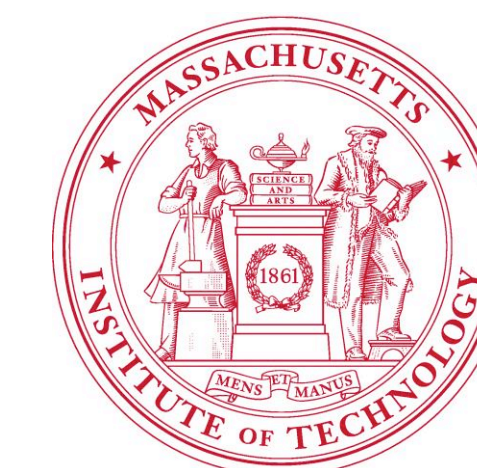# The ICRH System for the Ignitor Experiment

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Ignitor Project

ENEA Fusion Technologies **FUS-TEC**

Abstract

The ICRH system (80-120 MHz) is an important component of the Ignitor experiment as it provides the flexibility to reach ignition or nearly ignited regimes following different paths in parameter space and to shorten the time needed for this. The system is designed with a modular configuration and launches the power into the plasma through RF strap-antennas based on 4 straps per port. Each module consists of 4 high power generators whose power is split over two ports (8 straps). A 30 Ω vacuum transmission line transfers 0.4 MW of power per strap for a total power of 1.6 MW per port in order to keep the maximum electric field below 5 kV/cm in the vacuum region of the straps and transmission line. The RF configuration of the modules allows a full phase controls (toroidal and poloidal) of the straps though a PLL phase control. Two modules, involving 4 ports, produce 6 MW at 115 MHz for the envisioned RF "accelerated ignition" scenario. A detailed design of the ICRH antenna has been carried out, including the Faraday shield, the current straps, the vacuum transmission lines and the vacuum feed-through. Its integration of the antenna with the plasma chamber is underway. The mechanical assembly of the relevant components is fully detailed and ready for a prototype manufacturing of the VTL.

Evaluation of RF performance of plasma-facing components

Critical task for design: need dependable analysis tool

RF design based on performance evaluation obtained with the TOPICA© simulation suite (**TO**rino **P**olytechnic **I**on **C**yclotron **A**ntenna code)

Extensively tested: validated against commercial codes (in vacuo), ICANT and RANT3D (where applicable), against measurements of in-house and CEA mockups, against data in literature

TOPICA© simulation suite

- 3D antenna structure model (including FS, box)
- 1D plasma, non-homogeneous, FLR, absorption (FELICE code)
- Structure geometry drawn in CAD (e.g. Autocad®) and imported into TOPICA core
- Multi-port (typ.: 4 ports) circuit parameters (Z, Y, S matrices) calculation
- Coax, Voltage and current excitation of strap ports
- Accurate model of coaxial-to-strap feed
- Computes current, fields, and voltage everywhere around antenna and housing
- Boundary-element method, high efficiency, controllable convergence, affordable (yet important) CPU times (fastest guy in town…)

System specifications, constraints and input conditions

Main design requirements:
1. 8 to 16 MW generated
2. 4 to 6 ports allocated
3. 1-4 s RF pulse length
4. 16 x 80 cm access port dimensions
5. Withstanding of :
   - Specified thermal loads
   - Vertical Displacement Event (VDE) stresses
   - Specified neutron flux
6. Compliance with Remote Handling for assembly and maintenance
7. Variable frequency and multiple heating scenarios

