Nonlinear Transmission Line for RF Plasma Heating

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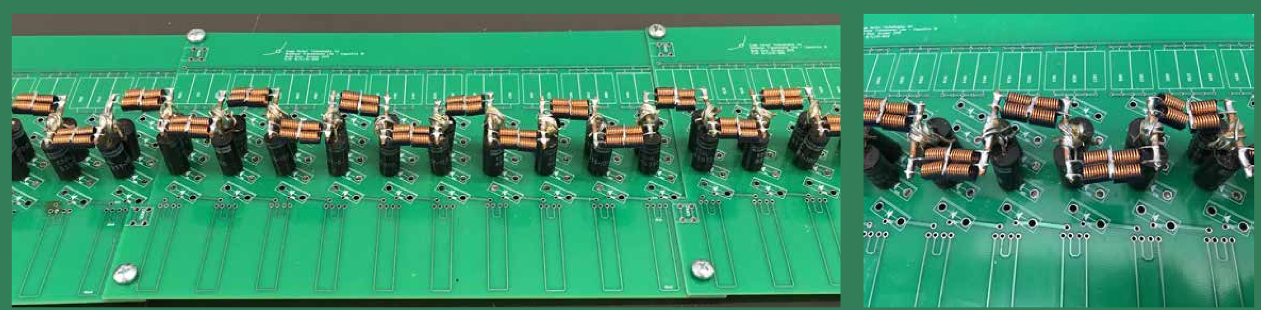
Introduction

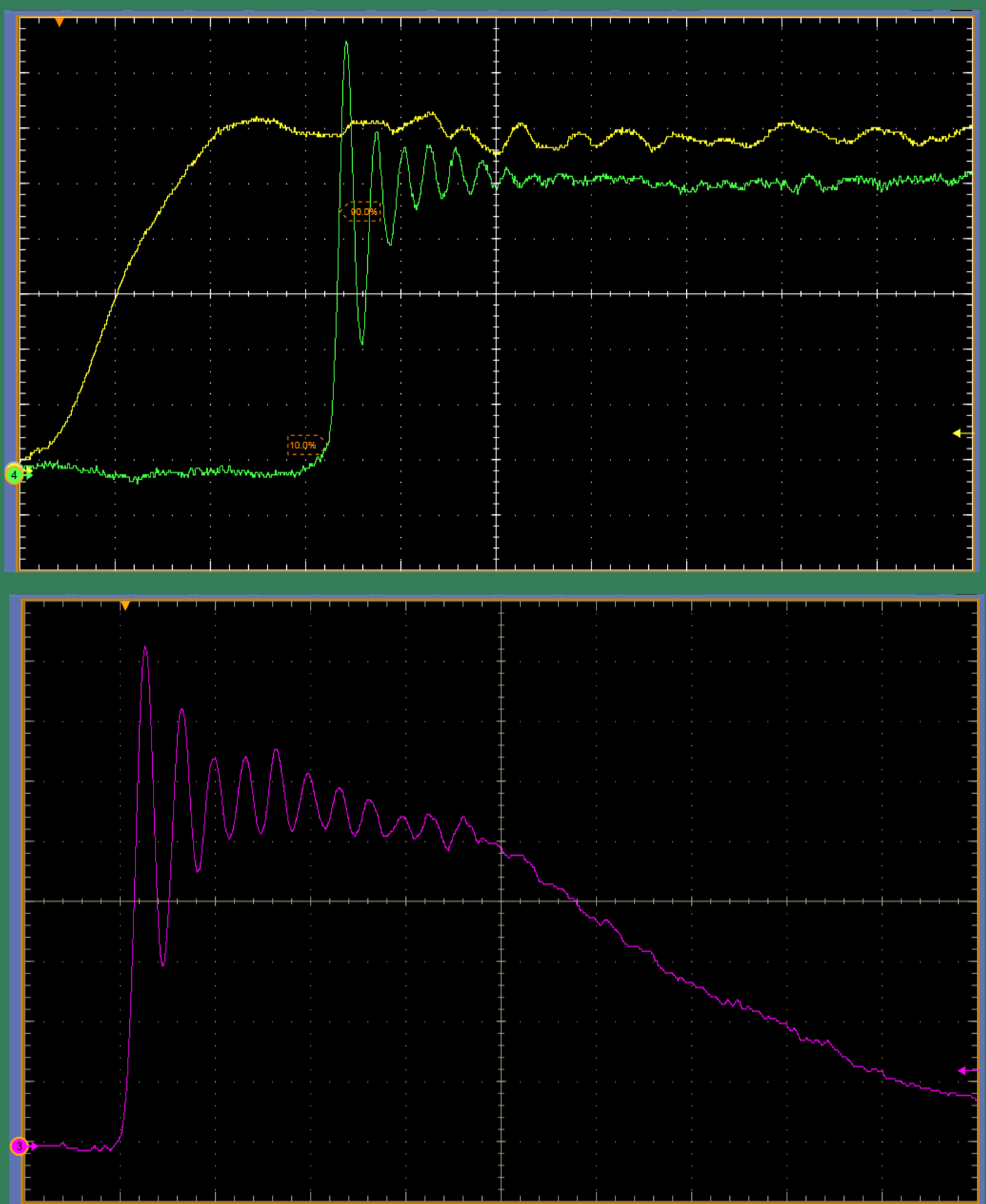
Eagle Harbor Technologies, Inc. (EHT) is developing a low-cost, fully solid-state architecture for the pulsed RF heating systems and diagnostics at fusion science experiments. EHT has constructed and tested a high voltage inductive adder to drive gyromagnetic and diode-based nonlinear transmission lines (NLTLs). The inductive adder is capable of 35 kV output with a 10-ns rise-time into 50 Ohm loads. During this program EHT has experimented with the development of diode-based lines as a method to produce high power pulsed RF at frequencies from 0.1 to 3 GHz. Here the concept is to utilize the system to demonstrate pulsed plasma heating with an inductive adder high power RF source. EHT will present results of a new diode based NLTL and show the design of the setup for plasma heating.

