Solid-State Radio Frequency Plasma Heating Using a Nonlinear Transmission Line

K.E. Miller*; T.M. Ziemba; J.R. Prager; I. Slobodov
*kemiller@eagleharbortech.com

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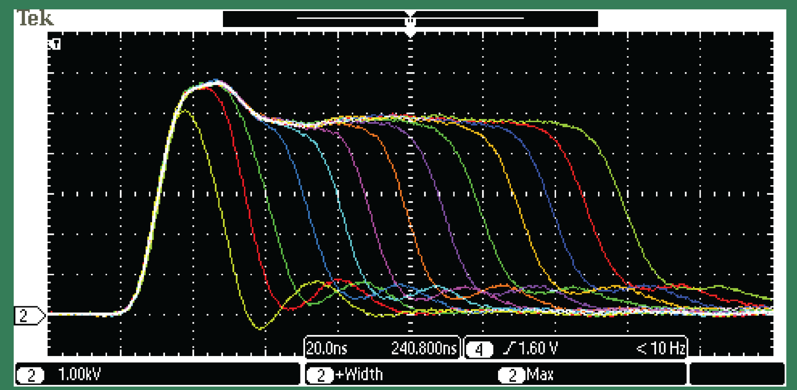
Introduction

Radio Frequency heating systems are rarely used by the small-scale validation platform experiments due to the high cost and complexity of these systems, which typically require high power gyrotrons or klystrons, associated power supplies, waveguides and vacuum systems. The cost and complexity of these systems can potentially be reduced with a nonlinear transmission line (NLTL) based system. In the past, NLTLs have lacked a high voltage driver that could produce long duration high voltage pulses with fast rise times at high pulse repetition frequency. Eagle Harbor Technologies, Inc. (EHT) has created new high voltage nanosecond pulser, which combined with NLTL technology will produce a low-cost, fully solid-state architecture for the generation of the RF frequencies (0.5 to 10 GHz) and peak power levels (~10 MW) necessary for plasma heating and diagnostic systems for the validation platform experiments within the fusion science community. The proposed system does not require the use of vacuum tube technology, is inherently lower cost, and is more robust than traditional high power RF heating schemes. Design details and initial bench testing results for the new RF system will be presented.

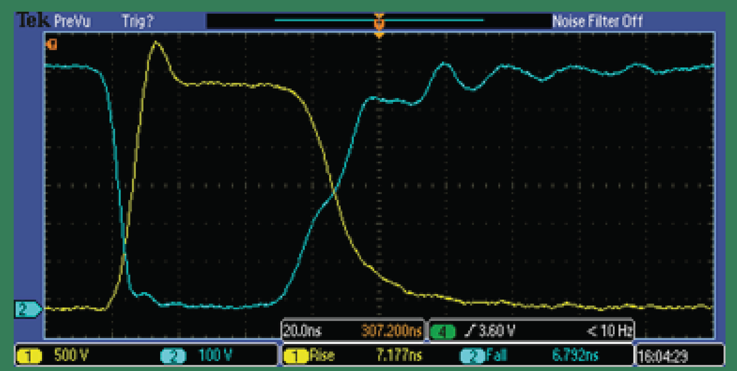
NSP-5000-20-F

To drive the NLTL for RF production, EHT is using our previously developed NSP-5000-20-F. This nanosecond pulser can operate at 5 kW while producing 20 kV output pulses into a 100 Ω load with adjustable pulse width (20 - 105 ns) at 100 kHz CW or be burst to higher frequency.

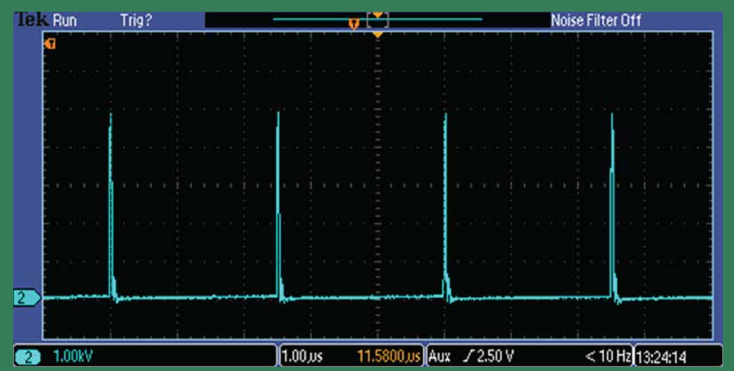


Composite image of multiple waveforms showing adjustable pulse width at 5 kV.

