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Plasma Reflectometry Diagnostic for Re-entry and Ground Plasma Facilities

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ESPAÇO: A CONTRIBUIÇÃO PORTUGUESA EM INVESTIGAÇÃO E DESENVOLVIMENTO

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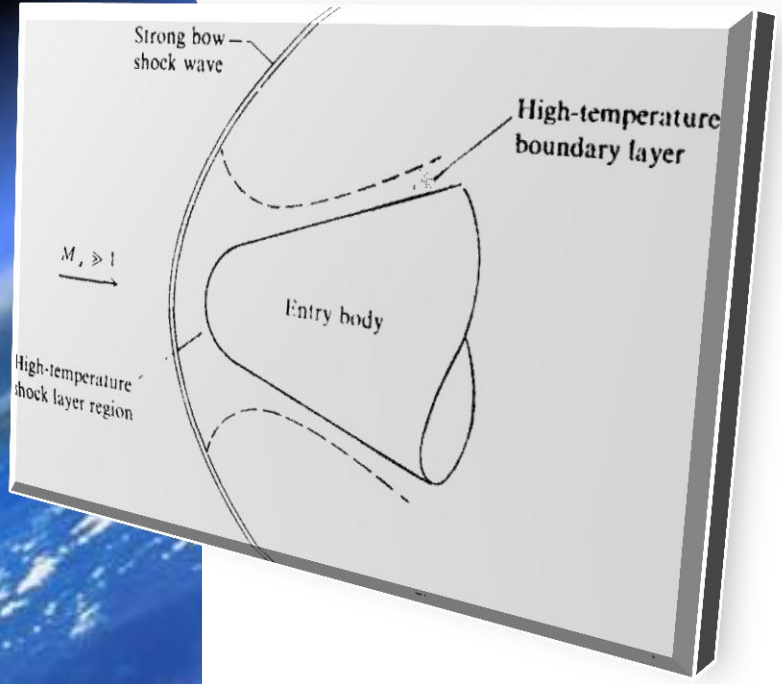
Re-entry Plasma

- Re-entry vehicle enters the atmosphere at velocities in the range 5 km/s to 11 km/s
- Strong, detached bow shock forms
- Kinetic energy from the hypersonic free stream converted to internal energy of the gas across the bow shock
- High temperatures, 9000 K to 11000 K
- Dissociation and ionization in the shock layer
- Plasma forms (f_{pe}, 2 GHz to 40 GHz, log-parabolic)

Re-entry Plasma



Re-entry Plasma

Importance of re-entry plasma density measurements:

- Plasma absorbs radio-frequency radiation, resulting in communications blackout for part of the re-entry trajectory
- Ionization levels and radiative heat transfer have a strong influence in the design of Thermal Protection Systems for the vehicle, specially for high entry velocity
- Validation of CFD simulations of hypersonic flow

Precursor Experiments

- Use of reflectometry in re-entry plasma dates back to NASA's Radio Attenuation Measurements (RAM), in the 1960's
- RAM CII payload included 8 Langmuir probes…
- + 15 reflectometers for differential phase measurements!
- Target frequencies: 1.1 GHz, 3.3 GHz, 10.0 GHz, 35.0 GHz
- Rough estimates for the position of the cutoff layers
- Discontinued in 1970

