Announcements

• No Lecture Wednesday (& Friday)
• Design Competition Begins Today
**Competition Specifications**

The *winning converter* will be the unit which achieves the *highest power density*, i.e. fits in the smallest rectangular volume, while meeting the following specifications.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
<th>Comment</th>
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<tbody>
<tr>
<td>Voltage Input</td>
<td>60 Vdc, 10 Ω series resistor</td>
<td></td>
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<tr>
<td>Maximum Output Power</td>
<td>60 W</td>
<td></td>
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<tr>
<td>Output Voltage</td>
<td>12 ± 1 Vdc</td>
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<tr>
<td>Input Ripple Current</td>
<td>&lt; 5% measured as $I_{pk-pk}/I_{avg}$</td>
<td></td>
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<tr>
<td>Output Ripple Voltage</td>
<td>&lt; 2% measured as $V_{pk-pk}/V_{avg}$</td>
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<tr>
<td>TPE Efficiency</td>
<td>&gt; 90% measured using TPE method¹</td>
<td></td>
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<tr>
<td>No-load Power Loss</td>
<td>&lt; 3W measured with load disconnected, but output voltage within specified range</td>
<td></td>
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<tr>
<td>Volume</td>
<td>&lt; 6 in³ measured as volume of minimum rectangle enclosing power stage</td>
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¹Tennessee Power Electronics (TPE) efficiency is a weighted power efficiency defined as:

$$\eta_{TPE} = 0.1\eta_{P=15W} + 0.15\eta_{P=30W} + 0.25\eta_{P=45W} + 0.5\eta_{P=60W}$$

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**Example Applications**

**EV 48V Architectures**

**Data Centers / Telecom**

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Audi, "Electric litter and hybridisation", 2014
AVL, "48V Mild Hybrid Systems"
Testing Setup

How Volume is Measured
**Schedule**

<table>
<thead>
<tr>
<th>Schedule</th>
<th>Oct 6</th>
<th>Nov 3</th>
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<tbody>
<tr>
<td>Oct 5</td>
<td>Oct 9</td>
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<td>Nov 21</td>
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<td>Nov 27</td>
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**Additional Details**

- Full competition specifications and example testing report on course webpage
- No regulation requirements
- First Deliverable: Monday October 17th
  - Design comparison of 4 topologies
Magnetism Losses

Physical Origin of Core Loss

- Magnetic material is divided into “domains" of saturated material
- Both Hysteresis and Eddy Current losses occur from domain wall shifting

Reinert, J.; Brockmeyer, A.; De Doncker, R.W.; "Calculation of losses in ferro- and ferrimagnetic materials based on the modified Steinmetz equation."
Inductor Core Loss

- Governed by Steinmetz Equation:

\[ P_c = K_{fe} f_0^a (\Delta B)^b \text{ [mW/cm}^3\text{]} \]

- Parameters \( K_{fe}, a, \) and \( b \) extracted from manufacturer data

\[ P_{fe} = P_c A_c l_m \text{ [mW]} \]

- Only valid for sinusoidal waveforms

\[ K_{fe}, a, b \text{ vary with frequency} \]

Steinmetz Parameter Extraction

Fig. 6 Specific power loss as a function of peak flux density with frequency as a parameter.

Fig. 7 Specific power loss for several frequency/flux density combinations as a function of temperature.
Non-Sinusoidal Waveforms

- Modified Steinmetz Equation (MSE)
  - "Guess" that losses depend on $\frac{dB}{dt}$
  - Calculate $\langle \frac{dB}{dt} \rangle$ and find frequency of equivalent sinusoid

![Graph](image1)

Albach, Durbau and Brockmeyer, 1996
Reinert, Brockmeyer, and Doncker, 1999

NSE/iGSE

$$P_{NSE} = \left( \frac{\Delta B}{2} \right)^{2-\alpha} \frac{k_N}{T} \int_0^T \left| \frac{dB}{dt} \right|^\alpha dt$$

$$k_N = \frac{k}{(2\pi)^{\alpha} \int_0^\pi |\cos \theta|^\alpha d\theta}$$

Simple Formula for Square-wave voltages:

$$P_{NSE} = k_N \left( 2f \right)^\alpha \left( \Delta B \right)^\beta \left( D^{1-\alpha} + (1-D)^{\beta-\alpha} \right)$$

where $f$ is the operating frequency;
$\Delta B / 2$ is the peak induction;
$D$ is the duty ratio of the square wave voltage.

Note: The second and third harmonics are dominant at moderate values of duty ratio $D$. For extreme values of $D$ (95%), a higher value of $\alpha$ could give better matching to the actual losses.

C. Venkatachalam, C.R. Sullivan, T. Abdallah, H. Taic, "Accurate prediction of ferrite core loss with nonsinusoidal waveforms using only Steinmetz parameters"
Additional Approaches

• History of Core Loss Approximation Techniques:

• Seminar on magnetic loss modeling:

Minimization of Losses
Spreadsheet Design

- Use of spreadsheet permits simple iteration of design
- Can easily change core, switching frequency, loss constraints, etc.

Matlab (Programmatic) Design

- Matlab, or similar, permits more powerful iteration and plotting/insight into design variation
Planar Inductors