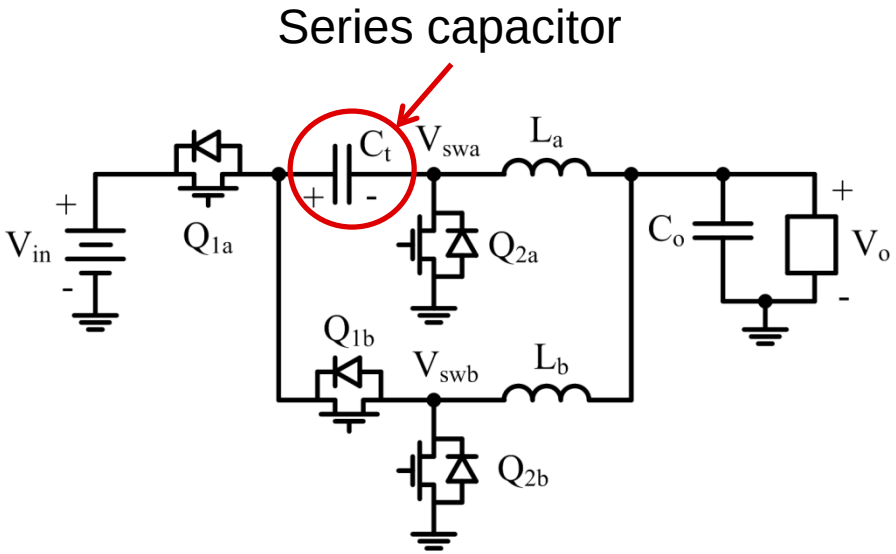
A High Density Series Capacitor Buck Converter

A low profile 10A voltage regulator achieving 1.25 kW/in^3 power density and over 300kHz bandwidth

Pradeep Shenoy, Kristen Parrish, and Chuck Devries

Series Capacitor Buck Topology

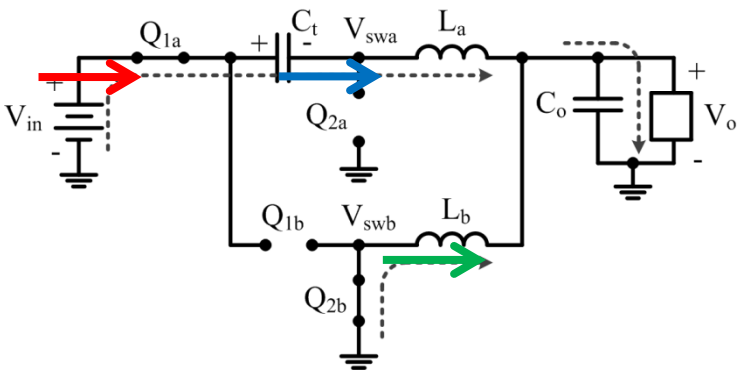


Two-phase, series cap buck converter

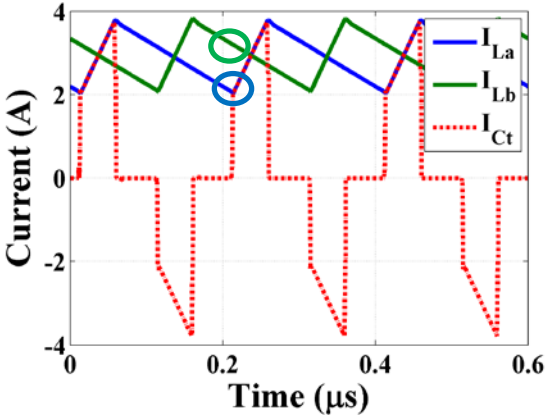
- ✓Benefits
  - ✓Single conversion stage
  - ✓Switching at reduced V_{ds}
  - ✓Series cap soft charge/discharge
  - ✓Automatic current balancing
  - ✓Duty ratio doubled
- Drawback
  - – 50% duty cycle limitation
    - Theoretical: $V_{IN,MIN} = 4 \times V_{OUT}$
    - Practical: $V_{IN,MIN} = 5 \times V_{OUT}$

P. S. Shenoy, M. Amaro, J. Morroni and D. Freeman, “Comparison of a Buck Converter and a Series Capacitor Buck Converter for High-Frequency, High-Conversion-Ratio Voltage Regulators,” *IEEE Trans. Power Electron.*, vol. 31, no. 10, pp. 7006-7015, Oct. 2016.

