# Active Feedback and Control of High Power Ćuk Converter for Fusion Applications

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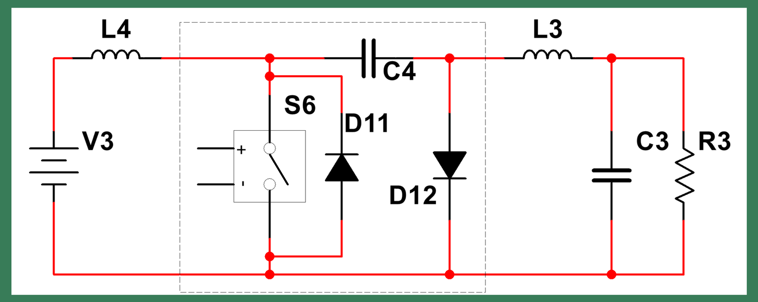
EAGLE HARBOR TECHNOLOGIES

## Introduction

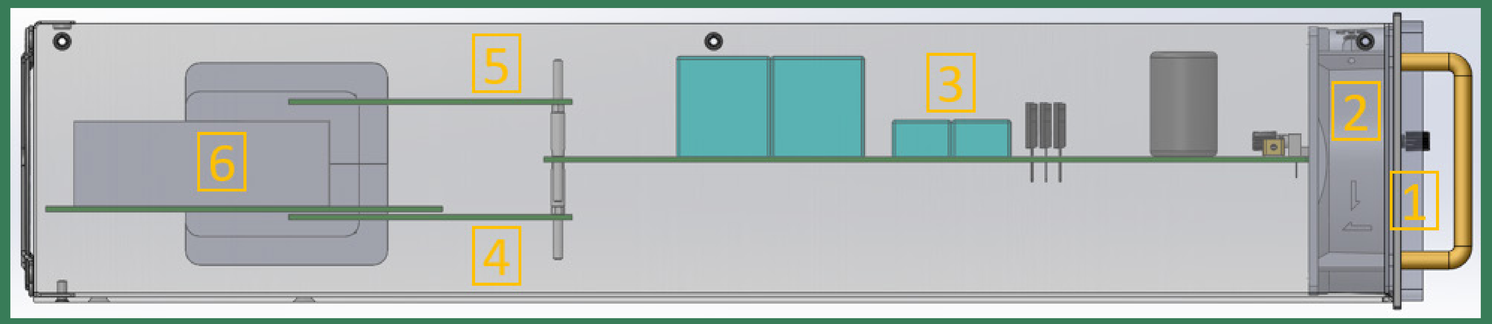
Eagle Harbor Technologies, Inc. (EHT) has developed a control module for active feedback and control a high power Ćuk converter. This control module will be used at Pegasus Toroidal Experiment to maintain a precision current flat top on the helicity injectors. The EHT controller allows for high-power arbitrary waveform on microsecond-timescales. EHT modeled the control algorithm and explored edge case scenarios for the Pegasus application. A hardware solution was designed around the STM32 microcontroller, and software was developed, including a graphical interface. EHT demonstrated precision waveform control with the controller on a small-scale Ćuk converter. We will present the modeling work, system capabilities, and initial data. This controller will allow Pegasus to extract the maximum energy from their capacitor bank while maintaining a flat-top current profile.

## EHT Ćuk Converter

EHT is developing a high-power Ćuk converter to drive the arc and bias circuits of the Pegasus helicity injectors. Each module will operate at 30 kHz and have an output of 330 V and 3.3 kA for 50 ms.



