GaN Power HEMT Tutorial: GaN Applications

GANPOWER INTERNATIONAL INC
(In collaboration with Digiq Power)

Fred Yue Fu (傅玥)
Co-founder and COO
GaNPower International Inc.
Contents

- Session 1: GaN devices basics
- Session 2: GaN Gate Driving
- Session 3: GaN Applications
  - GaN vs. Silicon, from Application Perspective
  - GaN Applications Survey
  - SCC Solution Demos (in collaboration with DigiQ Power)
  - A brief introduction to GaNPower International
Rough Comparison: GaN vs. MOSFET

<table>
<thead>
<tr>
<th></th>
<th>MOSFET</th>
<th>GaN</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switching speed</td>
<td>Slower</td>
<td>Faster</td>
<td>Very Good</td>
</tr>
<tr>
<td>$R_{ds}$</td>
<td>Larger</td>
<td>Smaller</td>
<td>Excellent</td>
</tr>
<tr>
<td>$V_{gs}$ range</td>
<td>Wider</td>
<td>Narrower</td>
<td>Bad</td>
</tr>
<tr>
<td></td>
<td>(5 - 20V)</td>
<td>(4.5 to 6.5V)</td>
<td></td>
</tr>
<tr>
<td>Avalanche</td>
<td>Yes</td>
<td>No</td>
<td>Bad</td>
</tr>
<tr>
<td>Price</td>
<td>Lower</td>
<td>Higher</td>
<td>Bad</td>
</tr>
</tbody>
</table>

Need new technologies optimized for GaN

- Take full advantages of GaN device
- Better Performance at higher / same cost
MOSFET as a Switch vs. GaN as a Switch

MOSFET used for past 30 years:
- All the problems ironed out
- All the lessons learned
- Very well understood
- Optimal topologies identified
- Application strategies found

30 years ago, initial MOSFET:
- As compared with BJT
- Very sensitive to noise
- Easy to get damaged
- Similar scenario as the GaN vs MOSFET

GaN as a new device:
- More expensive ( - - - )
- Faster switching speed ( + + )
- Lower on resistance value (R_{ds}) ( + + + )
- Higher “body diode” voltage ( - )
- No “body diode” reverse-recovery charge ( ++ )
- Narrow \( V_{gs} \) Range ( - - )
GaN is Expensive (---)

- How to justify the higher cost
  - Smaller sizes
  - Higher efficiency
  - Something that MOSFET cannot achieve

- Need a new eco-system for GaN switch
  - Topology
  - Control
  - Gate drive
  - Package
Faster Switching Speed (+ +)

Good:
- Lower switching loss
- Higher switching frequency

Bad:
- Large voltage ringing due to L*di/dt
- Coupled to gate signal causing higher GaN loss, even damage
- Increase gate resistor value

Consequence:
- Paramount to reduce AC loop (to reduce L)
- Extensive experience on layout
- Limited improvement for hard switching topology
Lower On Resistance ($R_{ds}$) (+ + +)

**Good:**
- Lower conduction loss
- Allow for higher conduction current

**Bad:** None

**Consequence:**
- Resonant converter is more advantageous
- Example: 250 – 400V, 12V / 500W

**Example:** 250 – 400V, 12V / 500W

<table>
<thead>
<tr>
<th></th>
<th>Conduction Loss</th>
<th>% of $P_{out}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSFB with MOSFET (0.11Ω)</td>
<td>1.70W</td>
<td>0.34%</td>
</tr>
<tr>
<td>LLC with MOSFET (0.11Ω)</td>
<td>2.75W</td>
<td>0.55%</td>
</tr>
<tr>
<td>LLC with GaN (0.05Ω)</td>
<td>1.25W</td>
<td>0.25%</td>
</tr>
</tbody>
</table>
Higher “Body Diode” Voltage (−)

Good:

- None

Bad:

- Higher loss when “Body Diode” Conducts

Consequence:

- Very important for dead time control
- Different (adaptive) dead time for different conditions
- Reduce the current through the “Body Diode”
No "Body Diode" Reverse-Recovery (+)