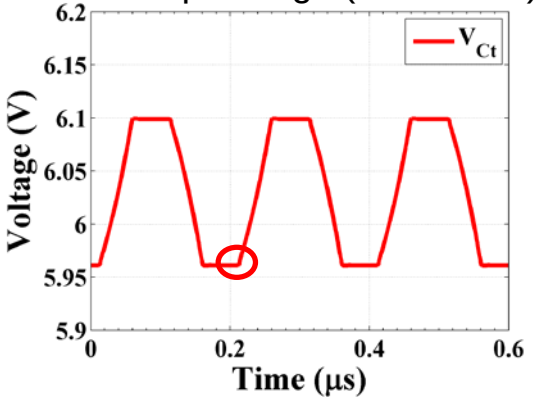
Steady-State Operation: Interval 1



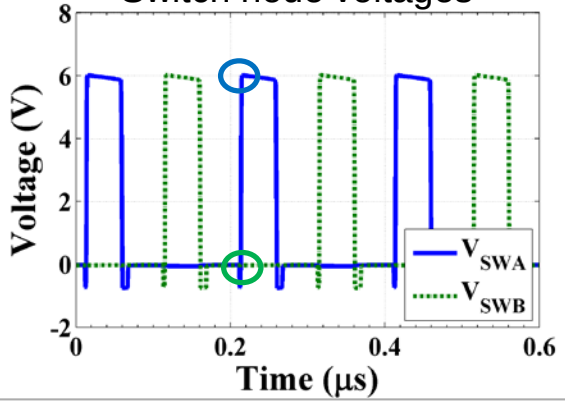
Inductor & series cap currents



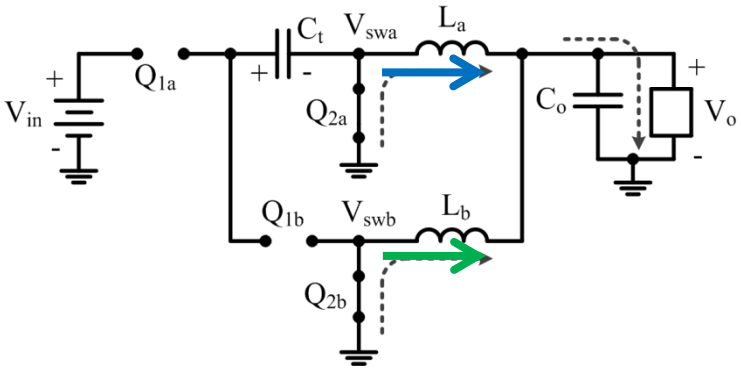
Series cap voltage (differential)



