35 kV Inductive Adder with NLTL for Plasma Heating

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EAGLE HARBOR TECHNOLOGIES

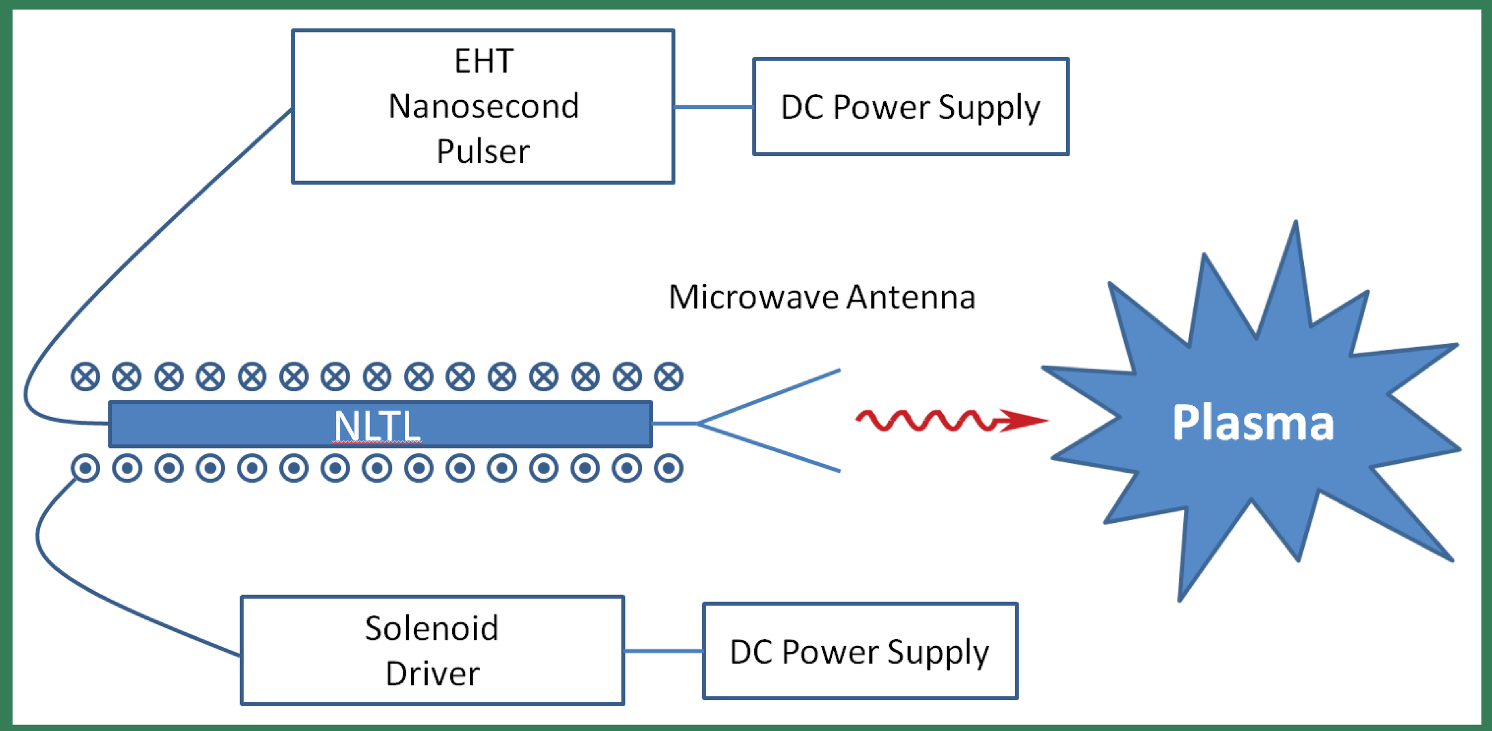
Introduction

Eagle Harbor Technologies, Inc. (EHT) has previously developed a 35 kV pulser for driving 50 Ω loads with nanosecond-scale rise times. This inductive adder drives nonlinear transmission lines (NLTL) to construct an all-solid-state RF plasma heating system for fusion science applications. The inductive adder configuration allows for independently adjustable control of the output voltage (35 kV), pulse width (20 – 200 ns), and pulse repetition frequency (up to 100 kHz). Previously, EHT has demonstrated 2 GHz RF production with a 20 kV version that can be pulsed to 100 kHz. EHT will present results showing high voltage, fast rise time pulses into low impedance loads. In addition to RF generation, this inductive adder has applications to high voltage kickers for accelerators, plasma loads, high power modulators, and other tube-driving applications.

