DI ELECTRIC BASED HG STRUCTURES: POWER EXTRACTION, TUNABILITY AND ENERGY TRANSFER EFFICIENCY

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Motivation/Outline

MW DLA issues: high gradient – drive beam, power extraction, tuning, efficiency, BBU, multipacting, ...

- High Gradient DLA
- 26 GHz Wakefield Power Extractor
- Tunable Dielectric Based Accelerator: Idea and Experiment
- Ferroelectric Based Fast High Power Switching
- Transformer Ratio X-Band Experiment, R>2 Demonstration
- Energy Modulation

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Dielectric Based Accelerator

Drive Gun

Linac & Steering Coils

Wakefield Structure

4.5 m

Single bunch operation
- $Q=1-150$ nC
- Energy=15 MeV
- High Current = 10 kAmp

Bunch train operation
64 bunches x 50 nC $\rightarrow$ 50 ns long

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ICFA Workshop on Novel Concepts for Linear Accelerators and Colliders.
SLAC, July 7-10 2009
Dielectric Based Linear Collider Concepts

Major features: Short pulses (<20 ns), high gradient (200 ~ 300 MV/m)
Drive beam structure directly

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26GHz Dielectric-Based Power Extractor*

- A 26GHz power detector has been built and bench tested.
- A load has been built and bench tested.
- Beam test has been performed at AWA facility.

### Parameters of 26GHz Dielectric Based RF Power Extractor

<table>
<thead>
<tr>
<th>Geometric and accelerating parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID / OD of dielectric tube</td>
<td>7 mm / 9.068 mm</td>
</tr>
<tr>
<td>Dielectric constant</td>
<td>6.64</td>
</tr>
<tr>
<td>Length of dielectric tubes</td>
<td>300 mm</td>
</tr>
<tr>
<td>R/Q</td>
<td>9788 Ω/m</td>
</tr>
<tr>
<td>Drain time Td</td>
<td>3 ns</td>
</tr>
<tr>
<td>Steady power from AWA bunch train (20nC/bunch)</td>
<td>148 MW</td>
</tr>
</tbody>
</table>

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Beam Test of the 26GHz Power Extractor @ AWA Facility (May~June, 2009)

Performed 3 experiments to date:

- Single beam--- to check the frequency
- 16-Bunch train--- to check the rf pulse formation
- 4-bunch train--- to achieve the high rf power

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Down-converted rf Trace of the 26GHz Power Extractor (4bunches)

\[ 11.44 + 14.576 = 26.016 \text{ GHz} \]

Background noise direct to the scope
Down-converted rf Trace of the 26GHz Power Extractor (16 bunches with 769ps separation)

4 bunches to reach the steady state

11.44 + 14.576 = 26.016 GHz
Number is the percentage of charge transmission out of the structure.

- Theoretically, $9nC \rightarrow 29.6\,\text{MW}$, $24.8\,\text{MV/m}$ if $\sigma z = 1.5\,\text{mm}$.
- Calibration will be taken after the experiment.
Summary for 26GHz Dielectric Based Power Extractor

- Successfully demonstrated the high frequency, high power rf source using dielectric-based scheme.
- Experiment will be continued in the upgraded AWA facility next year.
- Design of a fully featured power extractor (with transverse modes damping) is needed to prevent BBU in the high charge transportation.
Tuning/Nonlinear Effects in Dielectric-Based Accelerator

forsterite

BST(M)

ε(E) for ferroelectric dielectric composite

high intensity wakefields in nonlinear structure

Pulse steepening

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Temperature tuning of 14 MHz/°K

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Tunable DLA
Fast DC Voltage Tuning

6 MHz at 20 kV/cm

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New Ferroelectric
\( \varepsilon < 300, k > 10\% \) in air

Lower dielectric constant,
higher tuning range

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BST(M) Ferroelectric Based L-band High Power Tuner
Collaboration with Omega-P and FNAL

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Transformer Ratio

\[ R = \frac{\text{Max. energy gain behind the bunch}}{\text{Max. energy loss inside the bunch}}. \]

\( R < 2 \) under very general conditions: linear media; a relativistic, longitudinally symmetric drive bunch; and identical paths through the system of both drive and witness beams.
Some of the methods that can be employed to obtain $R>2$ include: a triangular drive bunch longitudinal profile; a train of Gaussian drive bunches of progressively increasing charge (ramped bunch train, RBT); the ring type driver, use of a proton drive beam so that the particles within the bunch can change positions during deceleration; and nonlinear plasma dynamics.

A single drive bunch was replaced by two bunches with charge ratio of 1:2:5 and a separation of 10.5 wavelengths of the fundamental mode.
two-bunch wakefield experiment setup

The field probe signal from the RBT in the 13.625 GHz DLA

Wakefields measurements

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Leading and Tailing
8 nC and 20 nC bunches

the transformer ratio increases correspondingly, from $R \sim 1.8$ to $R \sim 3$.

satisfying the requirement of an equal decelerating field inside each bunch
An average measured transformer ratio enhancement by a factor of 1.31 over the single drive bunch case was obtained, $R>2$ has been demonstrated.


Enhancement Factor of 1.31
Transformer Ratio $R \sim 2.3$
laser pulse stacking method to stretch the AWA laser pulse from FWHM = 8 ps to 26.5 ps.
Energy Modulated Bunch Train

For the same gradient: Ramped – 220 nC; Flat – 80 nC

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Charge distribution is 20-20-20-20 nC, 1.5 mm length AWA bunch generated at the diamond based DLA structure with the inner radius of 1.5 mm, outer radius of 2.62 mm, ID=3 mm, OD= 5.24. Spacing between the bunches corresponds to 1.3 GHz or ~ 23 cm. Maximal accelerating gradient behind the train is 150 MV/m.

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### Energy Modulation: pros and cons

#### Ramped Bunch Train

**Pros:**
- Laser beam manipulation for the train profile generation

**Cons:**
- Lower accelerating gradient
- High charge for the last bunches
- Transverse fields increase
- Focusing for ramped bunch charges

A. Kanareykin et al., in preparation

#### Energy Modulated Bunch Train

**Pros:**
- Higher accelerating gradient
- Flat and low charge bunch train
- Last bunches have higher energy
- Transverse stability

**Cons:**
- Energy modulated driver bunch train generation
- Focusing of the energy profiled bunch train

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SUMMARY

1. Successfully demonstrated the 26GHz, high power rf source using dielectric-based scheme.
2. Design of a fully featured power extractor (with transverse modes damping) is needed to prevent BBU in the high charge transportation.
3. Tunable dielectric based accelerator concepts is presented.
4. Transformer ratio experiment demonstrated R>2 for DWA.
5. Energy modulated beam is considered, pros and cons are discussed.

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