High Power, Solid-State RF Generation for Plasma Heating

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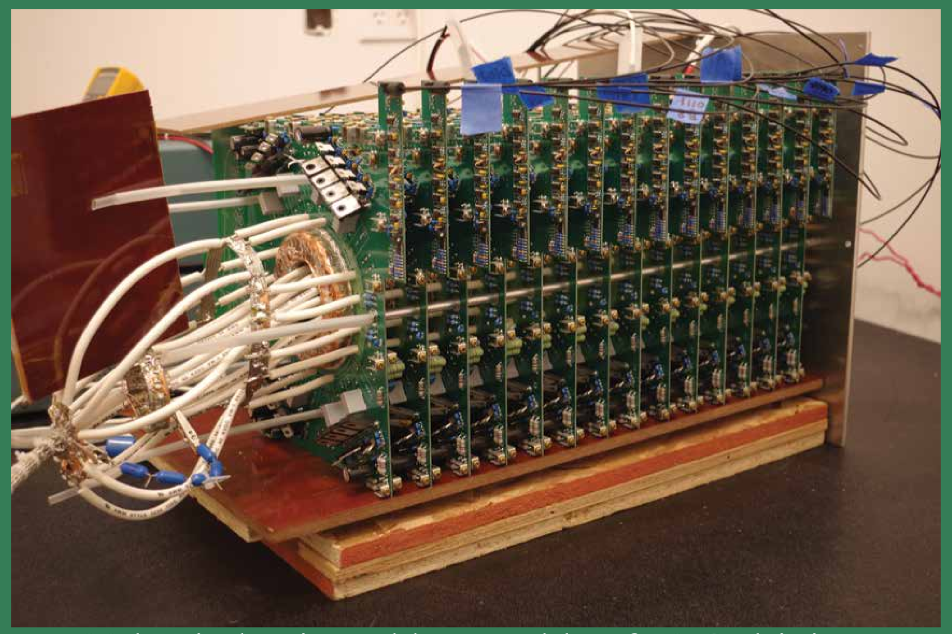
EAGLE HARBOR TECHNOLOGIES

Introduction

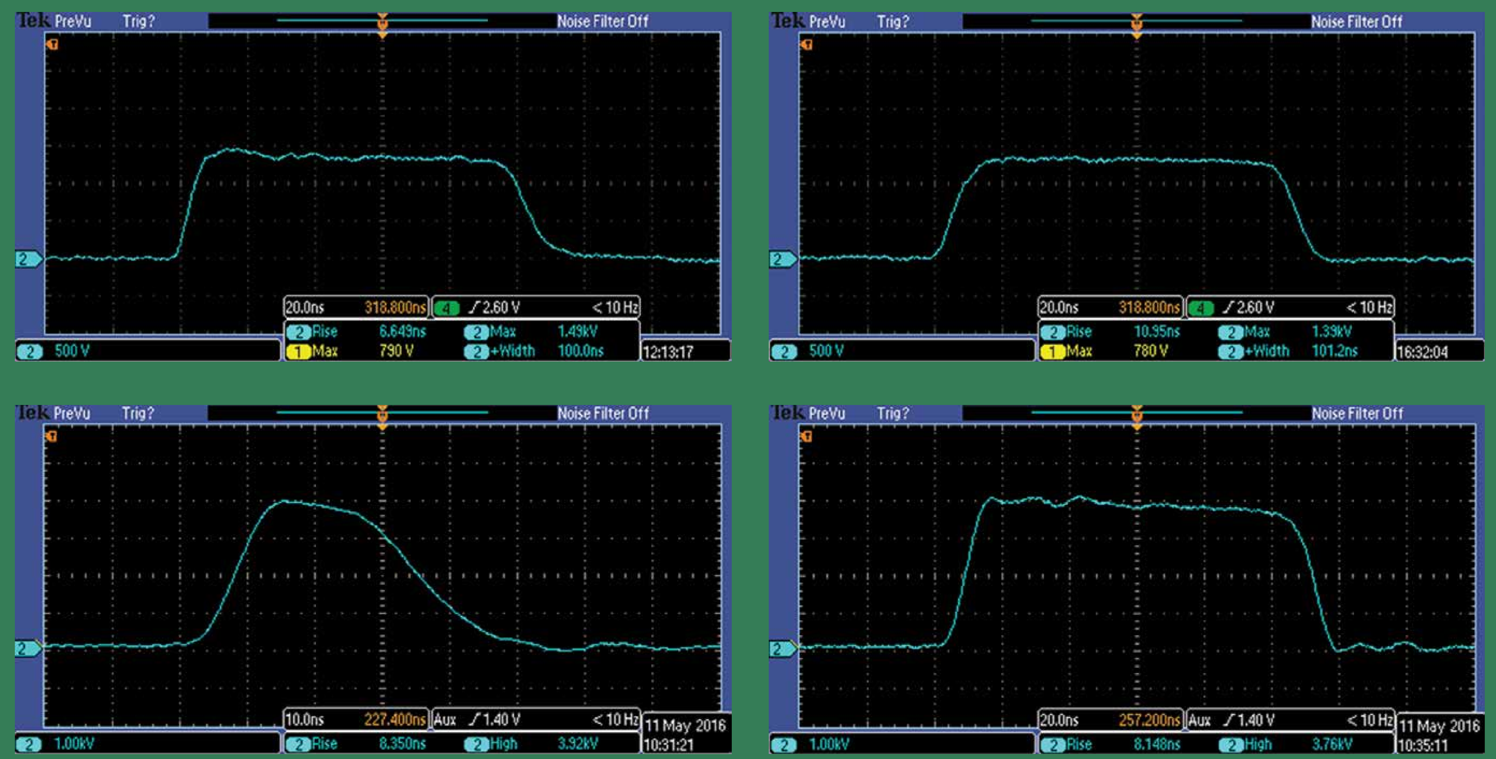
Radio Frequency heating systems are rarely used by the small-scale validation platform experiments due to the high cost and complexity of these systems. Eagle Harbor Technologies (EHT), Inc. is developing an all-solid-state RF plasma heating system that uses EHT's nanosecond pulser technology in an inductive adder configuration to drive nonlinear transmission lines (NLTL). The system under development does not require the use of vacuum tube technology, is inherently lower cost, and is more robust than traditional high power RF heating schemes. The inductive adder can produce 0 to20 kV pulses into 50 Ohms with sub-10 ns rise times. The inductive adder has been used to drive NLTLs near 2 GHz with other frequencies to be tested in the future. EHT will present experimental results, including RF measurements with D-dot probes and capacitive voltage probes. During this program, EHT will test the system on Helicity Injected Torus at the University of Washington and the High Beta Tokamak at Columbia University.

