High-Voltage Solid-State Trigger for HEDP Applications Phase I Results

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EAGLE HARBOR TECHNOLOGIES

Introduction

Eagle Harbor Technologies (EHT), Inc. is developing a solid-state thyratron replacement that can be used to trigger higher voltage spark-gap switches at Sandia and other laboratories. The current trigger generators used at Sandia are marginally reliable and have a long manufacturing and delivery time, and there is concern about the long-term availability of these thyratrons. When measured over short timescales, thyratrons typically have a jitter of a few nanoseconds; but over longer timescales, they can have a much larger drift. Additionally, thyratrons need stable, high-current, low-voltage power sources, have long warm-up times, and require conditioning shots to achieve a stable operating point. EHT recently completed a Phase I program to develop a first-generation prototype solid-state thyratron replacement. This unit produced 20 kV into 50 Ω with a sub-10 ns rise time and 100 ns e-folding fall time. EHT will present the design trade-off study, selected topology, and key waveforms results.

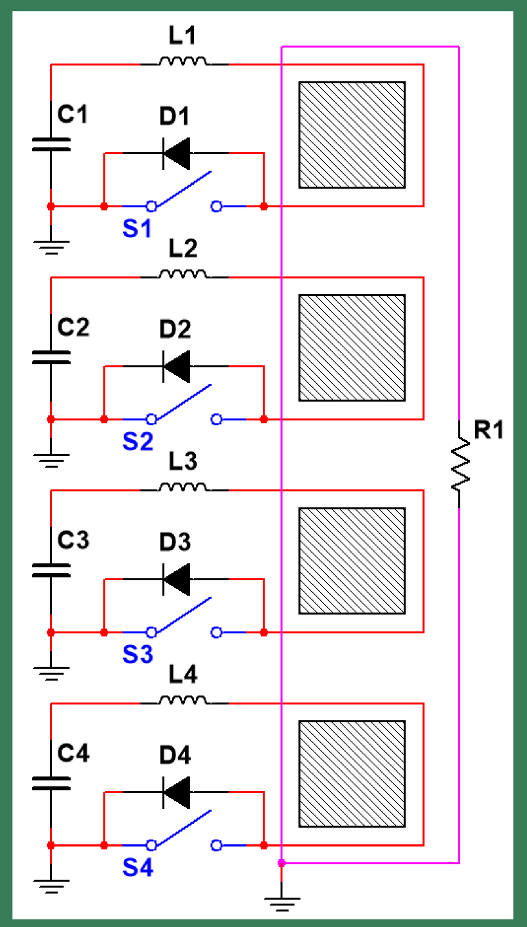
Solid-State Thyratron Replacement Requirements

A solid-state thyratron replacement suitable for HEDP applications at Sandia should meet the following specifications:

- Output voltage: 20 kV
- Capable of driving 50 Ω transmission lines
- One-sigma jitter: < 2 ns
- Rise time: < 10 ns
- Fall e-folding time: 120 ns
- High reliability
- Low volume
- Low cost (< $30k)
- Long lifetime

Topology Selection

Originally, EHT proposed a series/parallel arrangement of IGBTs that could drive a 50-Ω transmission line at 20 kV with a 10 - 15 ns rise time, which could be reduced with a nonlinear transmission line (NLTL). At the start of the Phase I, we reconsidered circuit topologies.



