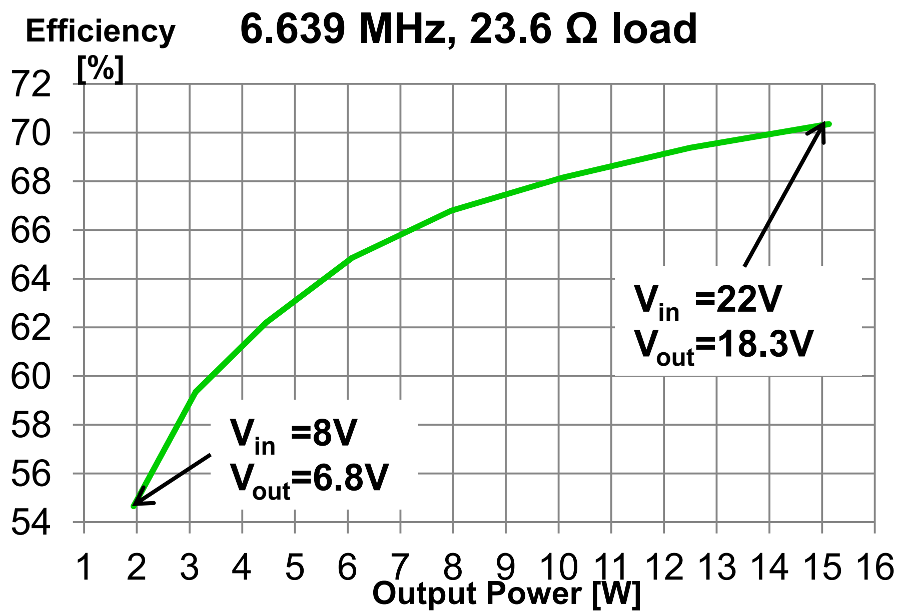


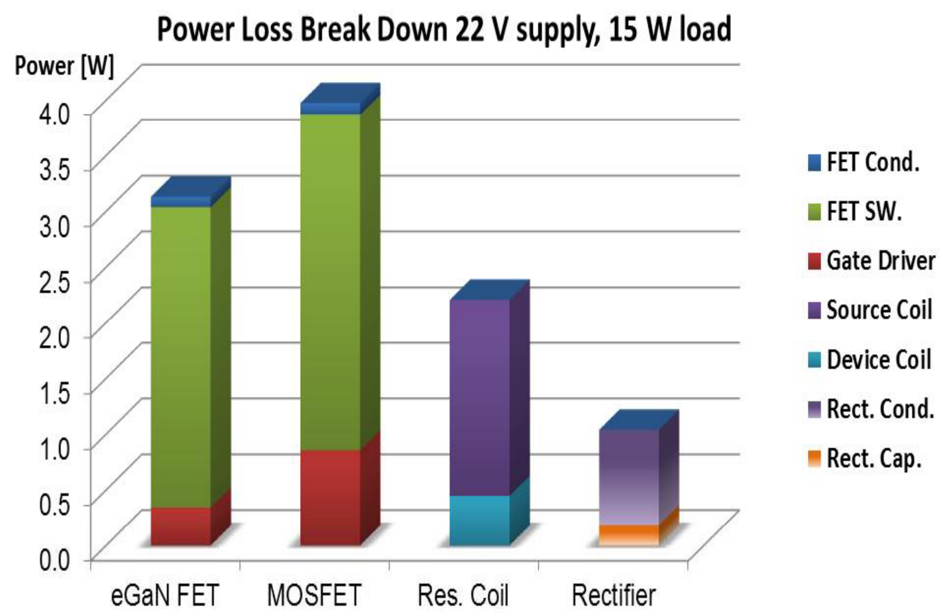
Source Board

Source Coil

