High Voltage, Fast Kicker Power Supply

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EAGLE HARBOR TECHNOLOGIES

Introduction

Short-pulse dielectric Two-Beam Accelerators (TBAs) have the advantage of producing high accelerating gradients near GV/m at significantly lower cost and complexity over traditional superconducting accelerators, which could significantly reduce the overall cost of accelerators for both scientific and industrial applications. One challenge is the development of a high voltage fast kicker system for the staged dielectric TBA. Kickers are electromagnetic devices that create very fast fields to deflect charged particles to divert a portion of the beam away from the accelerator for use. In general kicker systems require fast rise times and precision flat-top for uniform beam deflection. The requirements for the fast kicker system for dielectric short-pulse TBA are very demanding, and there is currently no power supply that can meet the all the necessary requirements. Eagle Harbor Technologies, Inc. has developed unique high voltage nanosecond pulse technology that can be utilized to meet the requirement for future TBA systems. EHT has demonstrated an 80 kV modular power supply system with fast rise time capability (~16 ns). To reach the desired output voltage of 160 kV EHT proposes to combine two of the 80 kV systems to enable the fast kicker power supply.

Kicker Driver Specifications

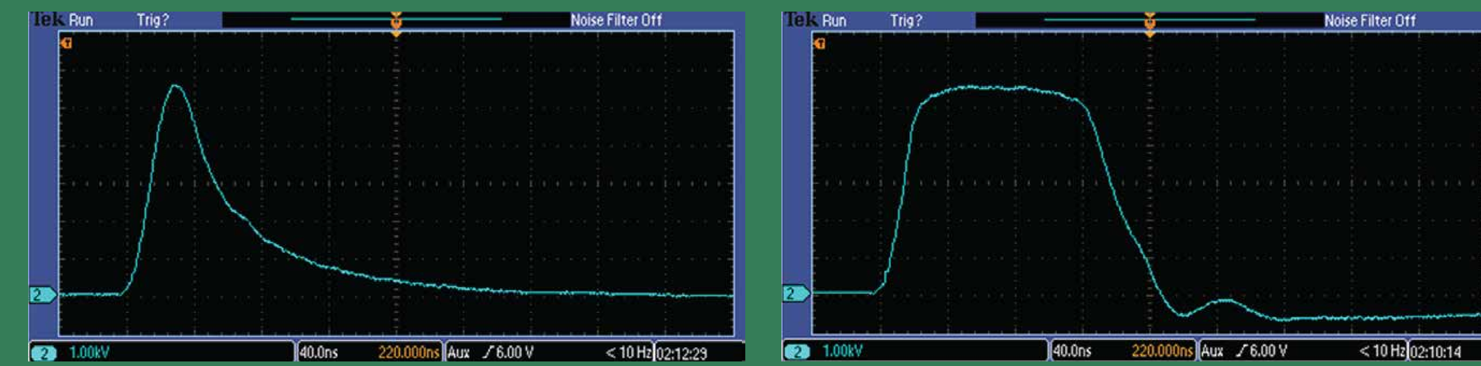
The challenge for the dielectric TBA accelerator is daunting. The strip-line must be charged to 156 kV during a 50 ns pulse with a 20 ns flat-top, which is necessary for optimum deflection of the microbunch train. At 160 kV and 50 ns rise-time with an estimated capacitance of 3 pF, the high voltage pulser must be capable of peak power levels on the order of 750 kW. In practice this value is much higher as any additional stray capacitance will increase the load capacitance value.

