Buck Converter with a PCB Air Core Inductor

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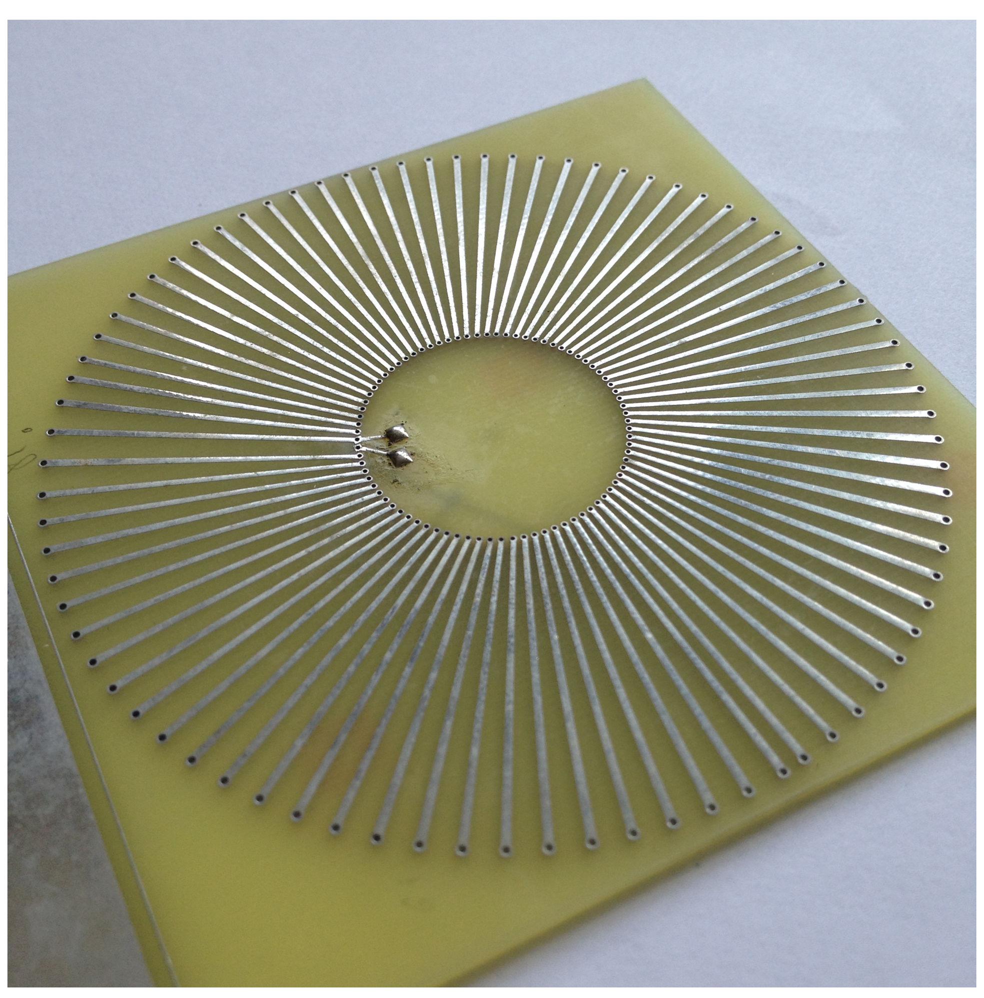
Overview

DC-DC step-down converters for power distribution in Mu2e have several challenges: the design has to perform in 1 Tesla magnetic field, maintain high efficiency (>80%) at high power, minimize space usage without limiting performance [1]. A regular buck converter that uses a ferromagnetic core inductor is very efficient, but it cannot operate properly in such a strong field. An air core inductor can, but is not commercially available in desired quantities. Hand winding an air core inductor is an expensive option that introduces more human error in each copy of the inductor. A possible solution is a PCB air core inductor. Manufacturing air core inductors using PCB technology is an economically reasonable option and it ensures the consistency of the design. During my internship I focused on testing inductor's geometry and prototyping a 48V to 3.6V buck converter.

