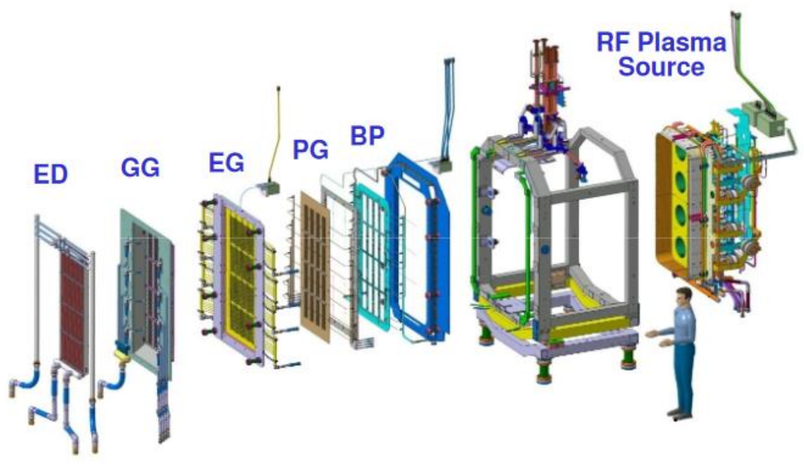
Techniques to widen the operational space of SPIDER Radio Frequency driven plasma source

R. Casagrande[1,2], M. Dan[1], A. Maistrello[1]

[1]Consorzio RFX, Corso Stati Uniti 4, I-35127 Padova, Italy
[2]Department of Applied Physics, Ghent University, 9000 Gent, Belgium

Corresponding author: riccardo.casagrande@igi.cnr.it

SPIDER Source for the Production of Ions of Deuterium Extracted from RF plasma



ITER Neutral Beam Injector ion source Full scale prototype

Main characteristics
- 4 RF oscillators rated for **200 kW** | **0,9÷1,1 MHz**
- 8 RF drivers rated for **100 kW**
- Acceleration voltage up to **96 kV**
- Extraction voltage up to **12 kV**
- Total beam current up to **70 A**
- Source nominal pressure **0,3 Pa**

SPIDER EARLY OPERATIONAL ISSUES

- **RF SYSTEM**
- **Ignition at low pressure** → FOCUS ON THESE TWO PROBLEMS
- Pumping system
- Breakdown immunity

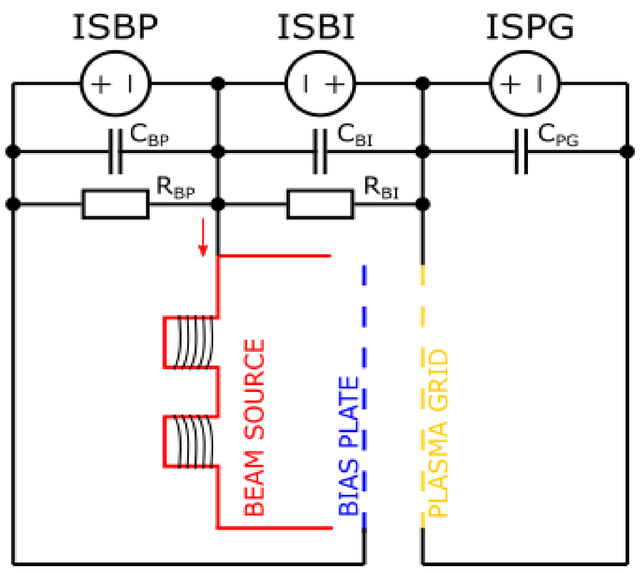
AIM OF THE WORK

Improving the reliability of SPIDER in a broad range of operational conditions

PLASMA IGNITION

The beam source is polarized with respect to:
- Bias plate → with ISBP
- Plasma grid → with ISBI

ISBI, ISBP, ISPG power supplies
- All Share the same topology (resonant switching PS)
- Large output filter (3 mF)



IGNITION WITH ISBI, ISBP FLOATING

n_e, T_e of plasma in contact with beam source **>** n_e, T_e of plasma in contact with plasma grid (or bias plate)

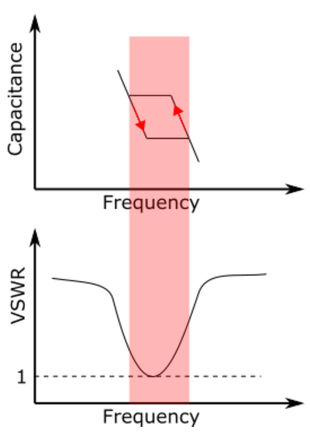
- Voltages across ISBI and ISBP reach an equilibrium
- Long charging transient of the PS output filters
- During this transient, electrons from the beam source plasma are lost → plasma switches off in some circumstances (low p)