Precursor Experiments

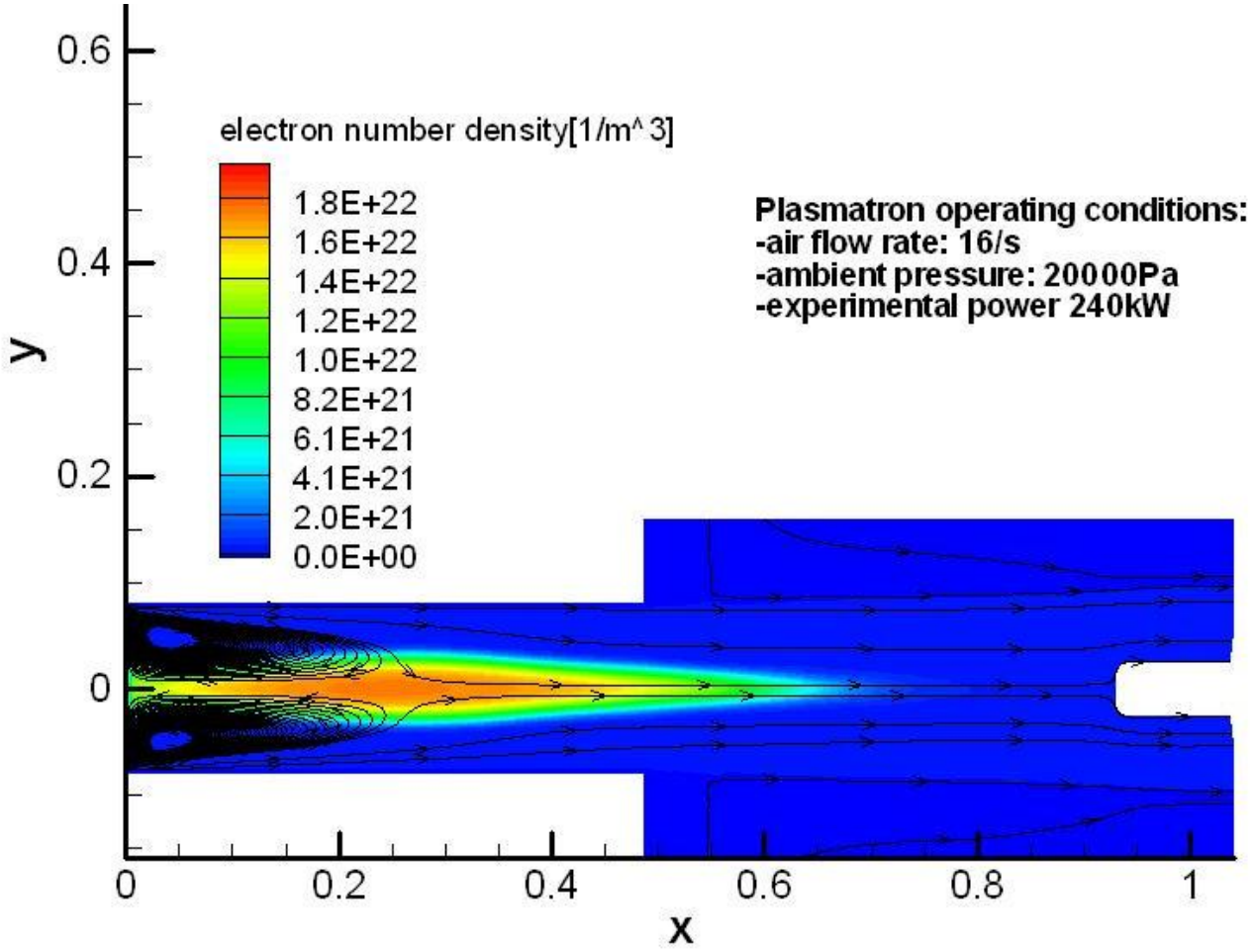
- In 1989, NASA launched Microwave Reflectometer Ionization Sensor program (MRIS, halted in 1991)
- MRIS was to include 4 reflectometers
- Target frequencies: 20 GHz, 44 GHz, 95 GHz and 140 GHz
- Bandwidth of 4 GHz, stepped frequency (64 x 64 MHz)

- Japanese Orbital Re-entry Experiment (OREX) in 1994
- ESA's Aerothermodynamic Re-entry Demonstrator (ARD) in 1998 (not much information available)

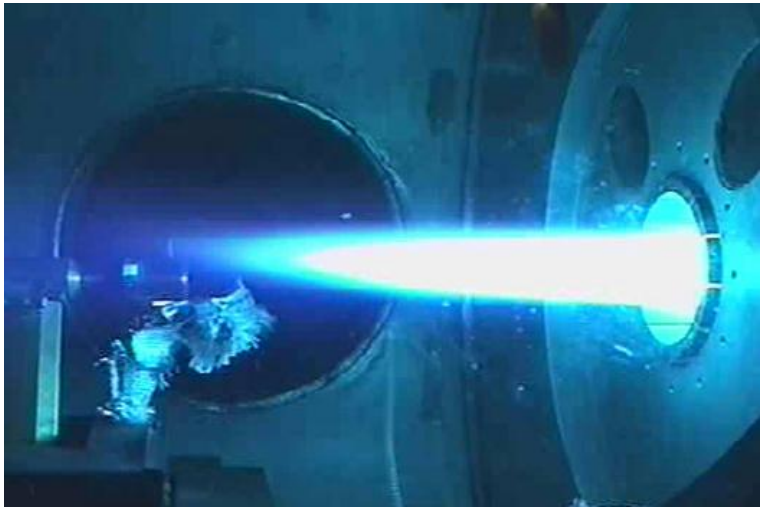
Plasmatron Facility

- Ground facility for testing TPS materials, located at von Kármán Institute for Fluid Dynamics (VKI), Belgium
- 1.2 MW Inductively Coupled Plasma wind tunnel
- 160 mm diameter torch for Air, CO_2 and Argon plasma
- Temperatures, 6000 K to 12000 K
- Reproduces conditions in the stagnation point for re-entries from orbit, the Moon and for entry to Mars
- Peak plasma frequencies, 8 GHz to 30 GHz (estimate)
- Hydrodynamic oscillations, 600 Hz and 1200 Hz