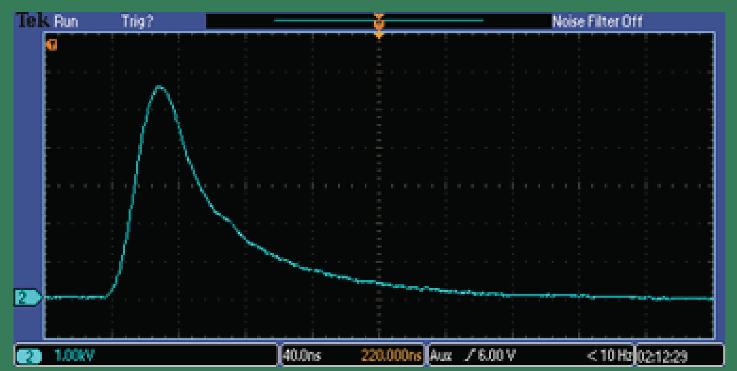
NSP-5000: 5 kW output with fully integrated front panel control.



20 kV single pulse into 100 Ω load



5 kV into 100 Ω load at 400 kHz CW

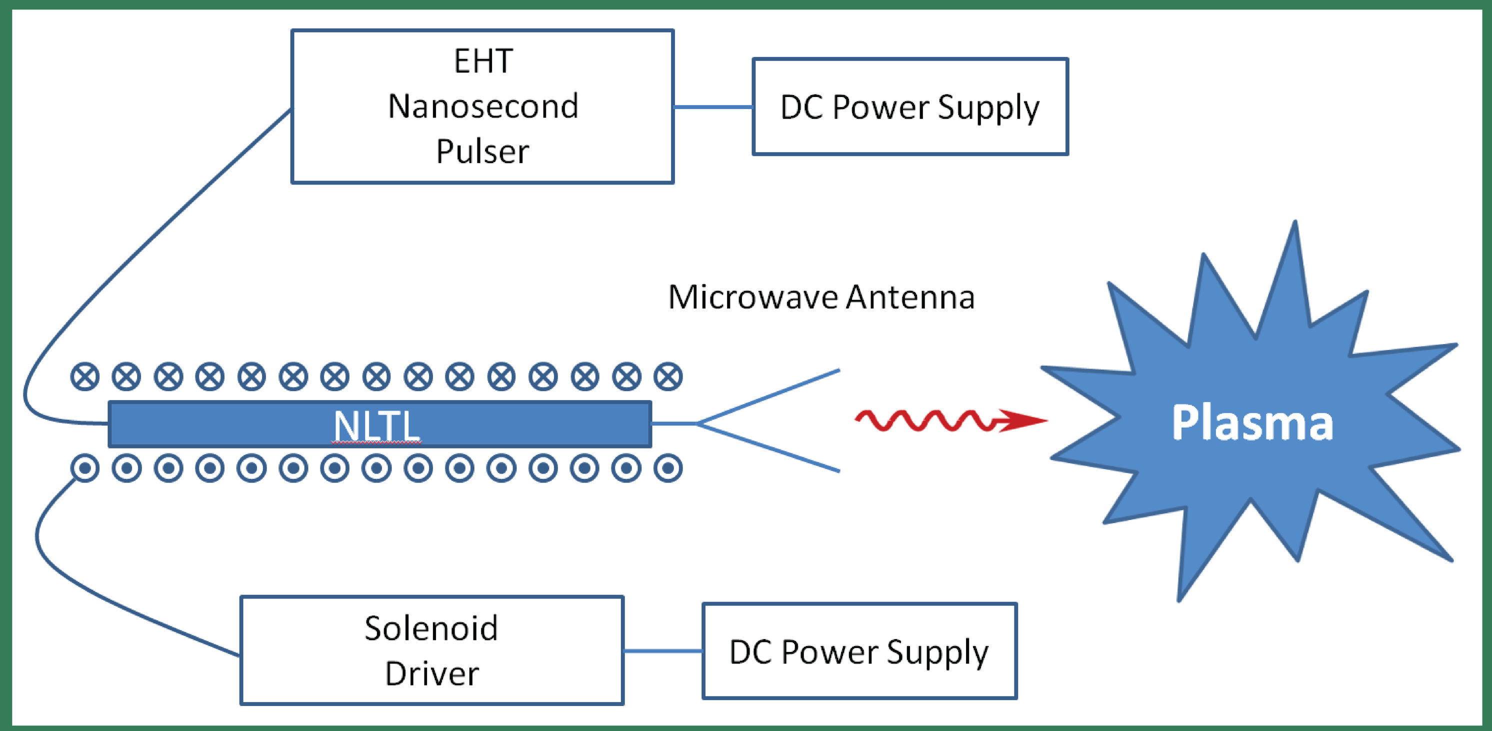


The next generation NLTL loads will be driven at higher voltage. EHT has demonstrated output pulses to 40 kV with 20 ns rise time and 40 - 130 ns pulse widths

NLTL Plasma Heat Diagnostic

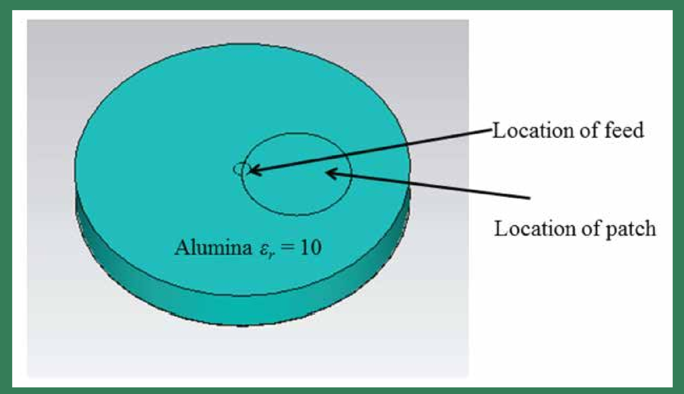
A new type of HPRF source, a gyromagnetic NLTL is an all solid-state dispersive media containing nonlinear circuit elements. NLTLs have several advantages over tube-based HPRF amplifiers:

