A Low-Cost, High Power RF Resonance System Phase II Results

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EAGLE HARBOR TECHNOLOGIES

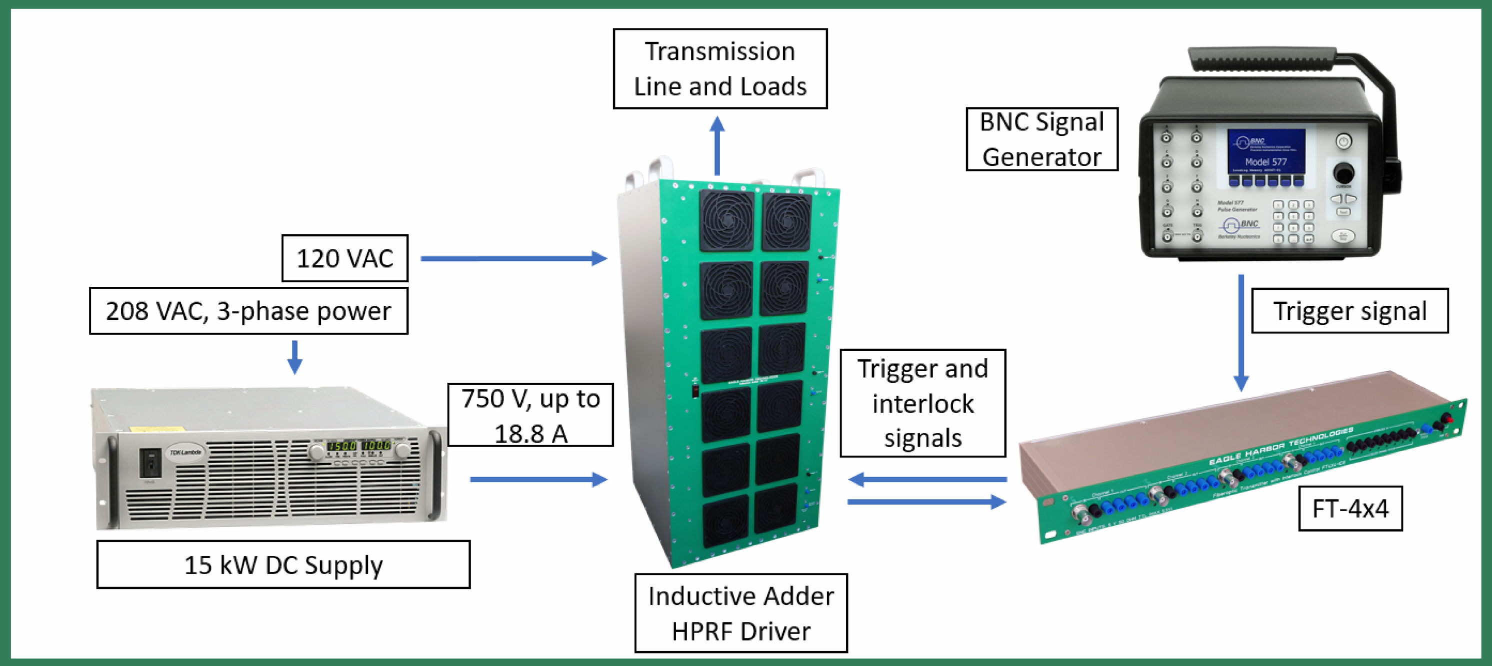
Introduction

Eagle Harbor Technologies, Inc. (EHT) has completed a Phase II program to develop a pulsed RF system for plasma heating and heat pulse diagnostic. The RF burst is produced by a nonlinear transmission line (NLTL) driven by an inductive adder. EHT designed several unique diode-based NLTLs with voltages up to 30 kV at output frequencies of several hundred megahertz to several gigahertz. To demonstrate RF plasma heating experiments were conducted in the EHT testing chamber. The EHT experimental system consists of a high-power helicon, which can generate high density hydrogen plasmas that are confined in a magnetic bottle configuration. We will present results showing RF generation and details of the plasma heating experiments.