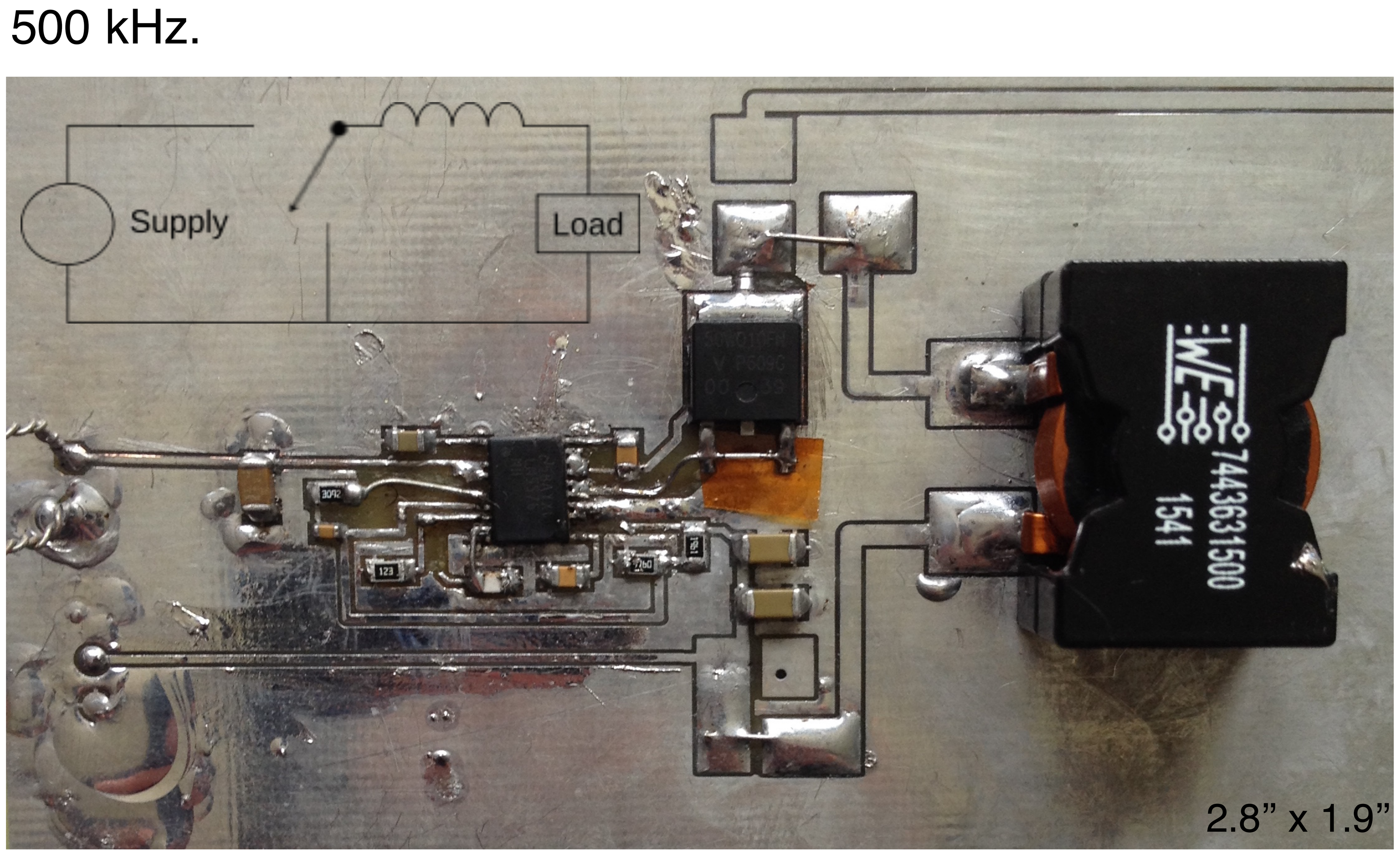
Inductor Design



The first prototype. Experiment requires the containment of inductor's magnetic field. Toroidal geometry design with a square cross section yields an easier calculation of the inductance and does not pose problems for manufacturing. The design was drawn using EAGLE software.

Buck Converter

Conversion in a nutshell. Switch is horizontal; there is a change in the current. Inductor stores energy whereby reducing voltage on the output. Switch is vertical; supply disconnects. Inductor acts as a voltage source supplying the stored energy to the load. Switch is horizontal. Process repeats. The goal of the first prototype was to establish a consistent working design with a regular inductor first. I used TI WEBENCH software to maximize the efficiency and EAGLE software to draw the PCB design of the circuit. For timed switching buck uses LM5576/-Q1 with maximum frequency of 500 kHz.



