DEVELOPMENT OF A HIGH-EFFICIENCY KLYSTRON BASED ON THE KLADISTRON PRINCIPLE

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1. CLIC and the Kladistron project

2. TH2166 klystron and the kladistron prototype design

3. TH2166 kladistron cavities development

4. TH2166 kladistron fabrication and testing
1. CLIC AND THE KLASTRON PROJECT
In this sub-task, CEA will develop and search for innovative concepts of X band RF power sources and components. The objective is to propose affordable and reliable solutions for future testing capabilities for the CLIC accelerating structures. The task includes the design and the fabrication of prototype RF devices to demonstrate the feasibility of the new concepts proposed. 

Budget available to build a (small) part of the RF power source or component

Collaboration with THALES ELECTRON DEVICES:
PhD funding: 50% CEA/50% Thales (Contrat de Thèse CEA Industrie)
Co-supervision:
Juliette Plouin/Franck Peauger/Claude Marchand @ CEA
Armel Beunas/Rodolphe Marchesin @ Thales

Collaboration with CERN: Igor Syratchev, Walter Wuensch…
MAGIC bought by CEA with “contribution exceptionnelle de la France au CERN”

Activity fully oriented towards R&D
Kladistron (Kl-adi(adiabatic)-stron) is a high-efficiency klystron with a large number of cavities (at least twice as many as in a classical klystron).

A Kladistron requires a high-efficiency klystron with a large number of cavities (at least twice as many as in a classical klystron).

CLIC Project needs a 12GHz-high-efficiency klystron, with a microperveance of 1.5 A.V^-3/2. Our preliminary AJDisk results show a higher efficiency than what we can expect from a klystron with such a high microperveance.

20 cavities – 12GHz
μP = 1.5 A.V^-3/2
Efficiency 78% (AJDisk simulation)
Length 285 mm
KLADISTRON AND CLASSICAL KLYSTRONS

Klystron Efficiency vs. Perveance

12GHz « KLADISTRON »

4.9GHz « KLADISTRON »
(technical demonstration)

$k_{\mu} = \frac{1}{\sqrt{V_3/2}}$

Fig. 1 The empirical relation of efficiency to the perveance.

2. TH2166 KLYSTRON AND THE KLADISTRON PROTOTYPE
TH2166 klystron was designed by Thales electron devices (TED) for Mainz Microtron.

<table>
<thead>
<tr>
<th>Features</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>4.9 GHz</td>
</tr>
<tr>
<td>Output power</td>
<td>56 kW</td>
</tr>
<tr>
<td>Efficiency</td>
<td>50%</td>
</tr>
<tr>
<td>Ibeam</td>
<td>4.3 A</td>
</tr>
<tr>
<td>Vk</td>
<td>26 kV</td>
</tr>
<tr>
<td>µP</td>
<td>1.066</td>
</tr>
<tr>
<td>Number of cavities</td>
<td>6</td>
</tr>
<tr>
<td>Interaction line length</td>
<td>233mm</td>
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</tbody>
</table>

This klystron will be modified to verify the kladistron principle.
The design we are looking for would let us:

- Use the TH2166 klystron test and conditioning bench
  - Total interaction line length of 233mm, same input and output cavities, same solenoid

- Use the TH2166 klystron electron gun and collector
  - Same microperveance of 1μA.V^(-3/2)

- Check the kladistron principle
  - More than 6 cavities

- Avoid cavities coupling
  - Drift space between cavities larger than 9mm

- Avoid gain peaks
  - Low coupling cavities (low R/Q and Q0 values)
Our kladistron simulation results reach an efficiency of six points above TH2166 simulation results. The electron bunching and the beam current growth are also smoother.
3. TH2166 Kladistron Cavities Development
According to our COMSOL simulations, these low-coupling cavities are fit for smooth electron bunching.
FREQUENCY SHIFT: A RELIABLE TUNING SYSTEM IS REQUIRED

For each computation we shift the frequency of one of the cavities. Kladistron efficiency is sensitive to its cavities frequency shifts, especially at the end of the interaction line.

The cavities fabrication must also be accurate: a 1-µm error might induce a 2.5MHz frequency-shift (COMSOL).

\[ \Delta f / \Delta z\text{gap} \approx 2.5\text{MHz/µm} \]

\[ \Delta z\text{gap} \approx -4\mu m \]
The tuning system we designed is inspired by CLIC accelerating cavities design: a thigh copper membrane is misshaped to adjust cavities frequencies. This strain is controlled by an accurate screw thread.

Although the airtightness had been preserved during our tests, the pin's thread had been broken. The tuning system assembling is too rigid and the extra mechanical stress is reported on the screw thread.
We then removed one of the bronze bearing to make the assembling more flexible. We tested our tuning system on two complete cycles (+4/-8 screw revolutions). Despite the hysteresis induced by the assembling modification, the overall frequency shift after two complete cycles is negligible. **We validate our tuning system design.**
Our preliminary Musicc3D (CNRS code) simulations demonstrated that we would face multipactor phenomenon in our cavities’ gaps. We then designed new asymmetrical cavities to apply a titanium layer.

The graph on the left is the number of charges generated in the cavity’s gap, in a Musicc3D simulation: an electron is sent from a chosen area; an electric field with a given phase and amplitude is applied on the charge. The simulation stops after the 20th electron impact, if it has not been absorbed by the material.

Without titanium, a single electron in an electric field of 2MV/m can extract up to $10^6$ charges in the cavity’s gap. With a titanium layer, the maximum number of charges extracted drops to 60.
We designed and ordered 6 prototype cavities to test our titanium deposition method. The “flat” parts (Ti1 to Ti6) have a 0.1mm deflection for the titanium deposition. We have cut and brazed titanium discs on these parts. The “flat” and the “concave” parts are assembled to form a cavity to test.

The titanium sheet had been misshaped during the brazing process therefore the frequency shift is below our expectations. Although these pieces are being machined to fit the drawings dimensions, we are also working on the improvement of this brazing process to guarantee the adequate cavity geometry.
4. TH2166 KLADISTRON FABRICATION AND TESTING
These elements have already been delivered.
The company VDL (Netherland) won the call for tenders and will machine the pieces of the interaction line and the tuning system. We expect the pieces to be delivered by the end of the month.

Assembling and brazing operations and the kladistrion tests will stand at Thales Electron Devices Vélizy. We are working on the assembling, brazing and test procedure.
CONCLUSION AND OUTLOOK

✓ Tuning systems and titanium deposition method tested

✓ TH2166 kladistrong’s cavities fabrication almost finished

➢ Assembling, tuning and test procedure validation

☐ TH2166 Kladistrong to be assembled and tested in April, May and June.
Thank you for your attention