Boost Inductors:
Design for Cost and Loss Minimization

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President and CEO
West Coast Magnetics

ISO9001:2008 Registered
Loss and Saturation both Effect the Boost Inductor

- DC bias: saturation at peak current.
- AC ripple: losses in core and copper.
- Inductance: effects ripple.
Topics

Will discuss:
  Core material comparison, loss/cost/turns*Idc
  Gapped E core windings: cost and loss comparison

Will not discuss:
  Toroidal windings
  Sizing of inductor, choice of inductance value
  Reduction of size from thermal management

Scope: 1 kW to 100 kW
  1 kHz to 500 kHz
# Material Properties

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Fe</th>
<th>Fe</th>
<th>Fe Al Si</th>
<th>Fe Ni</th>
<th>Fe Si</th>
<th>Fe Al Ni Al</th>
<th>Fe Si</th>
<th>Fe Si</th>
<th>Amorphous</th>
<th>Mn Zn Fe</th>
<th>Fe Si</th>
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</thead>
<tbody>
<tr>
<td>POWDERED CORES (distributed gap)</td>
<td>200C rated</td>
<td>50-50</td>
<td>0.004&quot;</td>
<td>0.004&quot;</td>
<td></td>
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<tr>
<td>STRIP WOUND CORES (discrete gap)</td>
<td></td>
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<tr>
<td>SOFT FERRITES (discrete gap)</td>
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<td></td>
<td></td>
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<tr>
<td>LAMINATION S</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Trade Name</td>
<td>Iron Powder Material 52</td>
<td>Iron Powder Material 66</td>
<td>Kool mu</td>
<td>Hi Flux</td>
<td>Flux San</td>
<td>Optilloy</td>
<td>Microsil</td>
<td>JFNH</td>
<td>Metglas</td>
<td>3C90</td>
<td>Magnesil</td>
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<tr>
<td>Manufacturer</td>
<td>Micrometals</td>
<td>Micrometals</td>
<td>Micrometals Mag Inc</td>
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<td>JFE Steel Co.</td>
<td>Hitachi</td>
<td>Magnetics Inc.</td>
<td>Tempel Steel</td>
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<td>Cost ($/cm³)</td>
<td>.066</td>
<td>.138</td>
<td>.141</td>
<td>.35</td>
<td>.15</td>
<td>.26</td>
<td>.81</td>
<td>.9</td>
<td>.73</td>
<td>.1</td>
<td>low</td>
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<tr>
<td>Density (gm/cm³)</td>
<td>7</td>
<td>6.2</td>
<td>5.5</td>
<td>6.87</td>
<td>6.8</td>
<td>6.64</td>
<td>7.7</td>
<td>7.7</td>
<td>7.8</td>
<td>5.1</td>
<td>7.5</td>
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<tr>
<td>Bs at (gauss)</td>
<td>18000</td>
<td>15000</td>
<td>10500</td>
<td>7500</td>
<td>16500</td>
<td>14000</td>
<td>18000</td>
<td>18000</td>
<td>15600</td>
<td>5000</td>
<td>18000</td>
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<tr>
<td>Cont. Operating Temp (deg. C)</td>
<td>100</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>500</td>
<td>500</td>
<td>150</td>
<td>200</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Curie Temp. (degrees C)</td>
<td>770</td>
<td>750</td>
<td>460</td>
<td>400</td>
<td>700</td>
<td>400</td>
<td>750</td>
<td>750</td>
<td>399</td>
<td>200</td>
<td>750</td>
</tr>
<tr>
<td>Available Geometries</td>
<td>E-core, Toroid</td>
<td>E-core, Toroid</td>
<td>E-core, Toroid</td>
<td>Toroid</td>
<td>Toroid</td>
<td>Toroid</td>
<td>C-core</td>
<td>C-core</td>
<td>C-core, toroid</td>
<td>All</td>
<td>EI, UI</td>
</tr>
</tbody>
</table>

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**West Coast Magnetics**

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Core Loss at 100 kHz

Specific Power Loss vs. Flux Density @ 100kHz

Flux Density (Gauss)