High Voltage Switch

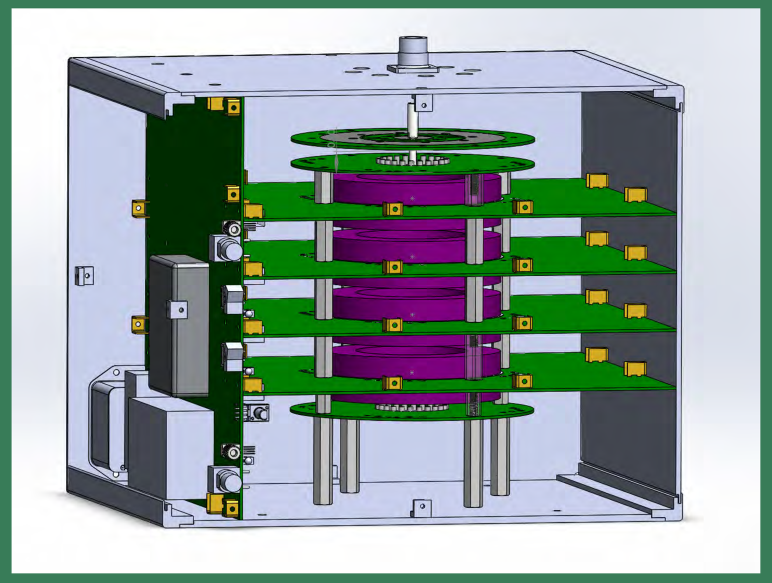
- Expensive charging supply
- Corona issues at DC
- Needs snubbers for safety
- Isolation transformer needed
- More fibers (increases cost)

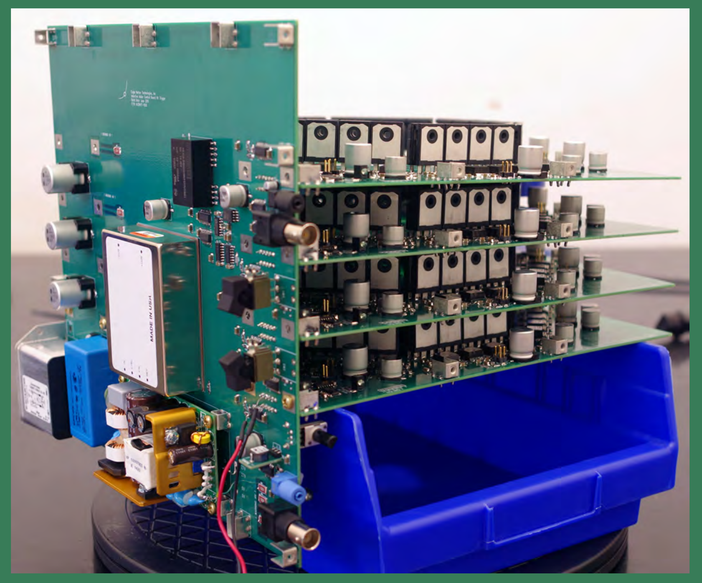
Inductive Adder

- No HV DC
- No corona
- More fault tolerant
- Less complex
- Modular/scalable
- Better NLTL integration
- Coated transformer cores

Inductive Adder Construction

After each stage was tested individually, the four-stage inductive adder was mated with the control/power board. Testing was conducted to optimize transformer design and circuit component values (energy storage, diodes, etc.). The inductive adder produced a 20 ns rise to 20 kV into a 50 Ω load.

