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ITER……

Technology development at Cadarache

The CEA program for the development of the ITER IC system

- **CEA has responded, as other EU Associations, to the EU-EFDA call for proposals for the procurement of the ITER ICH system.**
- **A development taking place in the framework of a collaboration among EU Associations and other interested Parties is proposed (CCFW 31, Brussels and CCFW3, Culham).**
- **The development covers the time period of EU FP6 and FP7.**
  - **Phase 1: years 2002-2003 - selection of the design options;**
  - **Phase 2: years 2003-2007 (FPVI) - development of ITER system,**
  - **Phase 3: years 2007-2011 (FPVII) - procurement of ITER system.**
- **The development is aimed at the validation and, where necessary, at the improvement of ITER IC system design, assumed as reference.**

Operational issues of ITER IC system

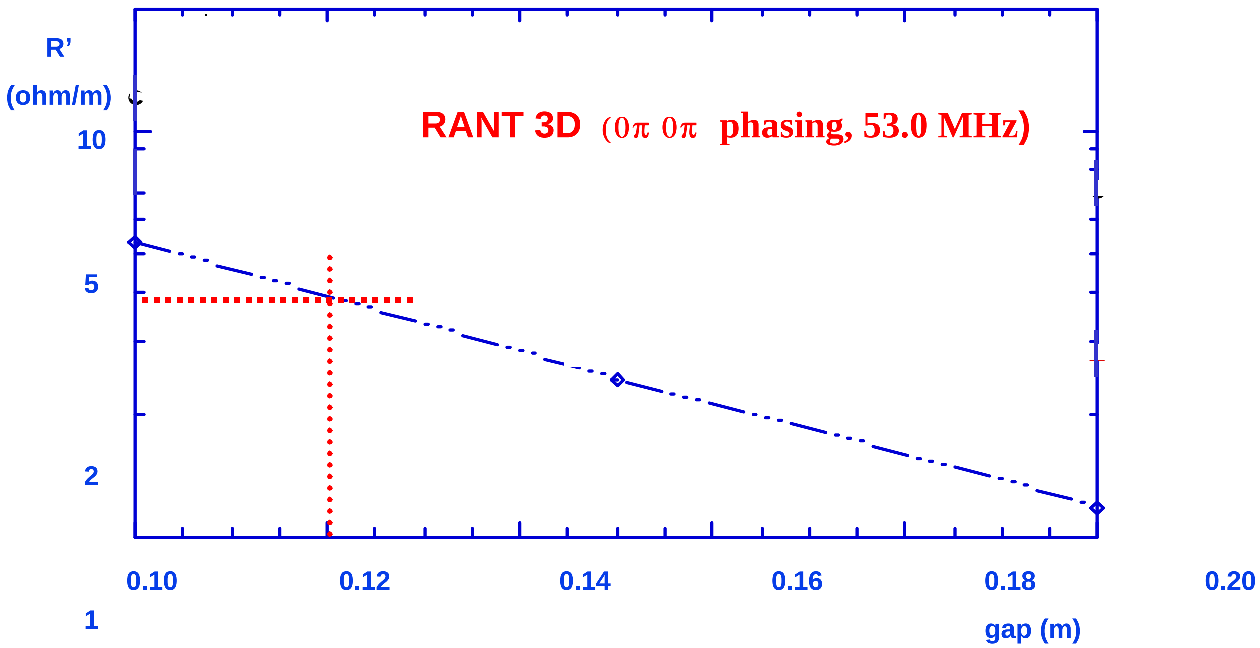
ITER IC antenna is likely to operate in more difficult conditions than in the present machines

Foreseeable *Antenna issues:*

- **Low coupling & high power density**
  - ***High RF voltage operation*** ⇐ **AU, JET, TS**
- **Operation in presence of ELMs**
  - ***Tolerance to load variations*** ⇐ **JET, AU**
- **Long pulse operation** ⇐ **TS**
  - ***Power losses in the plasma edge***