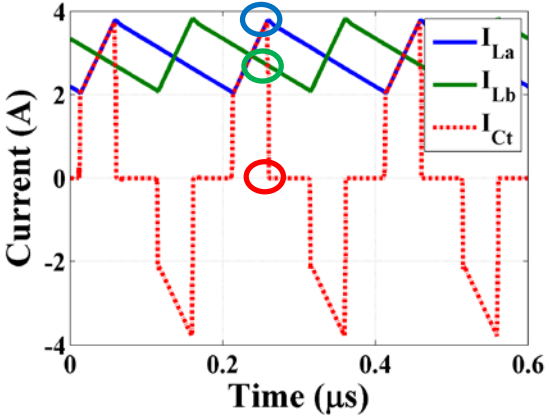
Switch node voltages



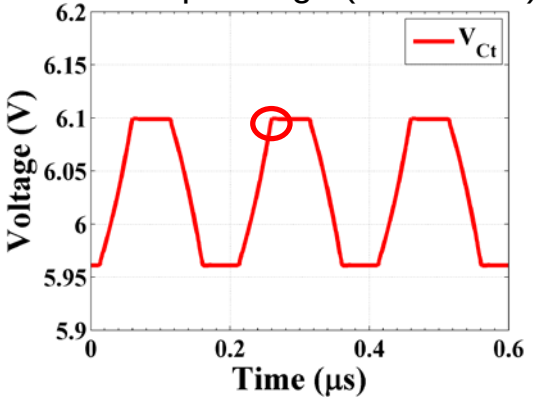
Steady-State Operation: Interval 2



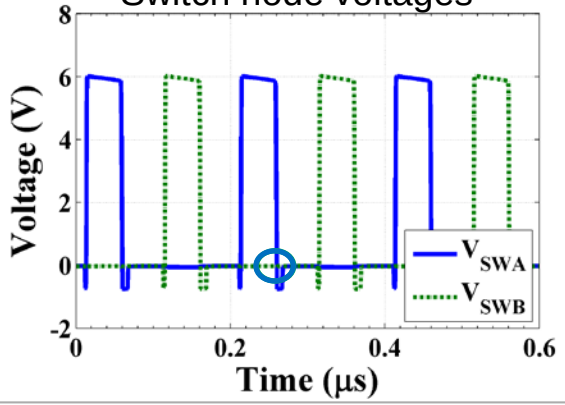
Inductor & series cap currents



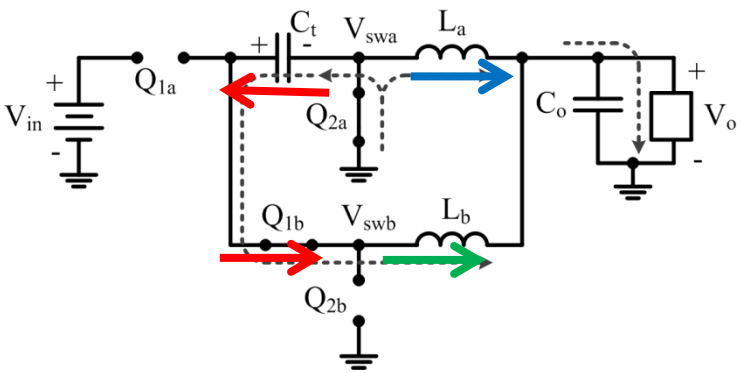
Series cap voltage (differential)



