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

#### Solder side View

**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

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<th>Max. $R_{DS(ON)}$ (mΩ) ($V_{GS} = 5V$, $I_D = 0.5$ A)</th>
<th>Min. Peak Id (A) (Pulsed, 25 °C, $T_{pulse} = 300 \mu s$)</th>
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<th>Typical Capacitance (pF) ($V_{DS} = 20$ V; $V_{GS} = 0$ V)</th>
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eGaN® is a registered trademark of Efficient Power Conversion Corporation
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 50th 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
• Works like a MOSFET
  – Positive Gate to Source Voltage turns on bidirectional channel
  – Gate shorted to Source blocks from Drain to Source
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 $R_{DS(ON)}$
  – $Q_{OSS}$ - $< \frac{1}{2}$ of that of MOSFET with similar $R_{DS(ON)}$
    • Hard switched – losses proportional to $Q_{OSS}$
    • Soft switched – switching time proportional to $Q_{OSS}$
    • $Q_{OSS} \times R_{DS(ON)}$ 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
EPC2001 = 100 V, 5.6 mΩ typ.
BSC057N08 = 80 V, 4.7 mΩ typ.
EPC9107 Demonstration Board

Vin=12-28 V   Vout=3.3 V
Iout=15 A    FS=1 MHz
2 x EPC2015

Switching Node Voltage
Vin=28 V   Iout=15 A

~3V overshoot @ 15 Aout

~1.1ns rise time @ 15 A

5 V/ div
## Silicon Vs eGaN Wafer Costs

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With superior $R_{DS(ON)} \times \text{Area}$, eGaN FETs have many more devices per wafer.
Gen 3 eGaN FETs
Fast Gets Faster

![Graph showing the relationship between gate to source voltage (Vgs) and gate charge (Qg) for EPC8004 and EPC2014 devices.](Image)
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

\[ V_{\text{IN}} = 42 \, \text{V}, \quad V_{\text{OUT}} = 20 \, \text{V} \]
Wireless Power Transfer

Efficiency [%] vs. Output Power [W]

- **6.639 MHz, 23.6 Ω load**
  - $V_{in} = 8\,\text{V}$, $V_{out} = 6.7\,\text{V}$
  - $V_{in} = 8\,\text{V}$, $V_{out} = 6.9\,\text{V}$
  - $V_{in} = 22\,\text{V}$, $V_{out} = 18.2\,\text{V}$
  - $V_{in} = 22\,\text{V}$, $V_{out} = 18.3\,\text{V}$

- **EPC8004**
- **EPC2014**
- **MOSFET**
### Generation 3 eGaN® FETs

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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

- 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.

12 V to 1.2 V, 1 MHz
24 V to 1.2 V, 1 MHz
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:
Gate Drive and Reverse Conduction time
Gate Drive Considerations

- 4.5 V is sufficient for full enhancement
- $V_{GS(\text{Max})} = 6 \text{ V}$
  - 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](image)

![Figure 7: Reverse Drain-Source Characteristics](image)
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

- **40 V eGaN FET**
  - 70% loss reduction with external Schottky diode
  - ~1% efficiency drop per 10 ns total

- **40 V MOSFET**
  - No improvement for external Schottky diode
  - ~1% efficiency drop per 20 ns total

**Total dead-time cycle is twice per interval**

- eGaN FET, 5 ns dead-time
- eGaN FET, 10 ns dead-time
- eGaN FET + Schottky, 5 ns dead-time
- eGaN FET + Schottky, 10 ns dead-time
- MOSFET, 5 ns dead-time
- MOSFET, 10 ns dead-time
- MOSFET + Schottky, 5 ns dead-time
- MOSFET + Schottky, 10 ns dead-time

**Output Current (I_{OUT})**

- 4
- 6
- 8
- 10
- 12
- 14
- 16
- 18
- 20
- 22

**Efficiency (%)**

- 80
- 81
- 82
- 83
- 84
- 85
- 86
- 87
- 88
- 89
- 90
**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

  - **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 & low side drivers
  - 14ns propagation delay