EHT Inductive Adder

Most gyromagnetic NLTLs are designed with 25-50 Ω impedance that must be driven with sub-10 ns rise time. EHT is leveraging nanosecond pulser components, which can operate at high pulse repetition frequency (PRF), to build an inductive adder that is capable of driving these low impedance loads with fast rise times. EHT has built a six and twelve board stack that can operate at 10 kV and 20 kV, with adjustable pulse width, fast rise time, and PRF.



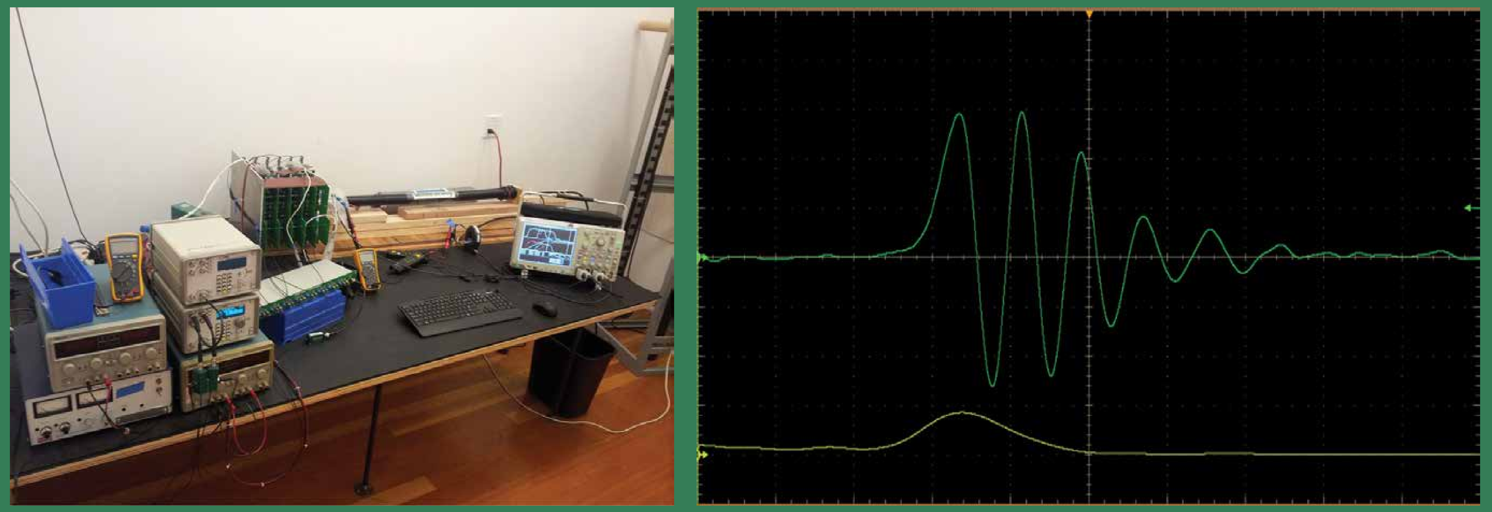
20 kV inductive adder capable of 50 Ω driving.