Phase II Program Plan

The goal of this program is to develop a solid-state pulsed RF system for plasma heating, diagnostics, and control that can be precisely controlled. To accomplish this the following technical objectives will be completed:

1. Continue development of the high power radio frequency (HPRF) system to increase output power level, frequency range, and efficiency.
2. Build and bench test a deployable HPRF system in year one of the Phase II SBIR.
3. Continue development of the new lumped-element NLTL with efficient dynamic pulse utilization.
4. Demonstrate RF heating at EHT plasma test chamber. Testing will include both plasma generation and plasma heating.
5. Demonstrate high power RF as a heat pulse diagnostic on the HIT at the University of Washington.
6. Demonstrate lower hybrid (LH) RF heating on the High Beta Tokamak at Columbia University using the new high efficiency lumped-element NLTL.



Acknowledgment

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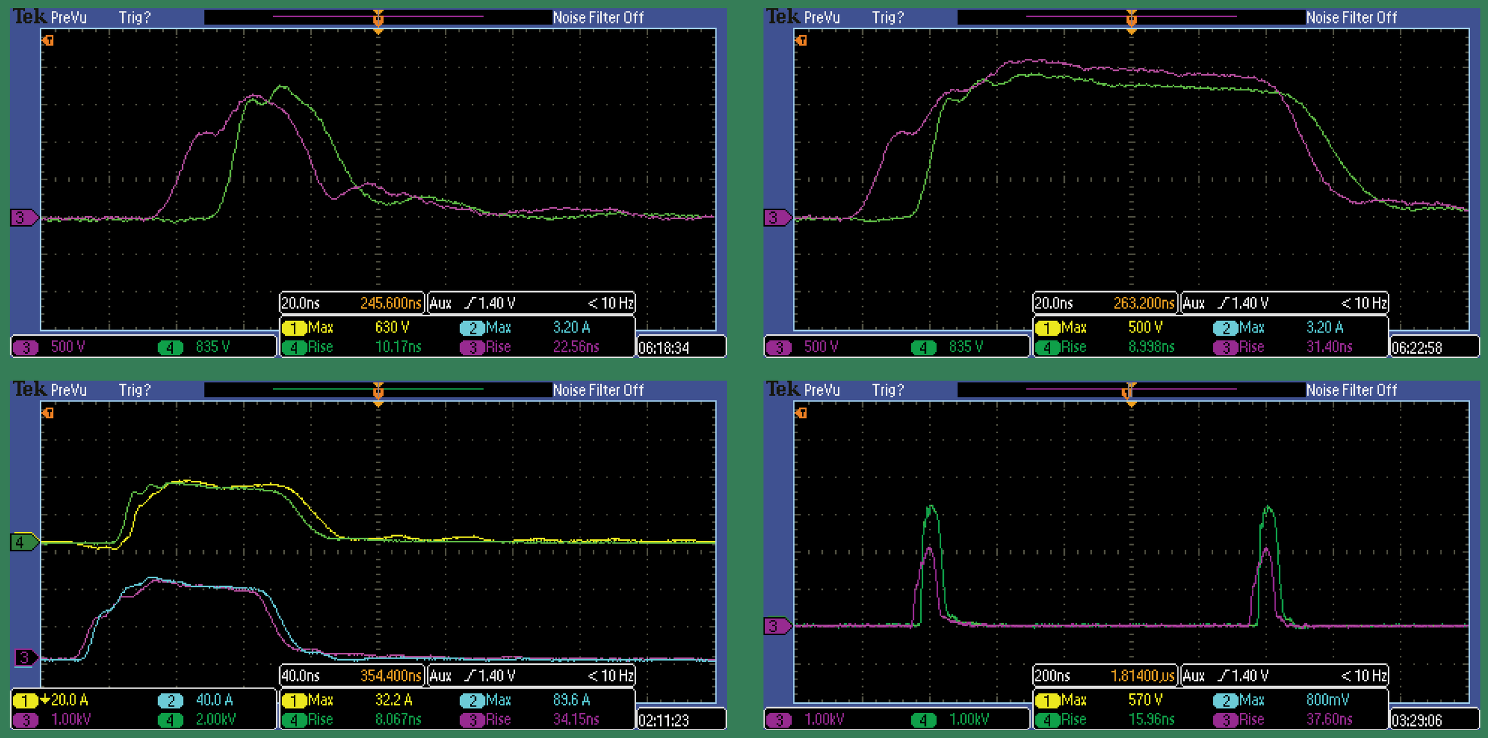
Diode-based NLTL for Rise Time Sharpening