Good:
- One less loss source

Bad:
- None

Consequence:
- For Totem-Pole Bridgeless Boost converter
- 99% + efficiency
- Only PWM converter with GaN
Narrow $V_{gs}$ Range (---)

**Good: None**

- 4.5V to 6.5V
- Reasonable for $V_{cc}$ circuit

**Bad:**

- $V_{gs}$ variation due to large $L \cdot di/dt$
- Common source inductor ($L_{cs}$) impact

**Consequence:**

- Paramount to reduce $L_{cs}$
- Integrated driver + GaN switch in same die
- Topology not sensitive to $L_{cs}$
GaN: ZVS and LLC

Zero-Voltage Switching for GaN device:
- Best operating mode for GaN
- Maximize the benefit of GaN devices
- Higher switching frequency and low conduction loss

DCM operation for PWM converter:
- Making the inductor current negative
- Using negative current to achieve ZVS
- ZVS operation of PWM converter

Resonant converter:
- LLC resonant converter
- Achieving ZVS over entire operating range
Why Hard-Switching is not for GaN?

Blue: Super Junction  Red: E-mode GaN  Both ~70 mΩ \( R_{\text{dson}} \)

- Superjunction capacitances are much higher when compared to GaN
- Superjunction \( C_{\text{oss}} \) and \( C_{\text{rss}} \) behave very nonlinearly with voltage
- Output charge \( Q_{\text{oss}} \) difference is very large (up to 10x at 100 V)
- Difference in \( E_{\text{oss}} \) is much smaller (e.g.: 20% at 400 V)

Source: Tim McDonald, GaN in a Silicon world: competition or coexistence? Infineon Technologies, APEC 2016

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Why Should We Use ZVS Switching for GaN?

- There is no large difference in $E_{oss}$ at 400V for GaN and SJ FET with same rated BV and comparable $R_{dson}$

- $C_{o(tr)}$ of GaN device is 10x lower than SJ FET, which can be leveraged in ZVS applications where it can result in lower power losses. This benefit grows with frequency (as a fixed deadtime grows in percentage of total switching cycle time)

- Hard switching turn-on loss is much higher than turn-off loss, use ZVS turn-on and fast hard turn-off can optimize the switching loss

Source: Tim McDonald, GaN in a Silicon world: competition or coexistence? Infineon Technologies, APEC 2016
Features of Resonant Converters

Frequency control

- Output voltage determined by ratio of $F_s$ and $F_r$
- Around 50% duty cycle with dead time

Zero Voltage Switching (ZVS)

- ZVS over entire input and output voltage / load current range
- Very low switching loss
- $L_{CS}$ is no long an impact

Higher Conduction Loss

- Higher circulating current through resonant tank
- Not an issue with GaN’s lower $R_{ds,on}$

The Topology is Optimized for GaN Devices
Contents

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GaN Applications Survey

First use of GaN: 100 V cascode device for class D audio amplifier

Leverages extremely low $Q_{rr}$

Improves Audio Quality

<table>
<thead>
<tr>
<th>Key values</th>
<th>GaN benefit vs Silicon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio Quality</td>
<td>Lower - THD improves from faster/cleaner switching characteristics</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Higher - from lower resistance</td>
</tr>
<tr>
<td>More channels, smaller size</td>
<td>Smaller – Full SMD w/o heatsink, high frequency for smaller LPF</td>
</tr>
</tbody>
</table>

Source: Tim McDonald, GaN in a Silicon world: competition or coexistence? Infineon Technologies, APEC 2016

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GaN Applications Survey: Totem-Pole Bridgeless Boost at ZVS

Benefits:
Smaller size and high efficiency

Z. Liu, FC Lee, etc, “Design of GaN-Based MHz Totem-Pole PFC Rectifier”, JESTPE 2016
GaN Applications Survey: Air Conditioning Inverter


© Fred Yue Fu (傅玥), GaNPower International Inc.
GaN Applications Survey:
3600W LLC 380V to 52V Converter from Infineon

Power Density: 3600W/22.5 in.³ = **160 W/in.³**

Moshe Domb, E-Mode GaN, 600V, 0.07Ohm, utilized in 3600W LLC 380V to 52V Converter, Infineon, APEC 2018

© Fred Yue Fu (傅玥), GaNPower International Inc.
GaN Applications Survey: 3600W LLC 380V to 52V Converter from Infineon

- CoolMOS requires much longer dead time between primary switches: 350ns compared to 130ns with GaN.

