NEW POWDER CORE MATERIALS FOR INPUT FILTER CHOKES
Edge™ and High DC Bias XFlux®

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OVERVIEW

• Integrated Magnetics Example
  • 2 Coil Differential Choke for Input Filter
• Core Material Considerations
• New Powder Core Options
  • High DC Bias XFlux®
  • Edge™
• Performance Summary
INPUT FILTER CHOKES

- Consider 2 Stage (LC) Differential Input Filter
- Same Concepts Apply For:
  - Differential Chokes For Output Filters
  - DC-DC, AC-DC, DC-AC
- 3 Stage and 2 Section Input Filters
COMMON MODE CHOKES

- Higher Amp 60Hz Flux Cancels
  - Mitigates Core Saturation Concerns
  - Allows for High Perm Materials
    - Ferrite: 3,000-15,000 perm typical
    - Nanocrystalline: 30,000-100,000 perm typical

- Only Lower Amp Common Mode Noise Is Impeded
2 COIL CONSTRUCTION OPTIONS

- **Toroid**
  - One piece best for high perm
  - Single Layer Turns
    - voltage isolation
    - low parasitic capacitance
  - Bifilar OK with proper insulation

- **2-Piece Shapes**
  - Typically Lower Amps
  - Air gap reduces perm
    - Might need higher turns
DIFFERENTIAL MODE CHOKES

- Higher Amp 60Hz and Lower Amp Noise In Phase
- No Flux Cancellation
- Must Avoid Core Saturation at Peak Amps
HOW TO AVOID CORES SATURATION?

• Must Avoid Saturation ($B_{\text{max}}$)
• Highest $B_{\text{max}}$ Materials have Highest AC Losses
• Use Low Permeability cores $\Rightarrow \mu = B/H$
  • Introduce Air in Magnetic Path, $\mu_{\text{Air}} = 1$
    • Discrete gap cores
    • Distributed gap cores
• Discrete Gap Needed for Ferrite & Strip Core Inductors
  • SiFe, Nickel, Amorphous Strip All need Gap
• Air gap introduced between 2 mating pieces
  • Grind Air Gap in Ferrite Center Leg
  • Or Nonconductive Shim between Mating Surfaces
• Hard Saturation Characteristic
Distributed Air Gap Powder Cores

Powder Core Options

- **Nickel Based**
  - 80% Nickel – MPP
  - 50% Nickel - High Flux, Edge

- **Iron Based**
  - Iron Powder
  - FeSiAl - Kool Mµ®, Kool Mµ Max, Kool Mµ Hf (Sendust)
  - FeSi – XFlux, High DCB XFlux

- **Blends**

- **All Have Soft Saturation Characteristic**

Microscopic Schematic View
(Gap exaggerated; alloy particles are really much closer than this.)

Non-magnetic insulation (Gap)
Perm is low (=1)

High Perm Magnetic Alloy
Hard Saturation materials must be kept safe distance away from rolloff. Small shifts in rolloff curve, or in operating point, could have disastrous effect. Curve shifts left as temperature increases.

Soft Saturation allows operation part way down curve. Curve doesn't shift appreciably with increasing temperature.
5 Powder Core Options For EMI Filter Example

<table>
<thead>
<tr>
<th></th>
<th>Kool Mµ®</th>
<th>XFlux®</th>
<th>NEW HDCB XFlux®</th>
<th>High Flux</th>
<th>NEW Edge™</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alloy Composition</strong></td>
<td>FeSiAl</td>
<td>FeSi</td>
<td>FeSi</td>
<td>FeNi (50%)</td>
<td>FeNi (50%)</td>
</tr>
<tr>
<td><strong>Available Perms</strong></td>
<td>14-125</td>
<td>19-125</td>
<td>26-60</td>
<td>14-160</td>
<td>14-125</td>
</tr>
<tr>
<td><strong>Core Loss</strong> (mW/cc) 50kHz, 1000G</td>
<td>190</td>
<td>575</td>
<td>625</td>
<td>250</td>
<td>160</td>
</tr>
<tr>
<td><strong>Perm vs. DC Bias</strong> (Oer) 50% of $\mu_i$</td>
<td>95</td>
<td>170</td>
<td>200</td>
<td>185</td>
<td>205</td>
</tr>
</tbody>
</table>

*Core Loss and DC Bias performance values for 60µ toroids*
5 Powder Core Options For EMI Filter Example