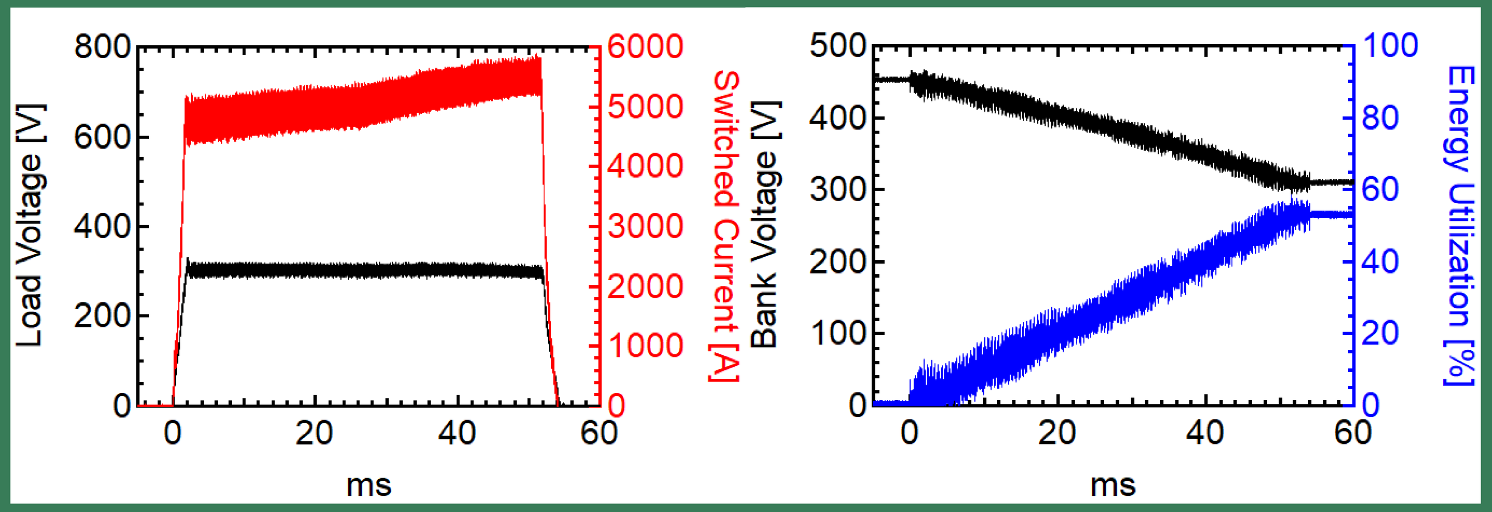

Ćuk converter circuit diagram.




Side view of the second generation Ćuk converter full module showing the input fiber (1), cooling fans (2), Ćuk switching components (3), input current limiter board (4), output current limiter board (5), and AC isolation transformer (6).

## Testing at Pegasus (Nov 2020)

EHT tested the prototype module with a large capacitor bank at Pegasus. It successfully switched at 30 kHz for 50 ms. More than 50% of the energy stored in the back was discharged with a constant output of 3.3 kA.