- The longer dead time for CoolMOS also forces a higher primary & secondary peak current, compared to GaN to deliver the same output current, which causes more loss.

Moshe Domb, E-Mode GaN, 600V, 0.07Ohm, utilized in 3600W LLC 380V to 52V Converter, Infineon, APEC 2018
GaN Applications Survey:
Active Clamp Flyback USB-PD Charger from TI and Navitas

✓ Zero voltage switching (ZVS) is achieved over a wide operating range with advanced auto-tuning techniques, adaptive dead-time optimization, and variable switching frequency control law.

✓ Using adaptive multimode control that changes the operation based on input and output conditions, UCC28780 enables high efficiency while mitigating audible noise.

✓ With a variable switching frequency of up to 1 MHz and accurate programmable over-power protection, which provides consistent power for thermal design across wide line range, the size of passive components can be further reduced and enable high power density.

Source: TI UCC28780 Datasheet
GaN Applications Survey:
GaN applications that are in Mass Production: PC Gaming Power

- The AX1600i uses Transphorm’s TPH3205WS 650V FETs in a bridgeless totem-pole power factor correction (PFC)—the topology that complements GaN’s performance and efficiency potential.

- With an increase of 6 percent within this topology, CORSAIR’s PSU efficiency now earns a better-than an 80 PLUS® Titanium rating.

- Previous CORSAIR power supplies used Silicon (Si) super junction (SJ) MOSFETs in a 2-phased interleaved PFC, reaching 93 percent efficiency.

Source: www.transphormusa.com
GaN Applications Survey:
GaN applications that are in Mass Production: 30W QR Adapters

- According to the teardown, this 30W power adapter is powered by Power Integrations InnoGaN.
- Quasi-resonant Flyback topology is used in this adapter.
- Input: 100 – 240V; output: 5V/3A, 9V/3A, 15V/2A, 20V/1.5A (30W)

Source: www.chongdiantou.com
GaN Applications Survey:
GaN applications that are in Mass Production: 45W ACF Adapters

- According to the teardown, this 45W power adapter is powered by Navitas NV6115 (650V 170 mΩ) and TI UCC28780 controller)

- Active Clamp Flyback (ACF) topology is used in this adapter


Source: www.chongdiantou.com
# GaN Applications Survey:
Commercially Available Ultra Compact 65W Adapters

<table>
<thead>
<tr>
<th>65W Adapter</th>
<th>Lenovo ThinkPlus</th>
<th>Delta PowerGear 60C</th>
<th>Finsix Dart</th>
<th>Zolt</th>
<th>Mi CDQ07ZM</th>
<th>RAVPower GaN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topology</td>
<td>Flyback</td>
<td>Flyback</td>
<td>3-level LLC</td>
<td>ACF</td>
<td>Flyback</td>
<td>QR</td>
</tr>
<tr>
<td>Power Switch</td>
<td>Si SJ MOS</td>
<td>Si SJ MOS</td>
<td>Si SJ MOS</td>
<td>SiC</td>
<td>Si SJ MOS</td>
<td>GaN</td>
</tr>
<tr>
<td>Size (Exclude Prongs)</td>
<td>35<em>74</em>30 mm</td>
<td>30<em>60</em>30 mm</td>
<td>28<em>70</em>28 mm</td>
<td>88.9<em>33</em>33 mm</td>
<td>60<em>57</em>28 mm</td>
<td>48<em>48</em>30 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>122g</td>
<td>88g</td>
<td>85g</td>
<td>100g</td>
<td>113g</td>
<td>175g</td>
</tr>
<tr>
<td>Max Power</td>
<td>20V/3.25A</td>
<td>20V/3A</td>
<td>20V/3.25A</td>
<td>20V/3.5A</td>
<td>20V/3.25A</td>
<td>20V/3A</td>
</tr>
<tr>
<td>USB-C/PD</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Date of Introduction</td>
<td>2018.11</td>
<td>2018.5</td>
<td>2016</td>
<td>2016</td>
<td>2018.6</td>
<td>2019</td>
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<tr>
<td>List Price</td>
<td>30 USD</td>
<td>109 USD</td>
<td>99 USD</td>
<td>49.99 USD</td>
<td>20 USD</td>
<td>37 USD</td>
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<tr>
<td>Product Pictures</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
</tr>
</tbody>
</table>
GaN Applications Survey:
High Frequency Magnetics