RF connection

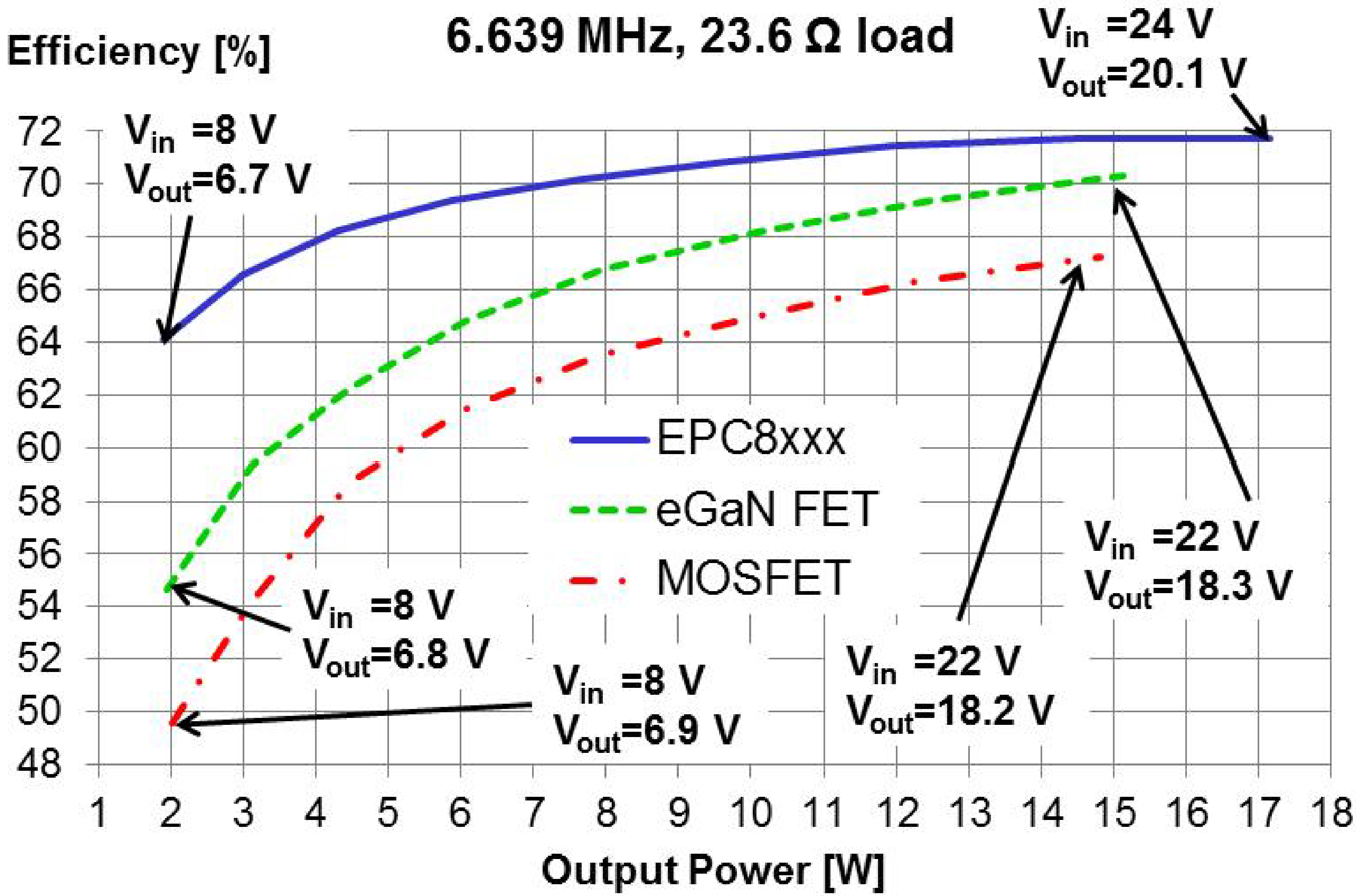
Wireless Power Transfer
End to End Efficiency