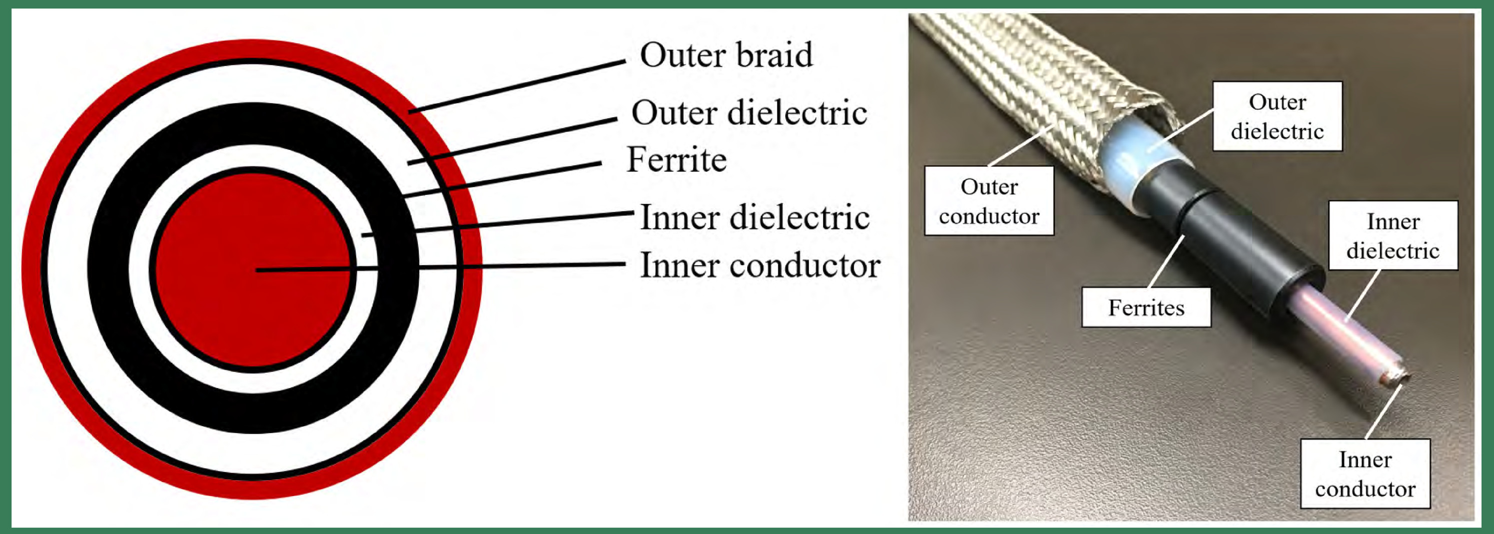




Left: CAD model of inductive adder in enclosure. Right: Four-board inductive adder stack with control board mounted on left side.