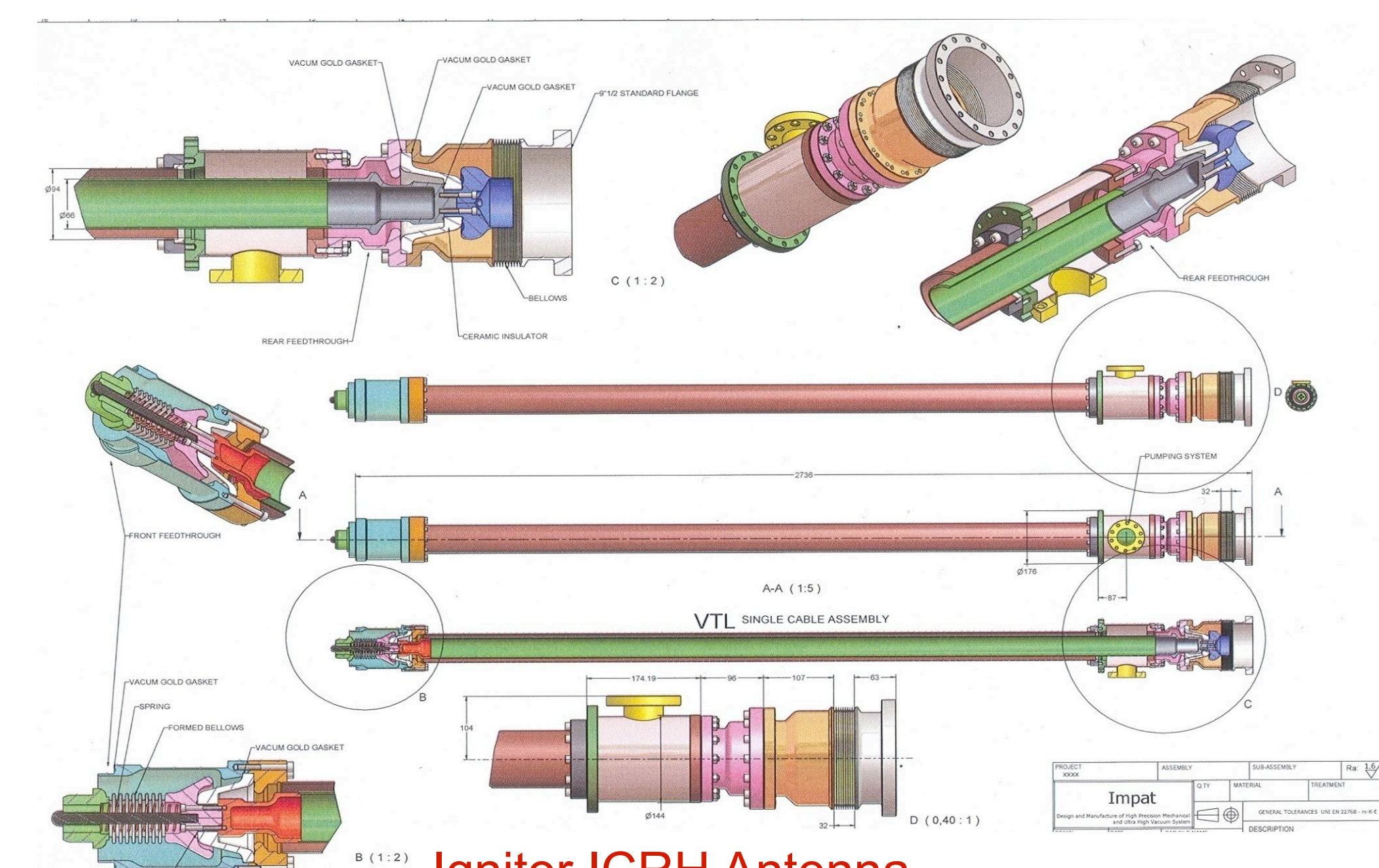## Optimal Heating Schemes for Ignition

- The RF system needs to operate on plasmas of different composition (D-T), with ramping magnetic fields (9 to 13 T) and plasma currents (6 to 11 MA). Flexibility is also required for other operational scenarios.

- The system can access a frequency range 80 <f< 120 MHz. The optimal results are obtained around 115 MHz ($2\Omega_{cT}$) and at power levels of 3 to 6 MW, coupled to the plasma by means of 2+2 strap antennas on 4(+2) ports of the machine.

- Different heating scenarios can be used during the magnetic field ramp:

1) at B= 9 - 10T the 2nd harmonic of D

2) at B>10T the 2nd harmonic of T (in this case the 2nd D harmonic is out of the plasma column while the 1st is on the high field side of the plasma column.