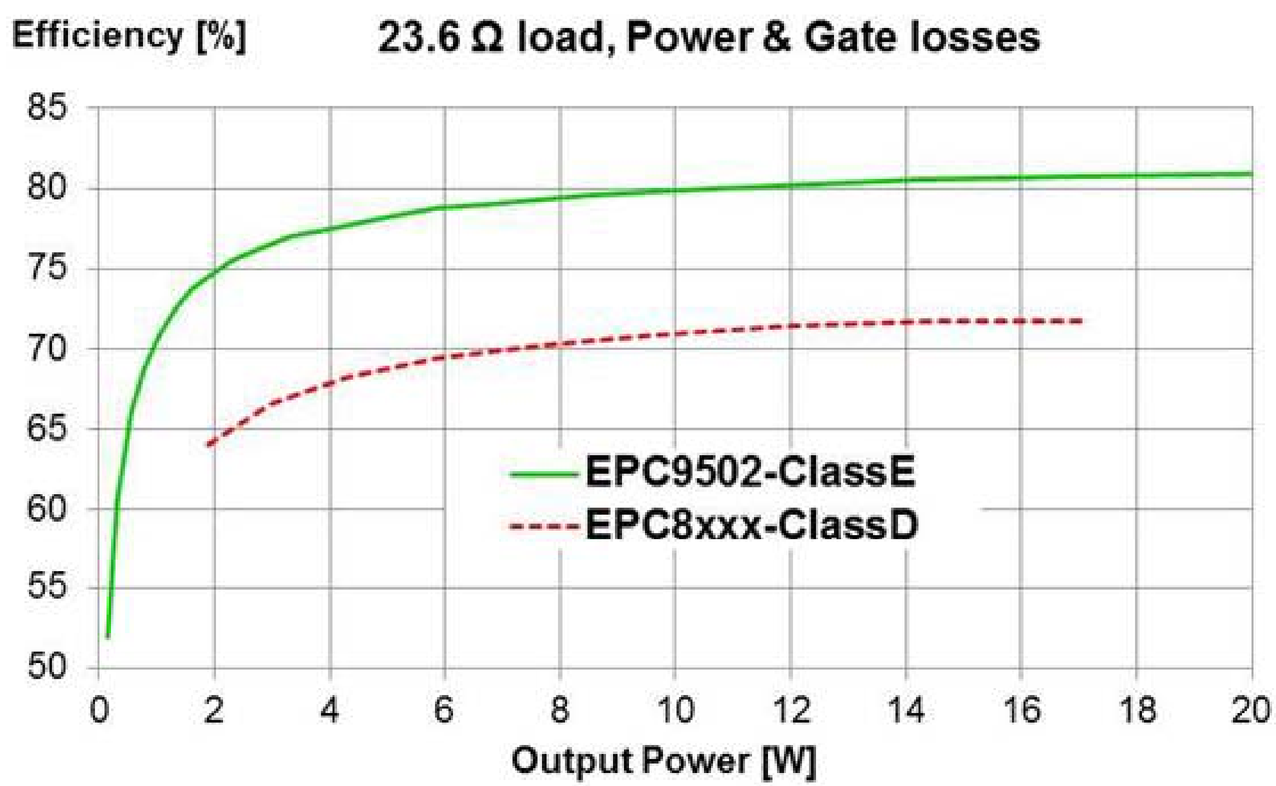


- Opportunity for optimization
  - EPC is looking for a partner to work with on product definition