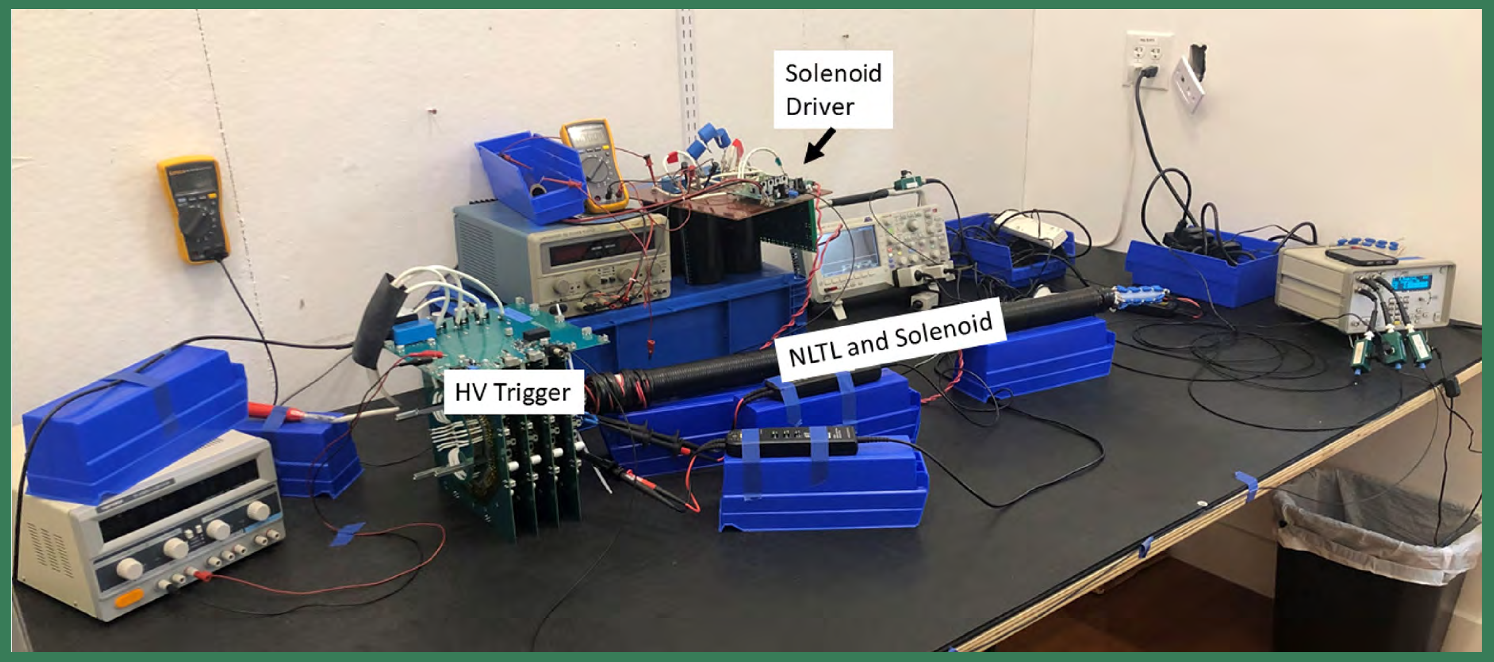
Nonlinear Transmission Line

To reduce the rise time of 20 ns to below 10 ns, an NLTL was used. NLTLs have a nonlinear permittivity, $\varepsilon(V)$, and/or nonlinear permeability $\mu(I)$. This NLTL is consists of an inner conductor surrounded by ferrite beads, encapsulated by a dielectric surrounded by an outer conducting braid.



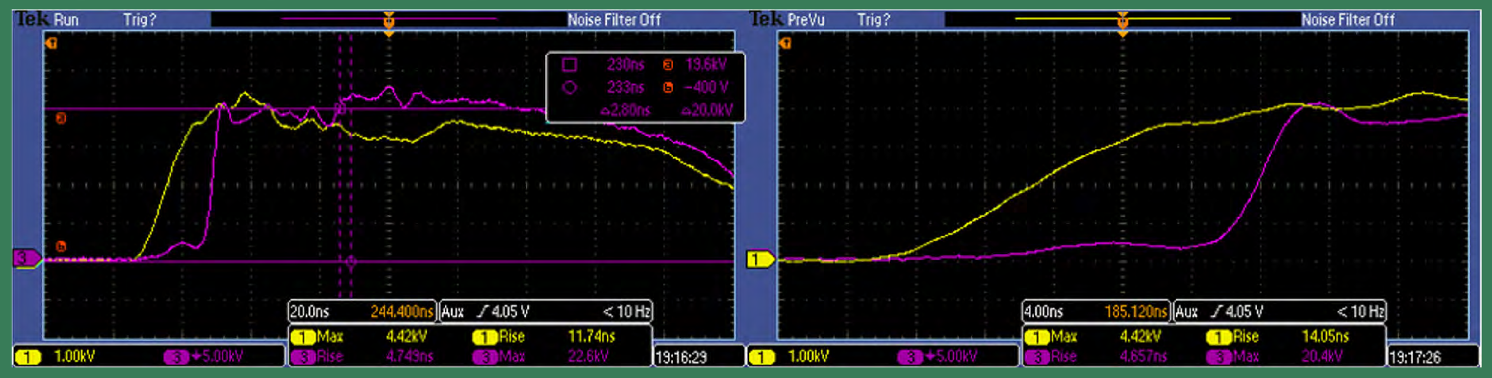
Ferrite-based NLTL design cross-sectional (left) and constructed NLTL (right).

