The eGaN® FET
Journey Continues

Giving New Life to Moore’s Law

Efficient Power Conversion Corporation
Agenda

• Moore’s Law is Alive and Well for GaN FETs
  – $R_{DS(on)}$ Improvements
  – Figure of Merit Improvements

• Where is GaN Going?
  – DC-DC Converters
  – Wireless Power
  – Envelope Tracking

• A Look Into the Future

• Summary
On-Resistance Comparison

\[ R_{DS(on)} \text{ (mΩ)} \]

Drain-to-Source Voltage (V)

\[ V_{GS}=5 \text{ V} \]

Generation 2
2011

2.6x

Generation 4
2014

2.3x
Hard Switching FOM

\[
FOM_{HS} = (Q_{GD} + Q_{GS2}) \cdot R_{\text{DS(on)}} (pC \cdot \Omega)
\]

\[V_{DS} = 0.5 \cdot V_{DSS}, \quad I_{DS} = 20 \text{ A}\]

Generation 2

2011

Generation 4

2014

1.4x

2.4x

2.4x
Hard Switching FOM

\[ \text{FOM}_{\text{HS}} = (Q_{\text{GD}} + Q_{\text{GS2}}) \cdot R_{\text{DS(on)}} \cdot (pC \cdot \Omega) \]

- **EPC Gen 4**
- **EPC Gen 2**
- **Vendor A**
- **Vendor B**
- **Vendor C**
- **Vendor D**
- **Vendor E**

**Equation:**

\[ V_{\text{DS}} = 0.5 \cdot V_{\text{DSS}}, \quad I_{\text{DS}} = 20 \, \text{A} \]
Soft Switching FOM

\[ FOM_{SS} = (Q_G + Q_{OSS}) \cdot R_{DS(on)} \cdot pC \cdot \Omega \]

\[ V_{DS} = 0.5 \cdot V_{DSS} \]

Generation 2
2011

Generation 4
2014

1.3x
1.5x
Soft Switching FOM

\[ FOM_{SS} = (Q_G + Q_{OSS}) \cdot R_{DS(on)} \cdot (pC \cdot \Omega) \]

- EPC Gen 4
- EPC Gen 2
- Vendor A
- Vendor B

\[ V_{DS} = 0.5 \cdot V_{DSS} \]

Drain-to-Source Voltage (V)

FOM vs. Drain-to-Source Voltage (V)

- 3.2x
- 2.5x
- 2.4x

www.epc-co.com
Die Layout

Alternating Source and Drain Bars

Gate

Drain

Source

Substrate
Where is GaN going...
Hard Switching Buck Converter
Low Voltage Buck Converter

![Graph showing efficiency vs. output current for different devices.](image)

- **eGaN FET Generation 4**
- **eGaN FET Generation 2**
- **30 V MOSFET Module**

**Graph Details:**
- **Efficiency (%)**
- **Output Current (A)**
- **$V_{IN}=12\, \text{V}$**
- **$V_{OUT}=1.2\, \text{V}$**
- **$f_{sw}=0.5\, \text{MHz}$**
- **$f_{sw}=1\, \text{MHz}$**
Hard Switching Buck Converter
Higher Voltage Performance

\[ V_{IN} = 48\, V \quad V_{OUT} = 12\, V \]

- **eGaN FET Generation 2**
- **eGaN FET Generation 4**
- **80 V MOSFET**

**Efficiency (%) vs. Output Current (A)**

- Solid line: \( f_{sw} = 300\, \text{kHz} \)
- Dashed line: \( f_{sw} = 500\, \text{kHz} \)
Envelope Tracking

- Envelope Tracking (ET) is used to reduce the peak power and increase the efficiency of power amplifiers.
- It is particularly useful in wireless communication standards like 3G (W-CDMA), 3.5G (HSUPA), and 4G (LTE / OFDM).
- The diagram shows the comparison between W/O ET and With ET for different mobile communication standards.

Reference: Nujira.com website
Very High Frequency eGaN FETs

![Graph showing characteristics of EPC8004 and EPC2014 eGaN FETs]

- **EPC8004 eGaN FET**
- **EPC2014 eGaN FET**
Efficiency Results

42 V_{IN} to 20 V_{OUT}, 10 MHz

EPC8005
Switching Waveforms

10 MHz switching, no load, large dead-time

Expected commutation based on eGaN FET $C_{OSS}$

Actual commutation based on total $C_{OSS}$ – including IC capacitance

Bootstrap $Q_{RR}$

Inverted Inductor current

Switch-node voltage

10V/div, 100mA/div, 10ns/div
Improving HF Performance

42 \( V_{\text{IN}} \) to 20 \( V_{\text{OUT}} \), 10 MHz

With improved driver

EPC8005
Wireless Power

The global wireless charging market is estimated to grow to $10B by 2018, a CAGR of 42.6%.
Wireless Power Setup

- Source Board
- Source Coil
- eGaN FETs RF connection
- Device Coil
- Device Board
- Coil Feedback
- RF connection
**Class-E Power Amplifier**

- **Diagram:**
  - Voltage source connected to a transistor (Q1).
  - Output impedance (Z_load).
  - Inductors (Le, L_RFchck).
  - Capacitors (C_sh, C_s).

- **Equation:**
  \[ V_{DD} \times 3.56 \]

- **Components:**
  - **LM5113 Gate Driver**
  - **EPC2012**
  - **Source Coil Connection**
  - **Le = 500 nH**
  - **C_sh = 100 pF**
  - **L_RFchck = 150 µH**
  - **Underneath Coil**
ZVS Class-D Power Amplifier

V_{DD} \rightarrow Q_1 \rightarrow L_{ZVS} \rightarrow C_{ZVS} \rightarrow Z_{load} \rightarrow Q_2 \rightarrow V_{DD}

LM5113 Gate Drive
EPC8009 x2
Source Coil Connection

L_{ZVS} = 500 \text{ nH}
C_{ZVS} = 1 \mu F
Dead-time Preset
Performance Comparison

V_{out} = 15 \, \text{V}

Efficiency [%] vs. DC Load Resistance [\Omega]

- \eta_{ZVS-CD}
- \eta_{CE-2012}
- P_{out}

Category 3 Power zone

Output Power [W]
Other Key Applications

• LiDAR
• High Resolution MRI Imaging
• Network and Server Power Supplies
• AC Adapters
• Class-D Audio
• Energy Efficient Lighting
• Robotics
Moore’s Law Revival

Generation 3
Higher Frequency
1 - 3 GHz
Launched September 2013

Generation 4
2 x Performance Improvement
June 2014

Integrated Circuits
Summer 2014

Generation 5
2 x Performance Improvement
September 2014

High Voltage
September 2014

Gen 2
2010-2013
40 V - 200 V
~500 MHz

Generation 4
2 X Performance Improvement

Integrated Circuits
Summer 2014

High Voltage
September 2014
Summary

• eGaN FETs continue to improve rapidly – even faster than Moore’s Law!

• Hard-switched POLs using forth-generation eGaN FETs realize double the benefit in efficiency when compared with second-generation eGaN FETs.

• eGaN FETs are enabling efficient RF envelope tracking for 4G-LTE base stations.

• New topologies that apply eGaN FETs in loosely coupled wireless power are the most efficient and stable.

• GaN is *always* better than silicon!