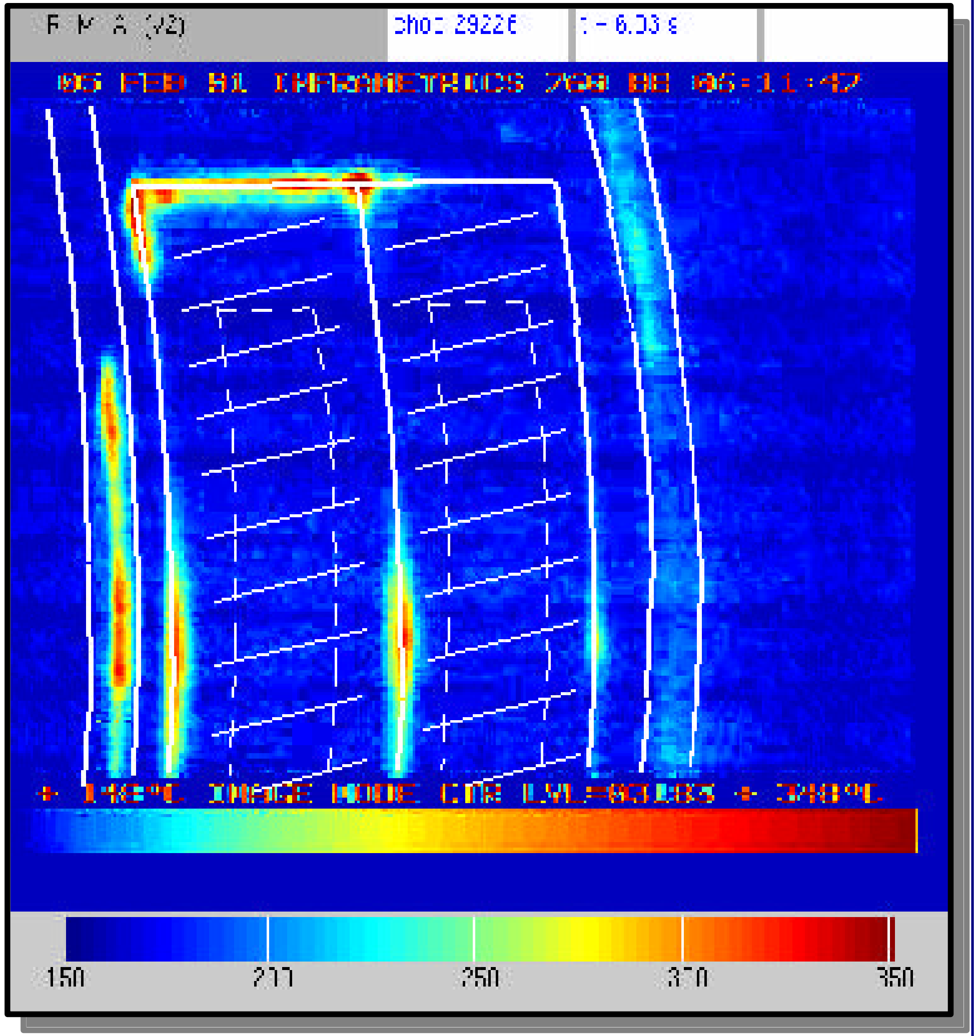
ICH coupling in ITER

- At nominal antenna loading (R' = 4 Ω/m) the antenna is designed for $E_{max} < 2$ kV/mm.
- However, there is no guarantee that the ITER IC array will actually operate at the reference conditions



ICH power dissipation in the edge

- **A significant fraction of the ICH power is lost in the plasma edge and could be responsible for experimentally observed local effects of ion acceleration, wall loading and production of metal impurities.**
- **The formation of rectified RF sheaths is a probable reason for these losses**
- **The sheath voltage is dependent on the strap current.**
- In ITER long pulse these effects can produce a local wall loading significantly higher than plasma radiation load.



Technical issues related to ITER IC system

- Antenna geometry optimization
  - *Array optimisation (low power test stand & 3D modelling)*
- Tuning
  - *CEA proposal : In-vessel capacitive reactance with hydraulic drive*
- Development and test of high power components
  - *Window….., transmission and/or tuning components,*
- RF monitoring for matching control and arc protection
  - *Low/high power test stand & plasma operation*
- Arc detection & protection
  - *Plasma operation*

