# Impedance Characteristic Analysis and Matching Network Design for a 100 mA $H^-$ Ion Source

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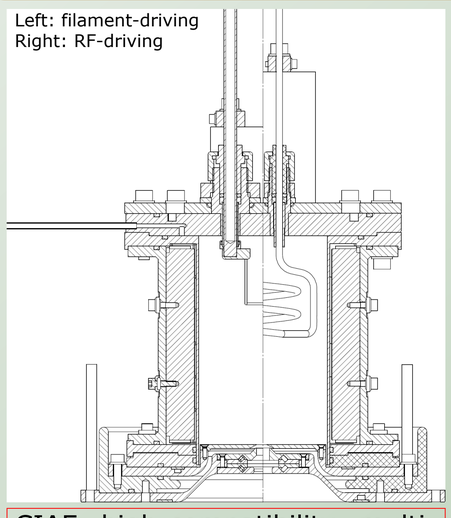
## Abstract

China Institute of Atomic Energy (CIAE) has developed a series of multi-cusp $H^-$ ion sources (IS) with DC beam intensity ranging from 3 to 18 mA for different applications. Most of them aim for high intensity proton cyclotron uses such as cyclotron PET application, neutron source and boron neutron capture therapy (BNCT) facilities. Based on previous experiences of $H^-$ ion sources, a new project of radio frequency (RF) antenna driving ion source has been launched for pulse accelerator research. This new ion source is expected to provide more than 100 mA peak intensity $H^-$ beams of 60 keV and a longer maintenance interval than conventional filament-driving ion sources mentioned above. Impedance matching is indispensable for RF power coupling in plasma igniting, simmering, and large volume hydrogen plasma generation for high intensity $H^-$ beam extraction. In this paper, impedance characteristic of the IS antenna with various plasma loading is analyzed for matching network design. Eight typical matching network topologies are discussed on their electrical requirements. Type-L and type-γ networks are finally selected for the plasma generating 2 MHz RF chain and the plasma excitation 13.56 MHz chain respectively. This design may provide a better compromise between the matching performance and the cost of implementation for a wide dynamic loading range. Each of the networks would be isolated by a transformer as the ion source and its antenna are to be placed on a negative high-voltage platform for $H^-$ extraction. Design of the whole matching network is evaluated on the power delivering efficiency in each of the two RF chains and isolation between one and the other. The ion source structure and near-future work plan are also presented.

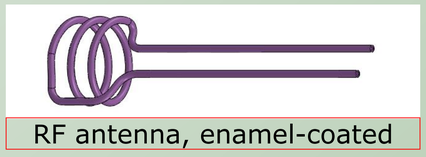
## Design of the RF-driving ion source




CIAE high-compatibility multi-cusp ion source test-bench

- **Internal antenna design**

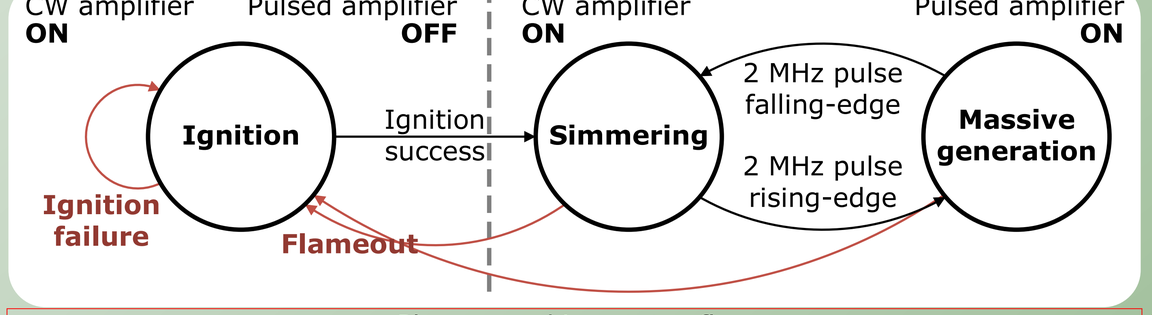
  Longer life-time expected:
  >50 hours immersed in plasma



RF antenna, enamel-coated

- **Dual RF driving chains**

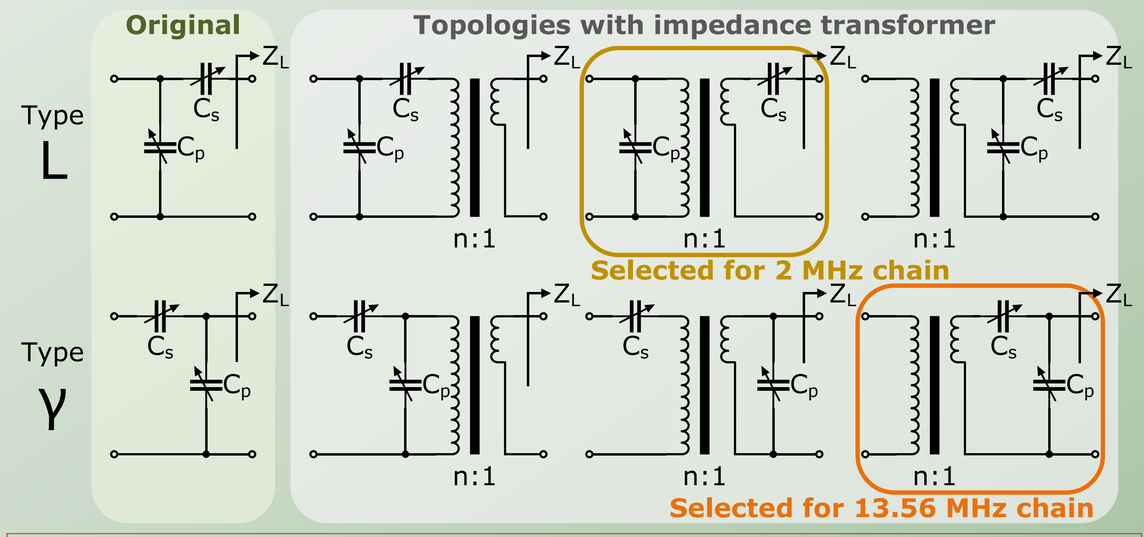
  **500 W 13.56 MHz**: to ignite plasma and to keep it simmering.
  **80 kW 2 MHz**: to generate massive hydrogen plasma for high intensity $H^-$ extraction.