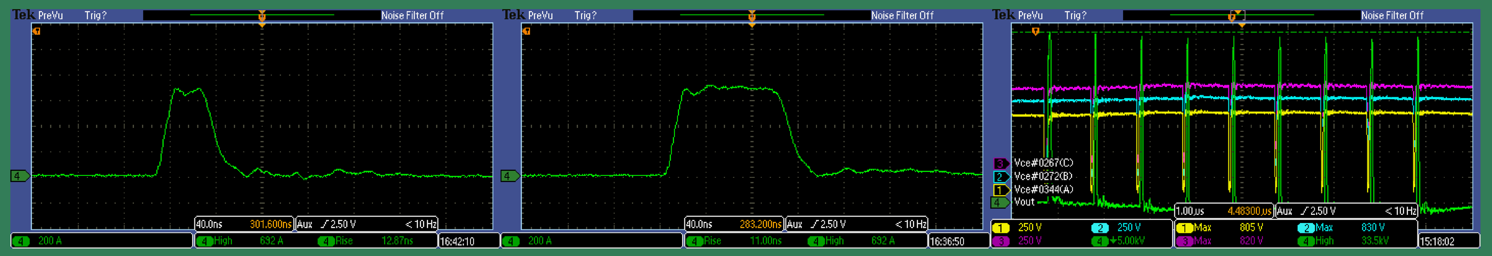
35 kV Inductive Adder

This inductive adder can produce 35 kV pulses into 50 Ω with 10 ns rise times. These pulses can be burst at 1 MHz. The system was designed to drive NLTLs. EHT updated the design of the inductive adder:

- Optimized the layout for ease of assembly
- Addressed corona issues in the transformer design
- Reduced stray inductance compared to previous design
- Increased the local energy storage to allow for more pulses per burst
- Added fault monitoring with current measurement and fast interlock



Inductive Adder system for driving gyromagnetic and diode-based NLTLs.



Inductive adder output measured by current monitor (Pearson 7713-03 with 1.5 ns usable rise time). Output was 35 kV into 50 Ω load. Pulse width was 40 ns (left) and 100 ns (middle). Rise time 11-13 ns. Right: A nine-pulse burst at 1 MHz and full voltage, showing output voltage (green) and VCE waveforms on three boards across the three different modules in the inductive adder yellow, blue, and purple).

Acknowledgment

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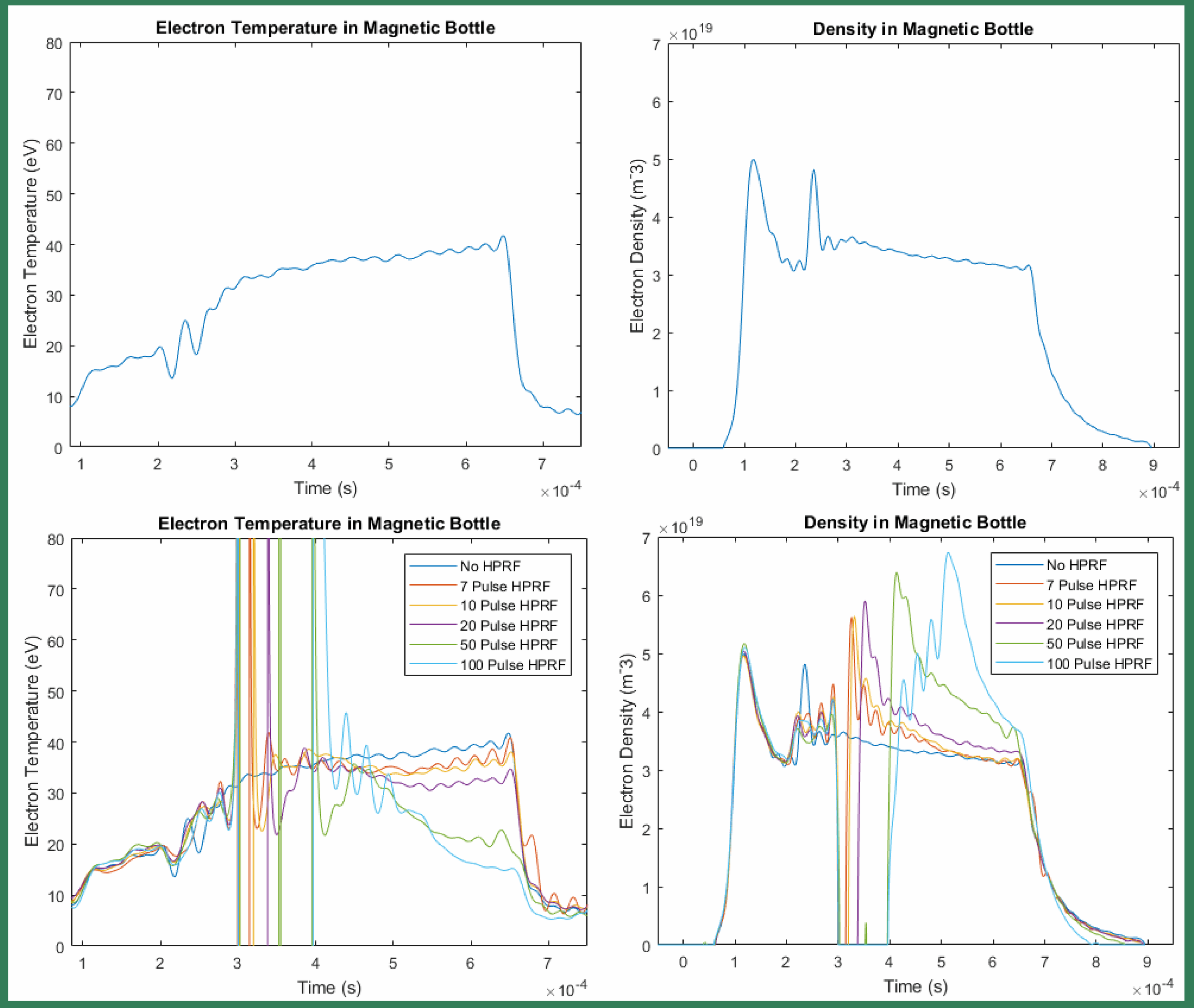
Plasma Testing of NLTL HPRF System

