Nanofarad-Scale Capacitor Charging on Sub-Microsecond Timescales

T. M. Ziemba (ziemba@eagleharbortech.com), J. R. Prager, K. E. Prager, C. Bowman, I. Slobodov, M. Quinley

EAGLE HARBOR TECHNOLOGIES

Introduction

Eagle Harbor Technologies, Inc. (EHT) has developed a Rapid Capacitor Charger (RCC) for charging nanofarad-scale capacitors on sub-microsecond timescales at high pulse repetition frequencies. These RCCs have been used to charge capacitors in applications where the voltage cannot be present across the capacitor for long periods of time. One example comes from photoconductive semiconductor switch research. This RCC can charge loads up to 10 nF to 4.4 kV in 1.44 µs and faster for smaller capacitances. At 2 kV, the RCC can operate up to 500 kHz with 5 kW of input power. EHT will present the details of the RCC development and outputs as well as the trade studies conducted showing the safe operating area.

Safe Operating Area Comparison

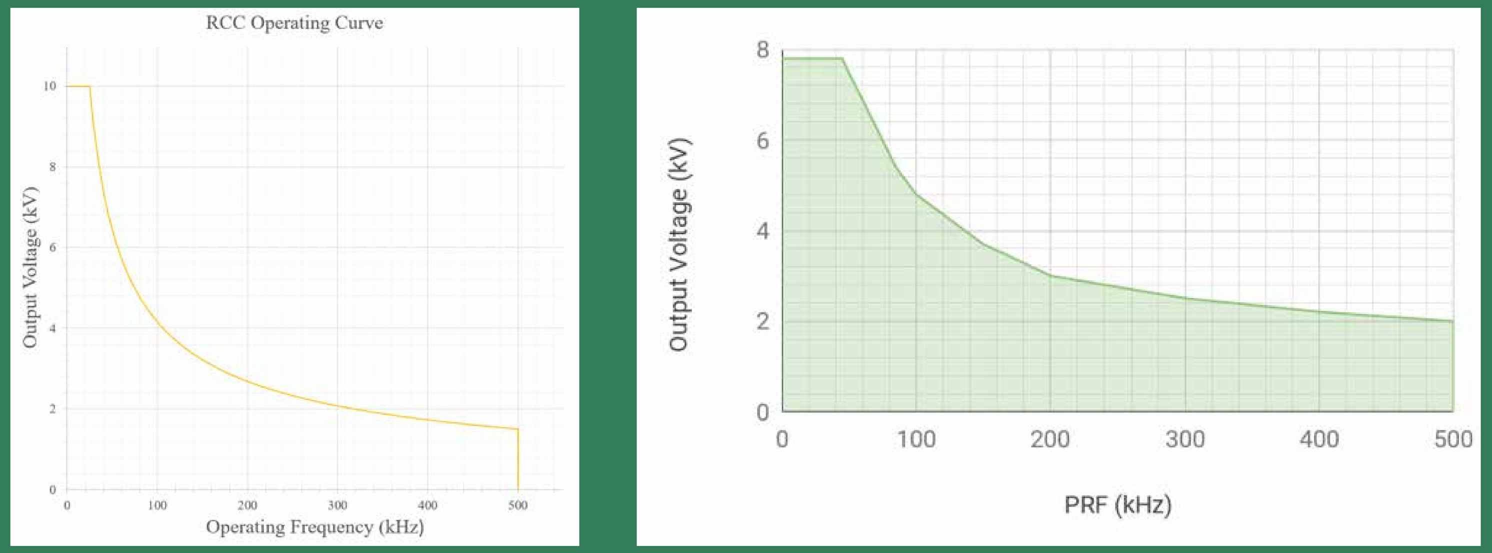
The NSP-RCC system consists of a high power (5 kW) nanosecond pulser NSP-5000 unit placed atop a resistive output stage (ROS).

EHT delivered a 3.5 kW RCC system to RDT in 2017 with the following specifications:

- Output voltage: 0 to 10 kV
- Load capacitance: 0 to 3 nF
- PRF: 500 kHz at 1.5 kV, 25 kHz at 10 kV
- Rise time into a 3 nF load: ~200 ns
- Pulse width into a 3 nF load: <440 ns FWHM

EHT has completed work on an improved RCC under its ONR-HPM SBIR that is relevant to the SiPCSS system. This 5 kW RCC system has these specifications:

- Output voltage: 0 to 7.9 kV
- Load capacitance: 0 to 10 nF
- Peak PRF: 500 kHz at 2 kV, 45 kHz at 7.9 kV
- Rise time into a 10 nF load: ~400 ns
- Pulse width into a 10 nF load: ~1.4 µs
- Continuous Power: 5 kW



Comparison of safe operating areas for NSP-RCC. Left: Operating curve of system delivered to RDT in 2017. Right: Operating area for RCC developed under ONR SBIR.

