Design of a Gyroklystron Amplifier for Accelerator Applications

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Outline

- Motivation
- Principles of klystron and gyrokylystron amplifiers
- Simulation results
  - MIG gun
  - Cavity simulations
- Future Work
Motivation

- **Accelerator (High acceleration gradient, CERN)**
  - The higher the operating frequency the greater the breakdown limit, and the larger the accelerating gradient
  - The shorter the accelerator

- **Lineariser (CompactLight, Cockcroft Institute)**
  - Correct the longitudinal phase space non-linearity from X-band (12GHz) linac
    - compensate for the curvature imposed on the bunch by the fundamental by adding harmonic
  - 3rd (36GHz) or 4th (48GHz) harmonic of X-band (12GHz) linac frequency
    - The higher the harmonic, the less amplitude (and thus microwave power) required
    - The higher the frequency, the shorter the lineariser

- **Project Goals**
  - Gyroklystron amplifier design
    - Verify model at 36 GHz, 2MW
    - Design 48GHz, 1.5MW
    - Pulse duration 2 μs, PRF 100 Hz
Both are amplifiers which operate by bunching an electron beam, then transferring energy from the electron bunch to the field to create microwave output.

- **Conventional klystron**
  - Bunching in axial direction, TM modes.
  - Operating frequency determined by the cavity size, difficult to achieve high power at high frequency (millimetre wavelengths).

- **Gyrokystron**
  - Bunching in azimuthal direction, TE modes.
  - Lower axial velocity, high beam alpha ($v_{\text{perp}}/v_{\text{para}}$).
  - Operating frequency determined by the external magnetic field.
  - Open output cavity, high power capability.
Gyrokylystron Operation

- Annular beam with helical trajectories
- Utilises the cyclotron resonance maser mechanism
- Phase modulation is applied in the input cavity and reinforced in buncher cavity
- In output cavity, bunch energy is transferred to the field and released as RF output
- For efficient operation, there must be no field in the drift tubes
## MIG-type electron gun

### Magnetic field

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emitter width $L_s$ (mm)</td>
<td>5.23</td>
</tr>
<tr>
<td>Emitter average radius $R_c$ (mm)</td>
<td>6.85</td>
</tr>
<tr>
<td>Anode angle $\phi_a$ (deg)</td>
<td>66.9</td>
</tr>
<tr>
<td>Current density $J_s$ (A/cm²)</td>
<td>20</td>
</tr>
<tr>
<td>Current $I_0$ (A)</td>
<td>45</td>
</tr>
<tr>
<td>Anode voltage $V_0$ (kV)</td>
<td>95</td>
</tr>
<tr>
<td>Modulating anode voltage $V_m$ (kV)</td>
<td>38.5</td>
</tr>
<tr>
<td>Magnetic field @ gun exit $B_0$ (T)</td>
<td>1.34</td>
</tr>
<tr>
<td>Magnetic compression ratio $f_m$</td>
<td>10.5</td>
</tr>
<tr>
<td>Velocity ratio $\alpha \left( \frac{v_{\text{pep}}}{v_{\text{para}}} \right)$</td>
<td>1.31</td>
</tr>
<tr>
<td>Transverse velocity spread $\Delta \beta_t$ (%)</td>
<td>2.31</td>
</tr>
<tr>
<td>Axial velocity spread $\Delta \beta_z$ (%)</td>
<td>4.09</td>
</tr>
<tr>
<td>Mean guiding center radius $r_{g0}$ (mm)</td>
<td>2.25</td>
</tr>
</tbody>
</table>

### Beam trajectories

([Graph of beam trajectories](#))
36GHz Gyroklystron

- Existing data from Strathclyde and UESTC
- The operating mode of input and buncher cavity is \( TE_{01} \). The mode of output cavity is \( TE_{02} \), to enable larger power capability.

<table>
<thead>
<tr>
<th>Structure</th>
<th>( f ) (GHz)</th>
<th>( Q )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavity 1</td>
<td>35.25</td>
<td>52.6</td>
</tr>
<tr>
<td>Cavity 2</td>
<td>34.58</td>
<td>23.5</td>
</tr>
<tr>
<td>Cavity 3</td>
<td>35.79</td>
<td>78.6</td>
</tr>
</tbody>
</table>

The normalized coupling coefficient as a function of the normalized size of beam radius.
48GHz Gyroklystron

- Suitable grid-size established by study of isolated cavities
  - Need to be precise in z and r directions, but can have fewer azimuthal divisions due to symmetry of modes
- Cavities are not isolated in the real device, so further fine-tuning of dimensions will be required
- To be followed by study of losses, Q-values, and power in each cavity
Cavity Study

• Isolated cavities and cavities attached to drift sections have been examined
• Gathered data which displays the reduction in eigenfrequency as either the dielectric constant or the thickness of the dielectric layer is increased
  – Using these results to adjust cavities toward desired frequencies
Preliminary results: TE01 mode in an example gyrokystron cavity ready for further design work to determine optimal frequency and properties.
Future Work

- Continue 48GHz cavity studies
  - Cavity frequencies, Q-Values, and positions
  - Beam-wave interaction
- Use results as the groundwork that guides the design and optimization of a 48GHz gyrokystron
- Ensure compatibility with power modulators and linearising cavity
Acknowledgement

This work is supported by the EPSRC with a partial contribution from the Cockcroft Institute, STFC, UK. This work is supported by the European Commission Horizon 2020 Project “CompactLight” (777431-XLS)

Thank you for your attention