Efficiency as Function of Load Power

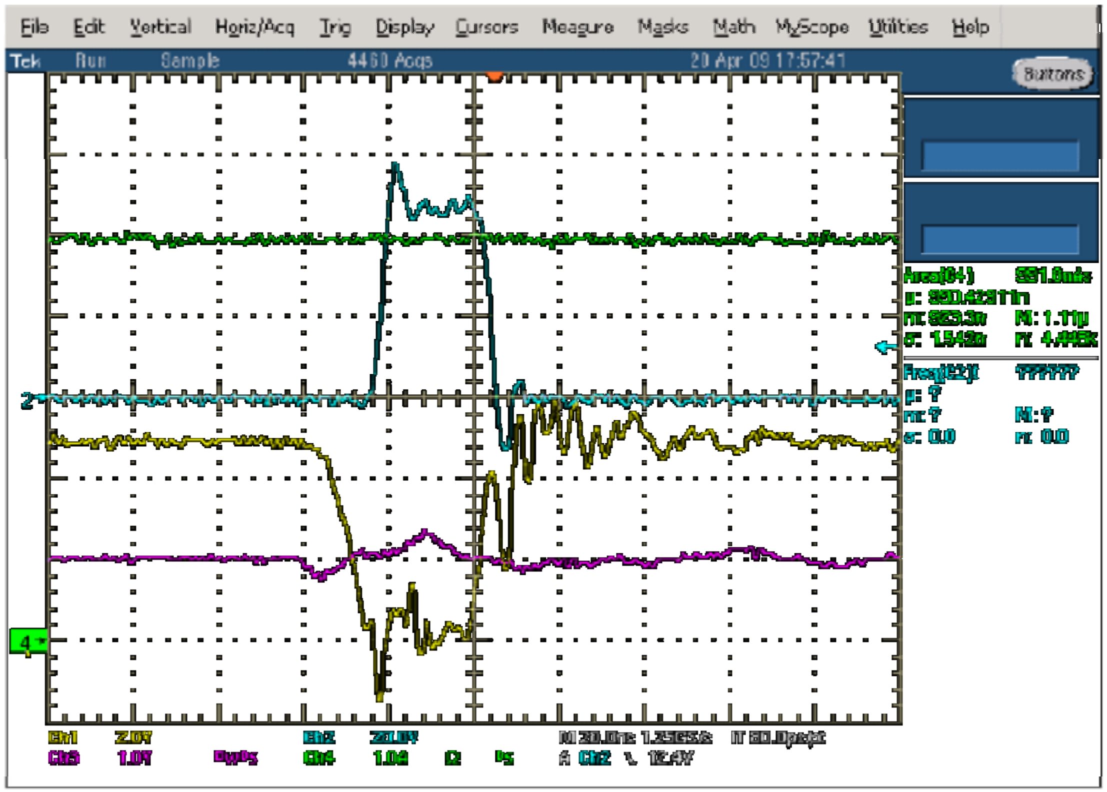


Class E results



- While Class E provides higher efficiencies under certain load and distance conditions, efficiency falls off significantly as load and distance change generating control challenges.

LiDAR Mapping, Sonar, Water Depth Measurement



- Fast switching and low $R_{DS(ON)}$ drive resolution and repetition rate
  - Collects better data faster

Other Applications

- Envelope Tracking RF Amplifier Power Supply
  – eGaN FETs enable bandwidth for effective tracking
- Ultra High Frequency Resonant Power Conversion
  – eGaN FETs enable air cores and ultra high power density
- Motor Drives
  – Higher frequency reduces harmonics increasing motor efficiency and reduced filtering

Other Applications

- MRI
  - – eGaN FETs enable broadband detuning and higher resolution
- Solar Power Generation – Inverter and Optimizer
  - – eGaN FETs enable higher efficiency and power density
- Power over Ethernet– PSE and PD
  - – eGaN FETs enable higher efficiency and power density

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search...

Design Support

- Applications
  - Design Basics
  - Assembly Basics
  - DC-DC Conversion
  - Notebook DC-DC
  - Power over Ethernet
  - Isolated Brick Converters
  - Envelope Tracking
  - Wireless Power
- eGaN FET Basics
- Device Models
- Demo Boards
- Training Videos
- eGaN® FET Reliability
- Technical Archives
  - Articles
  - Presentations

Device Models

Share

EPC has developed the world's first enhancement mode Gallium Nitride devices to be offered on the market. Our eGaN FETs provide designers employing any power conversion topology; full bridge, half bridge, buck converter, boost converter, PFC, flyback converter, forward converter, or LLC converter the opportunity to achieve significant performance enhancements compared with silicon power MOSFETs. In order to make EPC's eGaN FETs easy to use, we developed devices that behave very much like silicon power MOSFETs. User friendly tools make a significant impact in how easy it is to apply a new type of device. EPC has developed a comprehensive list of third-order device models so engineers can quickly design and implement circuits with minimum waste.

- Circuit Simulation Using Device Models

Part Number	V_{DS}(max) V_{DS}	$R_{DS(ON)}$(MAX) mΩ	PSPICE	LTSPICE	TSPICE	Spectre	Thermal Models
EPC2015	40	4		zip only			
EPC2014	40	16		zip only			
EPC2001	100	7		zip only			
EPC2007	100	30		zip only			
EPC2010	200	25		zip only			
EPC2012	200	100		zip only			

Click on a file icon to download individual configuration files, or click on zip icon at the bottom of the spice columns to download a .zip file containing all files for that SPICE type. Click on Part Number to access datasheet.

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Development Boards

Development Boards

EPC's half bridge development boards simplify the evaluation process of our eGaN FETs by including all the critical components and layout for optimal switching performance on a single board that can be easily connected into any existing converter.