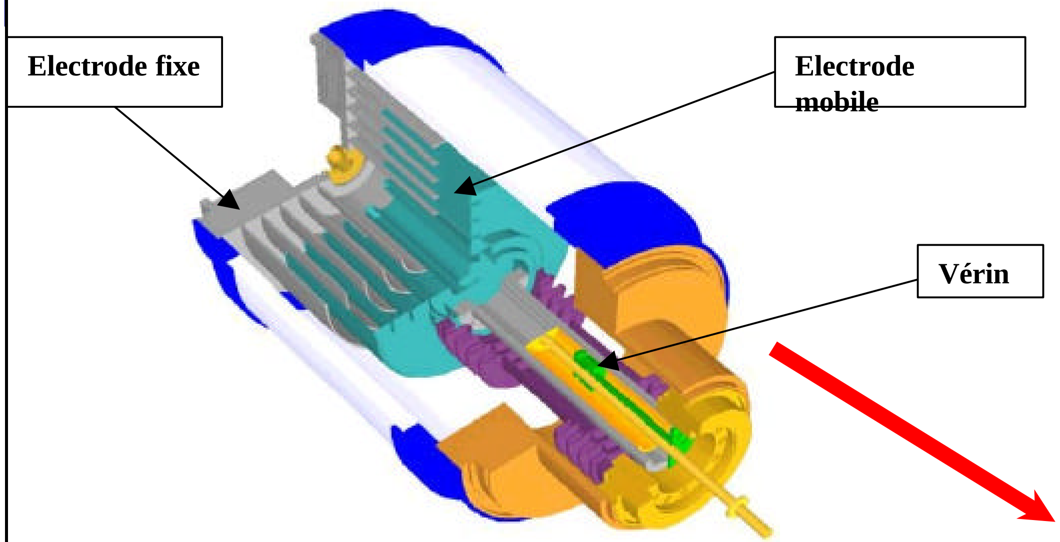
Tuning

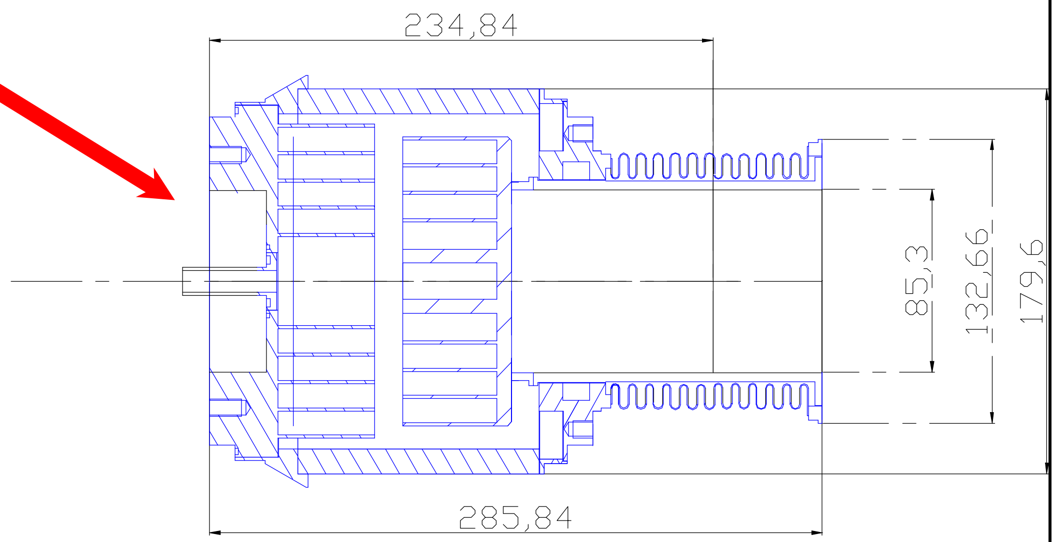
A comparative analysis based on experimental tests of different types of tuning components has shown that coaxial capacitors of the COMET type are the most appropriate device as starting point for the development of a tuning component applicable to ITER.

- Existing capacitors fall short from meeting all ITER antenna V/I specification.
- CEA proposes a tuning system integrated with the antenna and located in the vacuum vessel and intends to start a development for the upgrade of a coaxial vacuum capacitor to ITER specifications.
- Improvements include: construction materials, water cooling, hydraulic drive stress relieve of ceramic components from thermal and disruption loads, and (possibly) external getter pumping of the private vacuum.