The HPRF system was installed on the chamber containing the electrodeless plasma source (EPS). The antenna was a helical winding of the center conductor and polyethylene insulator of an RG-213 coaxial cable wound around a polyethylene form and connected in place with Teflon cable ties. High vacuum compatible epoxy was used to seal the center conductor to the insulator and to seal the insulator to the flange creating the vacuum boundary.

Left: HPRF antenna side view. Right: Electrodeless plasma source during operation.

With 230 kW, the EPS produced a hydrogen plasma with a density of 3.5 x 10^{19} m^{-3} and T_e = 30-40 eV measured on axis near the HPRF antenna with a double Langmuir probe. Langmuir measurements could not be made while the HPRF system was in operation; however the probe recovered quickly after the HPRF was turned off. The HPRF was pulsed at 500 kHz and approximately 35 kV via the Metamagnetics G-NLTL. The number of pulses delivered to the antenna is adjustable.

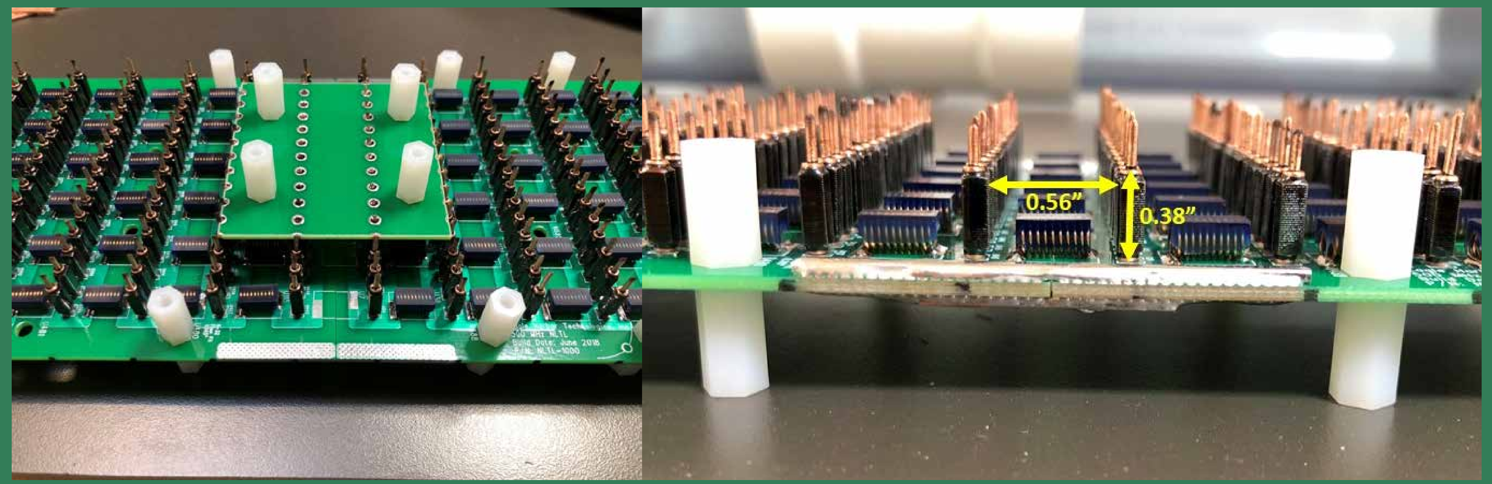


Baseline electron temperature (left) and density (right) near HPRF antenna with the HPRF system inactive (top) and active (bottom).