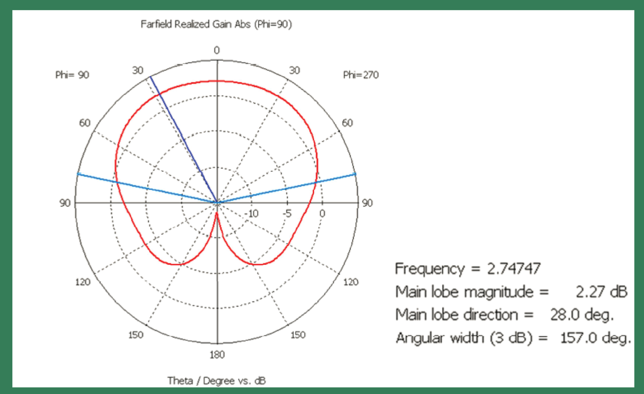
- Capable of very high peak power levels (~ 20 MW) with single NLTL.
- System efficiency can be very high (~ 80%).
- No start-up time and with tens of nanosecond response time.
- System scalability with multiple NLTL lines.
- Simpler system architectures consisting only of high power nanosecond pulser, NLTL, and antenna: no heating filaments or vacuum.
- System maintenance is low.
- Beam steering capability with phased array NLTL lines.
- Low cost makes NLTLs accessible for the VPE community.