10 kV Diode-based NLTL

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



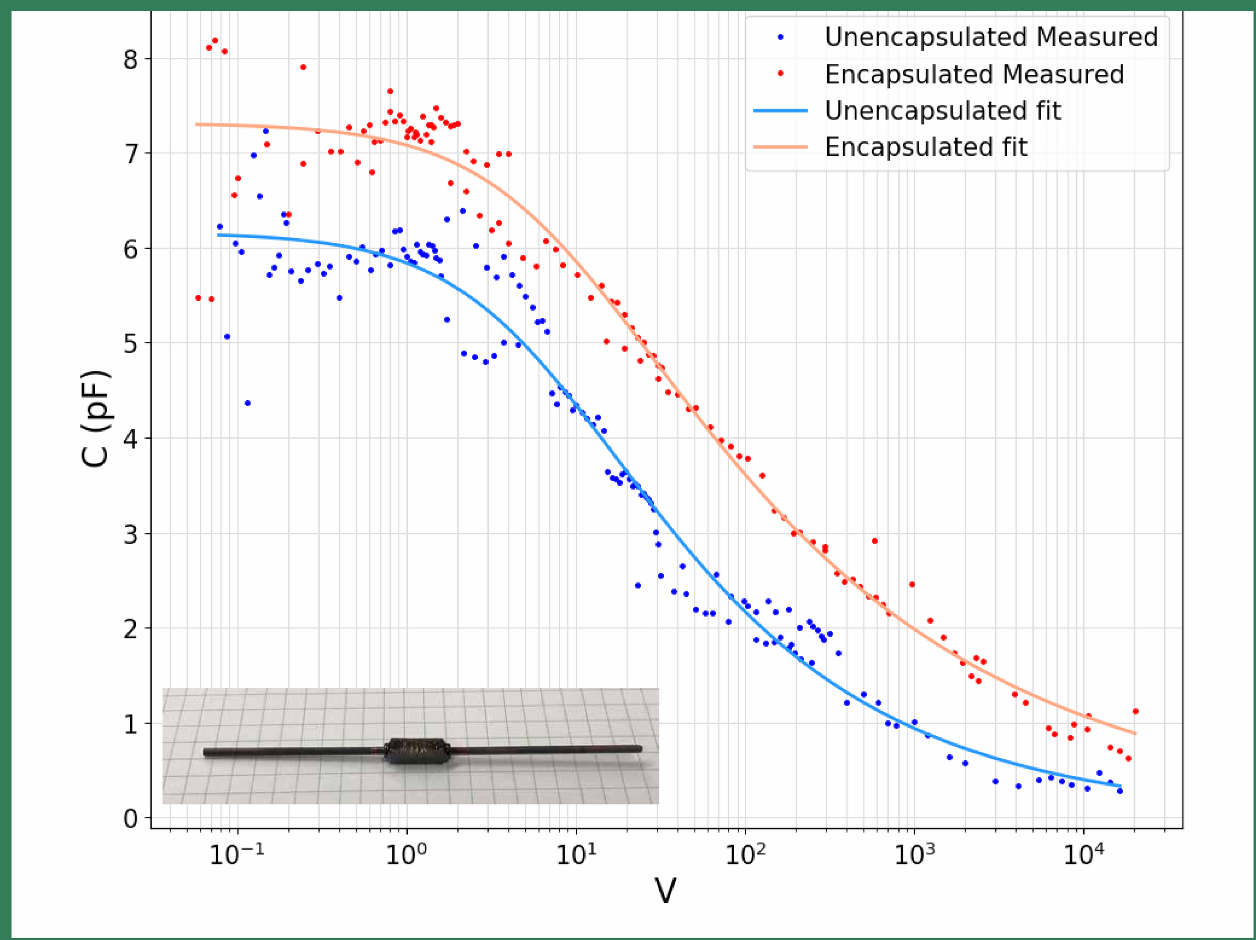
Left: Input pulse (yellow) and output pulse (green) from first generation RF NLTL. The frequency was 325 MHz, and about five oscillations were produced. Right: Output of second generation RF NLTL. The output frequency was 265 MHz and about double the number of oscillations. Time base is 10 ns/div.