System Architecture

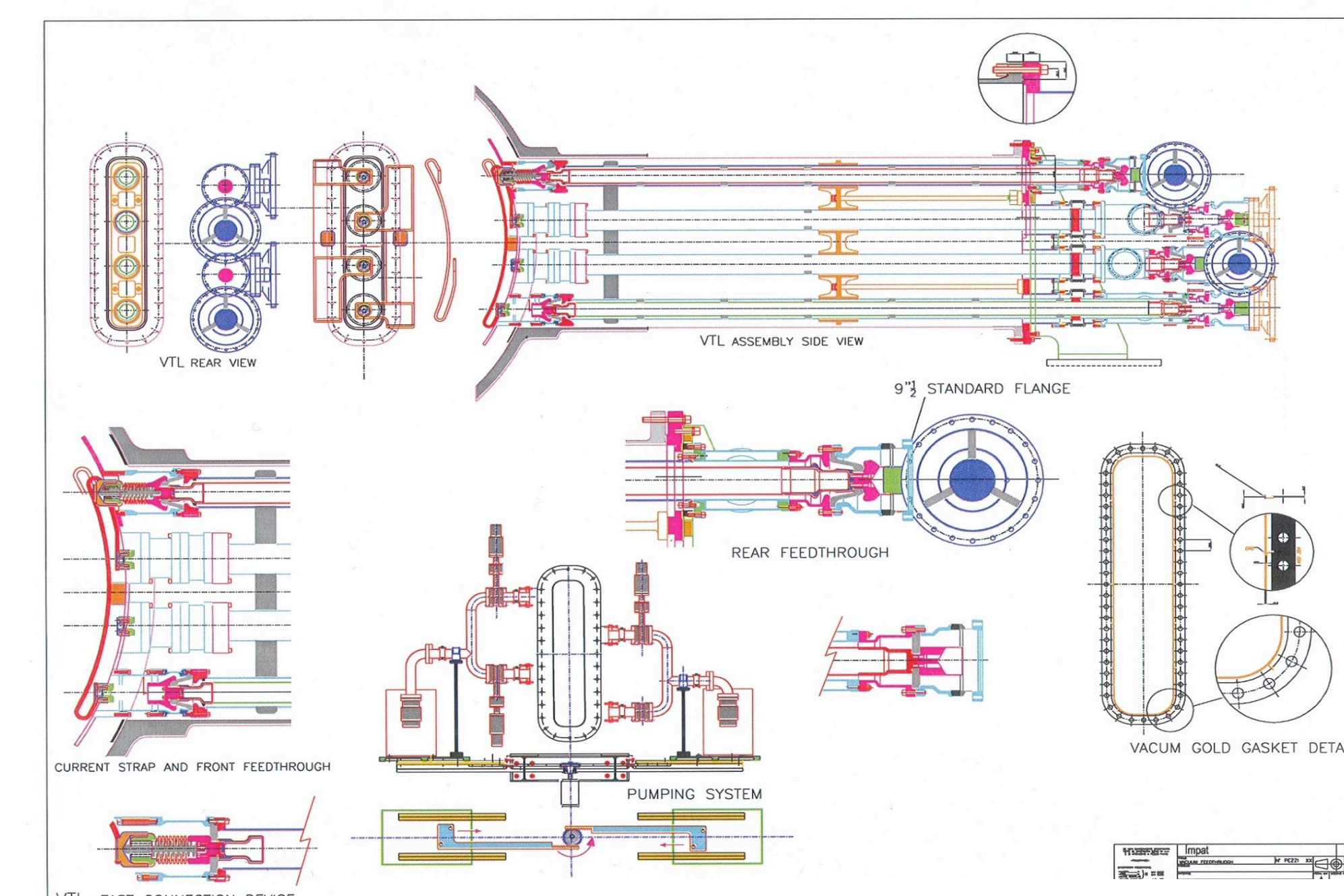The ICRH system has a modular configuration with the following performances per module:
- Operating Frequency Range   80 – 120 MHz
- Max RF Power @ 115 MHz   8 MW (generator)
- Max RF Power @ 80 MHz   6 MW
- Pulse Duration   4 s
- Generator Type: Cavity Coupled RF Tetrode
- Antenna Type   Four Strap
- Generators per Module (Strap)   4
- Antennas per Module   2