What is needed is a new and novel kicker power system that can produce 156 kV with 50 ns rise time and effectively drive a capacitive load represented by the strip-line kicker. The full system specifications for an optimal short dielectric TBA kicker and power system are as follows:

- Length of kicker strip-line: 30 cm
- Width of kick plates: 5 cm
- Distance between plates: 5 cm
- Stripe line capacitance ($C = \varepsilon_o A/d$): 2.6 pF
- Charge delivered to plates @ 156 kV: (Q = CV): 0.4 µC
- Power supply output current to load @ 50 ns rise time (I = dQ/dt): 13 A
- Required high voltage amplitude: 156 kV
- Required rise time: 30 to 50 ns
- Required flattop: > 20 ns
- Timing jitter: ~ 1-3 ns
- Ripple during flat top: TBD
- Pulse-to-Pulse stability: TBD, but expected to be high for all solid-state systems

EHT Nanosecond Pulser

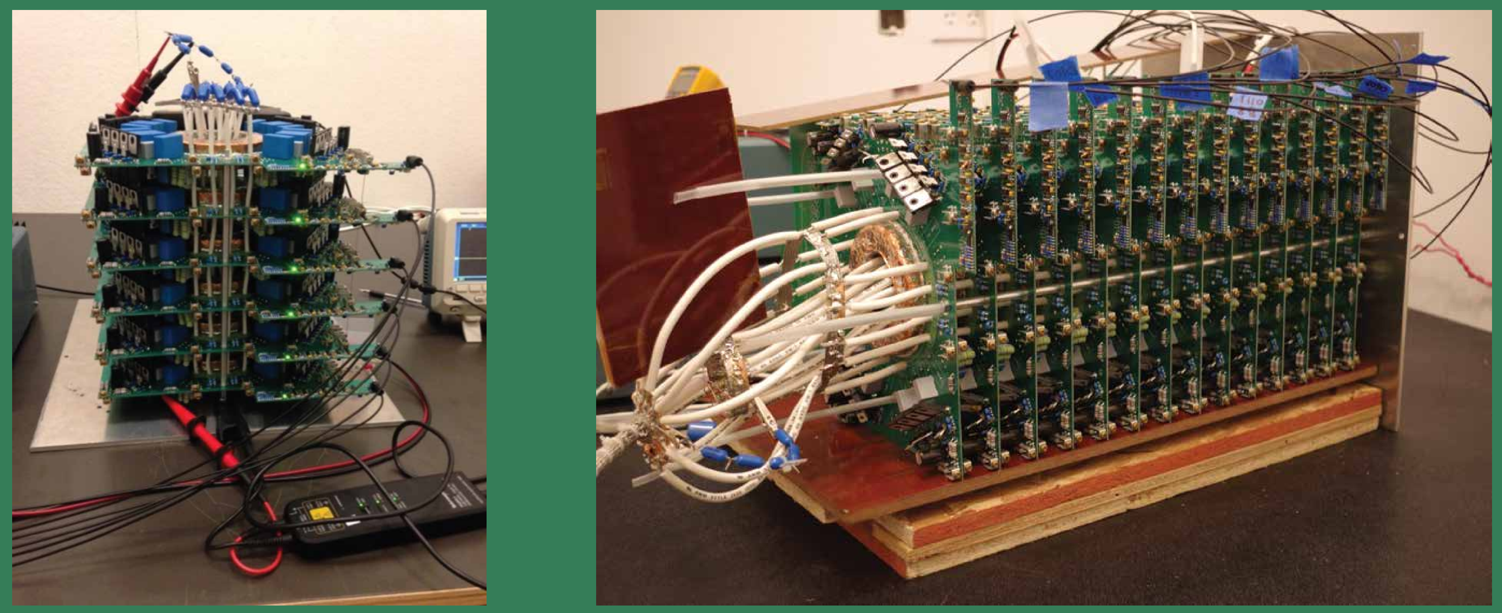
EHT produces off-the-shelf nanosecond pulsers with independently adjustable voltage (0-20 kV), pulse width (20 - 260 ns), and pulse repetition frequency (0-100 kHz). To generate 40 kV output pulses, EHT modified the transformer of an off-the-shelf unit. The board was tested outside the metal enclosure due to high voltage tracking constraints. The pulser could generate 40 kV pulses with 20 ns rise times into 7 kΩ. While this is impressive performance for the small package, many applications require lower impedance driving and/or faster rise times. To accomplish this, an inductive adder was required.