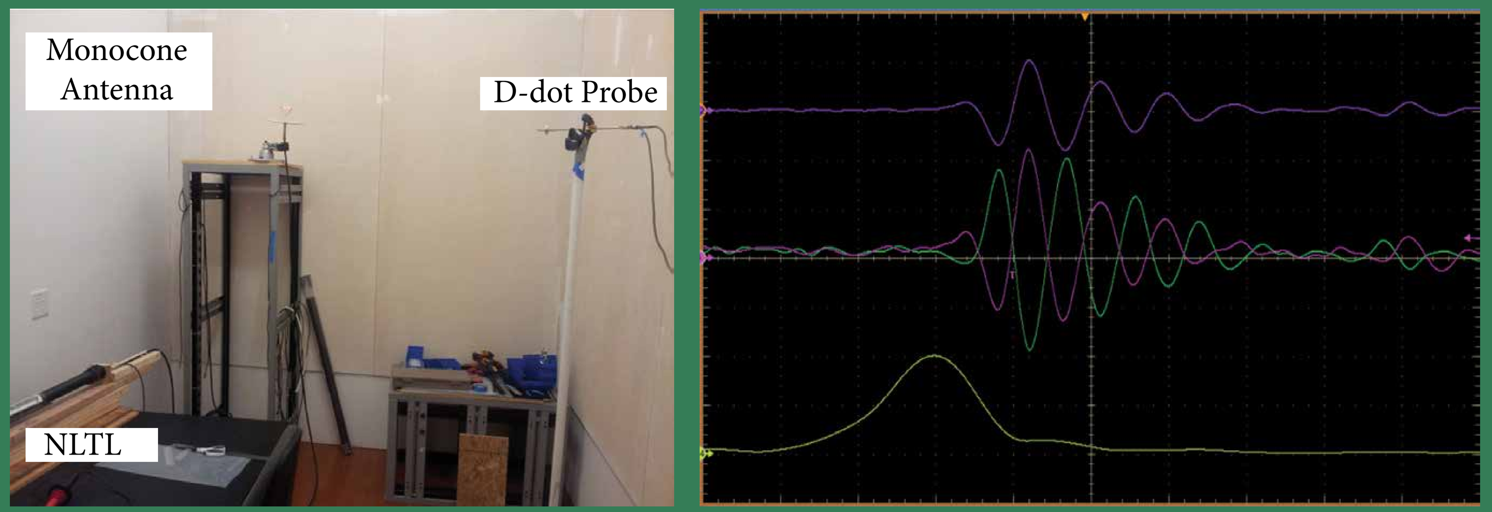
Top Left: 10 kV - 100 ns pulse into 50 load with 6.6 ns rise time. Top Right: 10 kV - 100 ns pulse into 25 Ω load with 11 ns rise time. Bottom: 20 kV, 51 ns (left) and 110 ns pulse widths into 50 Ω load with 8.4 ns rise.