Main Electrical Scheme of Module
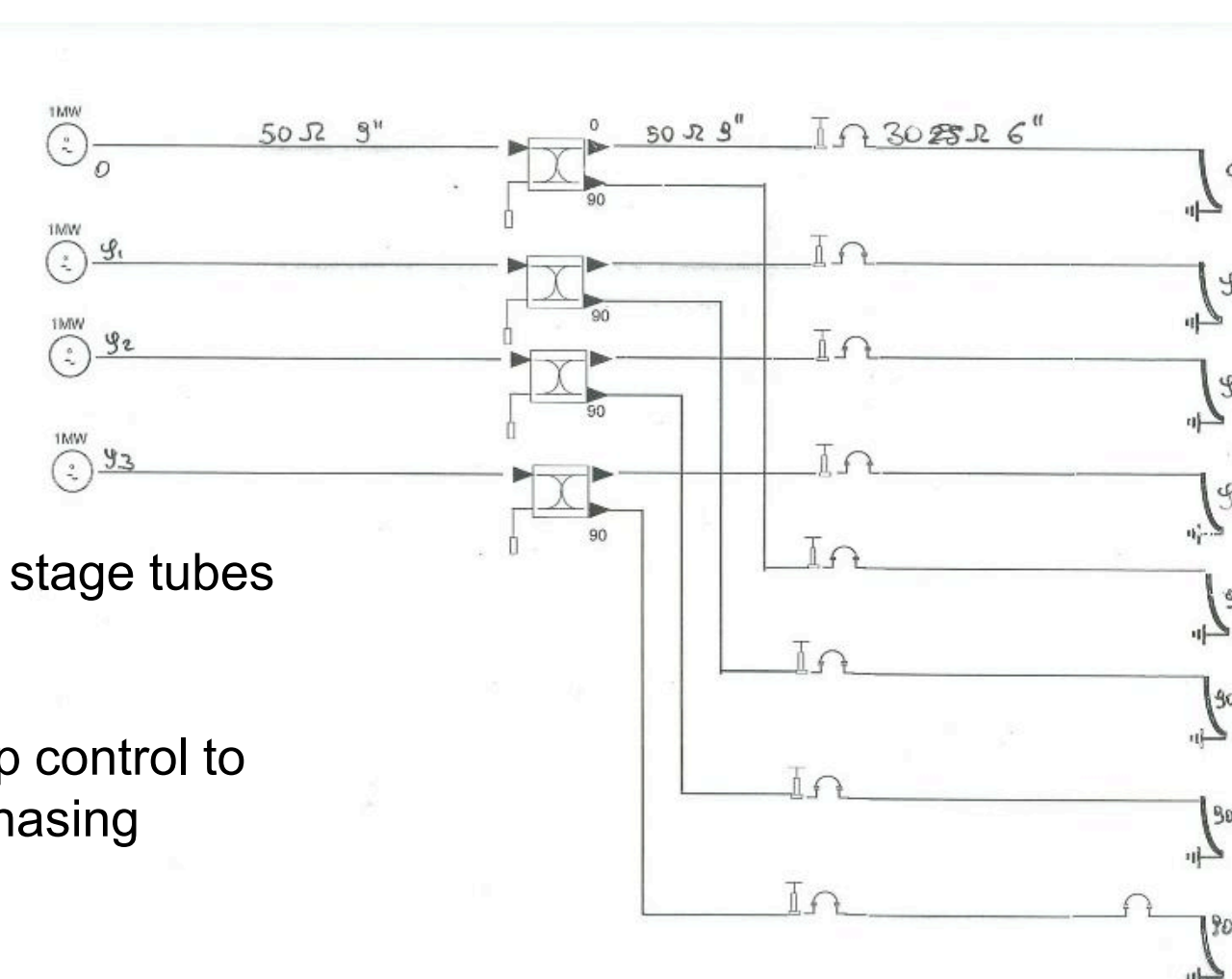
Generators
- 4 systems with Diacrode® final stage tubes
- Pmax = 2 MW at 80 MHz
- Phase-locking (PLL)
- Phase controlled by closed-loop control to enforce desired strap current phasing (overcome inter-strap coupling)