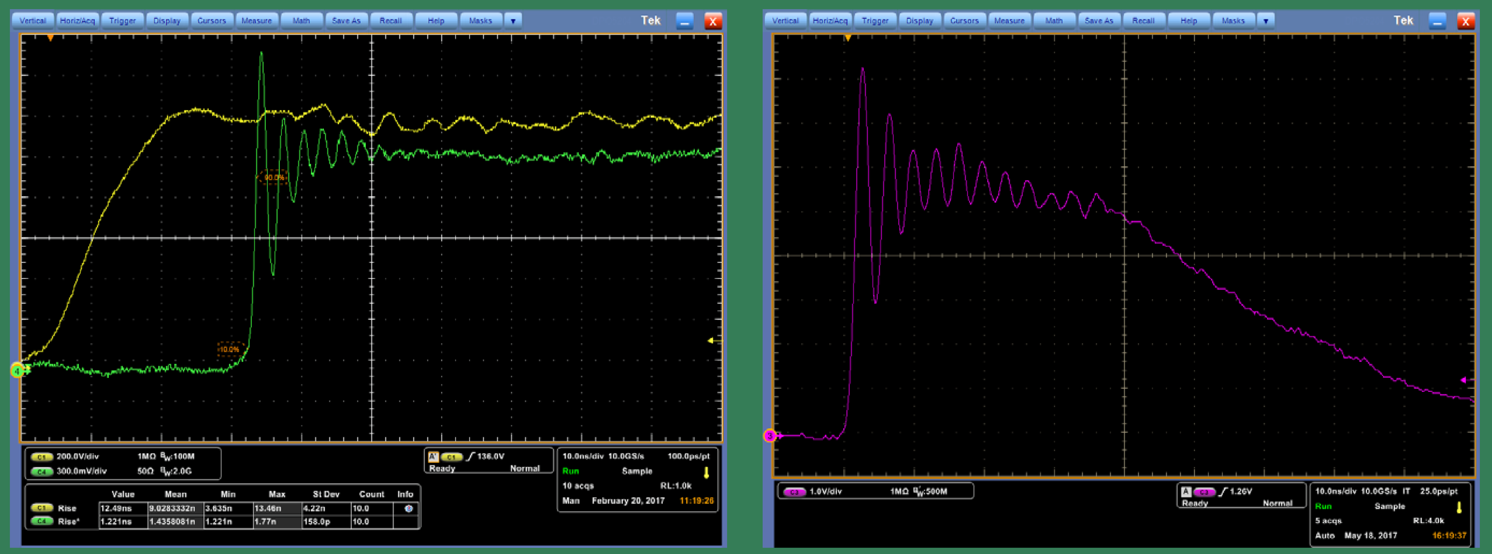
To improve pulser rise time, EHT is investigating lumped-element NLTLs with off-the-shelf components. A 10 kV NLTL with 20 elements was built and tested, which produced sub-10 ns rise time at 82-86% efficiency.



NLTL input and output for 40 ns (top right) and 120 ns pulse (top left). Measurement of efficiency (bottom left). High frequency burst at 1 MHz (bottom right). Input voltage (pink), input current (blue), output voltage (green), and output current (yellow).

Diode-based NLTL for RF Production

EHT designed a diode-based NLTL for RF production for the plasma heating program. Off-the-shelf, 10 kV diodes were used as the basis for the line. In the first generation, the inductors were just bent wire. While this produced RF, there were differences from inductor to inductor down the line. In the second generation, off-the-shelf inductors were used, which produced more RF oscillations. This frequency range is suitable for LH RF heating.