30 kV Diode Testing

EHT has tested encapsulated and unencapsulated diodes to characterize their $C(V)$ curves. This curve could then be used for modeling to design the NLTL.

$$C(V) = \frac{C_{j0}}{\left(1 + {}^{V}/_{\varphi}\right)^{m}}$$

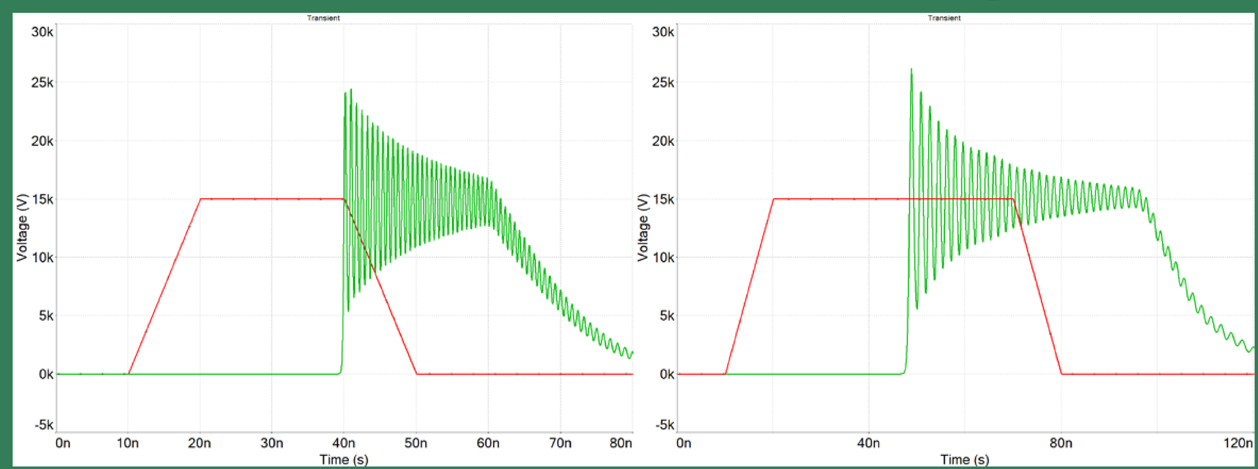
	Encapsulated	Unencapsulated
C_{j0} [pF]	7.31	6.16
φ [V]	7.81	6.46
m	0.268	0.372



$C(V)$ curves for the encapsulated and unencapsulated (see inset) 30 kV diodes. Diodes were driven with data pulser, EHT IPM, and EHT NSP. $I(t)$ and $V(t)$ measurements were made with fast voltage and current probes.