Modified Performance factor
$F_{3d,4} = B_{H1/4}(T \cdot Hz^{3/4})$

- 3C90 (Ferroxcube) ~1990s
- 3F35 (Ferroxcube) ~2000s
- ML915 (Hitachi Metal) ~2010s
- 67 (Fair-Rite) ~2015s

Future

Planar Magnetics

Vol (mm$^3$)

- Chrome book (65kHz)
  - RM10

- Innergie (200kHz)
  - ~ EQ25

- Navitas (400kHz)
  - ER25

- CPES (1MHz)
  - ER23

Freq (kHz)

- 65kHz → 200kHz
  - 2.5x size reduction

- 200kHz → 400kHz
  - 1.5x size reduction

- 400kHz → 1MHz
  - 1.5x size reduction

GaN ICs Enabling Next-Gen ACF for Adapter/Charger Application;
Navitas, APEC 2019
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1kW LCLC-SCC* Converter Demo
(in collaboration with Digiq Power)

*Switch-Controlled-Capacitor (SCC) is a GaNPower patented technology
Switch-Controlled-Capacitor (SCC) – LLC Converter

By compensating the resonant frequency due to L, C tolerance, Switch-Controlled-Capacitor (SCC) is designed to

- Achieve current sharing and interleaving for LLC
- Reduce the rms current and conduction loss
- Reduce the total system volume with higher switching frequency

\[ C_r = \frac{C_{SC} C_s}{C_{SC} + C_s} = \frac{2\pi C_a C_s}{2\pi C_a + 2\pi C_s - 2\alpha C_s + C_s \sin(2\alpha)} \]
Switch Controlled Capacitor (SCC)

Interleaving → Same switching frequency
Component tolerance → Different resonant frequency → Different voltage gain

Solution: Switch Controlled Capacitor (SCC) to equalize the resonant frequencies

Topology

Equivalent capacitor value \((C_{AB})\) depends on the conduction time of \(S_1\)

Waveforms
Benefits of SCC Technology

- High efficiency at high load current
  - Through parallel operation with current sharing
  - Lower conduction loss

- Lower input and output ripple
  - Through interleaving operation

- High switching frequency
  - Because of lower current for each phase

- Achieving both (at same time)
  - Higher power density
  - Higher efficiency
Introduction to LCLC Resonant Converter

LCLC Resonant Tank $\rightarrow$ Modified LLC with Changeable $L_m$

- **High $V_{in}$** $\rightarrow$ **High $f_{sw}$** $\rightarrow$ **Large $L_{m\_eq}$** $\rightarrow$ **Small RMS Current**
- **Low $V_{in}$** $\rightarrow$ **Low $f_{sw}$** $\rightarrow$ **Small $L_{m\_eq}$** $\rightarrow$ **High Voltage Gain**

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LCLC and LLC Efficiency Comparison

\[ V_{\text{in}} = 250 - 400V, \ V_o = 12V / 500W \]

LCLC vs LLC Efficiency (Same Gain)

Much higher efficiency at 400V for LCLC
LCLC-SCC Resonant Converter
## Design Parameters

