SAND2020-2488C

Sandia National Laboratories

Design and Evaluation of Nanocomposite Core Inductors for Efficiency Improvement in High-Frequency Power Converters

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Goals and Objectives

This work is aimed at developing inductors employing a novel Sandia superparamagnetic nanocomposite core. This new magnetic material nearly eliminates the hysteretic and eddy current losses associated with power conversion at MHz-scale switching frequencies. This will reduce power conversion losses and improve efficiencies.

Introduction

Modern megawatt (MW) data centers are motivated to reduce power costs through higher efficiency point-of-load (PoL) converters. Higher switching frequencies are needed to reduce these converter losses, particularly in the final conversion stage which is often the least efficient. However, these frequencies are limited to ≈1 MHz due to losses in the magnetic components, not those attributed to the wide bandgap (WBG) semiconductor devices, ultimately limiting converter performance. To reduce these losses, improvements in magnetic core materials are needed.

Inductor Design

A solenoid – type coil architecture with a bobbin style magnetic core enclosure using our magnetite nanocomposite is used (Fig.1). To first order, the inductance of a finite solenoid with a magnetic core is governed by the following:

$$L=\mu_r\mu_0 N^2 A/l$$

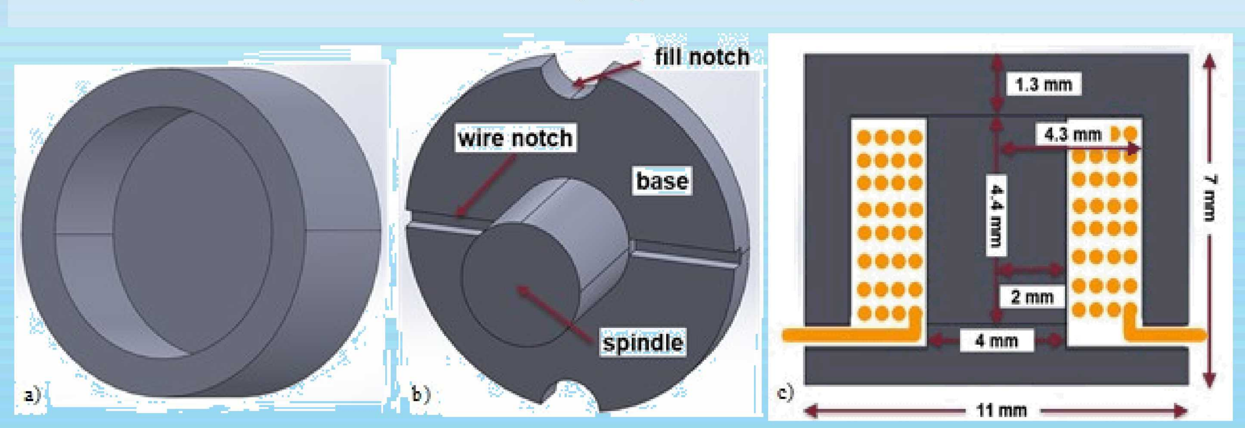

Fig. 1 a) Nanocomposite cap. b) Nanocomposite spindle & base with wire terminal and filling notches. c) Cross sectional image of the assembled inductor with a 4-layer, 31 total turns solenoidal coil.

Inductor Simulation

To improve design accuracy, COMSOL Multiphysics 5.3 was used. The design meets the required inductance and reduces electromagnetic interference (EMI) in the smallest form factor.

