Overview

• Motivation
• Challenges (and opportunities)
• Some solutions
• Where we are today
• Closing
Adapters Haven’t Changed Much

<table>
<thead>
<tr>
<th>Year</th>
<th>Power</th>
<th>Size</th>
<th>Efficiency</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>65W</td>
<td>10.1 cu. In.</td>
<td>87.3% full load</td>
<td>35C nom.</td>
</tr>
<tr>
<td>2013</td>
<td>60W</td>
<td>9.6 cu. In.</td>
<td>89.1% full load</td>
<td>30C nom.</td>
</tr>
</tbody>
</table>
Why Higher Frequency?

• Size
  – For constant Z, required L & C fall as frequency rises
  – Energy storage significant portion of total

• Weight
  – See size

• Cost
  – In the limit, much of cost material limited
  – Also, see size

• Benefits to end products
  – Reduced volume trades for functionality, cost
  – Customer delight
Transformer Comparison

65W

15.3 cc > 1.2 cc

> 12x smaller
Challenges

• Main challenges relate to full-power efficiency:
  – Devices
  – Magnetics

• Others:
  – Control
  – Availability of components
  – Supply Chain
  – Standards
  – Customer Requirements
Isolated $\Phi_2$ DC-DC Converter

- Fully resonant, ZVS, 0 dV/dt
- Low component count
- Low-ish voltage stress
- Wide load range
- Ground-referenced switches
Power Device Considerations

Circulating currents drive commutation losses
Power Device Considerations

- Devices are optimized to applications
  - They are today’s applications
  - 200V, 650V are common breakdown specs
  - 450V is desired for offline VHF
- Gate resistance is sometimes added
- Capacitances increasingly non-linear
- Packaging!

A near-term solution:
Use multiple, lower-voltage devices
Stacking of Converter Cells

- Halves voltages
  - Better device characteristics
- Better-scaled impedances
- Complicates:
  - Control
  - Auxiliary power
  - Startup
- Other options involve stacking devices
GaN

- **Much lower capacitances**
  - Excels at high frequency
  - Lends flexibility to achieve optimal tuning
  - Reduces auxiliary power requirements

- **Main Challenges**
  - Still some kinks as frequency goes up
  - Same voltage options as Silicon
  - Development risk is squared, either direction

**GaN and HF/VHF are a natural marriage**
Magnetics

- VHF favors air-core approach
  - Skin effect a problem, but Q increases w/ $f^{1/2}$
  - Inductance geometrically defined: stable, accurate
  - Optimization usually needs full-fields solution

- Current Low-u Materials good into deep HF
  - Little manufacturer data for power applications
  - Significant characterization effort
  - Some work remains: tolerances, parameters

Transformer: 680 W/cu.in., 96%+ efficiency @65W, 67 Material, planar windings, deep HF
Modified Performance Factor at HF

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Modified Performance Factor

\[ \frac{\mu}{\rho} = B f^3 \text{ (mT, MHz}^3) \]

**Frequency (MHz)**

*Data from Hanson, et. al., "Measurement and Performance Factor Comparisons of Magnetic Materials at High Frequency", ECCE 2015, Montreal Canada*
EMI

• **As frequency goes up EMI filters:**
  – Get smaller
  – Have less DC resistance

• **Compared: 65W offline converters**
  – Standard adapter at 100 kHz, shipping in high volume with major OEMs products
  – 13.56 MHz adapter design
  – Measured both conducted (55022A/Q) and radiated (FCC/CISPR class-B) performance at certified test lab
Filter for 13 MHz converter is:
>11x smaller in volume
>3.6x lower in conduction loss

<table>
<thead>
<tr>
<th>Converter</th>
<th>Min. Margin</th>
<th>Volume</th>
<th>DC Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>100kHz</td>
<td>7 dB</td>
<td>8 cc</td>
<td>400 mOhm</td>
</tr>
<tr>
<td>FINsix 13.56MHz</td>
<td>6 dB</td>
<td>0.72 cc</td>
<td>110 mOhm</td>
</tr>
</tbody>
</table>
Recap

• Devices
  – Near term: stacking
  – Next step: co-optimization, advanced devices

• Magnetics
  – Good performance with low-perm materials
  – Work to be done for VHF

• Systems
  – Complex, design-time and cost are key work areas
Today

• Two 65W products w/ > 95% AC/DC efficiency
  – All-in and in final form factor

• Designs for both after market and OEM
  – ~3 cu. in. (3-4x smaller than existing products), < 100g
FINSIX: SMALL, LIGHT, POWERFUL

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