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage</td>
<td>250 – 400 VDC</td>
</tr>
<tr>
<td>Nominal Input Voltage</td>
<td>400 VDC</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>12 VDC</td>
</tr>
<tr>
<td>Rated Output Voltage</td>
<td></td>
</tr>
<tr>
<td>Rated Output Current</td>
<td>84 A</td>
</tr>
<tr>
<td>Rated Output Power</td>
<td>1 kW</td>
</tr>
<tr>
<td>Series Resonant Frequency</td>
<td>320 kHz</td>
</tr>
<tr>
<td>Switching Frequency</td>
<td>170 – 240 kHz</td>
</tr>
<tr>
<td>Transformer Turns Ratio</td>
<td>18 : 1 : 1 (center tapped)</td>
</tr>
<tr>
<td>Resonant Inductor (L_r)</td>
<td>12.8 µH (Phase1) - 12.1 µH (Phase2)</td>
</tr>
<tr>
<td>Parallel Inductor (L_p)</td>
<td>230 µH (Phase1) - 223 µH (Phase2)</td>
</tr>
<tr>
<td>Resonant Capacitor (C_r)</td>
<td>20 x 1 nF = 20 nF ± 5%</td>
</tr>
<tr>
<td>Parallel Capacitor (C_p)</td>
<td>5 x 1 nF = 5 nF ± 5%</td>
</tr>
<tr>
<td>SCC Capacitor (Each Phase)</td>
<td>5 x 3.3 nF = 16.5 nF ± 5%</td>
</tr>
<tr>
<td>Input Capacitor (Electrolytic)</td>
<td>2 x 68 µF = 136 µF ± 5%</td>
</tr>
<tr>
<td>Output Capacitor (Ceramic)</td>
<td>20 x 47 µF = 940 µF ± 5%</td>
</tr>
</tbody>
</table>
Prototype with GaNPower HEMTs (TO-220)
Waveforms of Non-Interleaved LCLC-SCC Resonant Converter

\[ V_{\text{in}} = 250 \text{ V} - \text{Load}=70 \text{ A} \]

\[ V_{\text{in}} = 300 \text{ V} - \text{Load}=80 \text{ A} \]

\[ V_{\text{in}} = 350 \text{ V} - \text{Load}=80 \text{ A} \]

\[ V_{\text{in}} = 400 \text{ V} - \text{Load}=80 \text{ A} \]
Waveforms of Interleaved LCLC-SCC Resonant Converter

$V_{in}=250$ V - Load=70 A

$V_{in}=300$ V - Load=80 A

$V_{in}=350$ V - Load=80 A

$V_{in}=400$ V - Load=80 A
Output Voltage Ripple of Non-Interleaved LCLC-SCC Converter

$V_{in}=250 \text{ V} - \text{Load}=70 \text{ A}$

$V_{in}=300 \text{ V} - \text{Load}=80 \text{ A}$

$V_{in}=350 \text{ V} - \text{Load}=80 \text{ A}$

$V_{in}=400 \text{ V} - \text{Load}=80 \text{ A}$
Output Voltage Ripple of Interleaved LCLC-SCC Converter

$V_{in} = 250\, \text{V} - \text{Load} = 70\, \text{A}$

$V_{in} = 300\, \text{V} - \text{Load} = 80\, \text{A}$

$V_{in} = 350\, \text{V} - \text{Load} = 80\, \text{A}$

$V_{in} = 400\, \text{V} - \text{Load} = 80\, \text{A}$
Thermal Images of Output Capacitor with Fan Cooling

Non-Interleaved

Interleaved
Efficiency Curves (with 15 A GaN Power Devices)

1kW LCLC-SCC Converter (15A GaN Power TO-220)