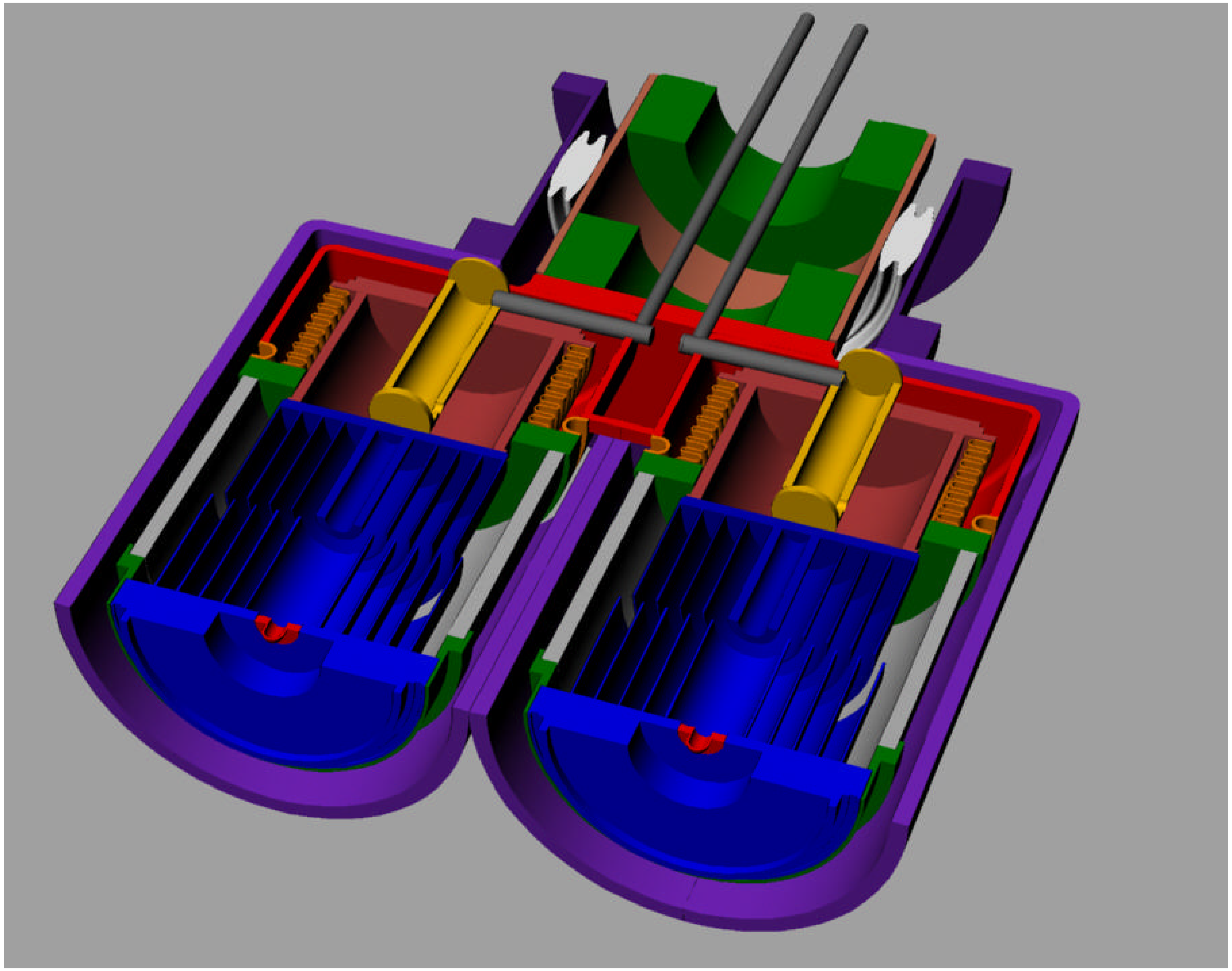
Evolution of vacuum coaxial capacitors

The voltage stand-off of vacuum coaxial capacitors exceeds 10 kV/mm

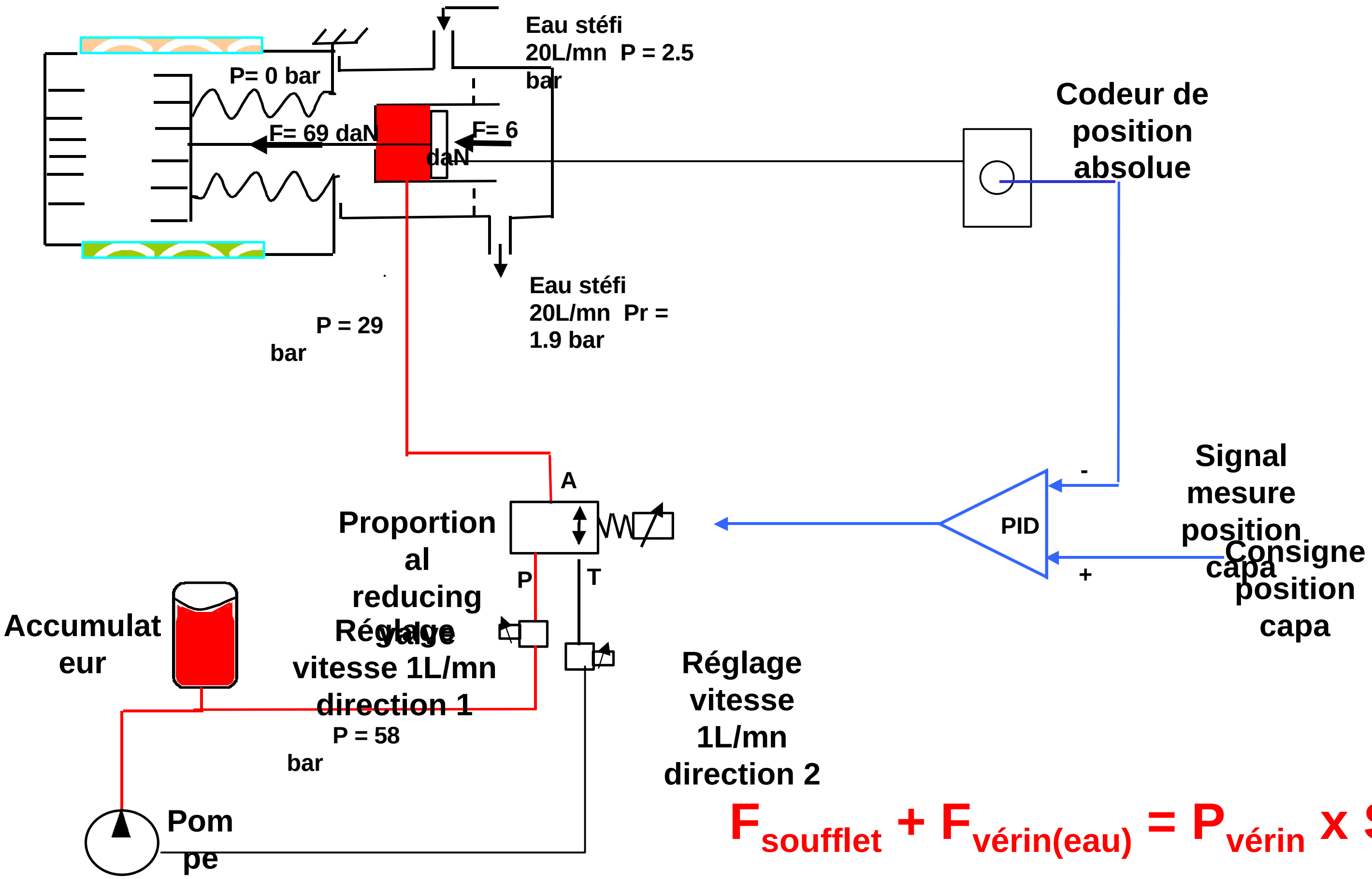




Integrated tuning system



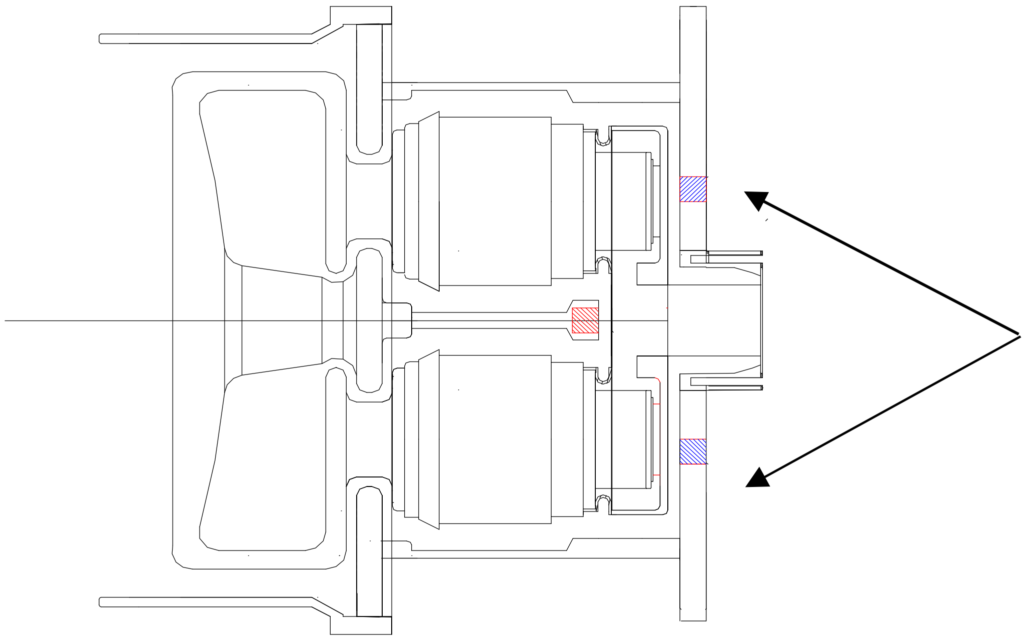
Control loop for hydraulic drive



$$F_{soufflet} + F_{vérin(eau)} = P_{vérin} \times S_{utile\ vérin}$$