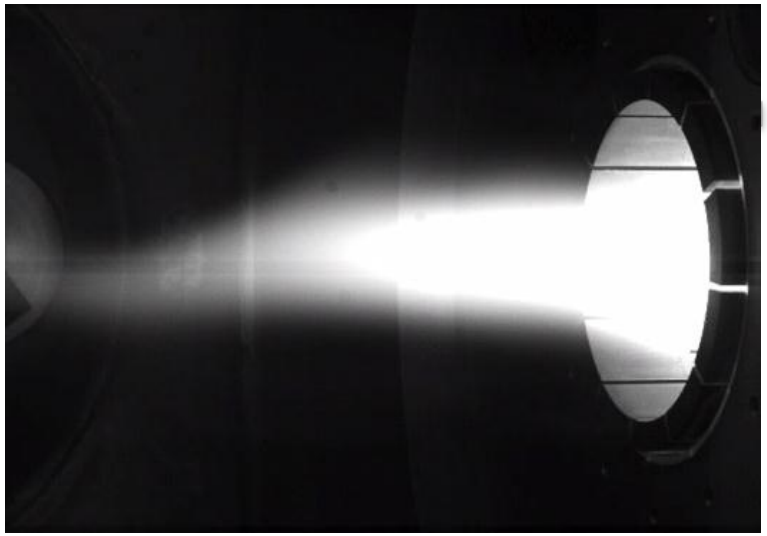
Plasmatron Facility



Plasmatron Facility



← CO_2 Plasma, 5 s @ 30 fps



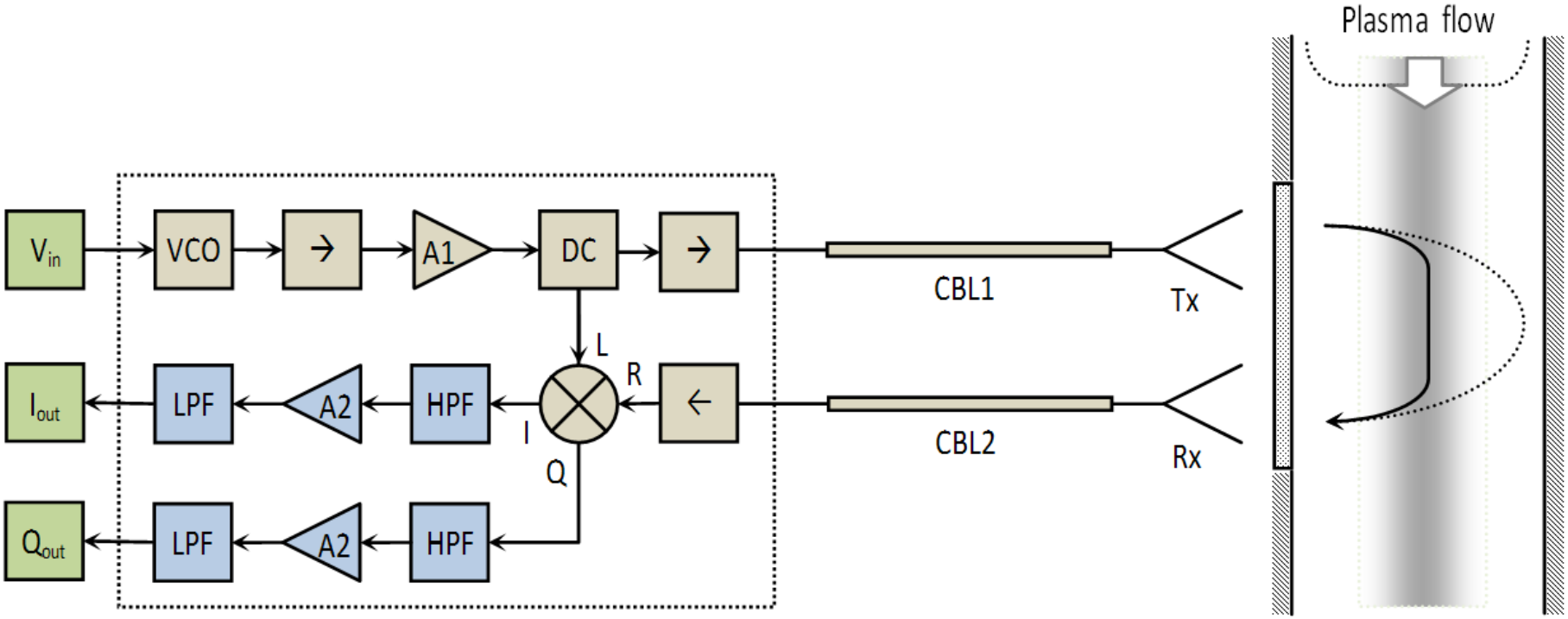
CO_2 Plasma, 50 ms @ 3000 fps →

Reflectometer

With support from ESA, a reflectometer prototype was tested at the VKI Plasmatron:

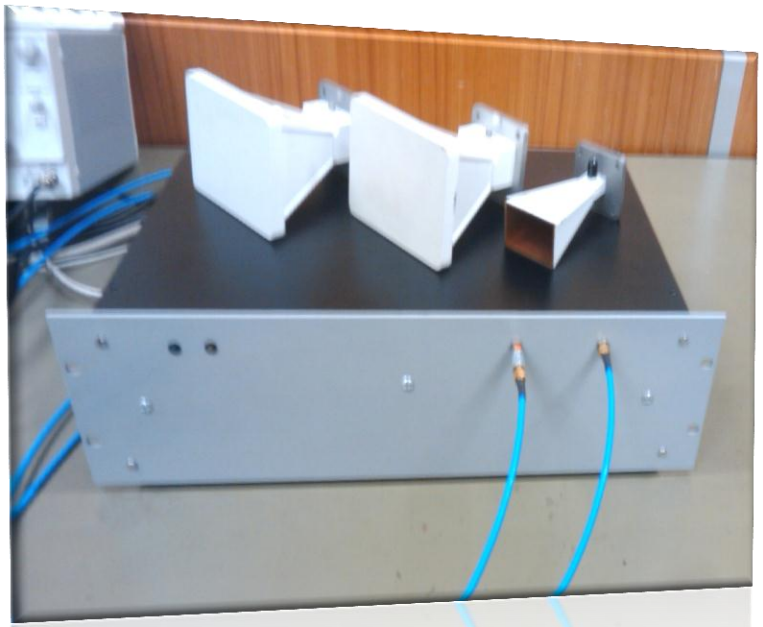
- Frequency band: 2 GHz to 18 GHz (Spinnaker HTO)
- Target plasma cutoffs: $2x10^{10}$ cm^{-3} to $5x10^{12}$ cm^{-3}
- Arbitrary waveform generator: 100 MS/s, 16 kS, 12 bits
- Sweep interval: 100 μs typ.
- Frequency rate: 60 MHz/μs avg.
- I/Q signals, beat frequency: 0.5 MHz to 2.0 MHz
- Acquisition board: 100 MS/s, 2 MB, 12 bits