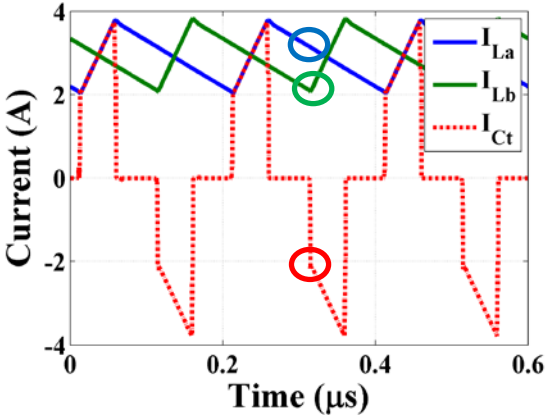
Switch node voltages



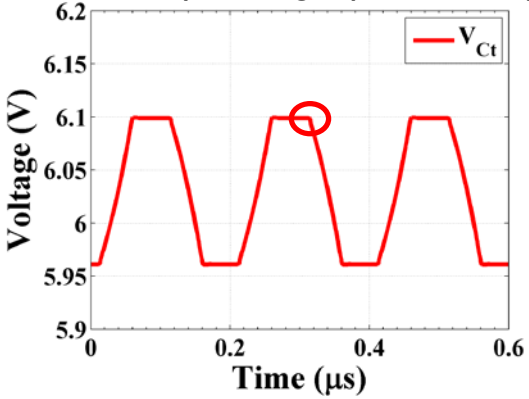
Steady-State Operation: Interval 3



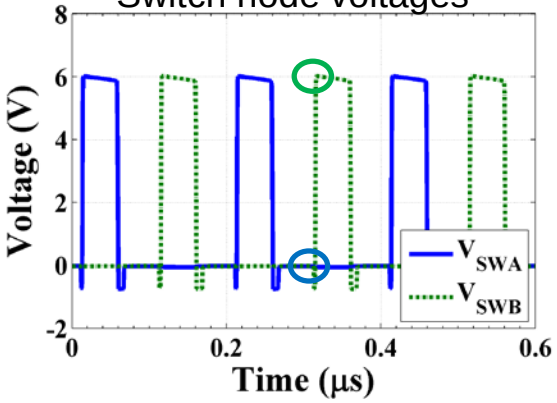
Inductor & series cap currents



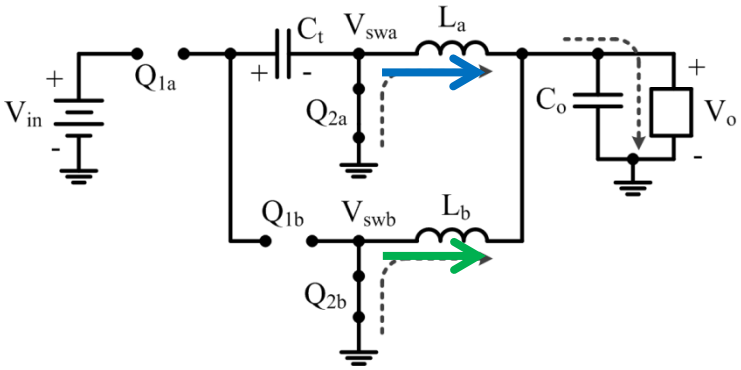
Series cap voltage (differential)



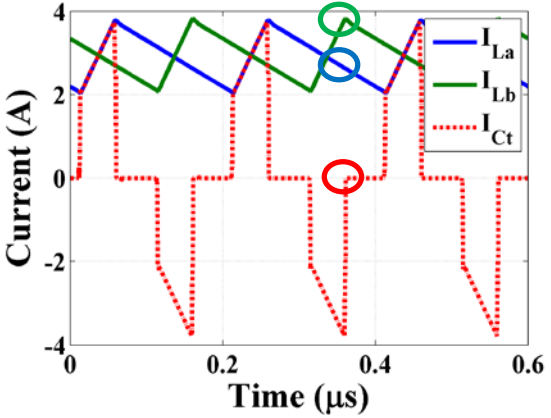
Switch node voltages



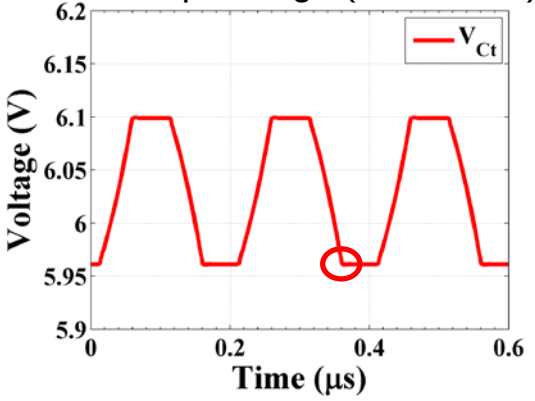
Steady-State Operation: Interval 4



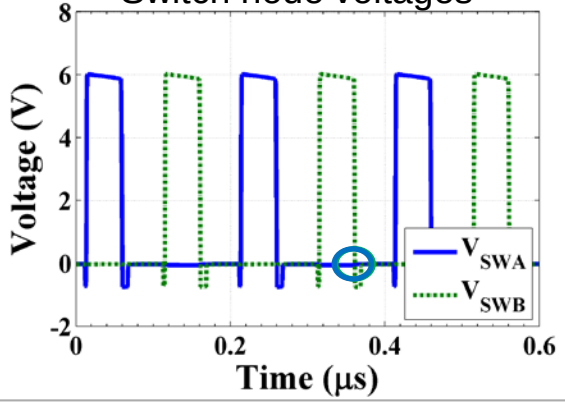
Inductor & series cap currents



Series cap voltage (differential)