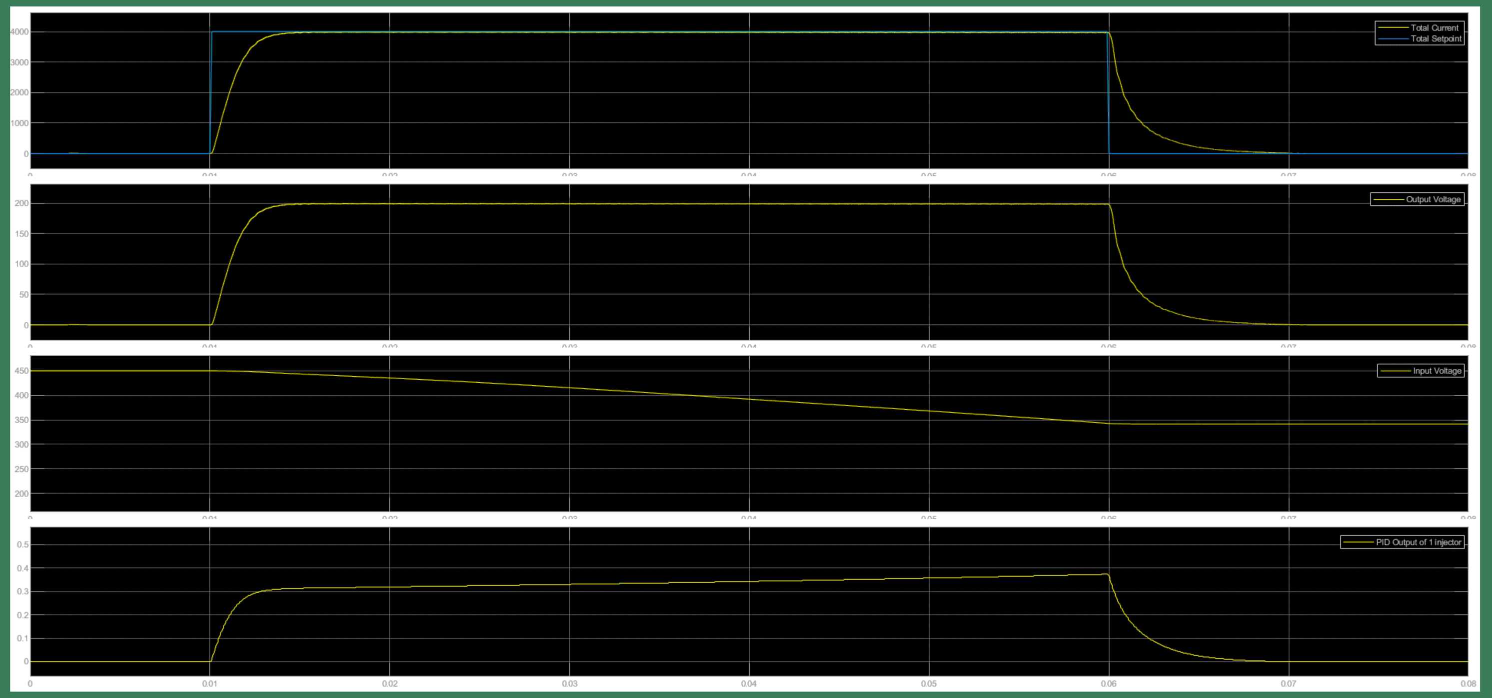



Ćuk module operating at the design specification. Left: output voltage (black) and total switch current (red). Right: Capacitor bank voltage (black) and percent of energy utilized from the capacitor bank (blue).

## Ćuk Control Modeling

Pegasus needs current control for both the bias and arc circuits. EHT selected PI control for real time feedback and control of the EHT Ćuk module. Using MATLAB/SIMULINK, EHT modeled the system and selected initial PI values.