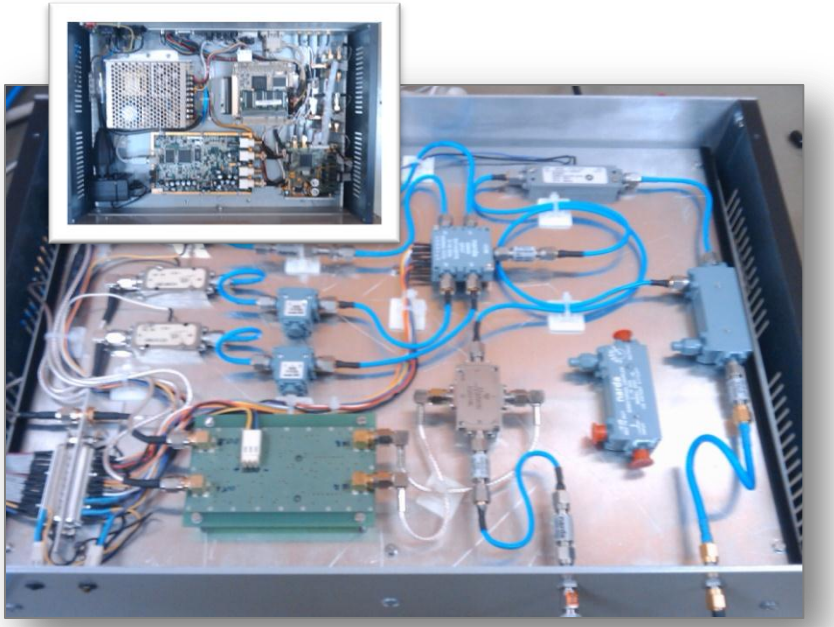
Reflectometer



* Monostatic antenna configurations also available

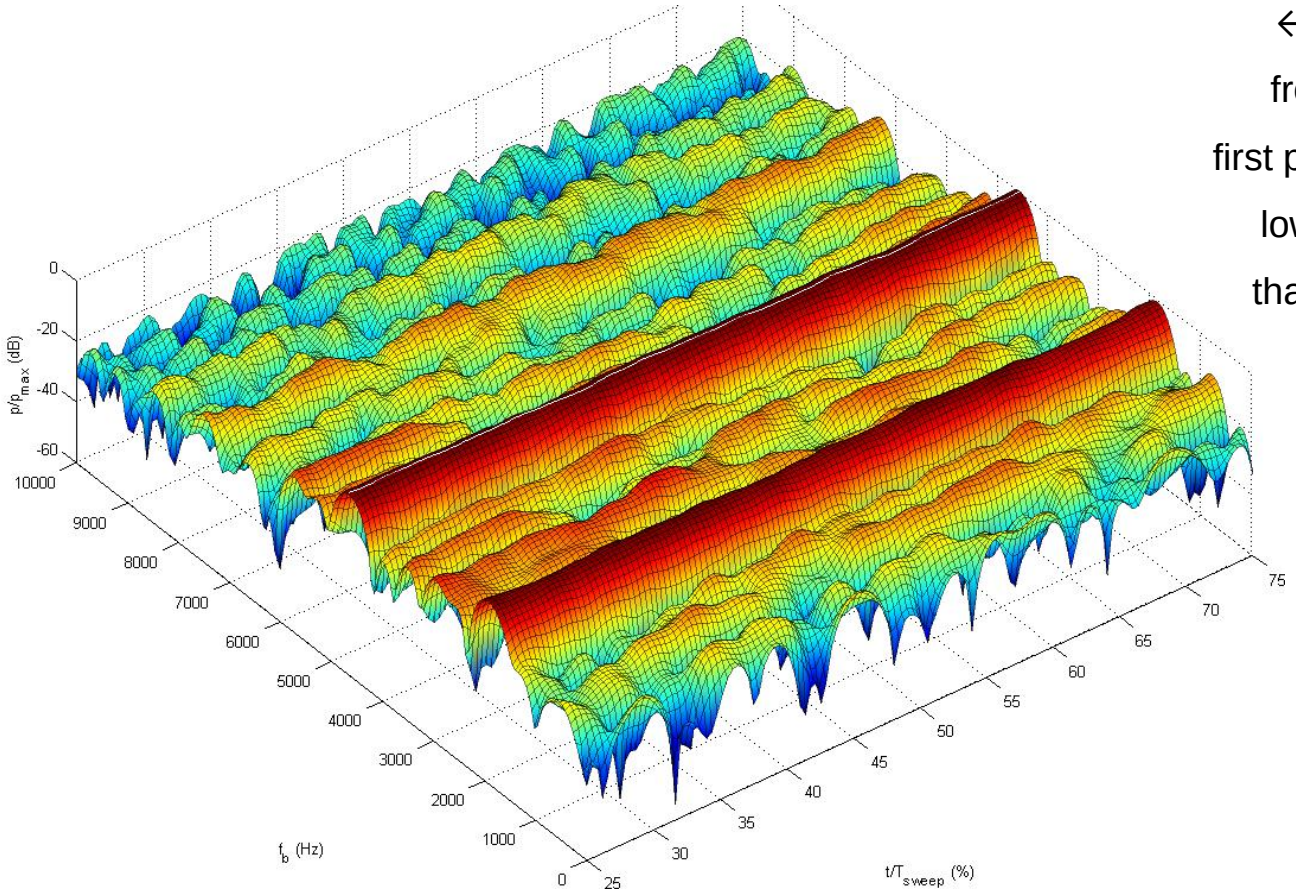
Reflectometer





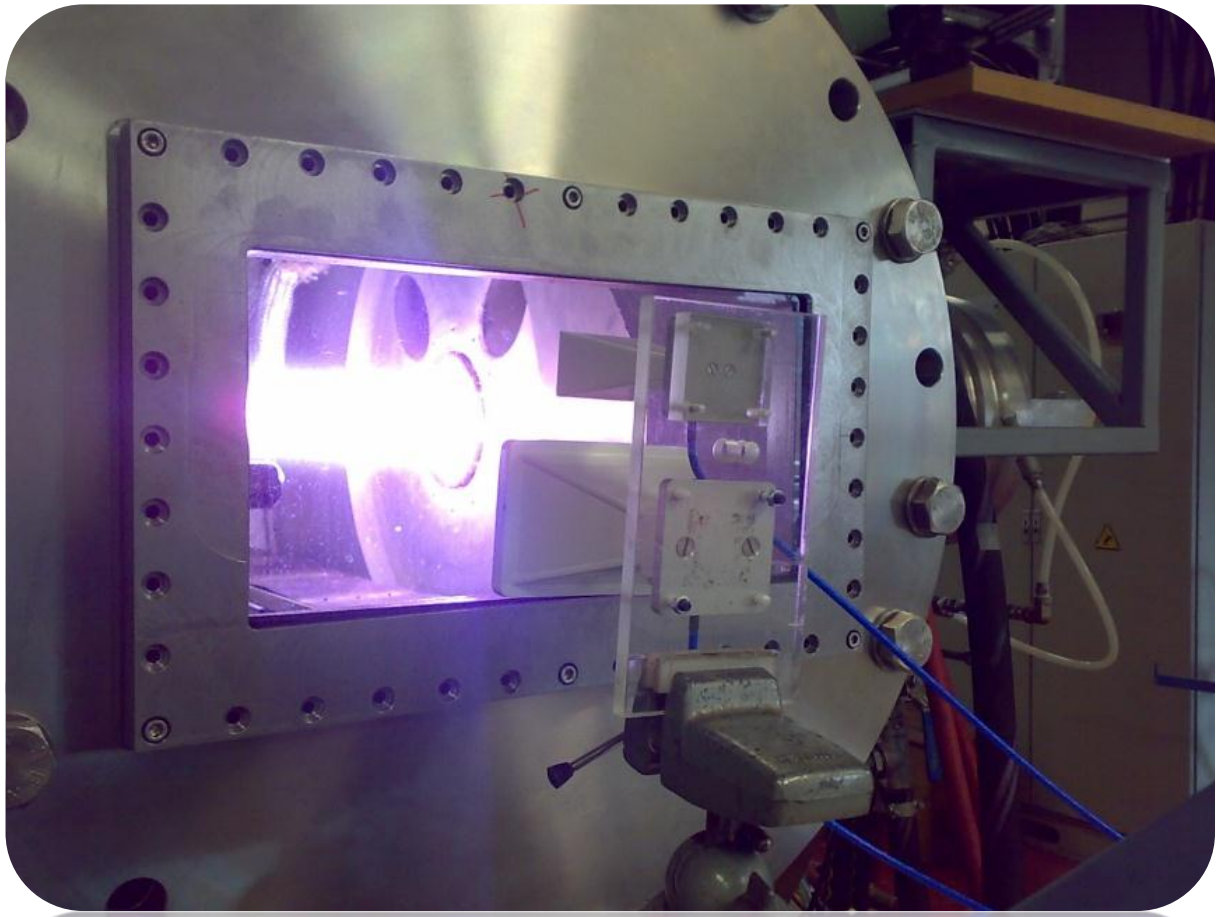
← Prototype used for pre-tests at VKI