Vectorial wave monitoring for match control and arc protection

Admittance measurement on both antenna branches



Current & voltage probes

Matching control algorithm

Solves implicitly

$$Im\ Y_1 + ImY_2 = 0$$

and

$$Re\ Y_1 + ReY_2 = 1/Z_0$$

by means of two coupled feedback loops, each acting on one capacitors

The loops are decoupled by different time constants, so that one is actually tracking the other

The antenna can be dynamically matched against resistive and reactive load changes

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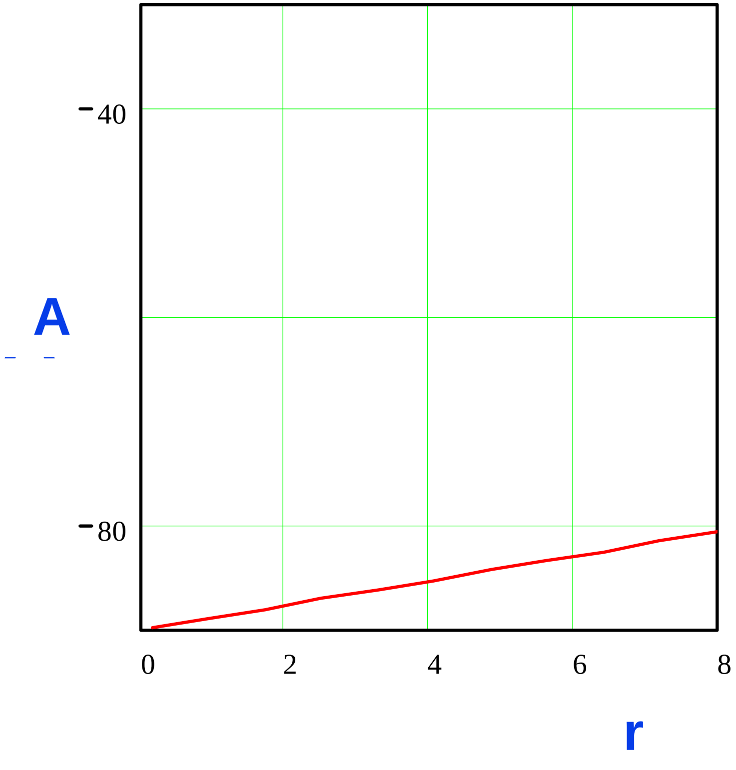
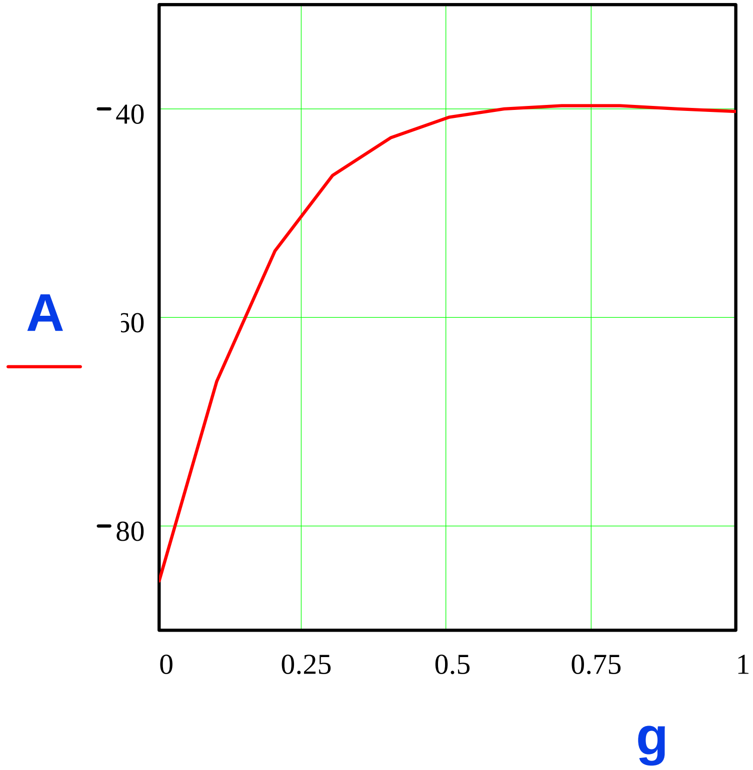
Arc detection by admittance and unbalance measurement

