National Taiwan University

Emerging Applications for GaN Transistors

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Agenda

• Why Gallium Nitride?
• Hard Switched Converters
  • Envelope Tracking
• High Frequency Resonant Converters
  • Wireless Power
• Summary
Why Gallium Nitride?

• Enhancement-Mode devices available (eGaN® FETs)
• $R_{DS(ON)}$ per unit area much smaller than silicon power MOSFET
• Much faster switching
• Very low capacitance ($C_G$, $C_{ISS}$, $C_{OSS}$)
• No parasitic PN junction body ($Q_{RR}=0$)
eGaN® FET Structure

- AlGaN Electron Generating Layer
- Dielectric
- Two Dimensional Electron Gas (2DEG)
- Aluminum Nitride Isolation Layer
Hard Switched Converters
Example: Buck Converter

- **Drive Circuit**
  - \( V_L \) 
  - \( Q1 \) 
  - \( V_a \) 
  - \( L1 \) 
  - \( V_O \) 
  - \( R_L \) 
  - \( C \) 
  - \( R_C \) 
  - \( R \)

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**Graphs**

- **Hard switching:**
  - Rise time \(~2.5\) ns
  - Peak \( dV/dt \) \(~30\) V/\( ns \)

- **Inductor current waveform**
  - Inverted, \(~8\) A load

- **Soft switching:**
  - Fall time \(~4\) ns
  - Switching time is load dependent
Ls: Common Source Inductance

L_loop: High Frequency Power Loop Inductance

V_in = 12 V, V_out = 1.2 V, F_s = 1 MHz, I_out = 20 A
**Packaging Evolution**

**Device Loss Breakdown**

- **V\textsubscript{IN} = 12V**
- **V\textsubscript{OUT} = 1.2V**
- **I\textsubscript{OUT} = 20A**
- **F\textsubscript{S} = 1MHz**

- **Power Loss (W)**
  - **So-8**: 18%
  - **LFPAK**: 27%
  - **DirectFET**: 47%
  - **LGA**: 82%

**Efficiency (%) vs. Switching Frequency (MHz)**

- **So-8**
- **LFPAK**
- **DirectFET**
- **eGaN**

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EPC - The Leader in eGaN® FETs  
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Layout Impact on Efficiency

Experimental Efficiency

\[ \text{Efficiency} (\%) \]

\[ \text{Output Current} (I_{\text{OUT}}) \]

\[ L_{\text{Loop}} \approx 2.9 \text{nH} \]
\[ L_{\text{Loop}} \approx 1.6 \text{nH} \]
\[ L_{\text{Loop}} \approx 1.0 \text{nH} \]

\[ V_{\text{IN}} = 12 \text{ V}, \quad V_{\text{OUT}} = 1.2 \text{ V}, \]
\[ F_S = 1 \text{ MHz}, \quad L = 150 \text{ nH} \]
Peak Voltage Comparison

Voltage Overshoot (%) vs. High Frequency Loop Inductance ($L_{\text{LOOP}}$)

$V_{\text{IN}}=12\,\text{V}$, $V_{\text{OUT}}=1.2\,\text{V}$, $F_S=1\,\text{MHz}$, $L=150\,\text{nH}$
Envelope Tracking
RF Transmission

- Peak efficiency up to 65%
- Average efficiency only 25%

Output Power (dBm)

PA Efficiency (%)

Fixed supply

Output Probability

Average Power

Peak Power

Average efficiency only 25%
Effect of ET

Average efficiency
~50% (incl. ET)

Envelope Tracking

Average Power

Output Probability

Output Power (dBm)

PA Efficiency (%)
Linear-Assisted Buck ET
45 V$_{\text{IN}}$  22 V$_{\text{OUT}}$

![Graph showing efficiency and power loss vs. output power for 4 MHz and 1 MHz operations.](image)
4MHz Loss Breakdown

Power Loss (W)

- Inductor
- Qoss
- Switching
- Gate drive
- Conduction

Top eGaN FET | Bottom eGaN FET | Other

Power Loss:
- Top eGaN FET: 5.0
- Bottom eGaN FET: 1.5
- Other: 2.5
Resonant Converters
eGaN® FET vs MOSFET

- Resonant Capacitor
- Secondary Devices
- Transformer
- Primary Devices
- Input Capacitors
Duty Cycle Comparison

\[ D_{\text{MOSFET}} = 34\% \]
\[ D_{\text{eGaN}} = 42\% \]

\[ F_S = 1.2 \text{ MHz}, \ V_{IN} = 48 \text{ V}, \text{ and } V_{OUT} = 12 \text{ V} \]
Efficiency Comparison

**1.2 MHz eGaN FET**

**1.2 MHz MOSFET**

\[ F_S = 1.2 \text{ MHz}, \ V_{IN} = 48 \text{ V}, \text{ and } V_{OUT} = 12 \text{ V} \]
Loss Breakdown

Power Loss (W)

- Gate Drive
- Transformer Core
- Conduction + Turn Off

F_S = 1.2 MHz, V_IN = 48 V, and V_OUT = 12 V
Wireless Power
Wireless Power
Wireless Power
Wireless Power

[Diagram showing wireless power transfer setup with labels:
- Coil Feedback
- eGaN FETs RF connection
- Device Coil
- Device Board
- Source Board
- MOSFET RF connection
- Source Coil
- RF connection]
Efficiency Comparison

Efficiency [%]

6.639 MHz, 23.6 Ω load

- $V_{in} = 8\, V$  
  $V_{out} = 6.8\, V$

- $V_{in} = 22\, V$  
  $V_{out} = 18.2\, V$

- $V_{in} = 22\, V$  
  $V_{out} = 18.3\, V$

- $V_{in} = 8\, V$  
  $V_{out} = 6.9\, V$

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Loss Breakdown

Power Loss Break Down 22 V supply, 15 W load

- eGaN FET
- MOSFET
- Ind. Coil
- Rectifier

Power [W]

- FET Cond.
- FET SW.
- Gate Driver
- Pri. Coil
- Sec. Coil
- Rect. Cond.
- Rect. Cap.
Summary

• eGaN FETs operate efficiently in multi-megahertz envelope tracking systems which can reduce transmit power by 50%.
• eGaN FETs reduce power losses by 25% or more in 1.2 MHz resonant DC-DC converters.
• eGaN FETs reduce power losses by 25% in 6.78 MHz wireless power transmission systems.
• You can always improve efficiency with eGaN FETs!
The end of the road for silicon..... is the beginning of the eGaN FET journey!