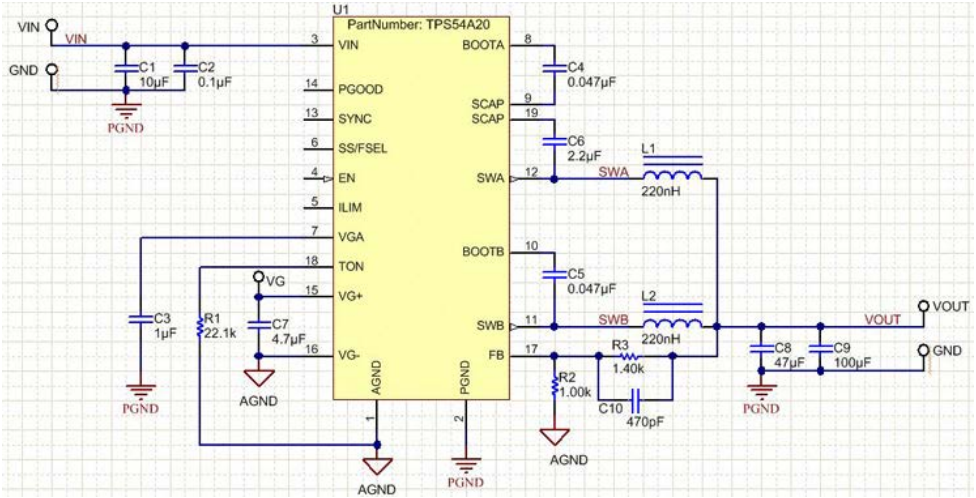


Switch node voltages

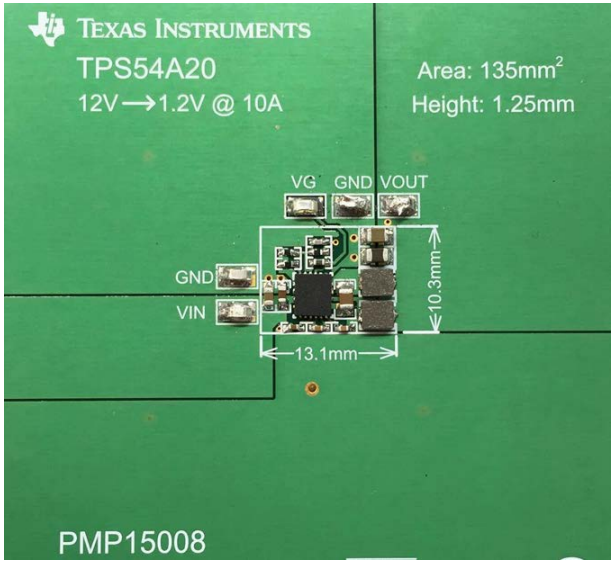


Reference Design PMP15008

"Tiny, Low Profile 10 A Point-of-load Voltage Regulator"

