Ultrafast High Voltage Kicker System Hardware for Ion Clearing Gaps

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RadiaBeam

• Founded in 2004
• ~50 employees and growing
• 30,000 ft² headquarters in Santa Monica, CA

• Accelerator R&D, design, engineering, manufacturing and testing all under one roof in a dynamic, small-business setting
Tour: Machine Shop

- Multiple CNC milling and turning centers, > $3 million investment
- Dedicated “clean shop” for RF and UHV machining
- Full-suite of inspection equipment, including CMM
- 10 highly-skilled machinists
- ISO 9001 compliant quality system
Project Goals and Specs

The ionization scattering of the electron beam with residual gas molecules causes ion trapping in the electron rings, both in the collider and electron cooling system. The trapped ions may cause emittance growth, tune shift, halo formation, and coherent coupled bunch instabilities. Therefore, the beam temporal structure needs gaps to clear the ions to prevent them from accumulating turn after turn. Typically, the gap in the bunch train has a length of a few percent of the ring circumference.

- A fast deflector (kicker) is needed for EIC ERL cooler to form a ~100ns gap at ~1MHz (37.5MHz, ultimately 98.5MHz micro-bunches)
  
  **Most recently 200ns at 470KHz**

- Stripline kicker is a practical solution for such need

- RadiaBeam is building a kicker and two-channel pulsed power source intended to be installed and tested at Jefferson Lab
  - Aperture 14 mm
  - Maximum insertion length 75cm

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Deflecting angle</td>
<td>20 mrad (deflecting voltage 140 kV)</td>
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<tr>
<td>Electron Beam Energy</td>
<td>7 MeV</td>
</tr>
<tr>
<td>Bunch Repetition Rate</td>
<td>37.5 MHz</td>
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<tr>
<td>Bunch rms transverse size</td>
<td>σ=1 mm</td>
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<tr>
<td>Deflecting Pulse Width</td>
<td>100 ns flat-top required to deflect 4 out of 31 bunches in train</td>
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<td>Kicker operation per rate</td>
<td>1.4 MHz (715ns between the pulses)</td>
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<td>Rise + Fall Time</td>
<td>&lt;20 ns (10ns desired)</td>
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<tr>
<td>Aperture (gap)</td>
<td>14 mm</td>
</tr>
<tr>
<td>Required pulsed power</td>
<td>27.6 kW peak power per channel (55.2 kW total); 3.8 kW average power per channel (7.6 kW total)</td>
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</tbody>
</table>
EM design

Power required for 20 mrad deflection

40 cm interaction length
Beam dynamics study

Exit offset spectrum over injection parameters

Kicked bunch (400mm)

Unkicked bunch (400mm)

Kicked bunch (600mm)

Unkicked bunch (600mm)

Beam loss with various interaction lengths

40cm interaction length
Engineering model

- Standard 1-5/8” EIA compatible
- XYZ Positioning stage
- No dielectric supports
Pulser testing setup

- 50cm-long 50 Ohm stripline, VSWR <1.1 from DC to 1 GHz
- Si MOSFET and GaN water-cooled high-power switches
- 2000 V / 10 A DC supply
Pulser testing (Si MOSFET)

Achieved:
- 7ns rise and 6ns fall times at 100 ns flat-top with 87ps rms timing jitter
- Highly stable and controllable pulse length
- 1.4 MHz repetition rate
- 50% efficiency
Pulser testing (Gallium Nitride)

Achieved:
• 6.8ns rise and 4.5ns fall times @ 107 ns flat-top with 100ps rms timing jitter
• Highly stable and controllable pulse length
• 1.4 MHz repetition rate
• 82% efficiency
Achieved:
• 10 ns rise and 11 ns fall times @ 107 ns flat-top
• 1.4 MHz repetition rate (short bursts)
• 85% efficiency

Up to 600V so far (to be improved)
Achieved*:
• 4.2 ns rise and 5.5 ns fall times @ 38 ns flat-top
• 100 Hz repetition rate
• 95% efficiency

*under Phase I project DE-SC0021548
2022 PHASE II for EIC pulser, 50kV 7 ns rise/fall (4.5 ns – achieved in Phase I), 30 ns * 100 Hz
Summary:

- Kicker EM and mechanical design are complete
- Improve GaN-based pulser to achieve 1175V, 5/6ns rise/fall, 1.4 MHz
- Assemble two-channel pulser
- Kicker fabrication, assembly and tests
- Installation and beam-based tests