Acknowledgements

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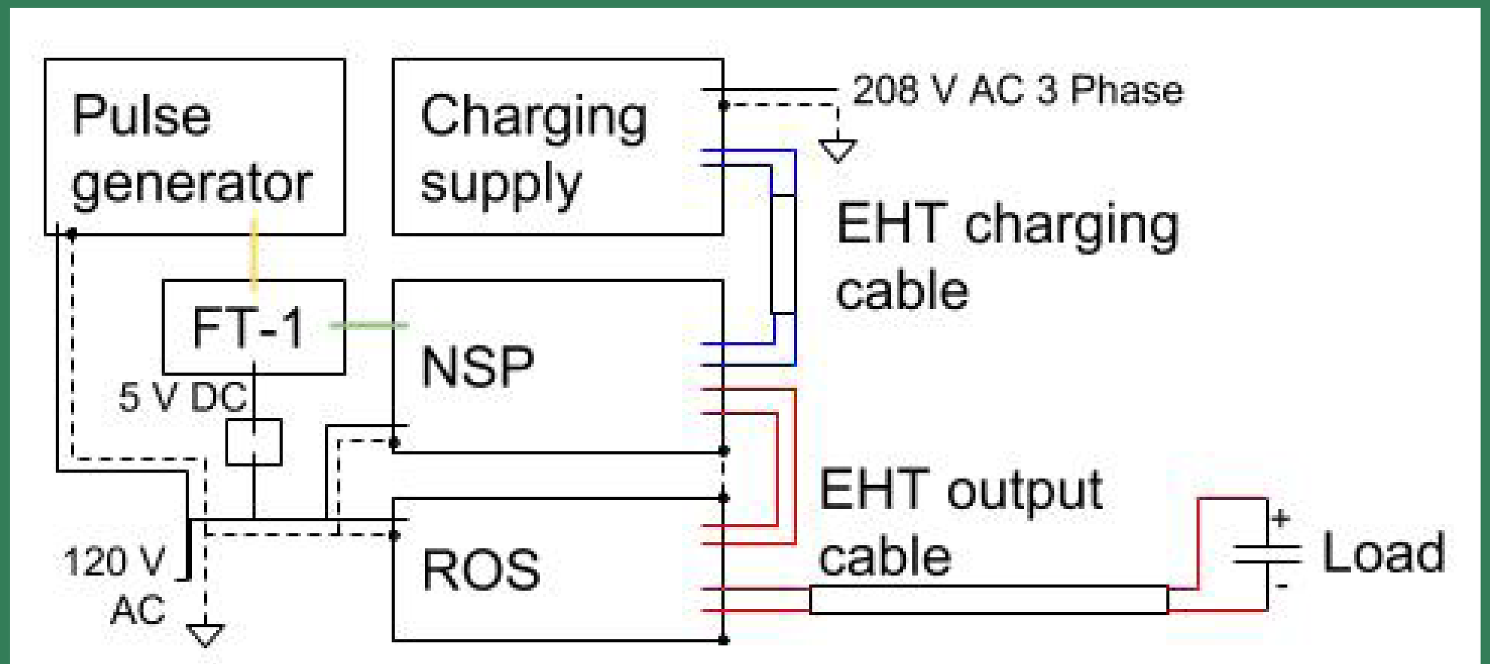
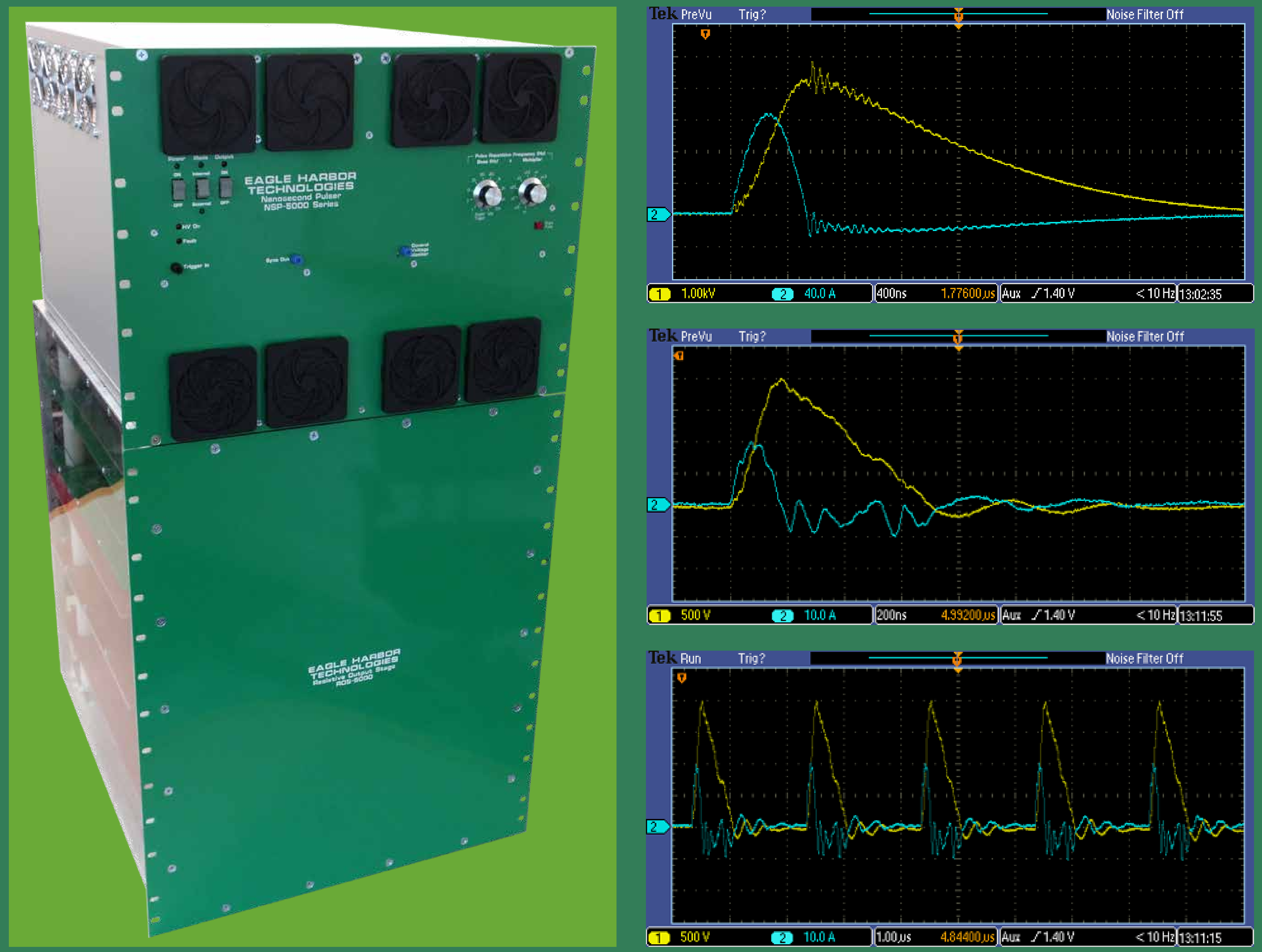
NSP-RCC Operation Overview