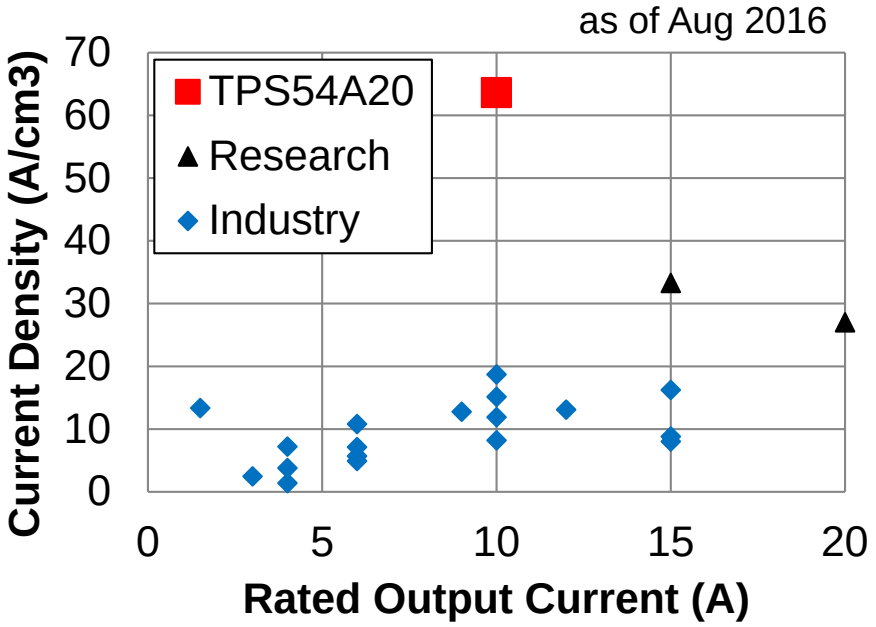


Board Image

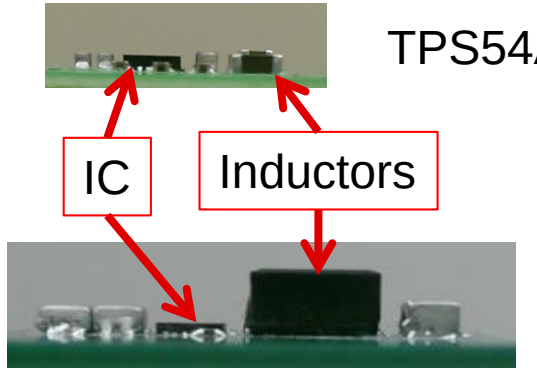


Total solution size is 135mm² and 1.25mm tall

Current Density Comparison



Series Cap Buck: **1.2 mm height**

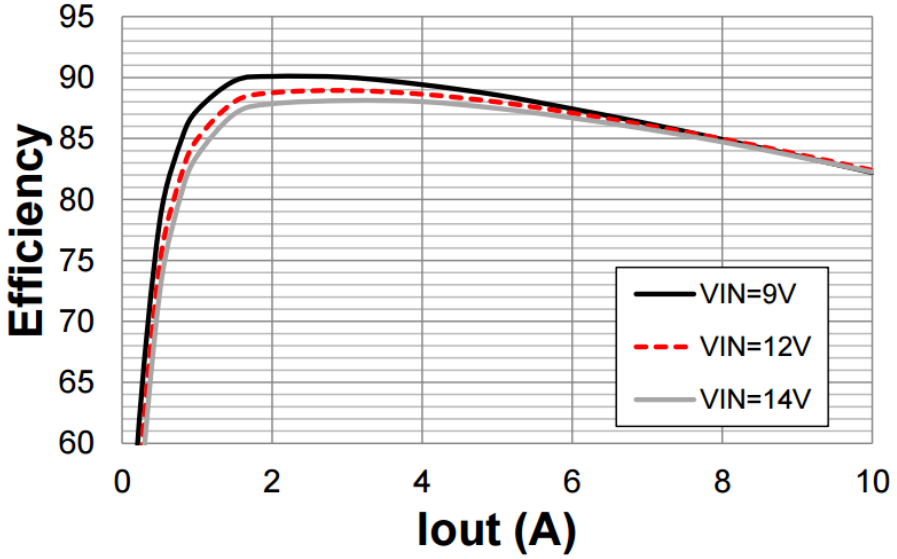


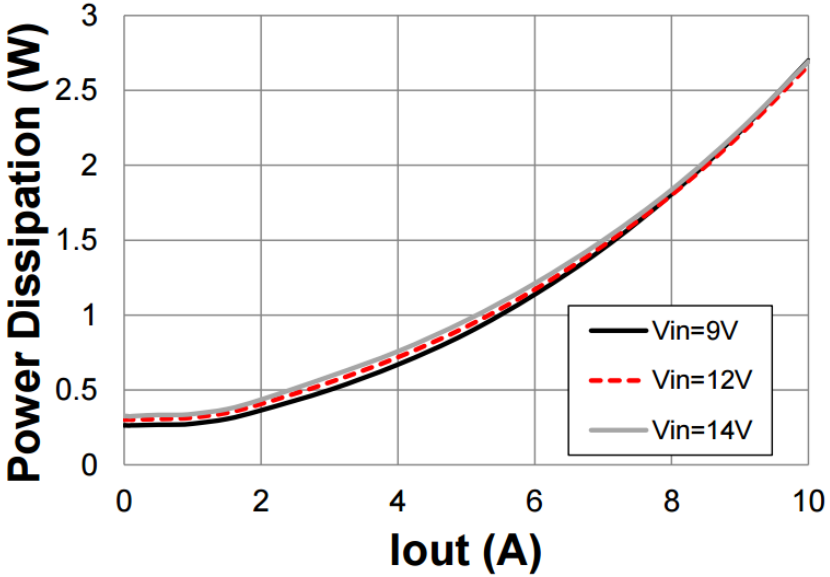
Conventional Buck: **4.8 mm height**