Specific Power Loss (mW/cm³)
Core Loss at 10 kHz

Specific Power Loss vs. Flux Density @ 10kHz

- Kool Mu Powder
- -52 Powder
- -66 Powder
- Powerlite Tape Wound
- P Ferrite
- 29 Gauge Steel Lamination
- 4 mil Silectron Tape wound
- Optiloy 60
- Flux San 60
- JNFH
- High Flux
Saturation of Core Materials

L vs. Idc

- 3C90
- KoolMu Powder
- 66 Powder
- 52 Powder
- Metglas
- JFNH
- HiFlux/Optilloy/Flux San
Design Comparison

- 65 uH, 30 Adc inductor
- Wind with 10 awg on toroidal core
- Design steps

  Ignore losses, choose the smallest toroidal core that will support 65 uH minimum at 30 Amps.

  Calculate loss and core T rise as a function of ripple and frequency.
  Determine size and estimate cost.
Components of Inductor Loss

\[ P_{dc} = I_{dc}^2 R_{dc} \]

\[ P_{ac} = I_{ac,rms}^2 R_{ac} \]

Winding only  Core and winding
Comparison of DC Resistance: Foil, Solid Wire & Litz Wire

- **Foil windings:**
  - Fast and easy to wind
  - Do not require bobbins or other supports

**DCR**
- **FOIL:** DCR = very low
- **SOLID WIRE:** DCR = low
- **50/40 awg LITZ WIRE:** DCR = medium/high
Current Distribution: Ungapped E-Core and Gapped E-Core

Full Foil: Ungapped Core

AC current evenly distributed on surface of foil across full width of foil.

Shaped Foil: Gapped Core

AC current pulled to small copper cross section in the vicinity of the gap.

Shaped Foil is a patented technology developed by Professor Charles Sullivan and Dr. Jennifer Pollock at Dartmouth College.
Experiment: What is the Loss/Cost Tradeoff for the Different Windings?

- Step 1: Define the Inductor
  - Inductance: 70 uH
  - Current: 40 Adc
  - Core: E70/33/32 Ferroxcube 3C90 material
  - Gap: 2.64 mm (1.32 mm each center leg)
  - Turns: 16

- Step 2: Wind inductors with conventional windings using best practices
  - Full window
  - Single layer

- Step 3: Determine winding losses for each inductor as a function of ripple magnitude
Winding Cross Sections

- DCR 2.44 mOhms
  - 420/36 litz

- DCR 3.46 mOhms
  - Solid Wire

- DCR 2.75 mOhms
  - 1050/44 litz

- DCR 8.12 mOhms

- DCR 4.38 mOhms

- DCR 7.88 mOhms
# Winding Cost Comparison

<table>
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<tr>
<th></th>
<th>12 awg</th>
<th>1050/44</th>
<th>210/36</th>
<th>full foil</th>
<th>0.4 cut out</th>
<th>0.3 cut out</th>
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<tbody>
<tr>
<td>$/LB</td>
<td>$5.061</td>
<td>$49.74</td>
<td>$16.97</td>
<td>$4.91</td>
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<tr>
<td>$/LB regained</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>$4.00</td>
<td>$4.00</td>
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<tr>
<td>Tape 3M56</td>
<td>$100.00</td>
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<td>Cost 3M Tufquin for 1000 parts</td>
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<td>-</td>
<td>-</td>
<td>$331.98</td>
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<tr>
<td>weight with bobbin</td>
<td>0.50766</td>
<td>0.35805</td>
<td>0.26974</td>
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<tr>
<td>without bobbin</td>
<td>0.48802</td>
<td>0.33841</td>
<td>0.2501</td>
<td>0.87325</td>
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<tr>
<td>LBs for 1000 parts</td>
<td>488.02</td>
<td>338.41</td>
<td>250.1</td>
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<tr>
<td>Cost for 1000 parts</td>
<td>$2,469.87</td>
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<td>Recovered cost for 1000 parts</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>$820.00</td>
<td>$356.00</td>
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<tr>
<td>Total Cost for 1000 parts</td>
<td>$2,569.87</td>
<td>$16,932.51</td>
<td>$4,344.20</td>
<td>$4,619.63</td>
<td>$3,799.63</td>
<td>$4,263.63</td>
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</tbody>
</table>
Total Winding Loss vs. Ripple Current 10 kHz
Total Winding Loss vs. Ripple Current 100 kHz
Thank you for your time

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