<table>
<thead>
<tr>
<th>Voltage</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
<th>65</th>
<th>70</th>
<th>75</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 V</td>
<td>91.0</td>
<td>92.3</td>
<td>93.3</td>
<td>93.8</td>
<td>94.0</td>
<td>94.2</td>
<td>94.3</td>
<td>94.3</td>
<td>94.2</td>
<td>94.0</td>
<td>93.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>300 V</td>
<td>92.9</td>
<td>93.7</td>
<td>94.5</td>
<td>94.9</td>
<td>95.1</td>
<td>95.2</td>
<td>95.3</td>
<td>95.3</td>
<td>95.2</td>
<td>95.0</td>
<td>94.8</td>
<td>94.7</td>
<td>94.5</td>
</tr>
<tr>
<td>350 V</td>
<td>94.0</td>
<td>94.8</td>
<td>95.3</td>
<td>95.6</td>
<td>95.7</td>
<td>95.8</td>
<td>95.8</td>
<td>95.7</td>
<td>95.7</td>
<td>95.5</td>
<td>95.4</td>
<td>95.3</td>
<td>95.1</td>
</tr>
<tr>
<td>400 V</td>
<td>94.4</td>
<td>95.2</td>
<td>95.7</td>
<td>96.0</td>
<td>96.1</td>
<td>96.3</td>
<td>96.3</td>
<td>96.3</td>
<td>96.2</td>
<td>96.1</td>
<td>96.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Summary for the 1KW LCLC-SCC Converter

- Small Deadtime is Required for GaN Switches (100ns – 200ns)
- GaN Switches Operate Well for Wide Input Voltage Range
- TO-220 Package GaNs Work Without Heatsink Under Full-Load
- Perfect Current Sharing is Achieved by SCC Technology
- Only Ceramic Capacitors are Used at the Output Due to Interleaving
- Peak Efficiency of 96.3% is Recorded for LCLC-SCC Converter
GaNPower SCC for EV OBC and DC/DC Converter
(in collaboration with Digiq Power)
SCC Technology for EV OBC with GaN

Requirements:

- Output power: 3.3kW and 6.6kW
- Wide input voltage range: 85 – 264V
- Wide output voltage range: 240 – 430V (battery)
- High output current: 14A for 3.3kW and 28A for 6.6kW
EV OBC Current Technology

- **First Generation:** Diode Bridge + Boost + Phase-Shift Full Bridge (PSFB)
- **Efficiency:** 92 – 93%, **Power Density:** 0.5 – 0.8 kW / L
EV OBC Current Technology

Bridgeless PFC
- Good performance

LLC Resonant DC – DC
- Not good for wide voltage gain range

Bridgeless Boost + LLC Resonant (in production)
- Current technology
- Efficiency: 94% (full load)
- Power Density: ~1 kW / L (16W / in³)

Bridgeless Boost + LLC Resonant (in lab, reported)
- Using GaN and / or SiC
- Efficiency: 95.7% (AC – DC: 98.2%, DC – DC: 97.5%)
- Power density: ~1.5 kW / L (24W / in³)
GaNPower SCC EV OBC

Bridgeless Boost PFC + 3-phase Interleaved LCLC (for 3.3kW)

- AC – DC stage: Bridgeless Boost, integrated GaN switches (similar)
- DC – DC: 3-phase interleaved SCC – LCLC for 3.3kW output (new)
GaNPower SCC EV OBC

SCC – LCLC topology for EV Battery charger

GaN Bridge Main Switches

GaN Bridge SR Switches or Diode Bridge

Vin 400V

GaN Bridge SR Switches or Diode Bridge

Vo 240 – 430V
Advantages

- Reduced output capacitor value, from 190uF / 500V to 12uF / 500V
  - Size reduction from 14 in³ (two 100uF / 500V film cap, $28 \times 2 = $56)
  - To 1 in³ (one 12uF / 500V, film cap, $8)

- Better thermal performance (no hot spot)

- Efficiency: 96.5% (system, full load)

- Size: ~ 1.2 Litre for 3.3kW
  - Power density: 2.5 – 3 kW / L (40 – 48W / in³)
GaNPower SCC GaN Based EV DC/DC Converter

Requirements:

- High output power: 2kW
- Wide Input voltage range: 350V nominal, 240 – 430V, from battery
- Wide output voltage range: 14V nominal, 9 – 16V
  - Voltage gain variation range: 15 to 48 (> 1:3)
  - Difficult to meet with LLC converter
- High load current: 150A
  - Needs bridge type converter with large inductor as a filter
GaNPower SCC GaN Based EV DC/DC Converter

- Four-phase interleaved SCC – LCLC in parallel
  - No need for large inductor
  - 40A each phase (~500W) to reduce the conduction loss
  - Interleaving to achieve very small output capacitor (< 500uF)

Small output capacitor with interleave technology (~500uF for 150A)

- Conventional: 8,400uF output capacitor
- 100V MOSFET for SCC is cheap and almost no loss

\[ \text{SCC-LCLC, } I_0=40A \]

\[ \text{Vin} \quad 240V-430V \]

\[ \text{Vout} \quad 9V \sim 16V \]
# OBC and DC/DC Solutions Using SCC Technology

## EV On-board Charger (OBC)

<table>
<thead>
<tr>
<th></th>
<th>Current Design</th>
<th>Reported Design</th>
<th>GaNPower’s Design I</th>
<th>GaNPower’s Design II</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size / Volume</strong></td>
<td>3.2 Litre</td>
<td>2.2 Litre</td>
<td>1.2 Litre</td>
<td>0.6 - 0.8 Litre</td>
</tr>
<tr>
<td><strong>Power Density</strong></td>
<td>1 kW / L</td>
<td>1.5 kW / L</td>
<td>2.5 - 3 kW / L</td>
<td>4 - 5.5 kW / L</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td></td>
<td></td>
<td>Proportional to volume</td>
<td></td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>92% - 94%</td>
<td>95.7%</td>
<td>96.5%</td>
<td>98%</td>
</tr>
<tr>
<td><strong>Operating Temp Range</strong></td>
<td>-45 - 105</td>
<td>-45 - 105</td>
<td>-45 - 105</td>
<td>-45 - 105</td>
</tr>
<tr>
<td><strong>Transient Speed</strong></td>
<td></td>
<td></td>
<td>No need to be fast</td>
<td></td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td>Same</td>
<td>Same</td>
<td>Same</td>
<td>Same</td>
</tr>
<tr>
<td><strong>Durability</strong></td>
<td>Same</td>
<td>Same</td>
<td>Same</td>
<td>Same</td>
</tr>
<tr>
<td><strong>Power Devices / Cost</strong></td>
<td>Large inductor</td>
<td>500V/200uF cap ($56)</td>
<td>500V / 12uF cap ($8)</td>
<td>500V / 12uF cap ($8)</td>
</tr>
</tbody>
</table>

Input: 85-265VAC, Output: 240-430VDC, 3.3KW, 14A

## 4X increase of power density using GaNPower’s GaN devices and SCC design

## EV On-board DC/DC Converter

<table>
<thead>
<tr>
<th></th>
<th>Current Design</th>
<th>Reported Design</th>
<th>GaNPower’s Design</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size / Volume</strong></td>
<td>1.8 Litre</td>
<td>1.3 Litre</td>
<td>0.7 Litre</td>
</tr>
<tr>
<td><strong>Power Density</strong></td>
<td>0.7 - 1.1 kW / L</td>
<td>1.5 kW / L</td>
<td>3 - 4 kW / L</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td></td>
<td></td>
<td>Proportional to volume</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>94% - 95%</td>
<td>95% - 96%</td>
<td>97%</td>
</tr>
<tr>
<td><strong>Operating Temp Range</strong></td>
<td>-45 - 105</td>
<td>-45 - 105</td>
<td>-45 - 105</td>
</tr>
<tr>
<td><strong>Transient Speed</strong></td>
<td>Same</td>
<td>Same</td>
<td>Same</td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td>Same</td>
<td>Same</td>
<td>Same</td>
</tr>
<tr>
<td><strong>Durability</strong></td>
<td>Same</td>
<td>Same</td>
<td>Same</td>
</tr>
<tr>
<td><strong>Power Devices / Cost</strong></td>
<td>MOSFET Large inductor</td>
<td>GaN 8,400uF cap</td>
<td>With GaN 500uF cap</td>
</tr>
</tbody>
</table>