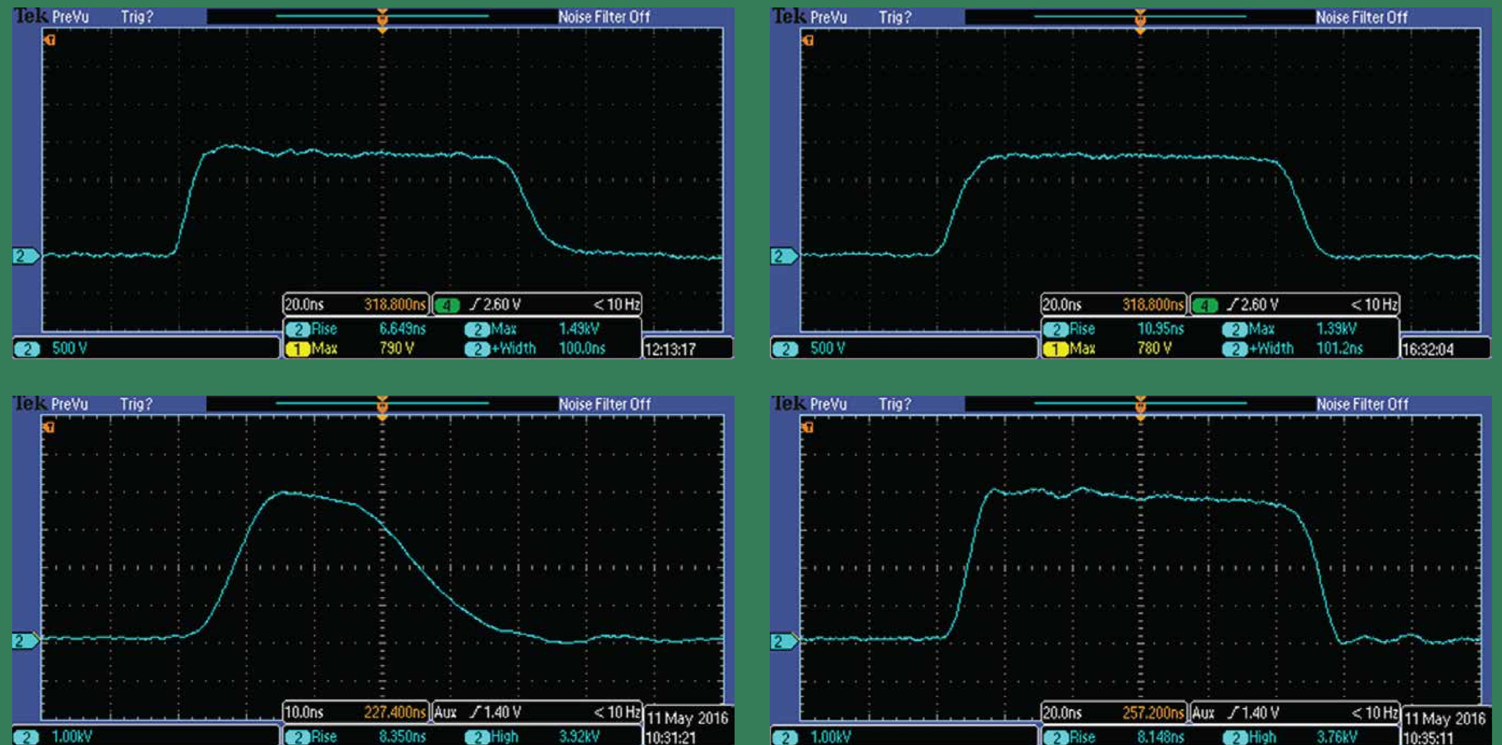
40 kV pulse with 20 ns rise and 40 ns FWHM (Left) and 130 ns FWHM (Right).

Low Impedance Driving Inductive Adder

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.