30 kV Diode NLTL Modeling

Two 50 Ω NLTLs were designed with output frequencies of 500 MHz and 1.24 GHz. The input for both NLTLs was a 15 kV pulse with 10 ns rise time, which is consistent with the inductive adder that was constructed earlier in the program. Resistance in both the diode and inductor legs of the NLTL was modeled with 10 mΩ resistors. This is probably an underestimate of the real resistance so the actual waveforms will have fewer peaks.



NLTL input and output pulses for the high frequency (left) and low frequency lines (right).

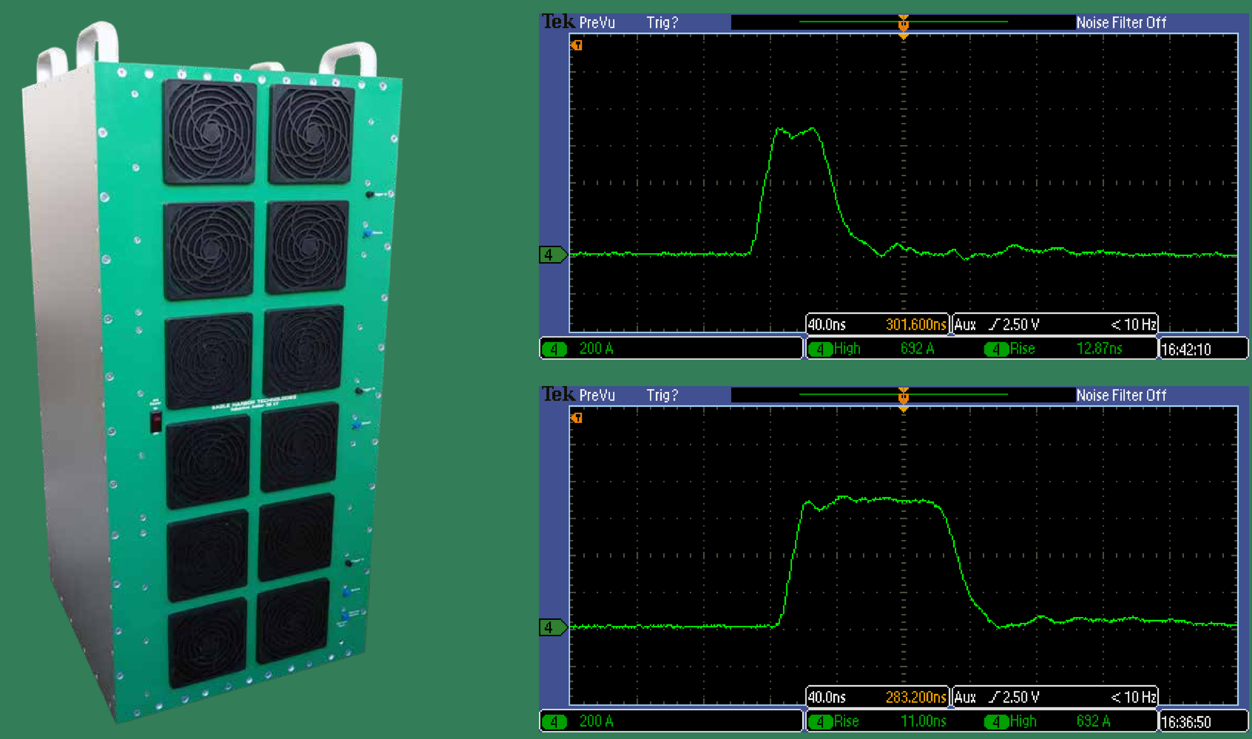
Parameter	High Frequency	Low Frequency
L/element [nH]	5	20
C @ 0V/element [pF]	24.64	98.56
Number of parallel caps/element	4	16
Number of elements	240	80
Total number of caps	960	1280
Output frequency [GHz]	1.24	500

The parameter m in the capacitance formula has a strong influence on the output of the NLTL. This resulted in different output frequencies as well as different line impedances. A good measurement is important.

