Envelope Tracking GaN Power Supply for 4G Cell Phone Base Stations

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Outline

• ET power supply background
• Design guidelines
• Experimental results
Wirelessly connected world

• 74% growth in global mobile traffic in 2015*

• 4G traffic exceeded 3G traffic for the first time in 2015*

Faster means higher PAR

Peak-to-Average Ratio (PAR)

<table>
<thead>
<tr>
<th>Link Speed</th>
<th>GSM</th>
<th>EDGE</th>
<th>WCDMA</th>
<th>LTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faster</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bandwidth* [MHz]</th>
<th>0.2</th>
<th>0.2</th>
<th>5</th>
<th>20</th>
</tr>
</thead>
</table>

<table>
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<tr>
<th>Envelope PAR* [dB]</th>
<th>0</th>
<th>3.4</th>
<th>10.6</th>
<th>~12</th>
</tr>
</thead>
</table>

* Source: 3GPP and Wikipedia – Spectral efficiency
PA efficiency

- PA efficiency is low with fixed supply voltage
- ET improves efficiency

![Diagram showing PA efficiency with and without ET supply.](picturereference: Nujira.com)
Envelope tracking power supply

• Introduced in 1928 [1]
• ET in phone (low power), 2014
• ET in base station
  ▪ Si, 10 MHz bandwidth, 8-phase switcher [2]
  ▪ GaN?
• This work:
  ▪ Technology: GaN
  ▪ Bandwidth: 20 MHz (4G LTE)
  ▪ Efficiency: > 90%
  ▪ Power: 60 W

Topology: synchronous buck converter

- Multi-phase (bandwidth and power)
- Zero-Voltage Switching (efficiency and current balancing)
- $R_L$ as the load -- representing a saturated PA

![Circuit Diagram]

$L_1$: 68 nH
$C_2$: 5 nF
$L_3$: 22 nH
$C_4$: 1.6 nF
$R_L$: 2.6 Ω
Switching frequency $f_s$

- $f_s = 10 \times \text{BW}$ with 2nd order filter
- $f_s = 5 \times \text{BW}$ with 4th order filter

- BW required: 20 MHz
- (Effective) switching frequency: 100 MHz
- 4-phase converter, per-phase switching frequency: 25 MHz

1. Half-bridge gate driver for eGaN FETs at 25 MHz?
2. How to get high efficiency at 25 MHz?
Gate driver with synchronous bootstrap FET[3]

- Use synchronous eGaN FET bootstrap for high side supply
- Use digital isolator for signal level shifting

Choosing FETs

- Synchronous bootstrap FET: EPC2038
- Main power FETs: EPC8000 series with 40 V rating

<table>
<thead>
<tr>
<th>EPC Part Number</th>
<th>Package (mm)</th>
<th>$V_{DS}$ (V)</th>
<th>$R_{DS(on)}$ @5V (mΩ)</th>
<th>$Q_G$ @5 V Typ. (pC)</th>
<th>$Q_{GS}$ Typ. (pC)</th>
<th>$Q_{GD}$ Typ. (pC)</th>
<th>$Q_{OSS}$ (pC)</th>
<th>$I_D$ (A)</th>
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<tbody>
<tr>
<td>EPC2038</td>
<td>BGA 0.9x0.9</td>
<td>100</td>
<td>2800</td>
<td>44</td>
<td>16</td>
<td>5</td>
<td>140</td>
<td>0.5</td>
</tr>
<tr>
<td>EPC8004</td>
<td>LGA 2.05x0.85</td>
<td>40</td>
<td>110</td>
<td>370</td>
<td>120</td>
<td>47</td>
<td>630</td>
<td>2.7</td>
</tr>
<tr>
<td>EPC8007</td>
<td>LGA 2.05x0.85</td>
<td>40</td>
<td>160</td>
<td>302</td>
<td>97</td>
<td>25</td>
<td>406</td>
<td>3.8</td>
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<tr>
<td>EPC8008</td>
<td>LGA 2.05x0.85</td>
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<td>325</td>
<td>177</td>
<td>67</td>
<td>12</td>
<td>211</td>
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Improving efficiency (1) – FETs

- Conduction loss \( P_c = I_{RMS}^2 R_{on} \) vs. switching loss \( P_s \)

\[
P_s \approx \frac{1}{2} C_{oss} V_{in}^2 f_s
\]

- Use analytical loss model similar to [4]

- Result: EPC8004

Improving Efficiency (2) – ZVS Inductor

Wide output voltage range (5 – 28 V)

1. 68 nH: 94.5% predicted tracking average efficiency
2. 56 nH: 93.7% predicted tracking average efficiency

Predicted static efficiency vs. signal PDF
Final Design

EPC2038

5 V

Q_BTST

R_damp

Digital Isolator

Logic gate

Vin

L1

L3

C2

C4

RL

vdd

68 nH x4

C2: 5 nF

L3: 22 nH

C4: 1.6 nF

RL: 2.6 Ω

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PCB Design

Transmission line delay match

- Accurate dead time (improve efficiency)
- Low distortion

100 Ω differential transmission lines

LVDS receivers

Phase 2 zoom in
Test Setup

- Envelope signal generated using 20 MHz LTE (OFDM) modulation
- Digital ‘on/off’ signals stored in FPGA memory
- 4.8 Gbps (~200 ps resolution) FPGAs:
  - Altera Stratix IV or Arria V

![Diagram of test setup]

Envelope signal -> Off-line signal processing -> FPGA memory -> PWM -> To gate drivers
Efficiency

- **Power stage efficiency**
- **Total efficiency**
- **LTE envelope PDF**
Oscilloscope Waveform

ZVS

Partial ZVS

\[ V_{sw1} \]

\[ V_{sw2} \]

\[ V_{sw3} \]

\[ V_{sw4} \]

\[ V_{dd} \]

20 ns
Waveform Comparison

Normalized RMS error: 1.2%

Target
Experimental
Thermal

- No heat sink, no fan
- Phase current balancing verified
Summary

- ET – Improves PA efficiency
- ET supply for 4G cell phone base stations
  - eGaN FETs – low $C_{\text{ISS}}$, $C_{\text{OSS}}$, fast switching time
  - 20 MHz bandwidth, 60 W average, 92% efficiency
  - Power level Scalable

Thank you! Questions?