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LM5113
eGaN FET Half Bridge Gate Driver

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)
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

- **EPC8005**
- **EPC2014**
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

\[ V_{IN} = 42 \, \text{V}, \, V_{OUT} = 20 \, \text{V} \]

- 5 MHz
- 10 MHz

- EPC8005
  - 65 V, 275 m\(\Omega\)

Efficiency vs. Output current (A)
Regulated, Isolated 48 V to 12 V

**GaN FET Efficiency vs Traditional MOSFET**

Input 36 to 75V; Regulated output 12V; Switching frequency at 333 KHz
GaN FET, 250 KHz MOSFET

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

FS = 1.2 MHz, VIN = 48 V, and IOUT = 26 A
eGaN FET Efficiency is Superior

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

\[ V_{IN} = 48 \text{ V}, \quad V_{OUT} = 12 \text{ V}, \quad F_s = 1.2 \text{ MHz} \]
48 V to 12 V Buck, 400 kHz

![Graph showing efficiency (%) versus output current (A) with power loss (W) on the y-axis.](image)
48 V Buck Power Stage

22.8mm
1/8th Brick Width

8 x EPC2001
4 Top Devices and 4 SR in parallel
eGaN FET Parallel Waveforms

$F_S = 300 \text{ kHz}$, $V_{IN} = 48 \text{ V}$, $V_{OUT} = 12 \text{ V}$, and $I_{OUT} = 30 \text{ A}$
Higher Current?...Parallel

Vin=48 V, Vout=12 V, Fs=300 kHz
Intermediate Bus Improvements

- 300 kHz eGaN FET Buck IBC
- 150 kHz Si Isolated IBC
- 1.2 MHz eGaN FET isolated DCX
- 245 kHz Si Isolated IBC

Output Current (A)

Efficiency (%)

V\text{IN}=48\ V\ V\text{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 eGaN FET Stereo Amplifier
Compact Heat Sink-less 150W/8-Ohm Class-D Amplifier

- Low-Voltage Power Supply
- eGaN FET Full-Bridge
- Output Filter
- Master Volume Control
- Gate Drive Trim
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
Wireless Power Transfer Demo Board

- Coil Feedback
- eGaN FETs RF connection
- Device Coil
- Device Board
- Source Board
- Source Coil
- RF connection

Dimensions:
- Source Board: 100mm x 100mm
- Device Board: 100mm x 50mm
- RF connection: 50mm x 25mm

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Wireless Power Transfer
End to End Efficiency

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

6.639 MHz, 23.6 Ω load

\[
\begin{align*}
V_{\text{in}} &= 22\text{V} \\
V_{\text{out}} &= 18.3\text{V}
\end{align*}
\]

\[
\begin{align*}
V_{\text{in}} &= 8\text{V} \\
V_{\text{out}} &= 6.8\text{V}
\end{align*}
\]

Power Loss Break Down 22 V supply, 15 W load

- FET Cond.
- FET SW.
- Gate Driver
- Source Coil
- Device Coil
- Rect. Cond.
- Rect. Cap.
Efficiency as Function of Load Power

6.639 MHz, 23.6 Ω load

- $V_{in} = 8$ V, $V_{out} = 6.7$ V
- $V_{in} = 8$ V, $V_{out} = 6.8$ V
- $V_{in} = 8$ V, $V_{out} = 6.9$ V
- $V_{in} = 22$ V, $V_{out} = 18.3$ V
- $V_{in} = 22$ V, $V_{out} = 18.2$ V
- $V_{in} = 24$ V, $V_{out} = 20.1$ V
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.
• 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
Device Models

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

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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.
## 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.

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<th>( I_{D} ) (max RMS)</th>
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## 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.

<table>
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<th>Part Number</th>
<th>Description</th>
<th>Vin</th>
<th>Vout</th>
<th>Iout</th>
<th>Featured Product</th>
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Beyond Discrete Devices

Driver On Board

Discrete FET with Driver

Full-Bridge with Driver and Level Shift
• 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
The end of the road for silicon.....

is the beginning of the eGaN FET journey!