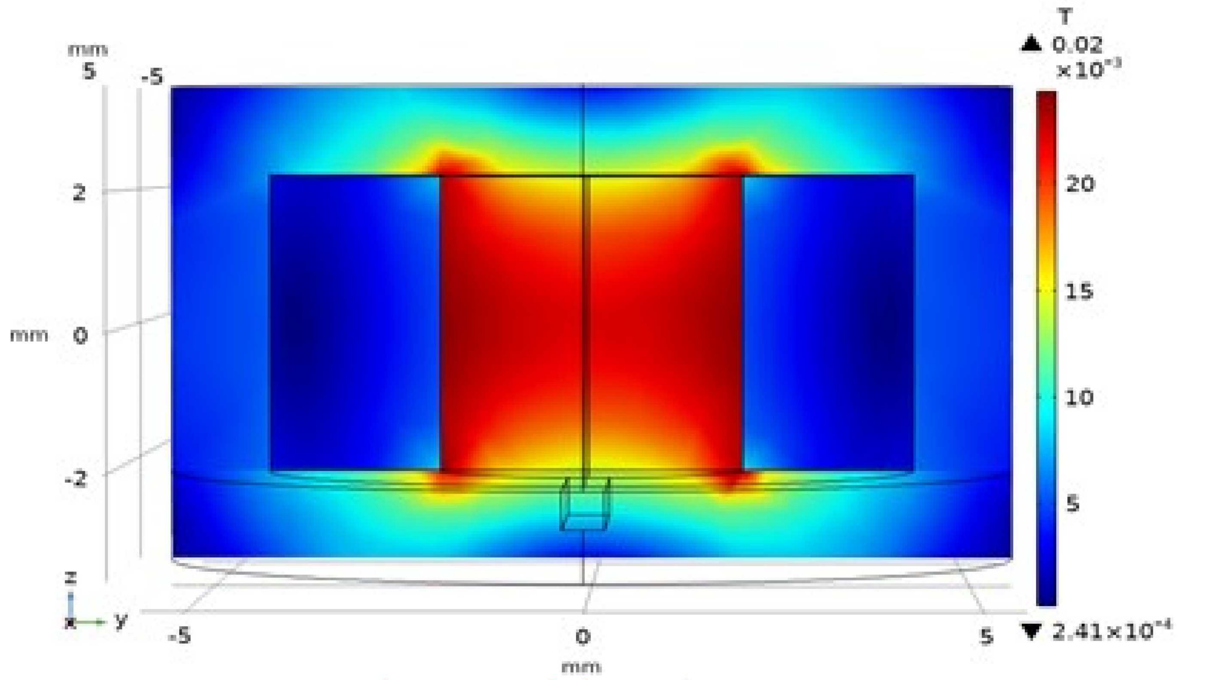

Fig. 2. Cross sectional image of the inductor magnetic core polarization, J, generated by COMSOL.

Nanocomposite Core and Magnetic Characterization

The new superparamagnetic material is comprised of ~20 nm magnetite (Fe_3O_4) spheres suspended in a dielectric epoxy matrix.

- Negligible magnetic hysteresis (Fig. 3 (inset))
- Negligible eddy currents
- Nearly flat relative permeability, **μ**′, out to 1 MHz (Fig. 3).