The RCC has three primary components: NSP, ROS, and DC charging supply. The NSP is triggered from a pulse generator, which is fiber optically isolated with the EHT FT-1.



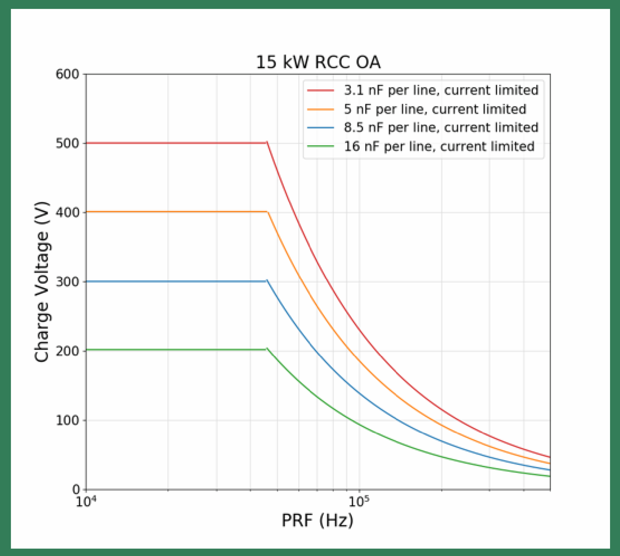
Block diagram of the NSP-RCC integrated into larger system.