Reflectometer



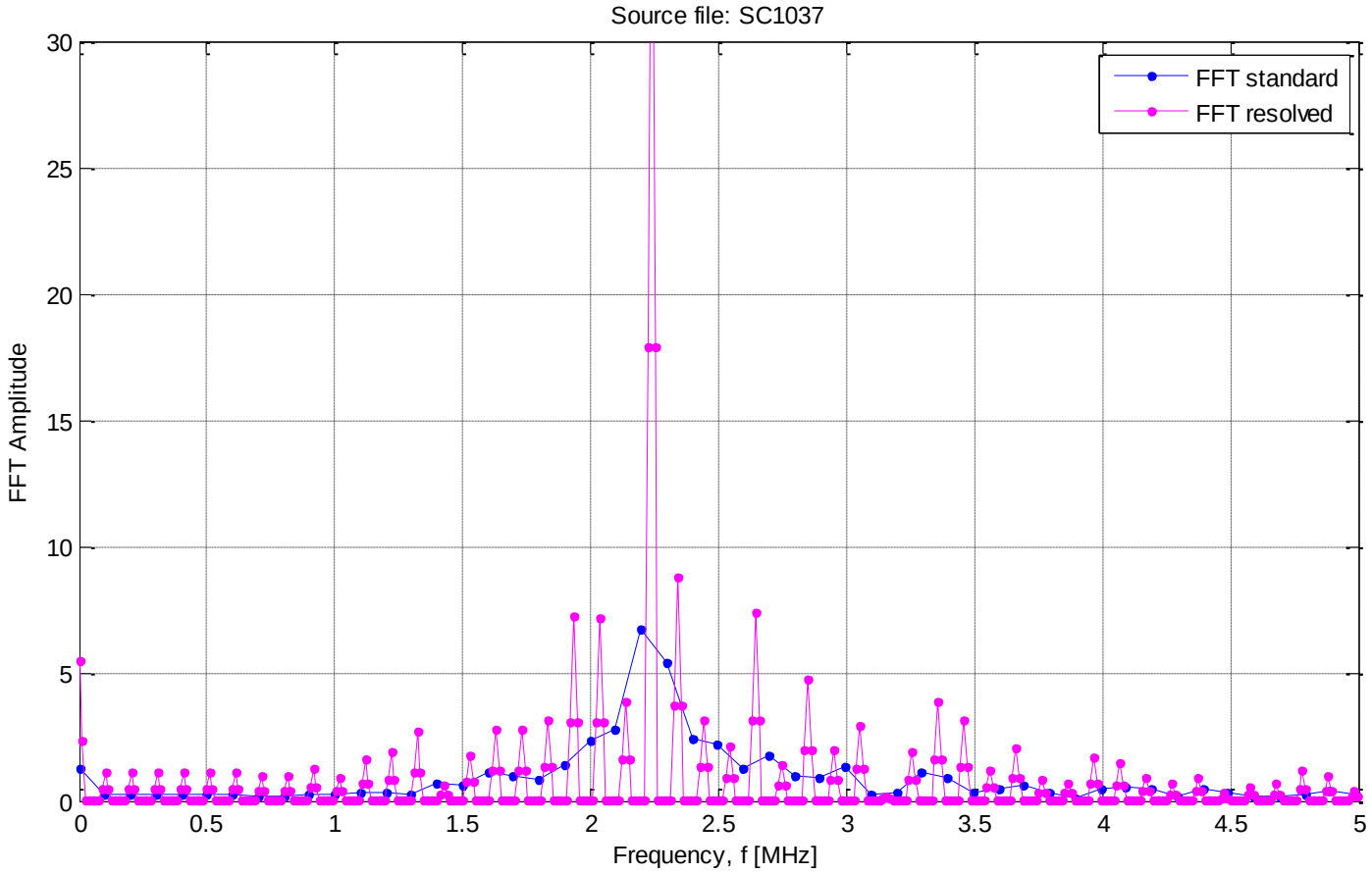
← Spectogram obtained from a calibration test for first prototype, using a much lower frequency rate than that being tested currently and on monostatic antenna configuration