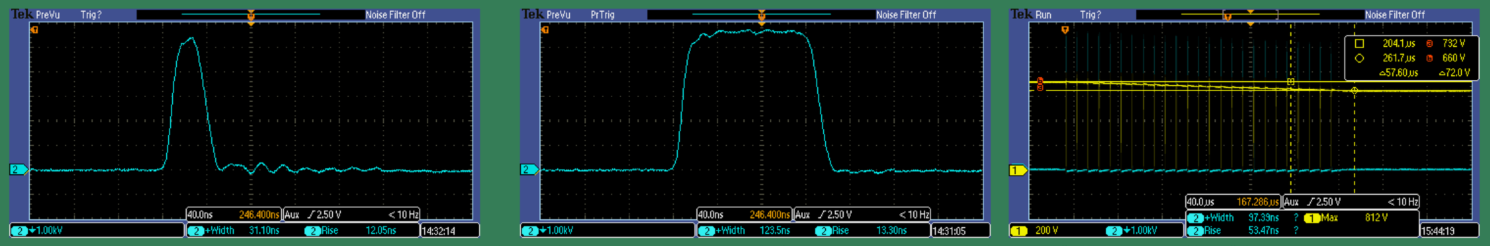


Left: Input pulse (yellow) and output pulse (green) from first generation RF NLTL. The frequency was 325 MHz, and about five oscillations were produced. Right: Output of second generation RF NLTL. The output frequency was 265 MHz and about double the number of oscillations.

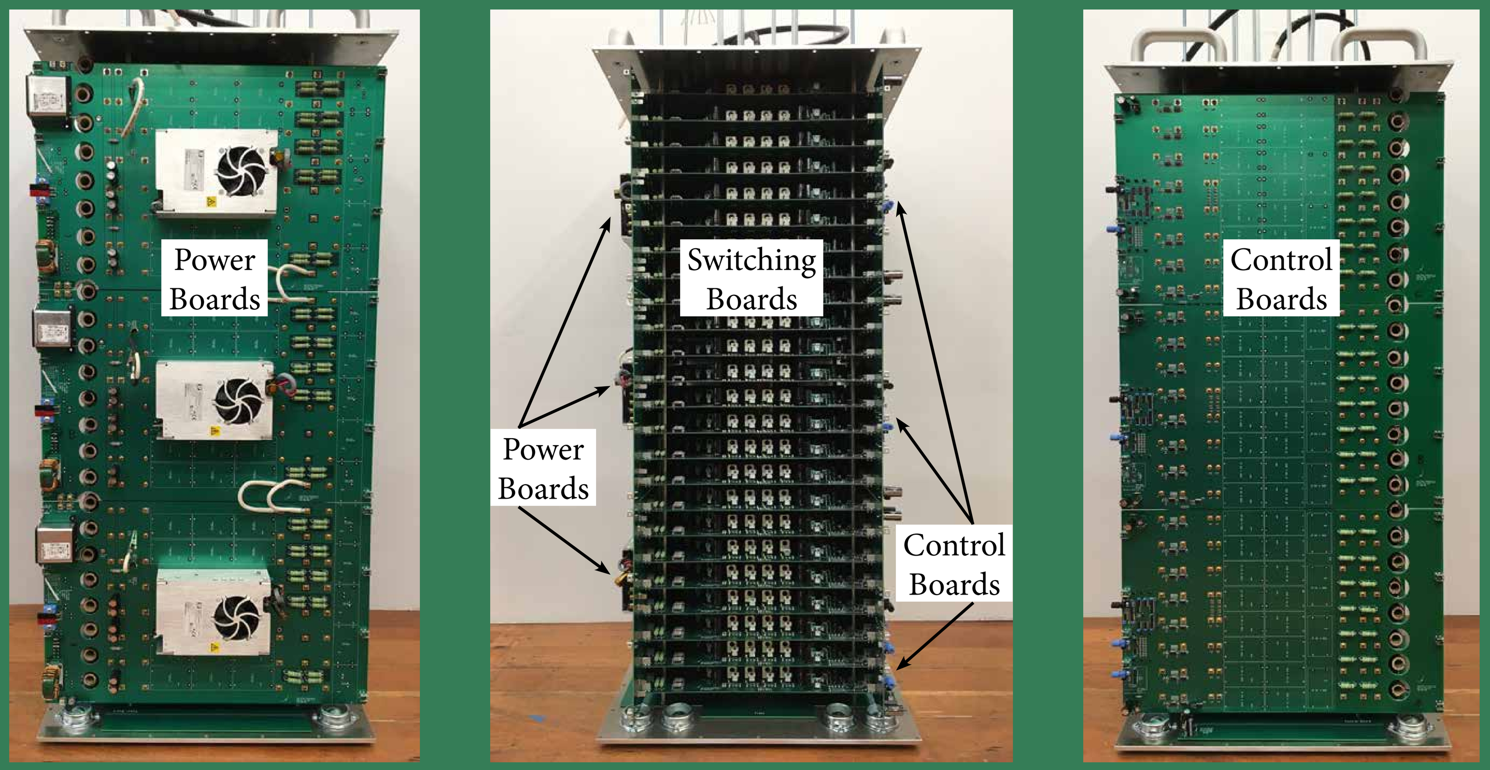
Left: Second-generation diode-based NLTL for RF production. Right: Close-up view of NLTL showing the new inductors.