Left: EHT NSP and ROS stacked into NSP-RCC configuration. Right: Load capacitor voltage (yellow) and RCC output current (blue). Top: 4.4 kV output onto a 10 nF load. Middle: 2 kV output onto a 1 nF load. Bottom: 2 kV output into a 1 nF load at 500 kHz pulse repetition frequency.

Max Power in Future Systems

EHT has demonstrated an average output power of up to 10 kW is possible for a single RCC system, with 15 kW+ possible with minor design changes. Plot (right) shows calculated operating area for a 15 kW RCC with air cooling. EHT has developed water cooling capabilities for the NSP, which could be added to RCCs for higher power.

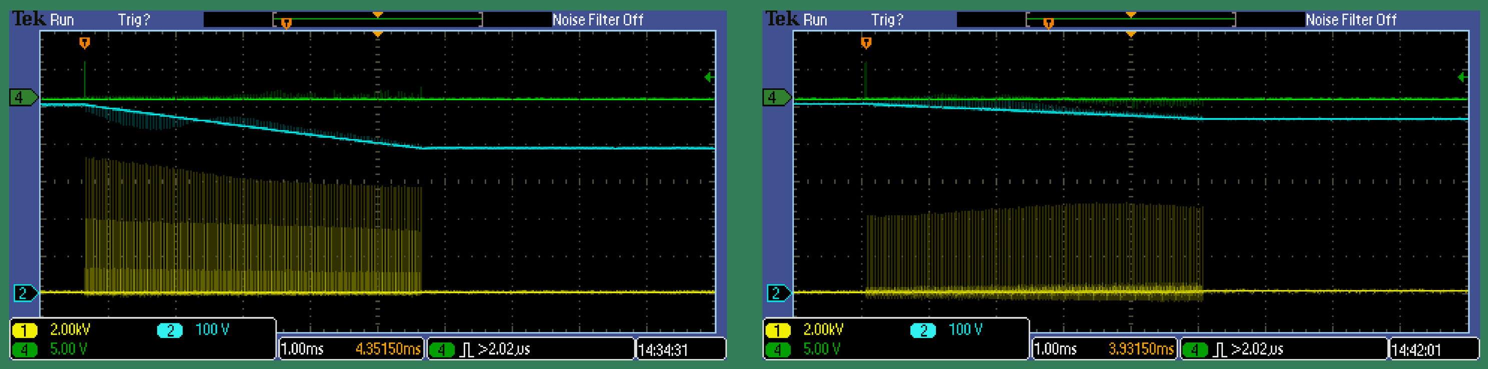


Energy Recovery

The ROS is a way to remove energy from the load capacitor so that it does not stay charged. If the capacitive load does not dissipate any energy, then all of that energy is dissipated in the ROS. EHT has developed a technique to make the system more energy efficient and eliminate the ROS.

EHT NSP-RCC with energy recovery.

In testing the energy recovery system, the initial energy in the primary energy storage was 75 J. The system was operated for 500 pulses. The final energy was 45.6 J in the ROS case and 64.9 J in the energy recovery case. This translates to an energy cost of 59 mJ/pulse and 20 mJ/pulse in the ROS and energy recovery cases respectively. The energy recovery is 66% more efficient than the ROS.



Energy recovery testing. Voltage droop on energy storage capacitors (blue trace), output voltage (yellow), and trigger (green) without (left) and with (right) energy recovery implemented.

Conclusion

EHT has developed a pulsed power system for rapidly charging nanofarad-scale capacitors to high voltage at high pulse repetition frequency. The new RCC can charge 10 nF to 7.9 kV in 400 ns at 45 kHz or 2 kV at 500 kHz. This represents a significant development over the previous RCC generation.

EHT developed a method of energy recovery that can increase the efficiency of the system by 66% compared to dumping the energy into the ROS. For other high power nanosecond pulsers, EHT developed water cooling heat sinks to allow for higher power operation.

Future work will focus on increasing the average power up to 15+ kW, adding water cooling, and implementing energy recovery.

More information

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