- **High DC Bias XFlux®**
  - High: 78S
  - Low: 78

- **High Flux**
  - High: 58
  - Low: 59

- **Kool Mµ®**
  - High: 79
  - Low: 76

- **Edge®**
  - High: 77
  - Low: 55
NEW EDGE™ FOR COMPACT, EFFICIENT POWER

- Material Composition: 50% Ni 50% Fe (same as High Flux)
- Optimized for high efficiency, high density designs
- Edge™ vs. High Flux
  - 30-40% Lower Core Losses
  - 10-30% Higher DC Bias

<table>
<thead>
<tr>
<th>Material</th>
<th>Perm vs. DC Bias (Oer)</th>
<th>Core Loss (mW/cc)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>100kHz,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1000G</td>
</tr>
<tr>
<td>60µ</td>
<td>80% µᵢ</td>
<td>50% µᵢ</td>
</tr>
<tr>
<td>80% µᵢ</td>
<td></td>
<td>205</td>
</tr>
<tr>
<td>50% µᵢ</td>
<td></td>
<td>375</td>
</tr>
<tr>
<td>Edge</td>
<td>130</td>
<td>160</td>
</tr>
<tr>
<td>High Flux</td>
<td>101</td>
<td>185</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing comparison between Edge™ and High Flux](image)
**DC Bias**

Initial Permeability = \(1 / (a+bH^c)\)

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>b</th>
<th>c</th>
</tr>
</thead>
<tbody>
<tr>
<td>26µ</td>
<td>0.01</td>
<td>3.65E-11</td>
<td>3.192</td>
</tr>
<tr>
<td>60µ</td>
<td>0.01</td>
<td>9.20E-10</td>
<td>3.044</td>
</tr>
</tbody>
</table>

**Core Loss**

\[ P = a \ (B^b) \ (f^c) \]

<table>
<thead>
<tr>
<th></th>
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<th>b</th>
<th>c</th>
</tr>
</thead>
<tbody>
<tr>
<td>26µ</td>
<td>227.54</td>
<td>2.209</td>
<td>1.27</td>
</tr>
<tr>
<td>60µ</td>
<td>211.51</td>
<td>2.309</td>
<td>1.28</td>
</tr>
</tbody>
</table>

B in Tesla, f in kHz

60µ Core Loss Density Graph shown
NEW HIGH DC BIAS XFLUX®

- Material Composition: Silicon Iron, same as XFlux®
- Provides Up To 20% Higher DC Bias with 10%-20% Penalty in Higher Cores Losses vs. XFlux®

<table>
<thead>
<tr>
<th>Perm</th>
<th>Perm vs. DC Bias (Oe)</th>
<th>Core Loss (mW/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>26μ</td>
<td>80% 50%</td>
<td>W₁₀₀₀ G, 50 kHz</td>
</tr>
<tr>
<td>High DCB XFlux</td>
<td>285 505</td>
<td>725</td>
</tr>
<tr>
<td>XFlux</td>
<td>270 450</td>
<td>600</td>
</tr>
</tbody>
</table>

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<tr>
<td>60μ</td>
<td>80% 50%</td>
<td>W₁₀₀₀ G, 50 kHz</td>
</tr>
<tr>
<td>High DCB XFlux</td>
<td>120 200</td>
<td>625</td>
</tr>
<tr>
<td>XFlux</td>
<td>100 170</td>
<td>575</td>
</tr>
</tbody>
</table>
% Initial Permeability = \frac{1}{(a+bH^c)}

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<tr>
<th>Material</th>
<th>a</th>
<th>b</th>
<th>c</th>
</tr>
</thead>
<tbody>
<tr>
<td>26\mu</td>
<td>0.01</td>
<td>2.81E-09</td>
<td>2.423</td>
</tr>
<tr>
<td>40\mu</td>
<td>0.01</td>
<td>4.25E-09</td>
<td>2.572</td>
</tr>
<tr>
<td>60\mu</td>
<td>0.01</td>
<td>5.69E-09</td>
<td>2.714</td>
</tr>
</tbody>
</table>

\[ P = a \cdot (B^b) \cdot (f^c) \]

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<thead>
<tr>
<th>Material</th>
<th>a</th>
<th>b</th>
<th>c</th>
</tr>
</thead>
<tbody>
<tr>
<td>26\mu</td>
<td>845.36</td>
<td>2.477</td>
<td>1.41</td>
</tr>
<tr>
<td>40\mu, 60\mu</td>
<td>842.18</td>
<td>2.388</td>
<td>1.33</td>
</tr>
</tbody>
</table>

