Rapid High-Frequency Transformer Simulation and Optimization

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Motivation

- Wide bandgap switches enable power converters to operate at HF
- Magnetics become limiting factor in converter performance
- Transformer design at high frequencies is difficult
- Current is not guaranteed to share evenly:
  - Between paralleled conductors
  - Within individual conductors
- Engineers rely on heuristics (e.g., interleaving) to design
- Verification is done with finite element analysis – slow!
- What if we could analyze the whole space of possible configurations?
  - Enable true optimization

Analysis Method (see [1])

- Assume high frequency operation
- Current flows in skins – treat as surface current densities with units A/m
- No B or H fields within conductors
- Assume negligible H field in core – relevant to many applications
- Maxwell’s laws are reduced to a linear algebraic system of equations
- Solving gives information about layer currents, surface current densities, and H fields
- Easily solved using numeric computing toolkit (e.g. MATLAB, numpy)

Implementation

- Must be able to specify & generate arbitrarily complex windings
- Accomplished through binary tree structure:
  - Layers identified by number and turn count
  - Connected via either series or parallel nodes
- Valid stackups have a primary and secondary tree, cumulatively identifying turn counts and interconnections for every layer.
- Can run analysis method on any valid stackup object, produce either a symbolic or numeric solution (if geometry is given)
- Can recursively generate stackups meeting certain turns ratio, layer count requirements

Software Tool

- Combination of two tools: Evaluator & Optimizer
- Evaluator – For given winding, calculate current distribution & loss
- Optimizer – For given number of layers & turns ratio, identify optimal designs

Tool can process thousands of designs per second!

Experimental Verification

- Constructed test transformers for experimental verification

References