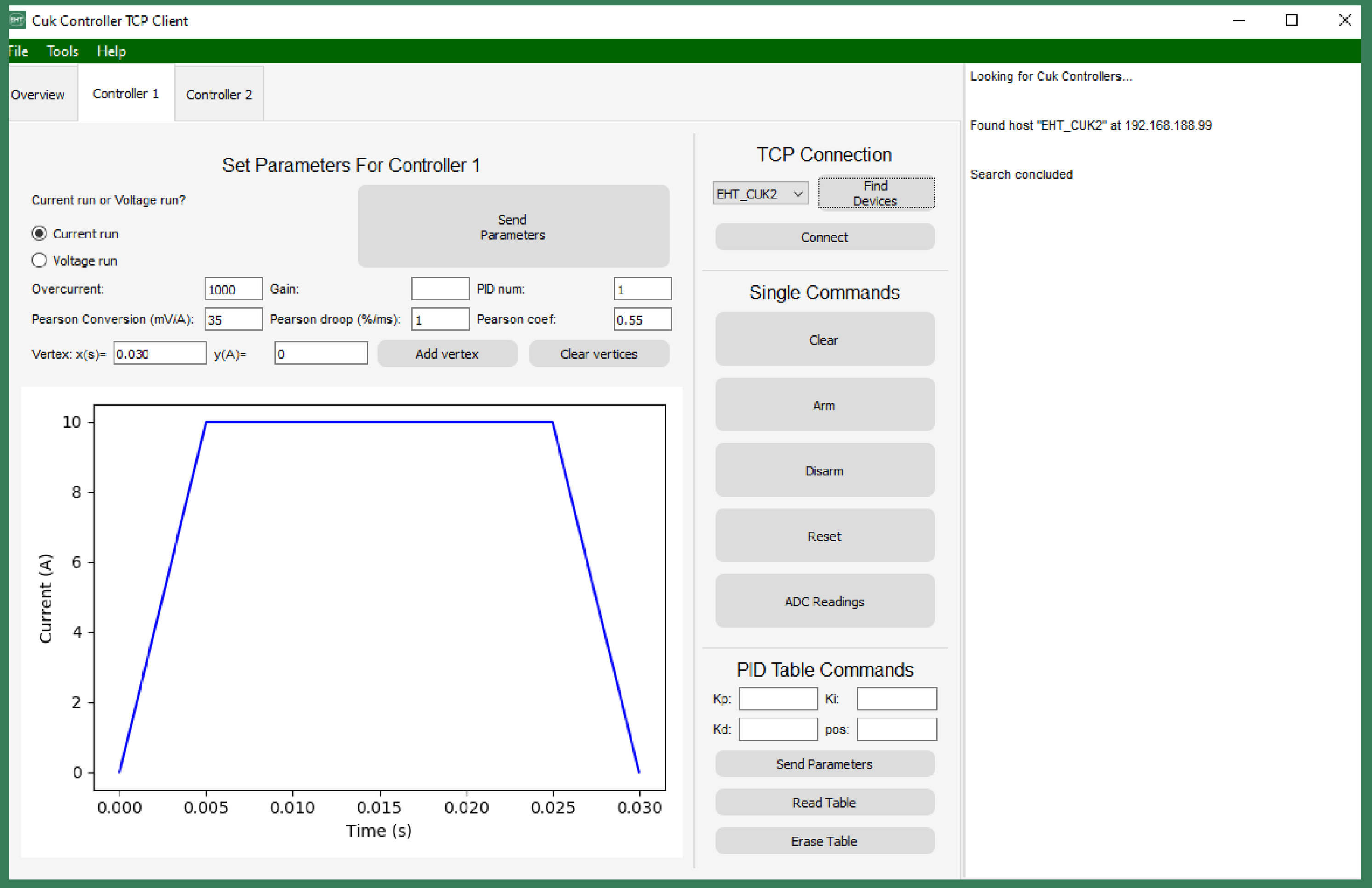
This model was then used to tune the PI values so that the power system would operate in a stable condition over a wide range of pulse parameters. We conducted analysis to examine controller response to fault conditions for both the bias and arc circuits. The goal was to demonstrate a rise time < 5 ms and flat top within 1% with PI controller.



MATLAB/SIMULINK results two Ćuk modules operating in parallel for the arc circuit (from top to bottom): output current, output voltage, input voltage, and PI output.