60\mu Core Loss Density Graph shown

B in Tesla, f in kHz
2 COIL DIFFERENTIAL CHOKE DESIGN

- Need 8uH nominal inductance per coil, with $25A_{\text{rms}}$ continuous load
- Select Core
  - $LI^2 = 0.008\text{mH} \times 25^2 = 5$, for 1 Coil with 40% Fill
  - Need larger core for 2 single-layer coils, assume $LI^2 = 10$-20 with Core Selector Chart
- Start with Kool Mu
- Select Wire
  - Need 11AWG based on 600 Amp/cm$^2$ at $25A_{\text{rms}}$
  - Use 4-strands x 17AWG for equivalent copper area
2 COIL DIFFERENTIAL CHOKE DESIGN

- Start with 77083A7
- 60 perm
- 39.9mmOD x 14.5mmH
- AL = 81 +/-8%
- Path Length = 9.84cm
2 COIL DIFFERENTIAL CHOKE DESIGN

- Calculate Turns for 8uH nominal inductance per coil
  - \( \mu H = A_L \times N^2 \times 10^{-3} \), use 10 turns per coil
- Evaluate Inductance Roll-off at Different Loads
  - Oersteds Law & Curve Fit Equation Tool
  - Flux Adds, - Must Add Oersteds for Both Coils
- 25 Amps rms
- 35 Amps peak
- 45.5 Amps, 30% overload for fault + noise

\[
H(\text{Oersteds}) = \frac{0.4\pi \times N \times I}{L_e}
\]

\[
L(\text{mH}) = \frac{A_L \times N^2}{10^6}
\]
# 2 Coil Differential Choke Design

Each design has the same core size, perm, and copper. The table below shows the inductance (uH) for different conditions and designs:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Oer</th>
<th>Kool Mu (77)</th>
<th>XFlux (78)</th>
<th>High DCB XFlux (78S)</th>
<th>High Flux (58)</th>
<th>Edge (59)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Load</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.1</td>
<td>8.1</td>
<td>8.1</td>
<td>8.1</td>
<td>8.1</td>
<td>8.1</td>
<td>8.1</td>
</tr>
<tr>
<td>25 Amps rms</td>
<td>63.8</td>
<td>5.5</td>
<td>7.5</td>
<td>7.8</td>
<td>7.5</td>
<td>7.9</td>
</tr>
<tr>
<td>35 Amps peak</td>
<td>89.3</td>
<td>4.3</td>
<td>6.8</td>
<td>7.3</td>
<td>6.8</td>
<td>7.5</td>
</tr>
<tr>
<td>45.5 Amps (30% overload, fault + noise)</td>
<td>116.2</td>
<td>3.3</td>
<td>5.9</td>
<td>6.6</td>
<td>6.0</td>
<td>6.9</td>
</tr>
<tr>
<td>Relative Cost</td>
<td></td>
<td>1.0</td>
<td>1.4</td>
<td>1.4</td>
<td>5.8</td>
<td>7.0</td>
</tr>
</tbody>
</table>
• Expect uH Measurements Higher Than Calculated
• No Load uH +6% Higher Due To Flux Leakage in This Case
• Leakage Adder Depends On Perm, Core Dimensions, & Turns
• Test Inductance with 2 Coils in Series to Minimize Leakage Effect
• Expect 4x inductance increase for 2x turn increase
• Core Loss Not Considered For This Input Filter Example
• **Kool Mu®**
  - 53% inductance at 35A peak, OK if 4.3uH squelches EMI noise
  - 41% inductance at 30% overload also OK, depends on Noise & Fault Conditions

• **Silicon Iron Alloys**
  - XFLux®: 58% Higher uH at 35A peak and 79% Higher uH at 30% Overload
  - High DC Bias XFlux®: 79% Higher uH at 35A peak and 100% Higher uH at 30% Overload
  - Better Filtering or Size Reduction
2 COIL DIFFERENTIAL CHOKE DESIGN
MATERIALS SUMMARY

• Nickel Alloys
  • High Flux provides 58% Higher uH at 35A peak and 82% Higher uH at 30% Overload
  • Edge™ provides 74% Higher uH at 35A peak and 109% Higher uH at 30% Overload
  • What Justifies Cost Adder?
    • Core Loss Advantage at 50kHz and 1000Gauss (0.1 Tesla)
      • High Flux -57% Lower Than XFlux®, Edge™ -72% Lower Than XFlux®
  • Push These Materials
    • At 35Amp peak, Edge™ has 93% and High Flux has 84% Permeability Remaining
    • Downsize
    • Raise uH, High Flux Available Up To 160 perm
THANK YOU!
QUESTIONS?, COMMENTS?, SUGGESTIONS?

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