Strategies for Scalable Low-Loss Multi-MHz Inductors

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Goal: Make low-loss HF magnetics design easier

Want inductor design approaches that:

- Achieve **low loss**
- Can span a **wide range** of applications
- Make the design process **easier**
Goal: Make low-loss HF magnetics design easier

HF Design Techniques:

- Field shaping
- Quasi-distributed gaps
Challenge: uneven current distribution

**Strategy:**
- **Field shaping**

**Imbalanced fields**

**Balanced fields**
Challenge: uneven current distribution
Strategy: **field shaping**

\[ R_{\text{inner}} = R_{\text{outer}} \]

Goal: Make low-loss HF magnetics design easier

HF Design Techniques:

- Field shaping
- Quasi-distributed gaps
Challenge: fringing field loss

lumped gap

Challenge: fringing field loss

Strategy: **quasi-distributed gap**

lumped gap

quasi-distributed gap

Design

$p/s < 4$

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HF Design Techniques:

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Goal: Make low-loss HF magnetics design easier

HF Design Techniques:

- Field shaping
- Quasi-distributed gaps

Combine?
A low-loss modified pot (MP) core inductor structure

Features:
• Field shaping
• Quasi-distributed gaps
• Modular

Example applications:
• DCM/BCM converters
• Resonant converters
A low-loss modified pot (MP) core inductor structure

Design guidelines optimize Q to easily achieve low loss designs.

Initial MP designs can be largely automated.
A low-loss modified pot (MP) core inductor structure

Design guidelines achieve high Q example design

Experimental Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q</td>
<td>720</td>
</tr>
<tr>
<td>Frequency</td>
<td>3 MHz</td>
</tr>
<tr>
<td>Current</td>
<td>2 A_{pk} (ac)</td>
</tr>
<tr>
<td>Inductance</td>
<td>13.4 µH</td>
</tr>
<tr>
<td>Material</td>
<td>Fair-Rite 67</td>
</tr>
</tbody>
</table>

PFC Converter, 1-3 MHz
98% efficiency, 80 W/in³

Proposed strategy: A family of scalable and modular MP core sets for low-loss HF inductors.
Proposed strategy: A family of scalable and **modular** MP core sets for low-loss HF inductors

One core set can yield many different inductors

MP core set

- end cap
- outer ring
- center disc

aspect ratio \((h/D)\)
Proposed strategy: A family of scalable and **modular** MP core sets for low-loss HF inductors

One MP core set can cover a **wide range** of applications

MP Core Set

\[ 0.5 \leq h/D \leq 2.0 \]
Proposed strategy: A family of scalable and modular MP core sets for low-loss HF inductors

MP Core Set 1
0.5 ≤ h/D ≤ 2.0

MP Core Set 2
0.5 ≤ h/D ≤ 2.0

smaller footprints

larger footprints

scales to kW designs
Proposed strategy: A family of scalable and **modular** MP core sets for low-loss HF inductors

A **few** MP core set **components** can cover a **wide range** of applications

MP Core Set 1  
0.5 ≤ h/D ≤ 2.0

MP Core Set 2  
0.5 ≤ h/D ≤ 2.0
Scaling factors for MP core sets have trade-offs

4x Volume Scaling

Core Set 1

Core Set 2

Core Set 3

Power (VA)

L

2600x

45x

More economical to manufacture

2x Volume Scaling
(typical of closed cores)

Core Set 1

Core Set 2

Core Set 3

Power (VA)

L

1500x

15x

Greater form factor flexibility
Experimental results: MP prototypes achieve high Q

<table>
<thead>
<tr>
<th>Core</th>
<th>L (µH)</th>
<th>VA</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 MP17/1.0</td>
<td>6.8</td>
<td>280</td>
<td>520</td>
</tr>
<tr>
<td>2 MP17/2.0</td>
<td>12.9</td>
<td>520</td>
<td>590</td>
</tr>
<tr>
<td>3 MP27/0.5</td>
<td>15.8</td>
<td>520</td>
<td>500</td>
</tr>
<tr>
<td>4 MP27/1.0</td>
<td>13.4</td>
<td>910</td>
<td>690</td>
</tr>
</tbody>
</table>

4x Volume Scaling Factor
solid wire, 3 MHz
Experimental results: MP prototypes perform \textbf{\~2x better} than EQ cores of similar volumes

<table>
<thead>
<tr>
<th>3 MHz</th>
<th>Core (Fair-Rite 67)</th>
<th>L (µH)</th>
<th>Q (solid wire)</th>
</tr>
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<tbody>
<tr>
<td>7400 mm$^3$</td>
<td>EEQ25/16</td>
<td>16.5</td>
<td>280</td>
</tr>
<tr>
<td>520 VA</td>
<td>MP27/0.5</td>
<td>15.8</td>
<td>500</td>
</tr>
<tr>
<td>(1.8 – 2.0 A)</td>
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<td>12.9</td>
<td>590</td>
</tr>
<tr>
<td>3700 mm$^3$</td>
<td>EEQ20/13</td>
<td>7.8</td>
<td>270</td>
</tr>
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Experimental results: MP prototypes perform ~2x better than EQ cores of similar volumes

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<th>Core</th>
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<th>Q</th>
<th>L    (litz wire)</th>
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*Note: The table shows the inductance (L) in microhenries (µH) and the quality factor (Q) for both solid and litz wires.*
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**Field shaping**

Scalable **MP inductor structure** can achieve high performance for a wide range of applications using a small set of parts.

**Quasi-distributed gap**

smaller footprints

larger footprints
Acknowledgements

This work was supported in part by the NSF under Grant 1609240 and by the Masdar Institute of Science and Technology (Ref. 02/MI/MIT/CP/11/07633/GEN/G/00). Special thanks to Fair-Rite for manufacturing the magnetic core pieces used in the prototypes.

References