Current density of over 60A/cm³ and power density of 1.25kW/in³

Efficiency and Power Loss

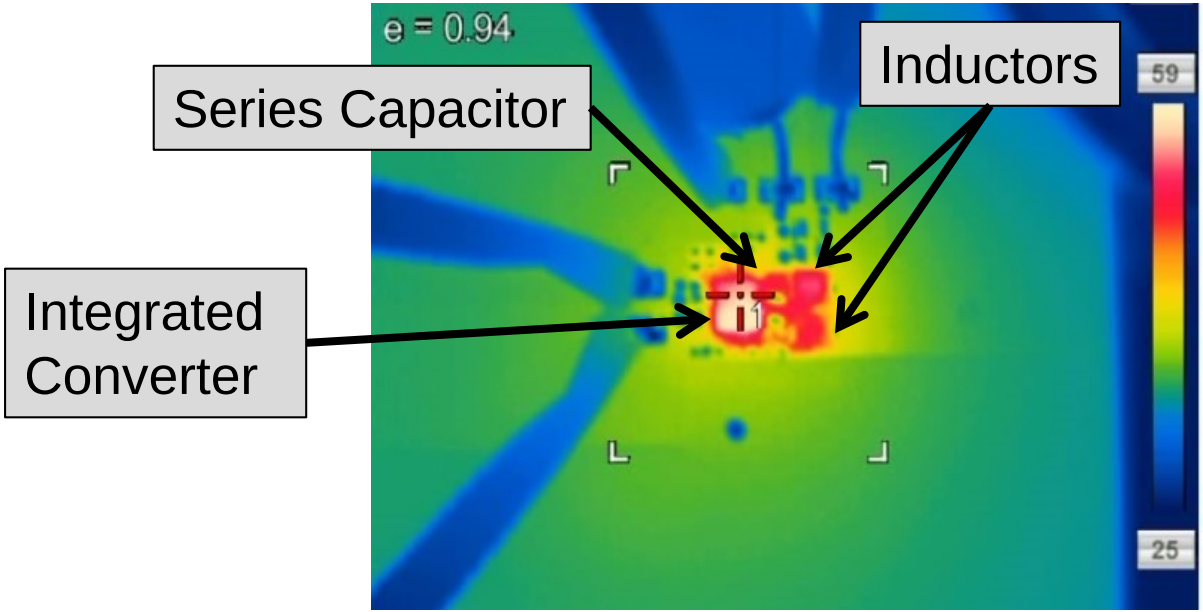
2 MHz per phase, 1.2V_{OUT}, room temperature, no air flow, two layer board





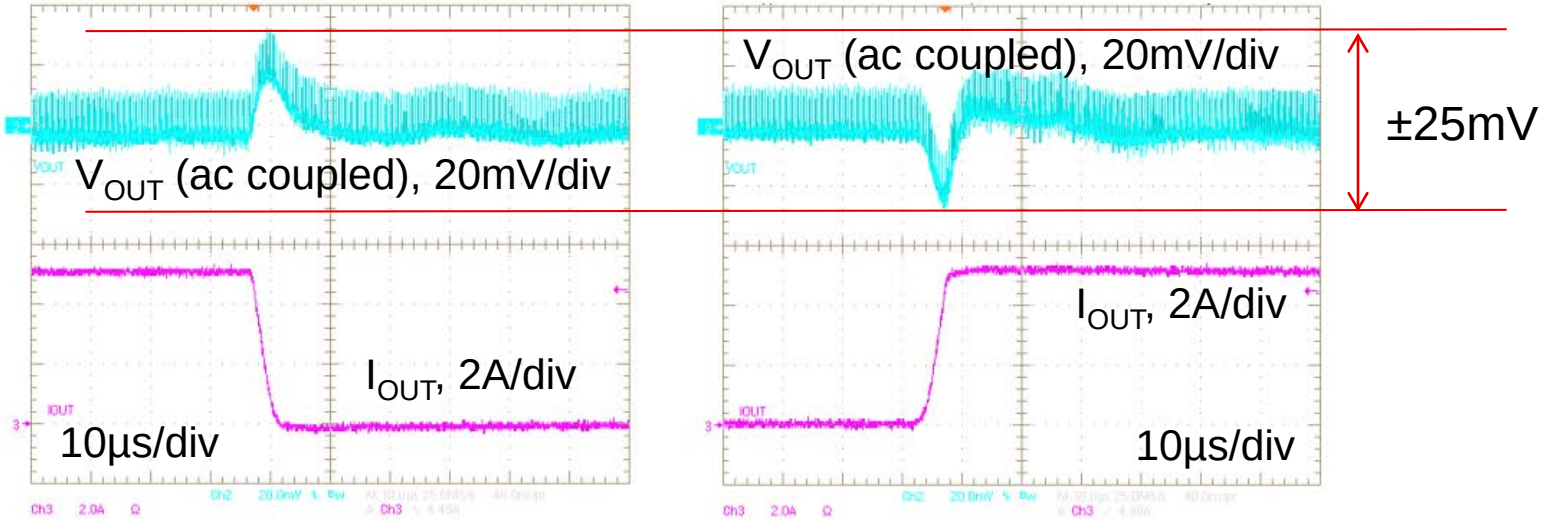
Over 90% efficiency at 9V input, less than 3W loss at full load