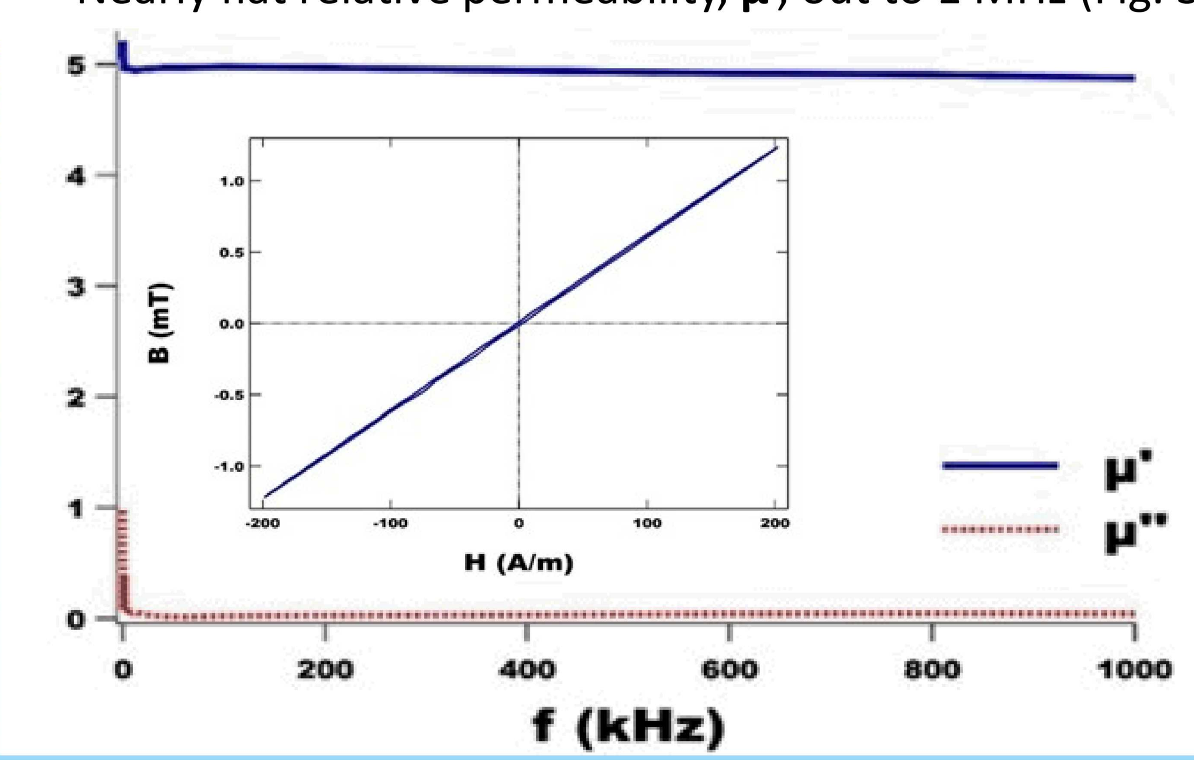

Fig. 3. Real and imaginary permeability of a toroidal nanocomposite core versus frequency. (Inset) Hysteresis loop of a toroidal nanocomposite core collected at 1 MHz.

Electrical Performance Testing

To test the performance of the nanocomposite inductor in circuit, a 3.3 V synchronous buck converter was developed with a small form factor using EPC 2012C GaN HEMTs controlled with an LTC7800 step-down controller.

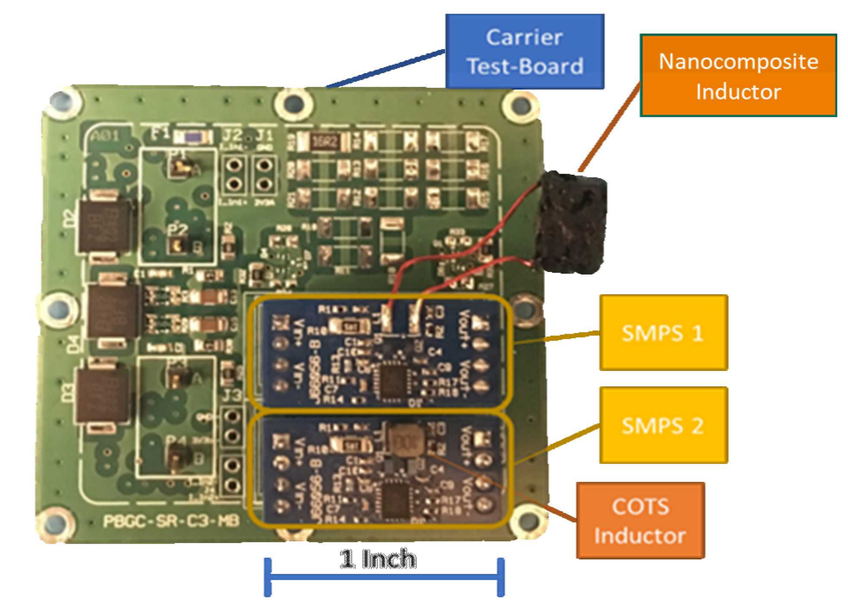

Fig. 4. 3.3 V synchronous buck converter used for testing the inductor performance.

