

Revision summary

October 13th – Requirements document posted

November 20th – [Updated ordering directions](#)



Introduction

The Tiny Box Competition is a hardware design competition, part of ECE 581: Power Electronics in Fall 2023. The goal of the competition is to design, build, and test in open-loop a high efficiency, high power-density DC-DC converter leveraging techniques discussed in class.

Questions regarding the competition requirements should be discussed in class, so that all teams have equal knowledge of the competition expectations. Questions may be e-mailed to the instructor at any time, and will be discussed at the start of class the following lecture. Answers to select questions will be posted on the course website.

This document may be modified periodically to reflect questions/clarifications/alterations in response to questions. All students in the course will receive an e-mail when this document is updated.

High Level 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. All specifications must be demonstrated experimentally. In the event of a tie on volume, efficiency will be used to determine the winner.

Parameter	Requirement	Comment
Voltage Input	48 Vdc	
Maximum Output Power	12 W	
Output Voltage	1.2 ± 0.1 Vdc	
Output Ripple Voltage	< 2%	Measured as V_{pk-pk}/V_{avg} from the DC supply, in steady state, at full output power
TPE Efficiency	> 85%	Measured using TPE method ¹
No-load Power Loss	< 3W	Measured with load disconnected, but output voltage within specified range
Volume	< 2 in ³	Volume of minimum rectangle enclosing power stage

¹Tennessee Power Electronics (TPE) efficiency is a weighted power efficiency defined as:

$$\eta_{TPEF} = 0.1\eta_{P_{out}=0.25 \cdot P_{max}} + 0.15\eta_{P_{out}=0.5 \cdot P_{max}} + 0.25\eta_{P_{out}=0.75 \cdot P_{max}} + 0.5\eta_{P_{out}=P_{max}}$$

Required Construction Details

For this competition, the design and prototype construction considers only the power stage, consisting of power semiconductor devices, passives, and gate drivers. Any requirements for additional isolated/non-isolated gate driver power supplies do not count towards total converter volume, nor does a gate driver

supply need to be included in efficiency measurements. No closed-loop control is required; the converter can be tested in open-loop at the various operating points necessary for the TPEF efficiency measurement, one-at-a-time.

The assessed volume of your converter is the volume of the minimum rectangular volume which encloses all components listed above. You may choose to make your PCB larger than this volume in order to include additional test points or connections for signals. If you choose to do so, a rectangle on the top silkscreen layer must be used to indicate the extent of the power stage.

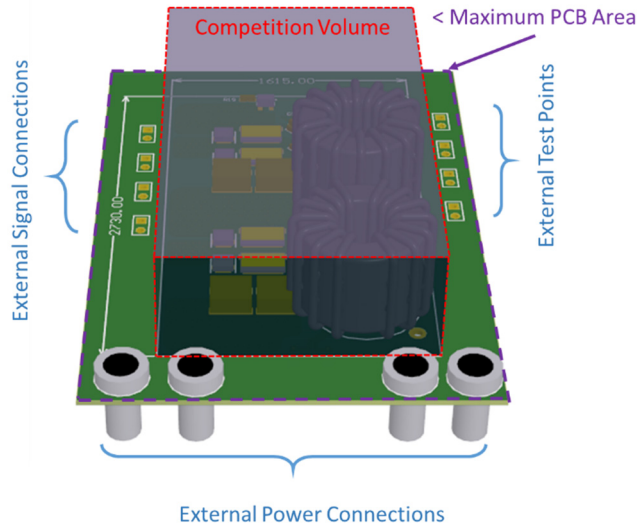


Fig. 1: Example hardware entry

Converter Realization

Converter Components

All components used in the initial converter design must be commercially available, and in stock at the time of purchasing. Digikey and Mouser are preferred vendors for general components.

Magnetics

If your converter contains magnetics of your own design, the cores must be available for commercial purchase in low quantities. Vendors of magnetic cores from multiple companies include

- Elna Magnetics (<http://www.elnamagnetics.com/>)
- Allstar Magnetics (<http://allstarmagnetics.com/>)
- Dexter Magnetics (<http://www.dextermag.com/>)

A limited selection of magnetic cores, as well as discrete inductors, are available from Digikey and Mouser.

The total cost of components for your converter is not to exceed **\$100 per converter**.

PCB

Printed Circuit Boards will be ordered on the date specified on the course schedule. All circuit boards will be ordered with Sierra Circuits' NoTouch, 4-layer specifications. Details are given at <https://www.protoexpress.com/NoTouch-pcb/product-specs.jsp>, except as specified below

Parameter	Requirement
Maximum Area ¹	10 in ²
Maximum single dimension ¹	6 in
Minimum trace/space	5 mil
Minimum finished hole size	10 mil
Surface Finish	ENIG
Turn Time	4 days
Quantity	2 boards
Board Outline	Top Soldermask; Must be a closed rectangle

¹maximum dimensions apply to the complete board, including power stage and any additional testing/connection in the layout.

Each group will receive one (1) copy of their PCB layout. Prior to submission, each layout must successfully pass the AFV check here: <https://www.protoexpress.com/orderProc/noTouchNew.jsp>, with no issues found.