## Ćuk Control Hardware Development

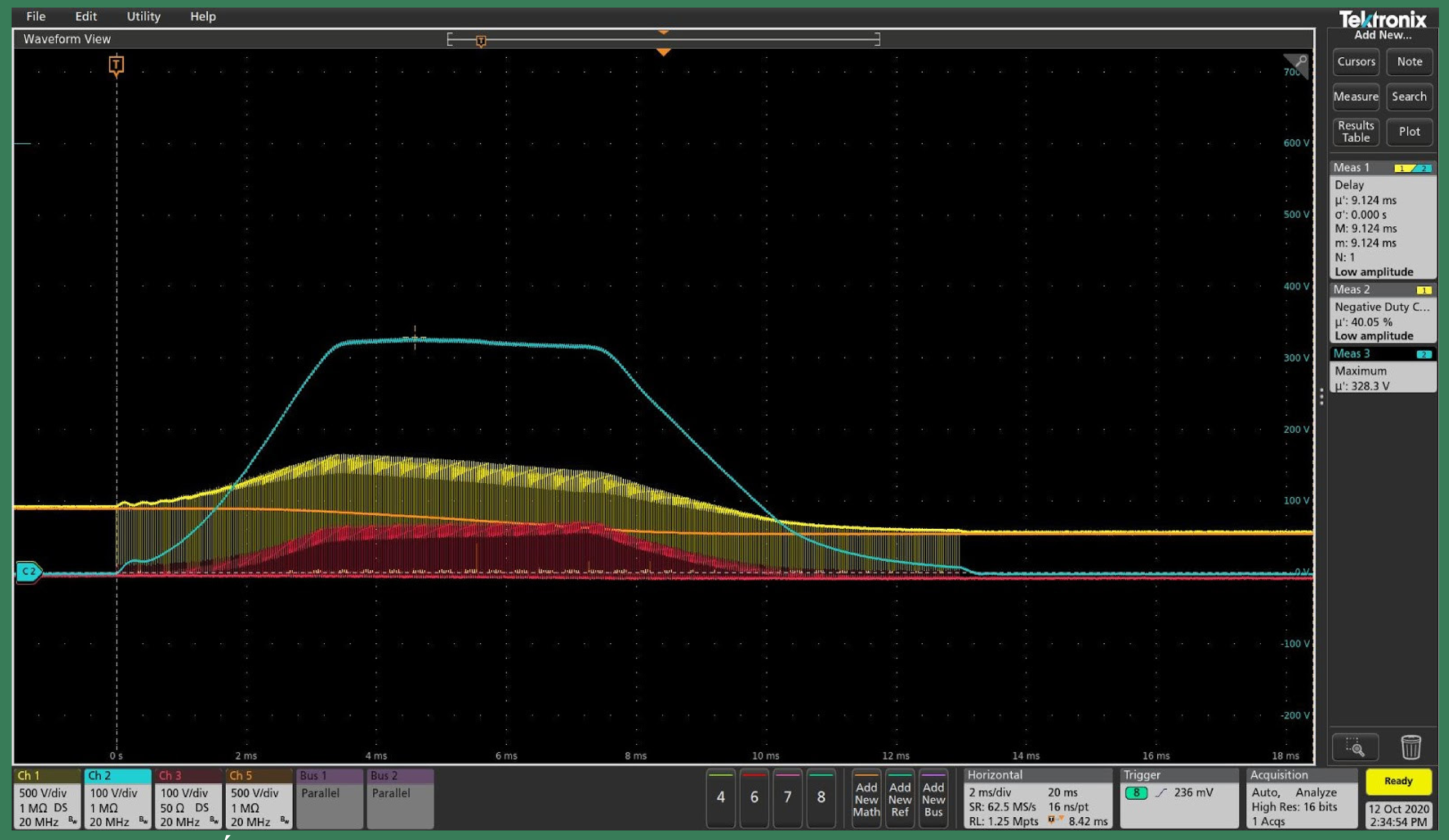
EHT selected the STM32 microcontroller, which meets the control requirements and allows for rapid development. The code for the control loop, GUI, and TCP communication was developed. The system was tested with a simple circuit to demonstrate ability to control complex waveforms. The system was operated for > 16 hours continuously without error.




Screenshot of the Ćuk module GUI.

## Ćuk Control Hardware Demonstration

The controller was tested with an 1/24 scale Ćuk module to demonstrate the ability to modulate the output current. The PI values were obtained from the modeling and tuned with the hardware under test. The output current was measured with a current transformer. An algorithm was developed to compensate for the droop of the current waveform over these long timescales. The user input the demand waveform, and the controller corrected the current transformer signal and used it to generate the PWM for the Ćuk module. This demonstrated that as input voltage falls (orange) the controller can modify the duty cycle in real time and maintain a constant output as required from the input demand waveform.




Small-scale Ćuk module operating with real-time PI controller: output voltage (blue), Vce (yellow), capacitor bank voltage (orange), switch current (red).

## Conclusion

EHT has developed a control module for the EHT Ćuk converter based on the STM32 microcontroller. The control module has a graphical user interface that allows the user to input a current waveform demand signal. Using a PI algorithm, the controller produces the control signal so that the output of the Ćuk converter follows the demand waveform. The PI algorithm was tuned using a model. EHT has demonstrated output current control as the bank voltage falls with a small-scale Ćuk converter.

EHT will delivered the controller and several Ćuk modules for testing on the bias and arc circuits of the helicity injectors. For more info: http://www.eagleharbortech.com/

## Acknowledgment

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