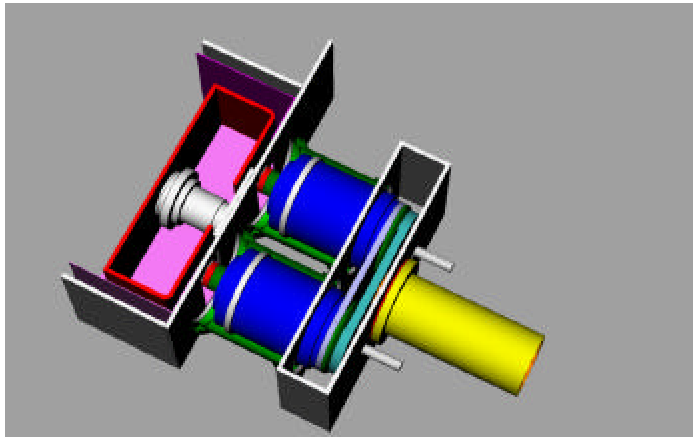




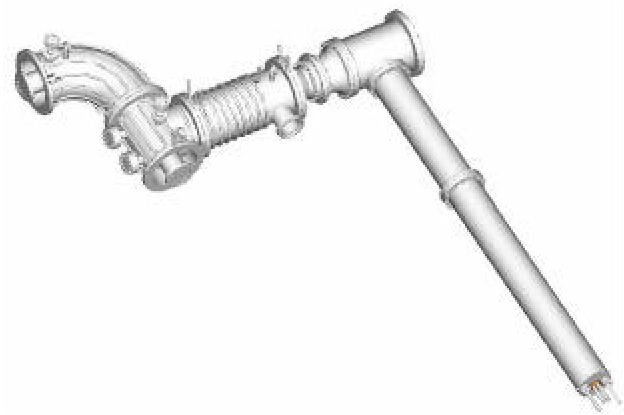
A = arg [Im(Y_{str})/Re(Y_{str})] r = strap series resistance g = strap parallel conductance

CEA existing test facilities

Maquette ITER-like



HP CW test stand



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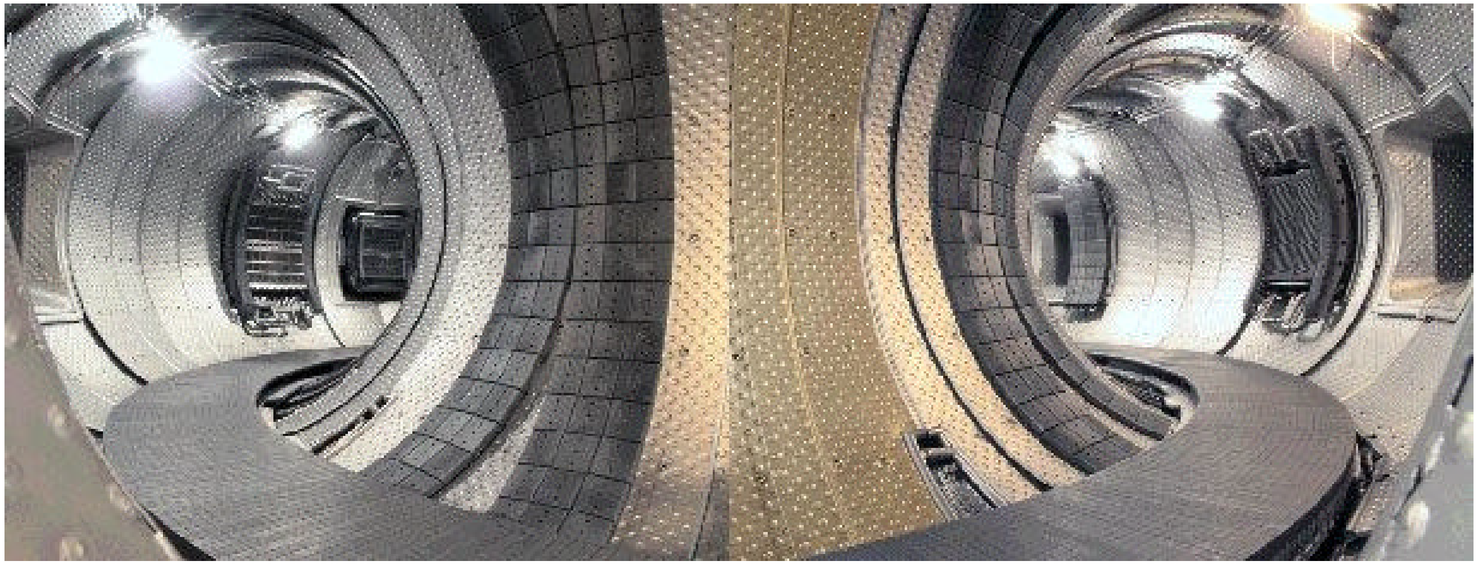

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Development of an ITER like CW RF source

- Ion Cyclotron (IC) heating and current drive requires a RF power source capable of an efficient, continuous operation for future experiments in existing machines and for ITER operation.