RF Production with NLTL

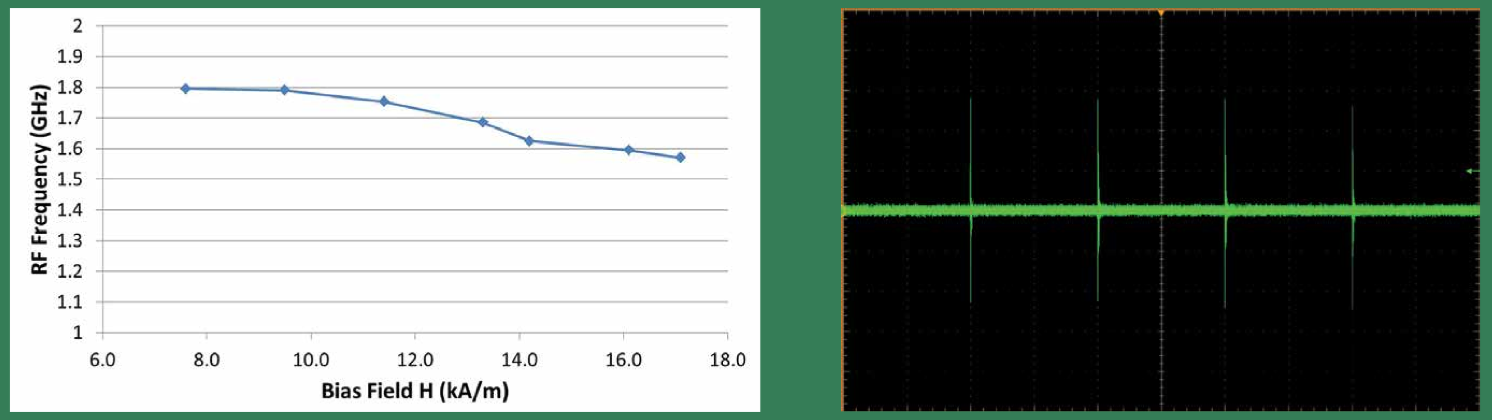
EHT measured the RF output of the gyromagnetic NLTL driven by a 10 kV inductive adder with a capacitive voltage probe (CVP) and D-dot probe.



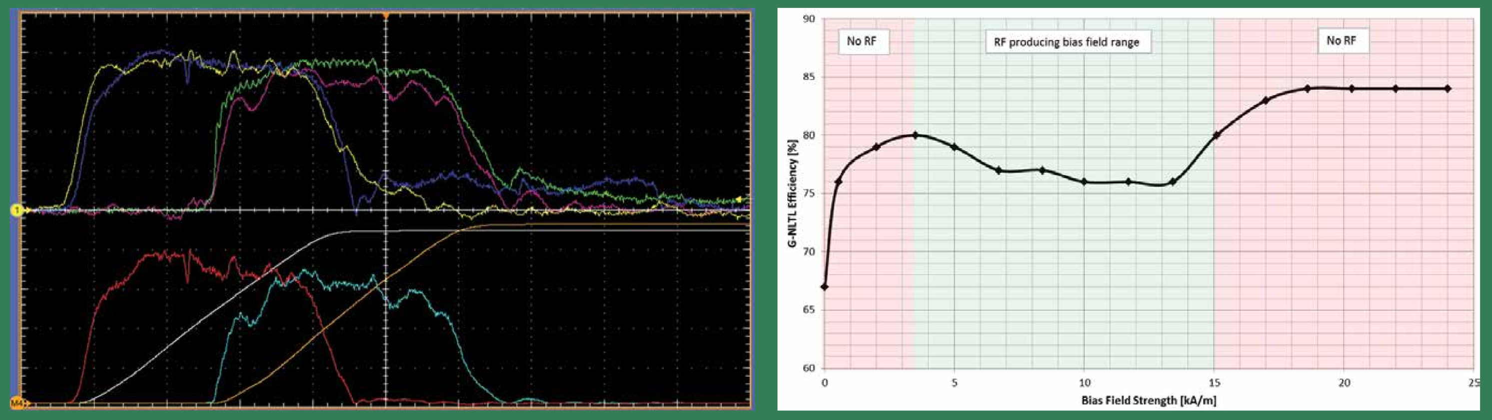
Left: Experimental setup showing the 50 Ohm pulse driver, the NLTL, and the CVP at the output of the NLTL. Right: CVP output (green) with 12.6 [kA/m] bias field. Horizontal scale 740 ps/div, vertical scale 3333 V/div. An FFT of the signal (yellow) has a peak at ~ 1.7 GHz. FFT scale is 25 mV/div vertical and 500 MHz/div horizontal.



Left: Experimental setup with D-dot in far-field of monocone antenna. Right: From top to bottom: Math 2, Ch3 (purple), Ch4 (green), Math4. Math2 = Ch3 – Ch4, Math4 = FFT(Math2). Vertical scale: Math2 = 2V/div, Math4 = 100mV/div, Ch3&Ch4 = 500 mV/div. Horizontal scale is 750 ps/div for signals and 500 MHz/div for FFT.



Left: NLTL RF output frequency as a function of magnetic bias field. Right: CVP output with 12.6 [kA/m] bias field. Burst of 4 pulses at 100 kHz. Horizontal scale 5 μs/div, vertical scale 3333 V/div.