Plasma working states flow

## Matching network topologies

- **Eight dual-capacitor matching network compared**




Eight only 2-port network topologies that one can obtain by two capacitors and one or none transformer. Each network is evaluated on the requirements of capacitance and RF voltage and current endurance in each of the two chains

- **Proper series inductor extends the matching-range**

## Impedance characteristic

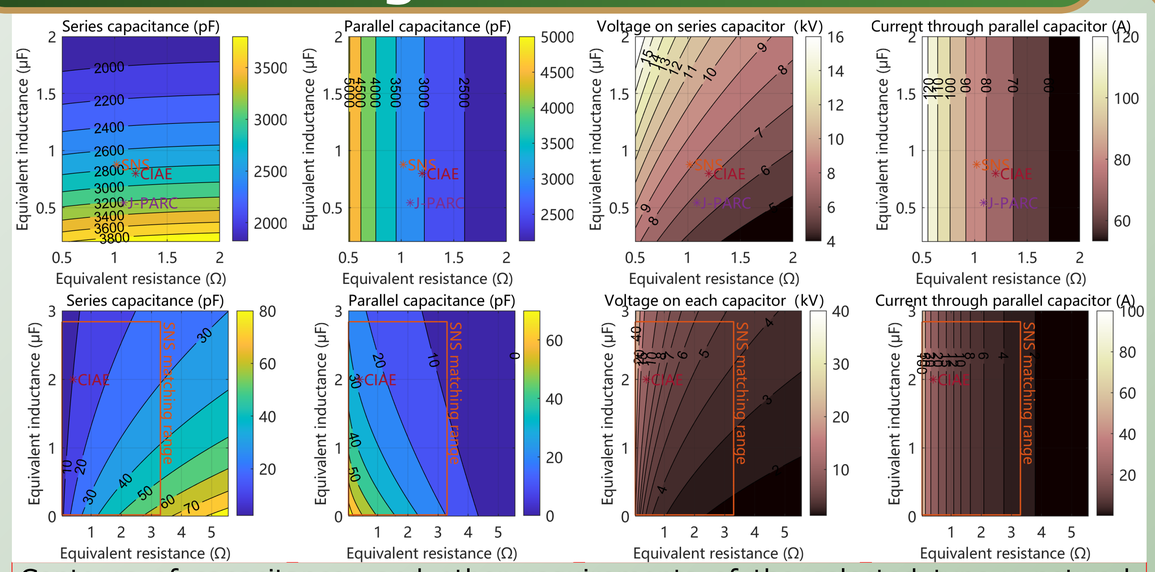
- **Equivalent resistance and inductance increases and decreases respectively as hydrogen plasma raises**

*Table: Equivalent resistance and inductance for pulsed ICP $H^-$ ion sources*

| Project | $H^-$ beam parameters | | | RF power supply | | Antenna impedance | |
|---|---|---|---|---|---|---|---|
| | Peak current | Pulse width | Repeat freq. | Frequency | Power | Equivalent resistance | Equivalent inductance |
| **CIAE** | 100 mA | 0.5 ms | 50 Hz | 13.56 MHz<br>2 MHz | 500 W<br>80 kW | ~0.4 Ω<br>~1.2 Ω | ~2 μH<br>~0.8 μH |
| **ORNL SNS** | 50 mA | 1.0 ms | 60 Hz | 13.56 MHz<br>2 MHz | 300 W<br>55 kW | 0.03~3.3 Ω<br>~1.02 Ω | 0.02~2.8 μH<br>0.878 μH |
| **J-PARC** | 60 mA | 0.5 ms | 25 Hz | 30 MHz<br>2 MHz | 60 W<br>38 kW | 7.611 Ω<br>1.085 Ω | 0.6226 μH<br>0.5428 μH |
| **IHEP CSNS** | 20 mA | 0.5 ms | 25 Hz | 2 MHz | 37.5 kW | 2.2 Ω | - |
| **LINAC4** | 80 mA | 2.0 ms | 50 Hz | 2 MHz | 75 kW | 2.2~2.6 Ω | 1.77~2.1 μH |

- **Coverage capability of large impedance range**
  **2 MHz pulsed chain**: 0.5~2 Ω and 0.2~2 μH
  **13.56 MHz chain**: 0.03~5.56 Ω and nearly any μH

## Network design and evaluation




Contours of capacitances and other requirements of the selected type-γ network (bottom) and the transformer inserted type-L one (top) for 13.56 and 2 MHz chain




Dual-chain network designed in this work




S21 for 13.56 MHz chain and S21, S31 for the whole network

## Conclusion

In the project of a RF-driving 100 mA $H^-$ ion source, a dual-channel impedance matching network is designed to realize a matching coverage of large impedance range. Evaluations show that such a structure provides a balance between its matching performance and the cost of implementation. LTspice XVII simulation proves the network's feasibility, and indicates that proper modulation helps to improve the generating efficiency of RF driven hydrogen plasma.