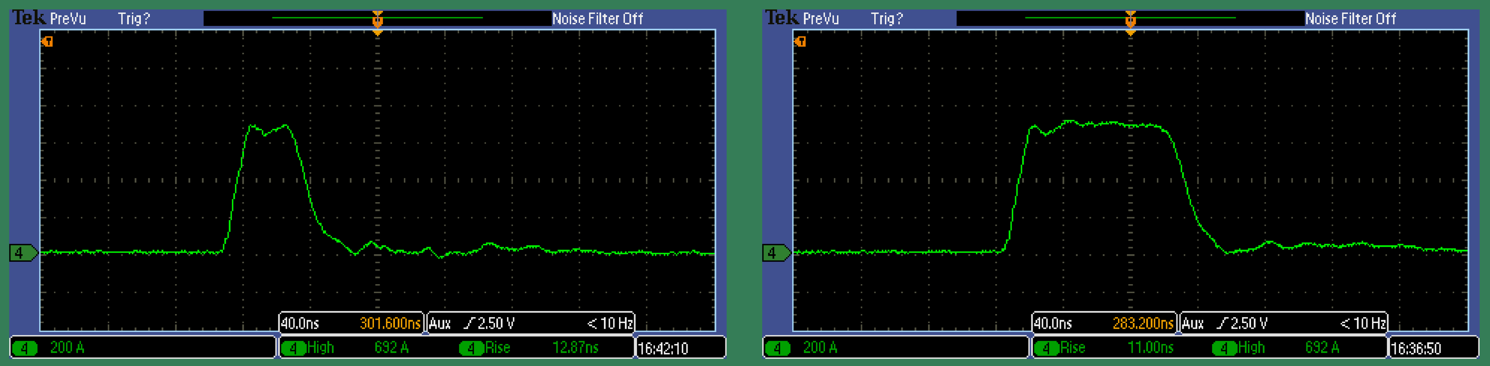
35 kV Inductive Adder into 50 Ω Load

Prior to full assembly of the 24-board stack, EHT conducted testing of the one-third stack. EHT has constructed a modular inductive adder.



One-third stack testing at 12 kV into 50 Ω with pulse widths of 30 ns (left) and 120 ns (middle). 100 kHz burst operation of 8-board stack, showing a 10% droop in voltage after 25 pulses (right).





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 (right). Rise time 11-13 ns.

Conclusion

EHT has constructed a 10, 20 (not shown), and 35 kV inductive adders that have adjustable pulse width and PRF and has tested them into resistive loads. All three have rise times on order of 10 ns. This 10 kV inductive adder has been used to drive a gyromagnetic NLTL to produce RF near 2 GHz over and a diode-based NLTL near 250 MHz.

EHT is in the process of testing a 35 kV inductive adder into NLTL loads for RF production. Future work will focus on RF production with the higher voltage NLTL at 100 kHz. This system will be used to demonstrate plasma heating at EHT before being deployed at two fusion science experiments over the duration of the Phase II program.

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