Preliminary Tests



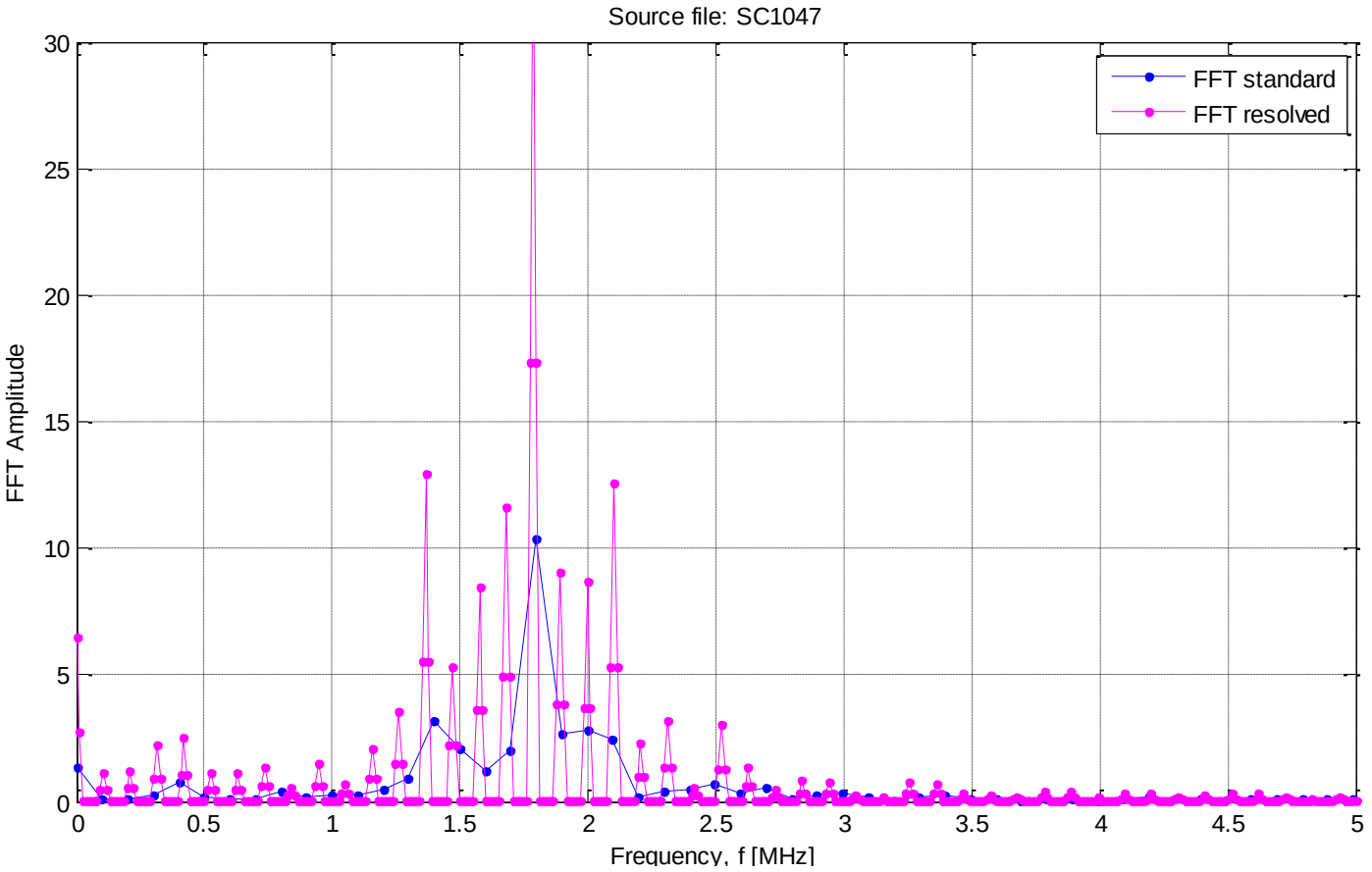
← Preliminary test conducted on the Plasmatron facility at VKI, to determine if it could be observed reflections from the plasma for the probing frequency range of 12 GHz to 18 GHz