2.8” x 1.9”

Measurements

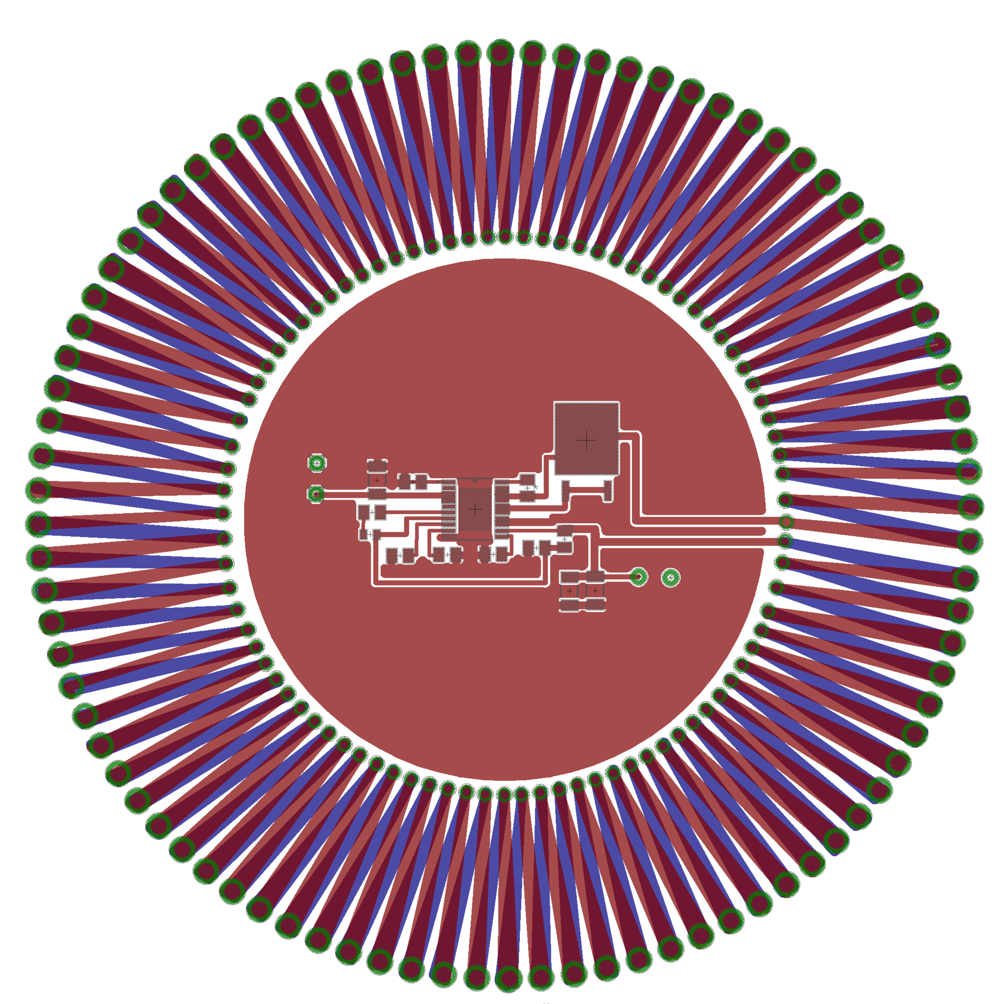
Inductor measurement. In order to measure the inductance, I connected the inductor in series with the known resistor and connected the two to a frequency generator with a sinusoidal wave. Using an oscilloscope, I measured the voltage amplitudes of the generator and inductor as well as phase shift and derived the inductance. Additionally, I measured the resistance of the inductor.

Buck converter measurement. I measured various voltage drops along the board, ramp control signal and switching node. I compared the results with simulations ensuring the proper operation. By measuring the input and output power, I calculated the efficiency of the board. The goal of the prototype was not high efficiency, but the test of the performance with the maximum load at 48V compared to the theory. The maximum load of a buck with a regular inductor is 1.5 Ω; PCB inductor is 3 Ω. The results are summarized below.

	PCB Inductor				Max load efficiency	
	Inductance (L)	%error (L)	Resistance (R)	% error (R)	Regular inductor	PCB Inductor
Theoretical	2.39 µH	25.3 %	4.7 Ω	10.6 %	73%	38%
Measured	3.20 µH		4.2 Ω		72%	24%

Resistance of the PCB inductor and a cap on higher frequencies of the switch are main flaws that lower the efficiency of the buck. Based on the measurements, I'd like to present the next prototype. The resistance will be lowered significantly and the frequency will reach up to 950 kHz, compared to 500 kHz.

The Next Prototype



The specs below correspond to the PCB inductor/circuit pictured on the left. Both the circuit and PCB inductor will be printed on one board. The trace thickness will reach up to 20 oz/ft^2. The design is complete and ready to be printed and tested.

	Predicted
Inductance	7.0 µH
Resistance	0.3 Ω
Dimensions	4” x 4” x .25”

References

[1] Puidak, M., “DC-DC Converters,” (2012) Mu2e-doc-2354.

Acknowledgments

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