Edge-Driven Circular Patch Antenna Design

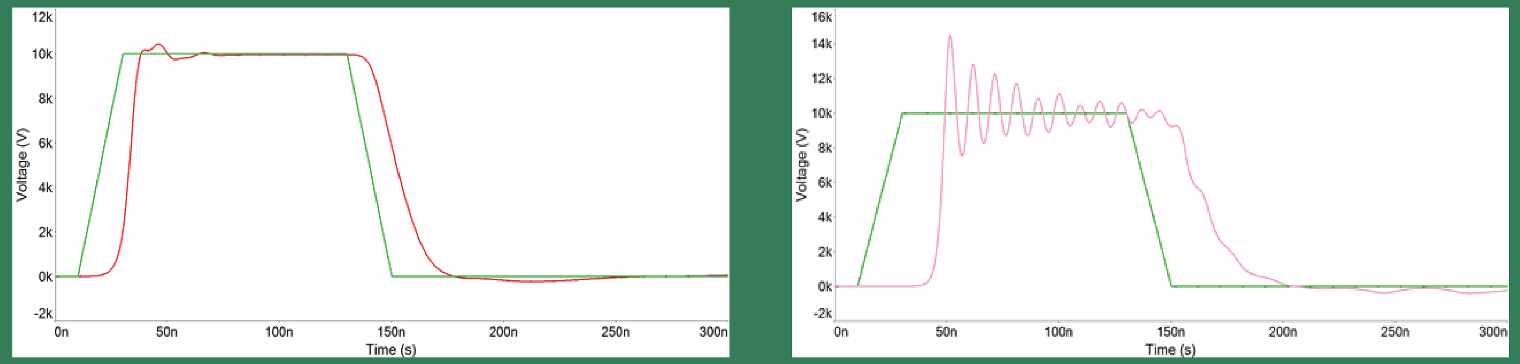
The patch is a thin circle of deposited metal (d = 1 cm) and is offset from the center by 1 cm such that the feed probe drives the patch at its edge. The plasma-facing side of the antenna is coated by a thin layer of alumina. The polar view of the far field pattern at approximately 2.75 GHz demonstrates the wide beam width of this circular patch. The plane of the polar plot is normal to the ground plane. This shows that the patch radiates normal to the plane of the patch/substrate. However, the beam is wide such that the gain is within 3 dB of its maximum value over an angular width of 157°. The max gain in this plane at 2.75 GHz is 2.27 dB.