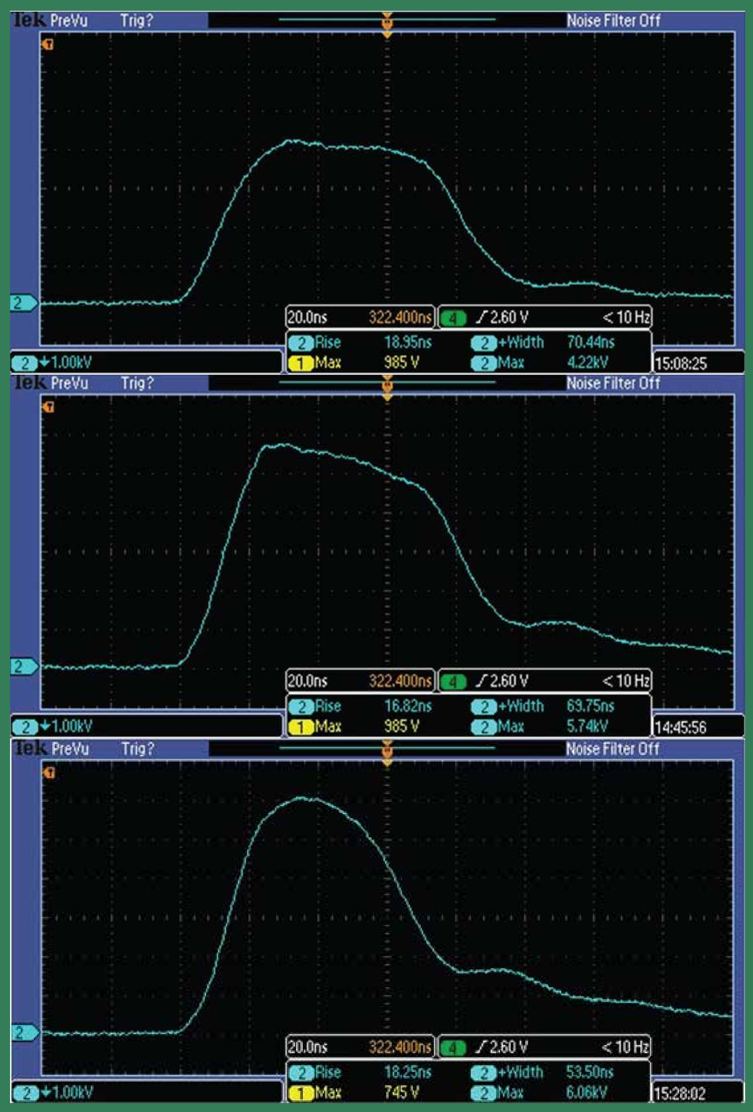
Left: 10 kV inductive adder. Right: 20 kV inductive adder.



Top Left: 10 kV - 100 ns pulse into 50 Ω 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.

80 kV Pulse Demonstration

EHT utilized the inductive adder with a custom pulse transformer to test the system capability for fast high voltage output. The system was able to achieve peak voltages of approximately 80 kV. Rise times were still very fast from 17 to 19 ns depending on load and output voltage. The faster rise time gives headroom for an optimized system, where rise time can be sacrificed for cleaner flat-top region by adding output filtering. The output transformer was based on our initial best guess and there is considerable room for improvement. The best flat top data is seen at 66 kV. It is expected that with improvements to the system that similar flat top will be maintained at over 80 kV.



Output voltage pulses at 66 (top), 74 (middle), and 80 kV (bottom).

Conclusion

EHT has demonstrated three techniques for generating high voltage pulses. The first technique used a pulse transformer on a single board, which was able to produce high voltage pulses (40 kV) with slower rise time (20 ns). EHT then constructed and inductive adder to demonstrate 50 Ω driving with fast rise (6 - 11 ns) times at 10 and 20 kV. Finally, EHT added a pulse transformer to the 10 kV inductive adder to produce 80 kV pulses with fast rise time (17 - 19 ns).

After optimizing the transformer design, this 80 kV unit will form the basis for the fast kicker supply. The next step will be to ground the 80 kV units. This is a more demanding requirement as the stray capacitance is increased.

In the future, EHT will combine two of the grounded 80 kV units to form a 160 kV unit, which will be tested into the relevant capacitive loads. This system will be optimized to produce the rise in the time required (30 - 50 ns) as well as the 20 ns flat-top. Additional work will focus on robustness testing as well as low capacitance high voltage vacuum feed through to bring the high voltage pulse to the kicker.

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