Vacuum Transmission Lines

- 50 Ohm
- External diameter: 155 mm
- inner conductor supports: ceramic disks
- with holes for vacuum pumping ("all-metal support" not feasible because of space constraints)

Coax (pressurized, 42psig) 50-Ohm lines
- Spinner 150-345
  Vmax > 100 kV
  Ø 355 mm
- Spinner 6 1/8"
  Vmax = 50 kV
  Ø 155 mm

Ignitor ICRH Antenna
Vacuum Transmission Line Components

Ignitor ICRH Antenna - VTL Preliminary Assembly

Development of a VTL prototype inclusive of the following components:

- #2 feedthroughs with conical geometry
- #2 feedthroughs with plane geometry, interchangable
- VTL joint; quick fastener between central conductor and strap (SPINNER –like solution); simulation of centering and flange clamping relative to the external vacuum vessel ground;
- Section of coaxial line (about 2.5 m) inclusive of vacuum flanges, separators etc.;
- #3 VTL mock-ups to complete the structure;
- Vacuum pumping station

A full size sector of the vacuum vessel with its horizontal port is available for testing of both VTL assembly and antenna straps.
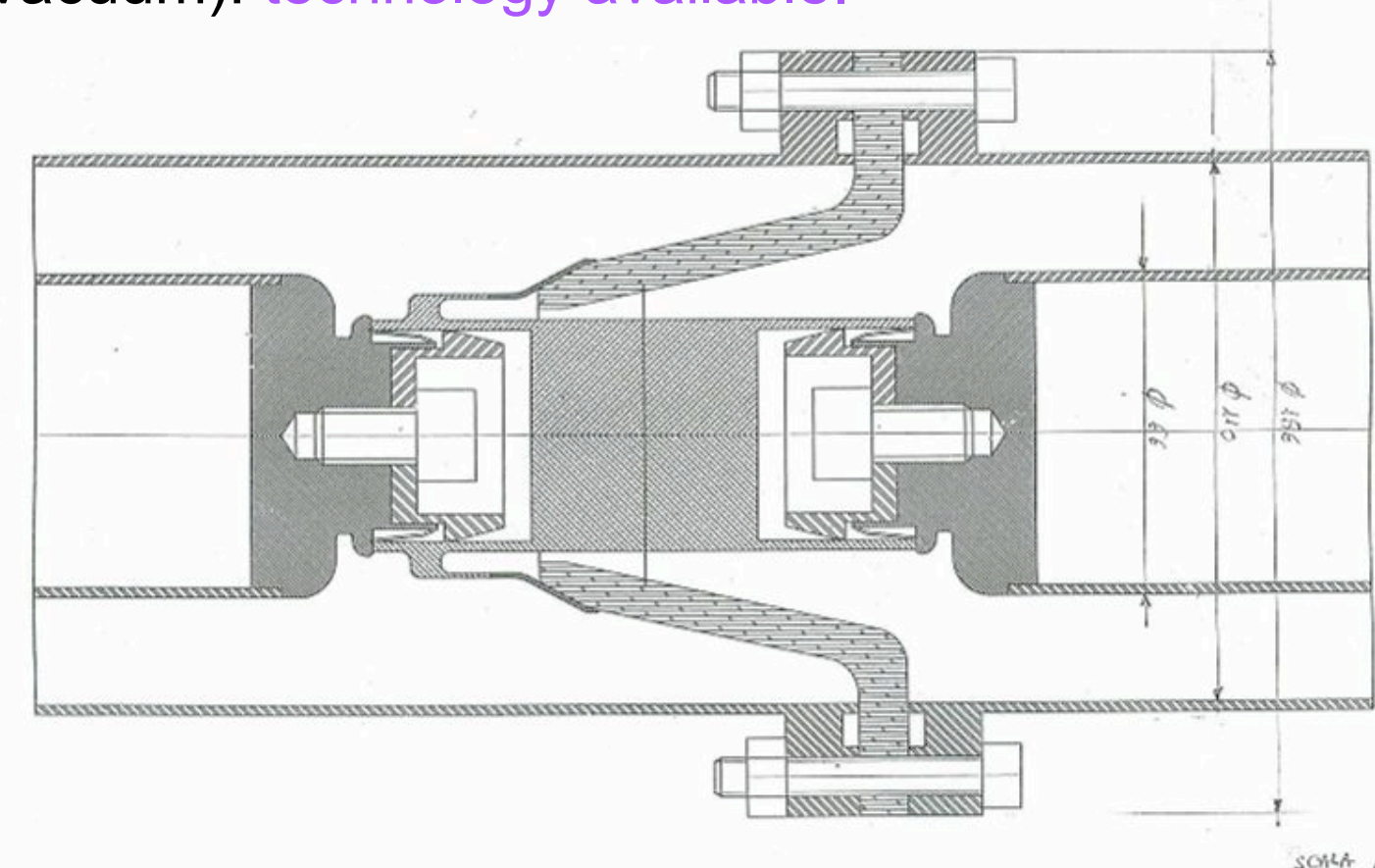
Out-of-vessel feeding system
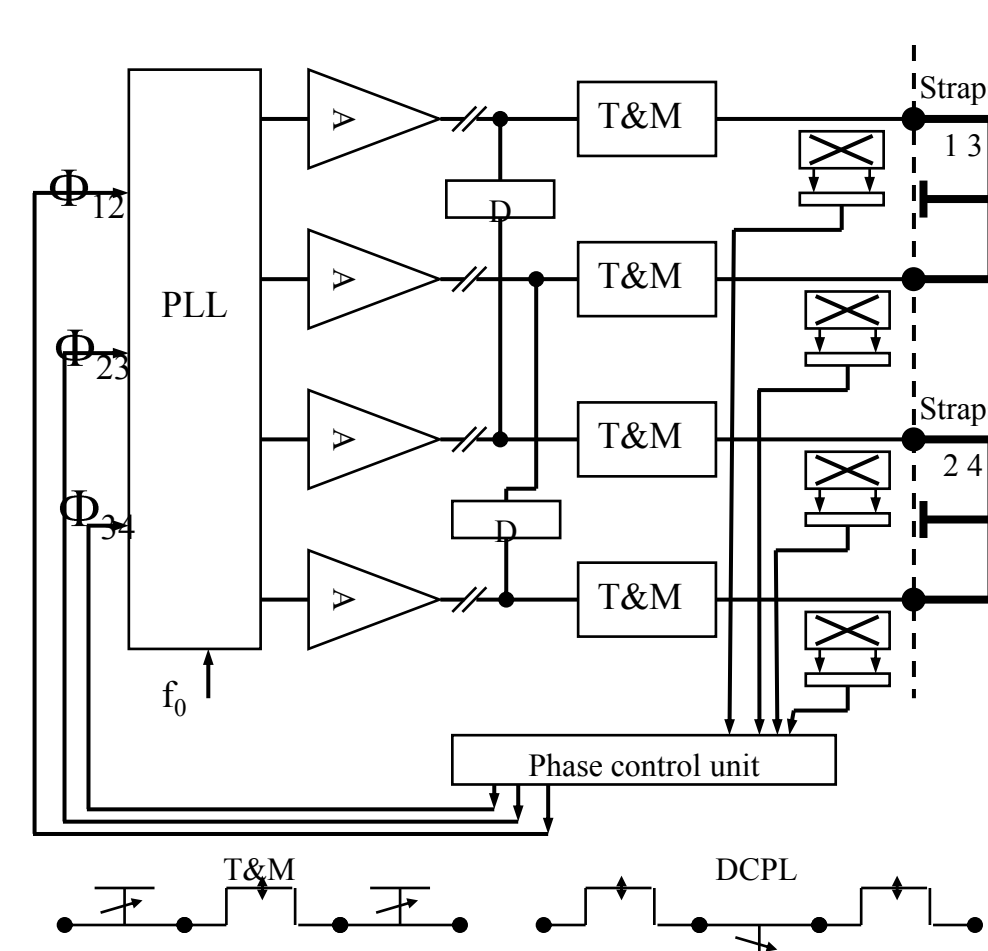
In-vessel feeding system

Feed-through (ceramic window between pressurized and in-vacuum): technology available.

Antenna