Part Number	Description	V_{DS} (max)	Id (max RMS)	Featured Product	Schematic	Gerber	Bill of Materials	
EPC9001	Half Bridge Plus Driver	40	15	EPC2015				Buy Now
EPC9002	Half Bridge Plus Driver	100	10	EPC2001				Buy Now
EPC9003	Half Bridge Plus Driver	200	5	EPC2010				Buy Now
EPC9004	Half Bridge Plus Driver	200	3	EPC2012				Buy Now
EPC9005	Half Bridge Plus Driver	40	7	EPC2014				Buy Now
EPC9006	Half Bridge Plus Driver	100	5	EPC2007				Buy Now
EPC9007	Dual Parallel Evaluation	40		EPC2015				Reference Only
EPC9008	Dual Parallel Evaluation	100		EPC2001				Reference Only
EPC9010	Half Bridge Plus Driver	100	7	EPC2016				Buy Now

Demonstration Boards

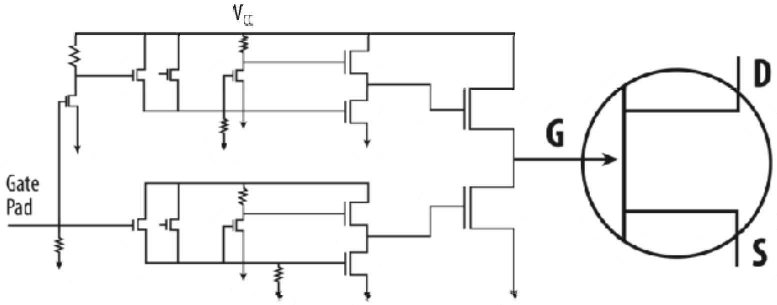
Demo Circuits

EPC's full circuit demonstration boards allow designers to evaluate the performance of EPC's eGaN FETs in a fully functioning working design.

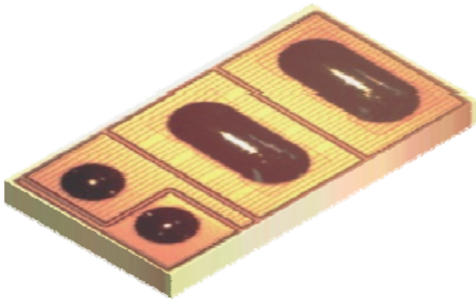
Part Number	Description	Vin	Vout	Iout	Featured Product	Schematic	Gerber	Bill of Materials	
EPC9101	19V to 1.2V Buck Converter	8V-19V	1.2V	18A	EPC2015/EPC2014				Buy Now
EPC9102	48V to 12V 1/8th Brick	36V-60V	12V	17A	EPC2001				Buy Now
EPC9104	15 W, 6.78 MHz Class D Wireless Power System	3V-24V	40V	10A	EPC2014				Request Demo
EPC9105	48V to 12V , 1.2 MHz Intermediate Bus Converter	36V-60V	12V	30A	EPC2001/EPC2015				Request Demo
EPC9107	28V to 3.3V Buck Converter	9V-28V	3.3V	15A	EPC2015				Buy Now

Beyond Discrete Devices

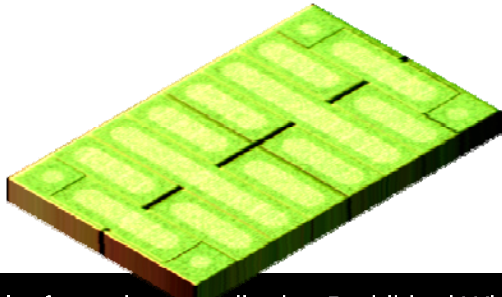
Driver On Board



Discrete FET with Driver



Full-Bridge with Driver and Level Shift



Status

- EPC and customers have demonstrated increased efficiency at increased frequency in many applications
- EPC eGaN FETs enable new ways of solving old problems
- Demand is strong and growing for EPC eGaN FETs
- New epi reactor is functioning well and will be qualified by August, 2013
- Process capable of 400 V

Actions

- What applications can eGaN FET technology help you increase output power, decrease size, or increase market share?
- Cooperation – work together to realize the value of GaN on
  - Demo Boards
  - Papers
  - Drive block
  - GaN IC

EPC

EFFICIENT POWER CONVERSION

The end of the road for silicon…..

is the beginning of the eGaN FET journey!