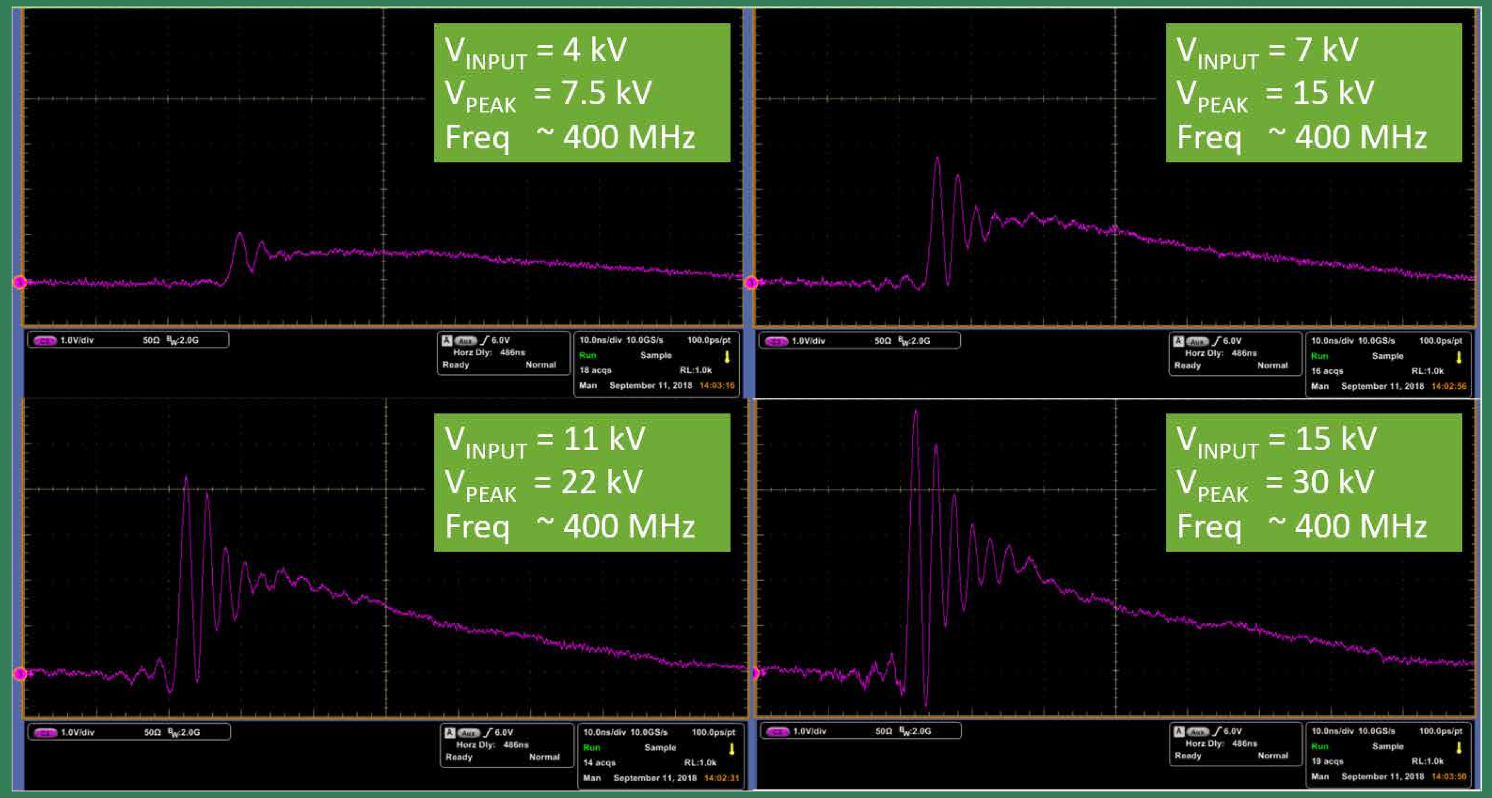
The helical antenna failed when it developed a vacuum leak after about 10 plasma shots at or near full voltage. After analyzing the Langmuir data and inspecting the damage on the antenna it became clear that the Langmuir probe was measuring an increase in density and decrease in temperature due to the high-Z material ablating off the antenna due to arcing with the plasma.

Diode-based NLTL

EHT designed, built, and tested a 30 kV diode-based NLTL with a center frequency ~ 400 MHz. Off-the-shelf inductors and unencapsulated diodes were used to simplify construction. Testing was also conducted with the line under oil, which reduced the frequency to 260 MHz and increased the damping (not shown). Future work will focus on oil properties.



Diode-based NLTL was constructed with 30 kV unencapsulated diodes to act as the nonlinear capacitors. Off-the-shelf inductors were used to simplify construction.



The NLTL's oscillation is shown as a function of input voltage. The greater the input voltage the greater the depth of modulation. Input pulse had a width of 50 ns.

Conclusion

EHT has completed a Phase II program with the following results:

- A 35 kV inductive adder with 10 ns rise into 50 Ω that could burst to 1 MHz was produced.
- Two low-frequency, high voltage, diode-based NLTLs were built and investigated.
- A high-gain helical antenna was designed, modeled, and tested.
- The system was installed on a plasma chamber and tested; however, there were significant PMI issues.

Future work will focus on increasing the frequency, investigating the loss mechanisms, and repetitive pulsing of the diode NLTLs.

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