- According to ITER specifications, the RF source should be capable of:

  - ***providing a continuous output power (CW) at ~ 2-2.5 MW power level, depending on operating conditions ;***
  - ***accepting a high level of transient reflected power, with infrequent protective actions;***
  - ***automatically recovering from a power trip to normal operation.***

- No existing RF source features the above requirements.

- It would be both a technical and a financial advantage if one single IC source covering all requirements could be developed in EU.

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Project Milestones

- 1999-2000 . A ITER-NET study contract for an ITER IC power source placed
- Oct 2000 . A proposal for the development of the new RF source . . . was presented to the EU CCFW.

A technical sub-group tasked to write the RF source technical specifications, starting from ITER RF source design study and ITER procurement specifications and to agree them among EU Fusion program associated laboratories, so as to have a single development.

- Jun 2001 Application for EFDA Art. 7 support in FP6
- Mar 2002 Development approved by EFDA Steering Committee
- Aug 2002 RF source specifications ready
- Oct 2002 EFDA/CEA TW3-THHI-GTFDS1 contract signed
- Jan 2003 First TW3-THHI-GTFDS1 contract progress meeting

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RF Power Source technical specifications

1	Nominal CW power output and operation at SWR=1.5 any phase SWR =2.0 any phase	2.5 MW, CW 2.0 MW, CW
3	Frequency range covered (in bands of 2 MHz)	25-80 MHz **
4	Frequency deviation over any central frequency (sinus) –1dB break point	±1 MHz
5	Max FM frequency (sinus)	1.0 kHz
6	Power modulation range	0.002 -2.5MW**
7	Max. AM frequency (sinus)	100 Hz
8	Phase regulation (respect to a fixed reference (any frequency)	±5 deg
9	Max. phase modulating frequency (sinus)	10 kHz
10	Electrical efficiency	> 65%
11	Emergency power cut-off (arc protection) response	< 10 μs
12	Coolant maximum input pressure (Bar)***	6.0
13	Pressure drop in coolant loop (Bar)***	3.5
14	Maximum coolant inlet temperature (deg C)	40
15	Maximum temperature outlet (deg C)	70

RF source development program - 1

- The NET industrial study for the ITER RF source indicates that no tube existing in EU specifications can fulfill ITER specification.

- The use of a two tubes end stage was imposed in the specifications and analyzed in detail in the study, with the conclusion that it would be technically feasible, but not desirable on both technical and financial point of views.
- The upgrade of an existing Diacrode® tube to a “Fusion Diacrode” was recommended.
- Contract stages :
- 1) Fusion Diacrode Assembly
- 2) FDA Driving stages
- 3) HVDC power supply

Fusion Diacrode Assembly

1. The development of a "Fusion Diacrode Assembly ", will take place in 2003 - 2004.
2. It includes the tube, cavities, grid and filament supplies (end stage). It is meant to be driven by by an existing power source (200 kW).
3. The assembly will be used to test the tube to full performance in the factory and in a dedicated test stand that CEA will construct in Cadarache within the scope of EFDA/CEA TW3-THHI-GTFDS1 contract.
4. The test stand will include 2.5 MW, 30 Ω, CW test load and mismatch equipment (also to be procured by CEA) needed to perform all FDA acceptance tests.
5. The driving stages of the FDA, including all monitoring and controls will be procured with a separate contract issued when the performance of the FDA will be demonstrated.
6. The Anode (driver and FDA) HVDC supply will be procured last.

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Conclusions

- A program of ICH technology development has started at CEA Cadarache, within the framework of the CIMES 2 Program
- As this development is ITER relevant, CEA has responded to the EU EFDA call for proposals for the ITER ICH system, with a technical proposal for both development and procurement, which should take place in the framework of a consortium of EU Associations and other interested Parties (CCFW 31, Brussels and CCFW3, Culham).
- A procurement of a CW 2.5 MW ITER IC power source started by EFDA
- These programs will cover two EU Framework programs (FP6 and FP7)