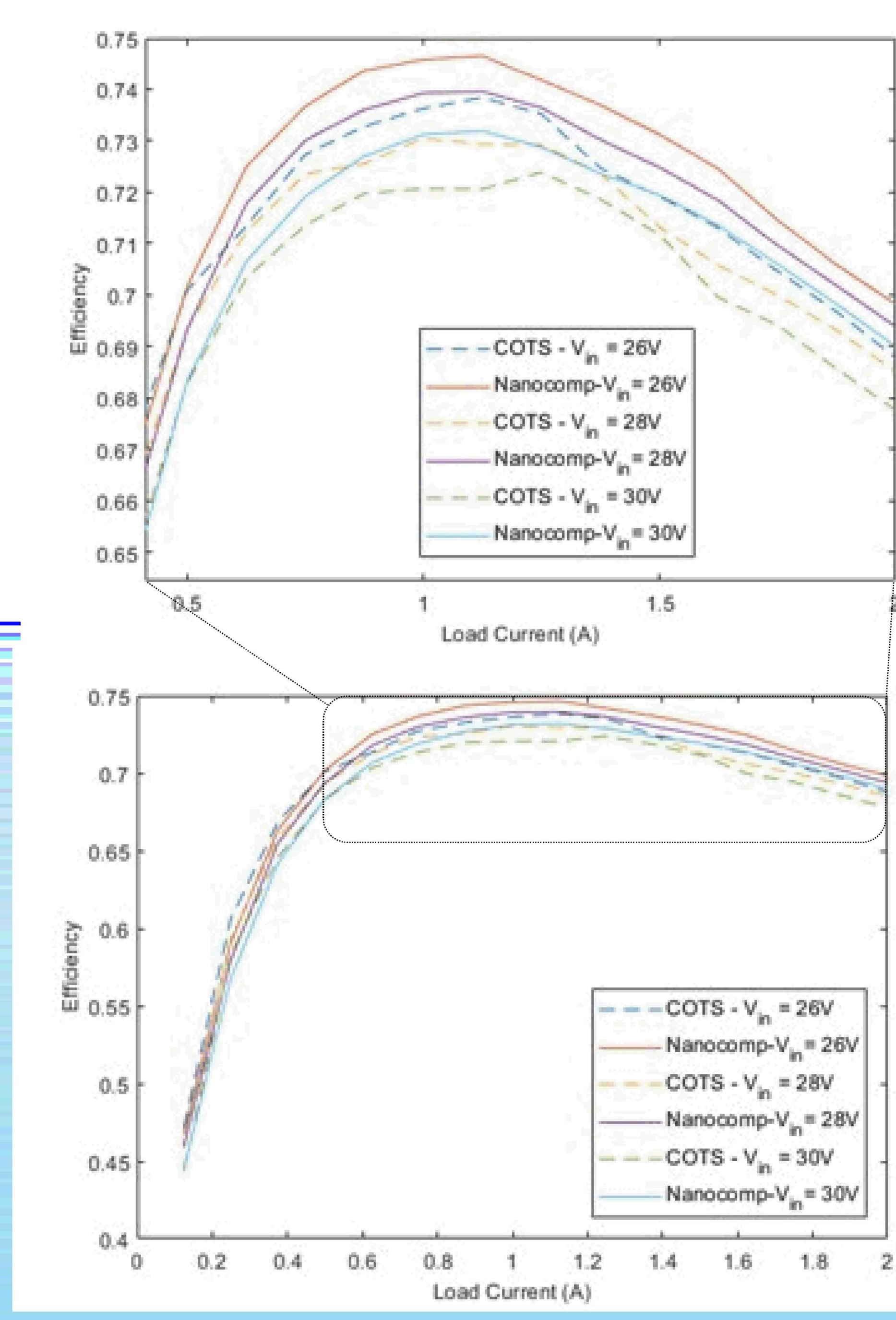

Fig. 5. Circuit efficiency comparison between the nanocomposite inductor and the COTS inductor with approx. 1 % improved efficiency at higher currents.

Table I. Experimental results comparing both inductors.

Measured Parameter	Nano-Composite Inductor	COTS Inductor (measured)
Inductance @ 1 kHz (μH)	4.38	3.40
Inductance @ 2 MHz (μH)	3.37	3.22
DC Resistance (mΩ)	56	49
AC Resistance @ 2 MHz (Ω)	2.41	1.11
Volume (mm^3)	810	48

Conclusions

A novel nanocomposite core inductor was designed to improve the efficiency in Point-of-Load (PoL) converters to reduce electrical losses in modern data centers.

- B-H analyzer measurements of the nanocomposite core were made verifying both it's superparamagnetic behavior and a nearly flat relative permeability, **μ**′, of around 5 out to 1 MHz
- 1 % improved efficiency at higher load currents demonstrated between the nanocomposite inductor vs. a COTS inductor (ASPI-4030S-3R3) in a 3.3 V synchronous buck converter test circuit transformer test circuit

Acknowledgment

This project was supported by Laboratory Directed Research and Development (LDRD) Project number 170341. This work was performed, in part, at the Center for Integrated Nanotechnologies, an Office of Science User Facility operated for the U.S. Department of Energy (DOE) Office of Science. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. Special thanks to Robert E. Delaney for his help with nanocomposite core testing. This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

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