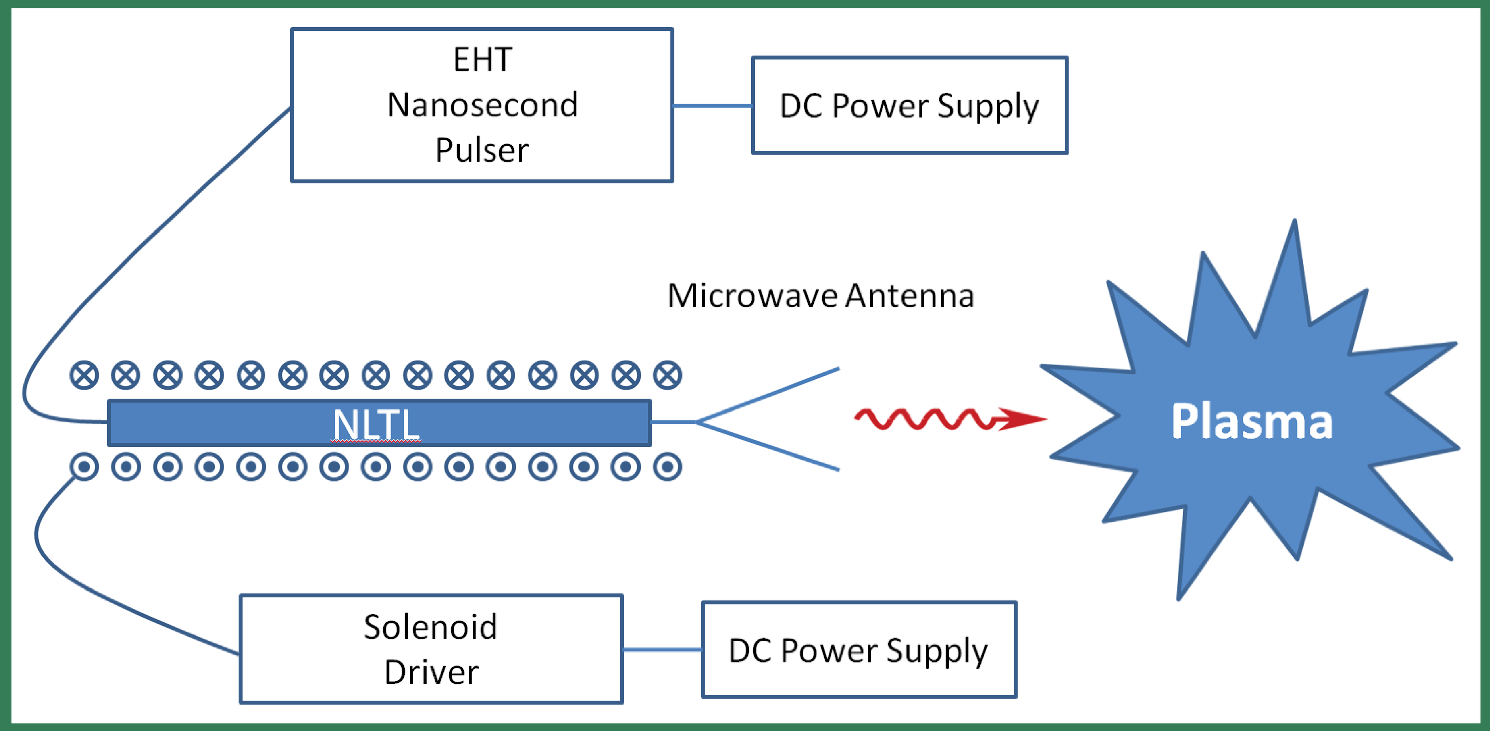


Left: Signals for G-NLTL single shot efficiency driving 52 Ω load at a bias field of ≈ 17 kA/m. Input voltage (yellow), input current (blue), load voltage (purple), load current (green), instantaneous input power (red), instantaneous output power (cyan), total input energy (white), and total energy delivered to the load (orange). Efficiency is ≈ 83 %. Right: Coaxial NLTL broadband efficiency vs bias field strength.

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 HPRF system to increase overall 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 HPRF as a heat pulse diagnostic on the HIT at the University of Washington.
5. Demonstrate LHRF heating on the HBT at Columbia University using the new high efficiency lumped-element NLTL.



Conclusion

EHT has constructed a 10 kV inductive adder that has adjustable pulse width and PRF and has tested it into resistive loads. This 10 kV inductive adder has been used to drive a gyromagnetic NLTL to produce RF near 2 GHz over a range of parameters.

EHT is in the process of testing a 20 kV inductive adder into resistive loads. Future work will focus on RF production with the higher voltage NLTL and increasing the pulse repetition frequency.

This system will be deployed at two fusion science experiments over the duration of the Phase II program.

For more info: http://www.eagleharbortech.com/

Acknowledgment

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