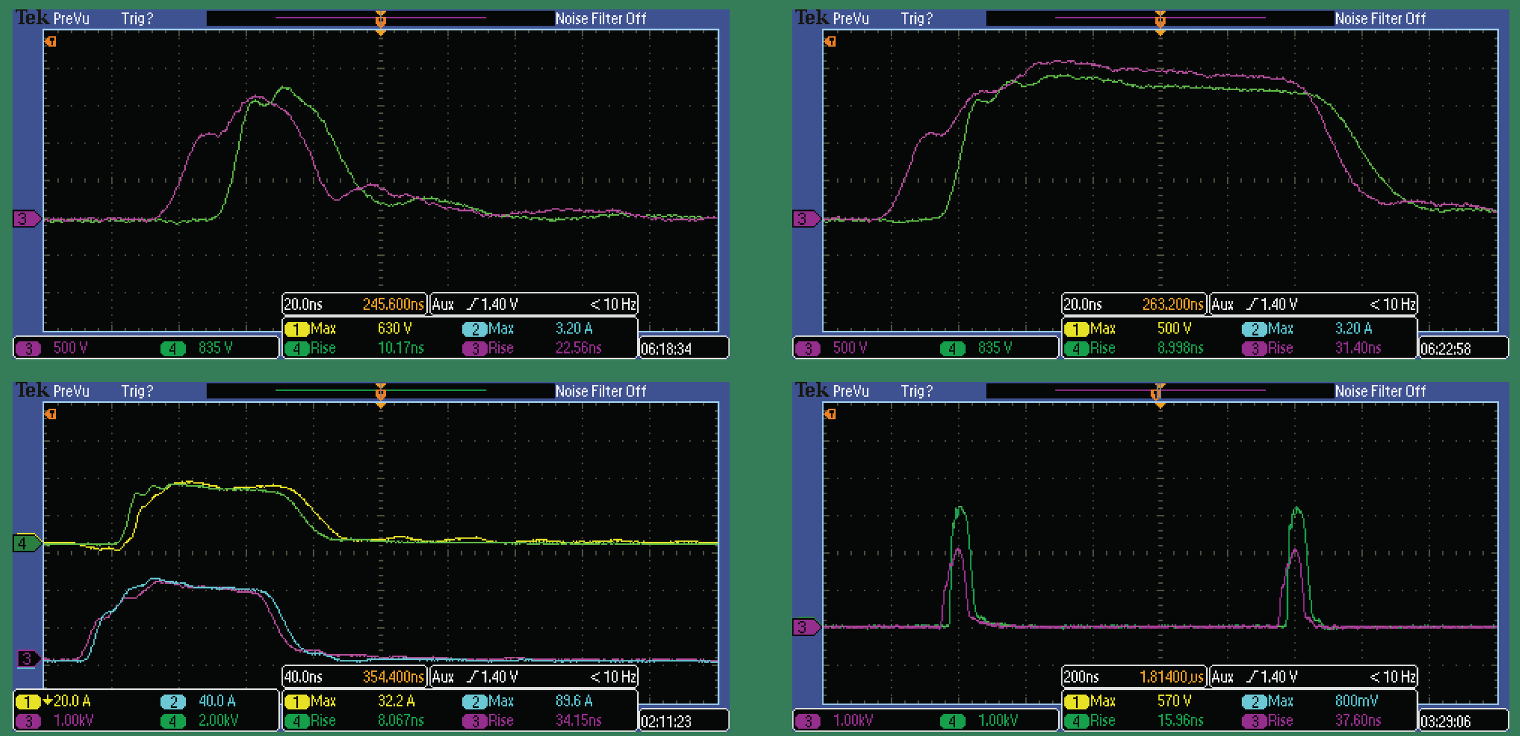


Lumped-element NLTL

To improve pulser rise time, EHT is investigating lumped-element NLTLs with off-the-shelf components. Spice modeling showed that the pulse rise time could be improved to below 10 ns. A 10 kV NLTL with 20 elements was built and tested, which produced sub-10 ns rise time at 82-86% efficiency.



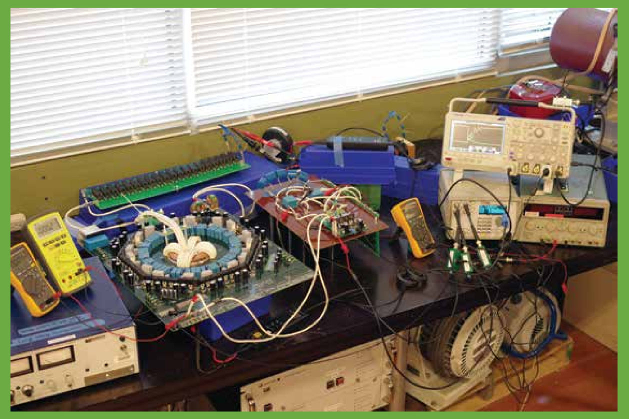
Spice model showing pulse sharpening from 16 ns to 8.4 ns (left). 100 MHz RF with lumped-element NLTL. Frequency can be changed by altering stray inductance.



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).

Conclusion

EHT is developing a heat pulse diagnostic in collaboration with HIT at the University of Washington. EHT has demonstrated that the EHT NSP can produce 20 kV pulses with sub 10 ns rise time, acquired the gyromagnetic NLTL, produced a bench test setup, and initial designs for microwave antenna. EHT has also conducted testing of a lumped-element NLTL, which can improve rise time for 50 Ohm driving. The next step will be to construct the antenna and bench the system. Afterwards, the system will be transported to HIT for plasma testing (HIT schedule allowing) to demonstrate plasma heating.



Acknowledgment

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Further Information

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