Input: 240-430VDC, Output: 9-16VDC, 2KW, 150A
Contents

- Session 1: GaN devices basics
- Session 2: GaN Gate Driving
- Session 3: GaN Applications
  - GaN vs. Silicon, from application perspective
  - GaN Applications Survey
  - SCC Solution Demos (in collaboration with Digiq Power)
  - A brief introduction to GaNPower International
About GaNPower International Inc.

GaNPower was established in June, 2015 by a group of professionals in Vancouver, Canada.
Our GaN HEMT Products

<table>
<thead>
<tr>
<th>Product Catalog</th>
<th>Current Ratings</th>
<th>Release date</th>
</tr>
</thead>
<tbody>
<tr>
<td>650V GaN HEMT (TO220) (GPI650XXTO)</td>
<td>10A, 15A, 20A, 30A</td>
<td>2018 Q1</td>
</tr>
<tr>
<td></td>
<td>40A, 60A, 80A</td>
<td>2018 Q3 – 2019 Q2</td>
</tr>
<tr>
<td>650V GaN HEMT (DFN 5X6) (GPI650XXDFI)</td>
<td>7.5A, 10A, IC</td>
<td>2019 Q2</td>
</tr>
<tr>
<td>650V GaN HEMT (DFN 6X8) (GPI650XXDFO)</td>
<td>15A, 20A, 30A, IC</td>
<td>2018 Q2 ~ 2019 Q2</td>
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<tr>
<td>650V GaN HEMT (DFN 8X8) (GPI650XXDFN)</td>
<td>15A, 30A</td>
<td>2018 Q3</td>
</tr>
<tr>
<td></td>
<td>30A, 60A, Co-package, Monolithic IC</td>
<td>2019 Q1 – 2020 Q3</td>
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<tr>
<td></td>
<td>LGA Half-bridge module: 60A, 120A</td>
<td>2019 Q3 – 2020 Q3</td>
</tr>
<tr>
<td>1200V GaN HEMT (TO252 DPAK) (GPIHVXXDDK)</td>
<td>15A, 30A</td>
<td>2018 Q3 ~ 2019 Q2</td>
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<tr>
<td>100V GaN HEMT (LGA) (iGaN100XXX)</td>
<td>7.5A, 10A, 30A, 60A, 80A, 100A</td>
<td>2020 Q1 ~ 2021 Q1</td>
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</table>

<table>
<thead>
<tr>
<th>Product number</th>
<th>GaNPower</th>
<th>Super Junction MOS</th>
<th>SiC</th>
<th>Cascode GaN</th>
<th>E-mode GaN</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPI65015TO</td>
<td>XXXXXXXX</td>
<td>XXXXXXXXXC7</td>
<td>XXXXXXXXXB3</td>
<td>XXXXXXXXLD</td>
<td>XXXXXXXX4B</td>
</tr>
<tr>
<td>Rated BV</td>
<td>650V</td>
<td>700V</td>
<td>650V</td>
<td>600V</td>
<td>650V</td>
</tr>
<tr>
<td>$R_{dson}$</td>
<td>92mΩ</td>
<td>125mΩ</td>
<td>100mΩ</td>
<td>150mΩ</td>
<td>100 - 130mΩ</td>
</tr>
<tr>
<td>$Q_g$</td>
<td>3.3nC</td>
<td>35nC</td>
<td>51nC</td>
<td>6nC</td>
<td>3nC</td>
</tr>
<tr>
<td>$FOM = R_{dson} * Q_g$</td>
<td>304</td>
<td>4375</td>
<td>5100</td>
<td>900</td>
<td>300 - 390</td>
</tr>
</tbody>
</table>
THANKS FOR WATCHING!

Contact us (Vancouver Headquarters):

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