Preliminary Tests



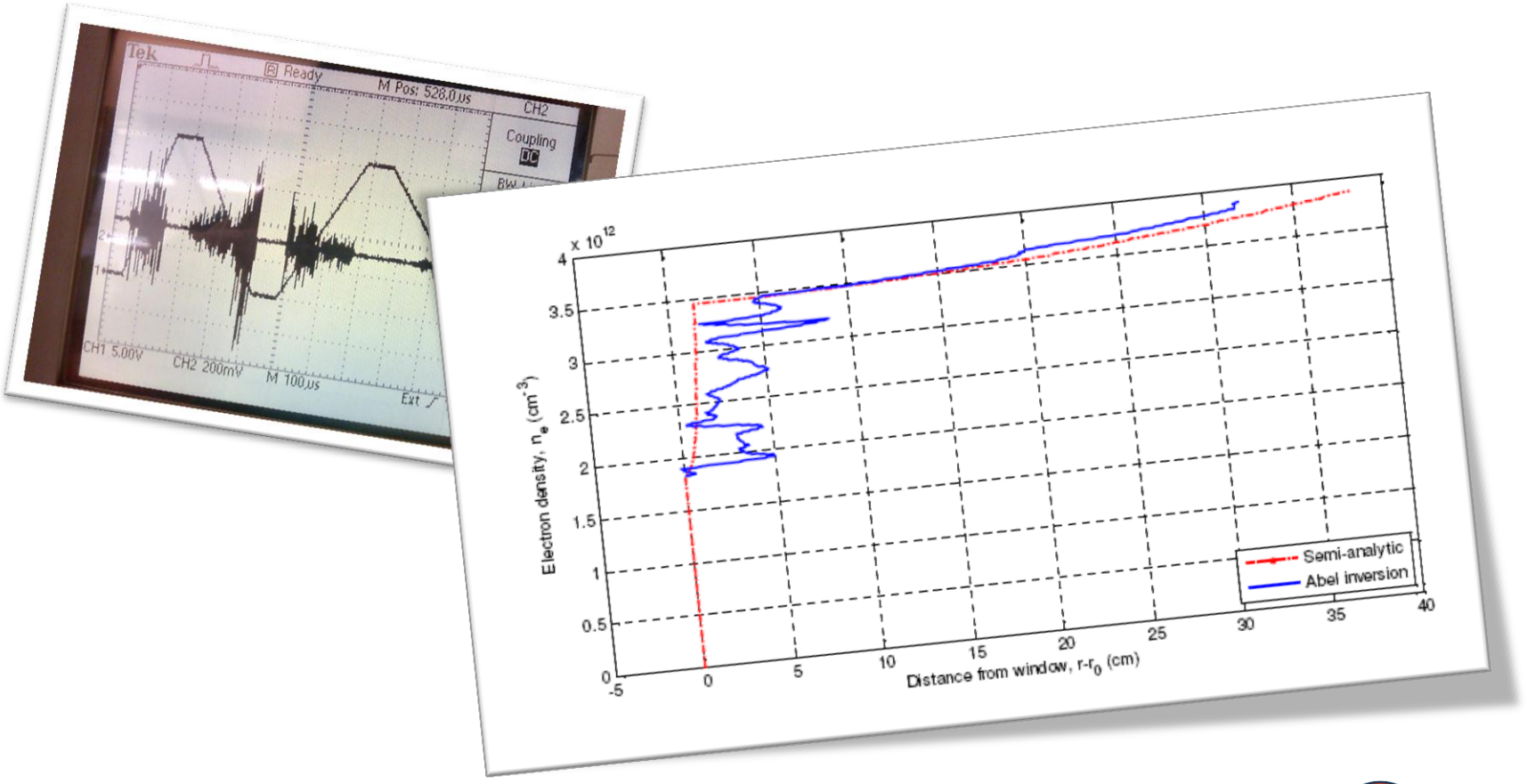
Plasma OFF | Reflection from opposite wall at 2.2 MHz

Preliminary Tests



Plasma ON | Reflection from plasma at 1.8 MHz

Profile inversion



Signal | Plasma profile

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