IGNITION WITH PRE-BIAS ON ISBI, ISBP

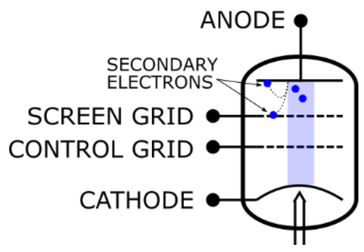
Biasing at foreseen equilibrium voltage →
- Charging transient of PS output filters is avoided
- No significant loss of electrons from plasma
- Ignition is facilitated at p ≤ 0,3 Pa

RF SYSTEM LIMITATIONS

FREQUENCY FLIP



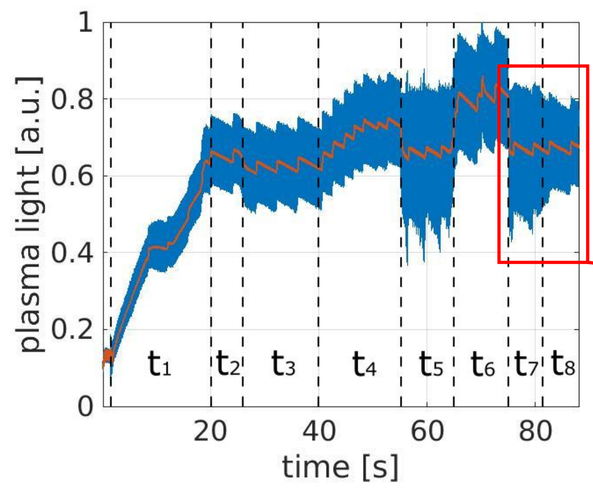
Forbidden frequency band
- Oscillators work in mismatched conditions
- Even at reduced power, high anode and screen grid voltages are required



UNSTABLE PLASMA

Higher chances to trigger the protection system of the screen grid power supply

RF LOAD STABILITY

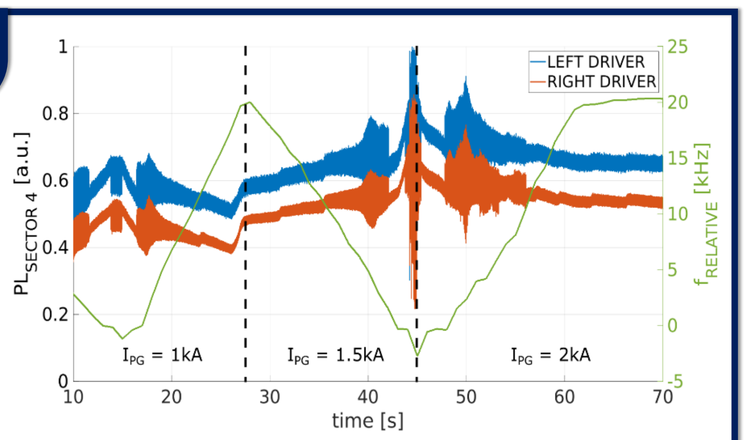


Effect of operational parameters on plasma oscillations
- t2,t3 → PG current ↑
- t4 → p ↑
- t5 → PG current ↑
- t6 → ISBI-ISBP on
- **t7,t8 → f_{REL}* ↑**

*relative frequency between two adjacent oscillators

OSCILLATORS RELIABILITY

Selection of working frequencies
- Relative frequency scan is performed for adjacent RF drivers (higher coupling)
- Unstable regions in proximity of frequency locking and frequency locking are avoided



REDUCED PLASMA OSCILLATIONS → **IMPROVED RELIABILITY OF 4 OSCILLATORS OPERATING SIMULTANEOUSLY**

TRADE-OFF
- The single oscillators are not optimized, so the limit power cannot be reached
- The overall performance at high power with 4 oscillators (4x100 kW) is greatly improved → protection system of the screen grid power supply is not triggered

CONCLUSION

- **We identified two strategies to improve the reliability of SPIDER plasma ignition and steady-state operation in a broad range of working parameters**
- **Plasma ignition at pressures below 0.3 Pa is facilitated by pre-biasing ISBI and ISBP**
- **4 oscillators can operate reliably up to 4x110 kW if the working frequencies are chosen to reduce plasma oscillations**