The total cost of the PCB for your converter is not to exceed **\$200 per converter**.

Total Cost of Prototype

Total construction of the prototype converter is limited to \$300 per converter, for both components and PCB. With permission, you may exceed the components or PCB budget above, but the total must be under \$300. Discuss with the instructor if you feel this limit impedes your ability to realize your design

Measurement Procedure

All measurements taken in order to verify the converter performance experimentally must be taken after the converter has been operating in steady-state for more than 60 seconds to ensure thermal stability. Ripple requirements need only be measured at full output power.

To obtain accurate measurements, be sure to employ Kelvin voltage sensing, particularly at the high-current output port.

Additional Resources

Each group will be given access to sufficient testing equipment as needed outside of students' current access. Additionally, each group will optionally receive a controller platform and associated code capable of generating PWM signals.

Assignments and Schedule

Competition Schedule

- October 13th – Competition Begins
- November 10th – Paper Design and Comparison Report Due
- November 17th – PCB Layout Due
- December 6th – Testing Report Due

For all assignments, only one copy needs to be produced per group. All teams must work as a group of two, unless prior approval is received from the instructor. All deliverables are due at the start of class on the specified date.

Paper Design and Comparison Report

(Due November 10th)

A minimum of three (3) topologies must be considered. Among the topologies selected for consideration, at least one must be from Class IV, as defined by the table below. No Class I topology may be considered. At most one Class-II topology can be considered, and it may not be a traditional small-ripple design. Selection of a Class IV topology will likely require examination of the relevant literature.

	Class I	Class II	Class III	Class IV
<i>Definition</i>	Two-switch PWM topologies	Isolated variants of PWM topologies*	AC-link topologies	Any topology not conforming to Class I-III
<i>Examples</i>	Buck, Boost, Buck-Boost, Cuk, SEPIC, etc.	Flyback, Forward, push-pull, half-bridge, full-bridge	DAB, DAHB, SRC, LLC, Full Bridge, etc.	Switched capacitor, sigma-delta, multilevel, etc.

* Fully small-ripple, hard-switched Class-II topologies may not be used.

For each topology, the team must solve the converter operation for all parameters necessary to examine operation in steady-state (Average and RMS currents, modulation signals, peak voltage stresses, passive sizing, etc.). Additionally, teams must state and justify predictions for converter performance in terms of

1. Efficiency at full power
2. Power loss at zero load
3. Output voltage ripple
4. Volume of main passive components

Broad comprehensive optimization does not need to be completed, but the predictions must be made for real component values and a specific operating scenario, and should be indicative of converter performance with good-faith efforts to examine each of the three candidates.

In addition to the analysis of these three topologies, the teams must provide a discussion of the relative merits of each, and propose one of the selected topologies for construction.

For the single, selected topology, teams must report on the process and results of optimization to meet all specifications with the minimum total volume. This includes justification and final selection of

1. Power Devices
2. Gate Driver Circuitry
3. Passive Devices and implementation
4. Switching Frequency

The report must include a complete converter schematic with part numbers for all devices.

PCB Layout Submission

(Due November 17th)

Teams must submit, through canvas, one .zip archive of the completed PCB layout. The layout must successfully pass Sierra Circuits' AFV check prior to submission. The zip archive should contain the following file types from the Altium project:

- | | |
|-----------|-----------|
| 1. PrjPcb | 4. PcbLib |
| 2. SchDoc | 5. PcbDoc |
| 3. SchLib | |

Also in canvas, submit your username and password (make sure to change your password to something not used for any other personal account) to the Sierra Circuits webpage. Prior to submission, move all quotes *except* the one final board which has passed AFV to your old/hidden folder. The quote should be specified with

- 4-day turn
- 6 mil minimum trace/space
- 15 mil hole size
- 1 board quantity
- (up to) 4 layers

Note: Sierra Circuits' AFV process may be unable to complete outside of business hours if the board has issues that cannot be resolved in an automated manner. Plan to complete your layout well before the deadline to ensure that an error-free AFV can be submitted before the deadline.

Additionally, teams must submit one (1) spreadsheet containing the parts required to construct the PCB. An example file will be posted on the course webpage. The columns, order, and formatting must match the example file exactly, and must show that the sum of costs for all components ordered is such that the total cost with PCB fabrication is below \$300.

For all parts that the teams are requesting to be ordered, teams must submit immediately actionable resources for ordering. For vendors including Digikey and Mouser, this can be achieved by links to carts. For other vendors, quote documentation with ordering information will suffice.

Once your PCB layout has been reviewed and approved, you may proceed with submitting the parts and PCB order by e-mail to eccs-orders@utk.edu (Dwayne Kelly). When e-mailing, you must

- Include a description of why the order is being placed in the e-mail body (i.e. for a student design competition in ECE581)
- Include actionable ordering links for components and have Sierra Circuits configured as described above for ordering
- CC Daniel.Costinett@utk.edu for approval of the order

Testing Report

(Due December 6th)

The testing report contains only a listing of the objective testing results of the converter. An example template is posted to the course website. The submitted document must follow the template format exactly.