HV Test Setup

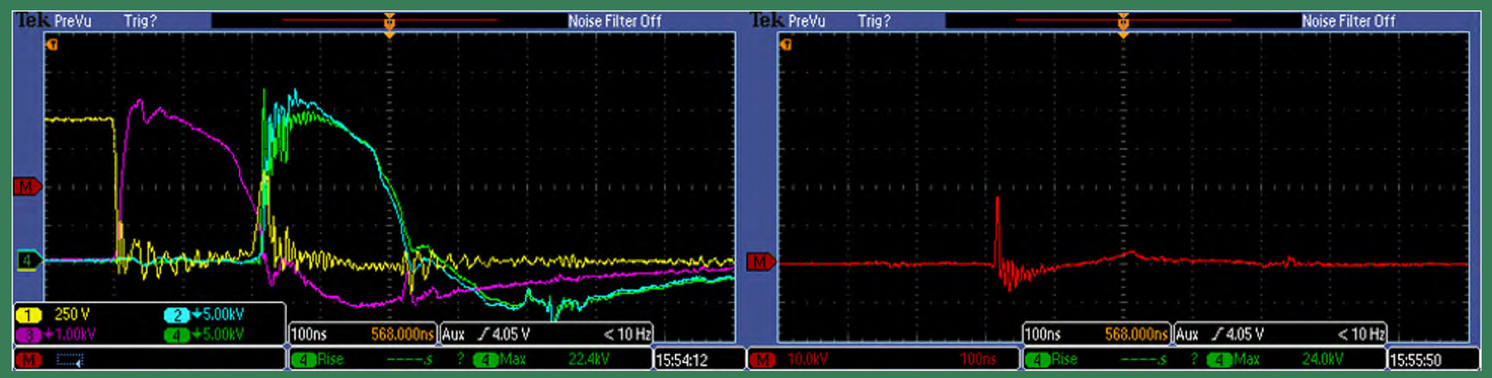


High voltage test setup for the HV Trigger based on the inductive adder and NLTL.

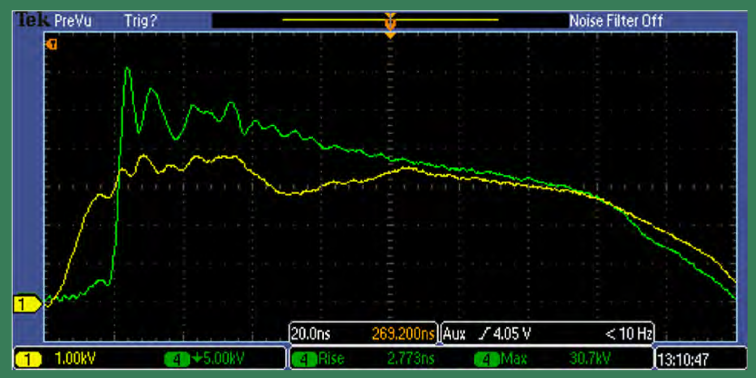
High Voltage Testing



The transformer output (yellow) and NLTL output across the 50 Ω load (magenta) with 20 ns/div (left) and 4 ns/div (right). The cursors in the left image indicate 20 kV. NLTL solenoid bias magnetic field was 29 kA/m, DC charge voltage of 950 V.



HV Trigger driving a 0.15" spark gap at the end of the delay line (left) and spark gap voltage (right). V_{CE} (yellow), voltage across 50 Ω resistor in series with the spark gap (blue), output voltage of the transformer (magenta), the voltage across the spark gap and 50 Ω series resistor (green), and spark gap voltage.



HV Trigger with second NLTL design driving 50 Ω resistor. This NLTL did not require an external magnetic field, but produced 30 kV with a sub-3 ns rise time. Inductive adder output (yellow) and NLTL output (green).

Conclusion

Facilities such as Sandia National Labs' Z Machine would benefit greatly from the increased reliability and decreased jitter and cost offered by modern solid-state switching technology. EHT successfully designed, built, and tested a compact (< 1500 in^3) proof-of-concept solid-state HV trigger system that met the waveform specifications outlined for use as a thyratron replacement for spark-gap switch triggering. This HV trigger system utilizes proven inductive adder and NLTL technology developed at EHT to achieve a 20 kV pulse into a 50 Ω load with a sub-10 ns rise time. Future improvements would optimize the pulse-sharpening stage for compactness and reduce the complexity of the high voltage pulse transformer design.

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

Acknowledgment

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