m	Δt [ns]	f [GHz]
0.27	1.25	0.83
0.32	1.00	1.00
0.37	0.80	1.25
0.42	0.67	1.49

Inductive Adder

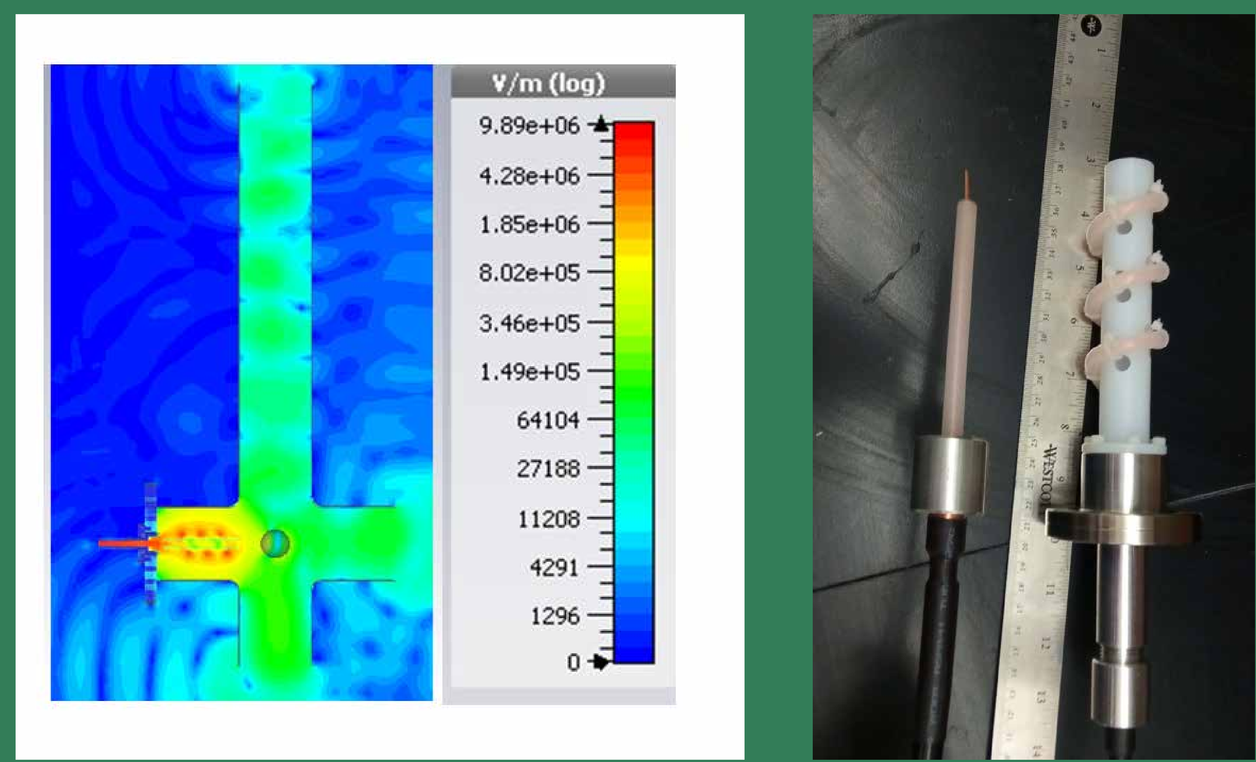
EHT has developed an inductive adder that will be available for NLTL testing. The adder can drive 50 Ω loads at 35 kV with ~10 ns rise times. These pulses can be repeated at >25 kHz.



Left: Boxed inductive adder. 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 (top) and 100 ns (bottom). Rise time 11-13 ns.

Microwave Modeling and Construction

NanoEM has modeled the vacuum chamber and antenna. They have also constructed a UHV antenna



Conclusion

EHT has developed a 10 kV diode- based NLTL that can produce high power RF at 265 and 325 MHz. The next generation line will have lower stray components and be capable of higher voltage operation. The inductive adder will be used to drive the 30 kV diode NLTL.

The EHT plasma chamber has been modified for the high power RF experiments. An antenna has been designed and the RF has been modeled. The next step will be to pulse the RF and conduct plasma heating experiments.

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

Acknowledgment

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