Thermal Image



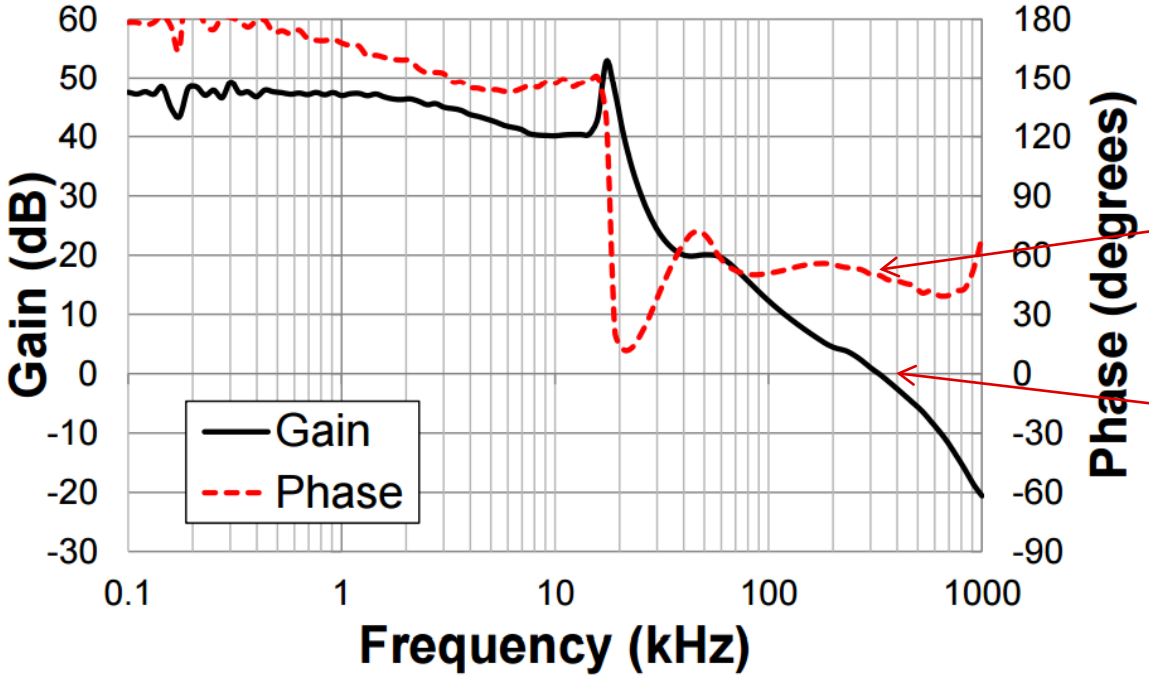
Less than 35 deg. C temp rise at 12V input, 8A output

Load Transient Response



2% variation in V_{OUT} during 5A load change

High Bandwidth and Ample Phase Margin



Over **50 degrees** of phase margin

Over **300kHz** bandwidth

Bode plot taken with 12V input, 5A output