Advanced plasma sources for space applications

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Curriculum: STASA

September 16th, 2016

Outline

1. Framework
   - Introduction
2. Motivation, and objectives
3. Project description
   - Where were we?
   - Where we are now...
   - Future work

Framework

Plasma exhibits complex Electromagnetic (EM) wave phenomena.
It can be exploited in a broad range of advanced application:

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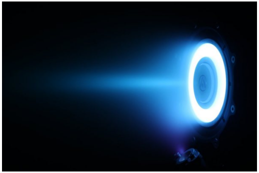
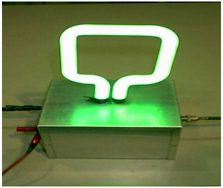
Space Propulsion:

Plasma Thrusters



Space Communication:

Gaseous Plasma Antennas



Plasma propulsion systems

Use electric power to ionize the propellant and impart kinetic energy to the plasma.

Critical issues:

- Limited lifetime
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- Low power density.

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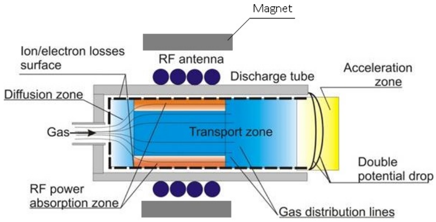
Helicon Plasma Thruster (HPT)

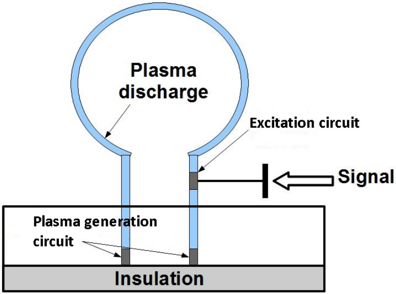


Gaseous Plasma Antennas (GPAs)

Devices relying on an ionized gas to radiate EM waves.

Feautures:

- Electrically reconfigurable;
- Low RCS, and thermal noise;
- Minimize co-site interference and signal degradation;
- Virtually *transparent* above the plasma frequency and *invisible* once turned off.



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Motivation, and Objectives

Although different in shape, fields of applications, and working conditions, GPAs and HPTs share:

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Plasma generation

Wave-plasma coupling

Plasma transport

Motivation, and Objectives

Objectives

- Physical investigation into plasma generation, charged particle transport in a magnetized plasma, and wave-plasma coupling mechanism
- Clarify the role of the antenna in the source of HPTs, and the behavior of GPAs taking into account realistic excitation circuit and plasma transport
- Coupling of the EM solution with the plasma transport
- Design, and development of two innovative plasma sources.

Where were we? I

Plasma models

Plasma transport

within a plasma source modeled by a 0-D fluid model.

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Global Model

It solves for the density profile.

Wave plasma coupling

modeled throug a dyadic permittivity

$$\bar{\varepsilon}_{rk} = \begin{bmatrix} S_k & jD_k & 0 \\ -jD_k & S_k & 0 \\ 0 & 0 & P_k \end{bmatrix}$$

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ADAMANT

Full-wave numerical tool
It solves the EM problem.

Where were we? I

Plasma models

Plasm

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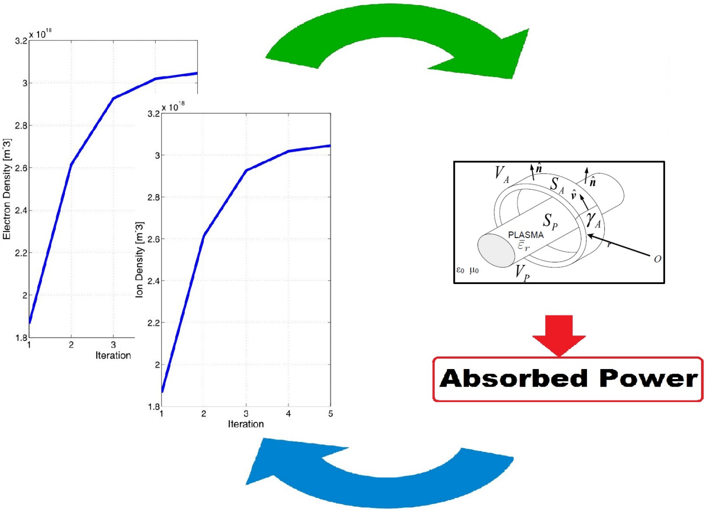
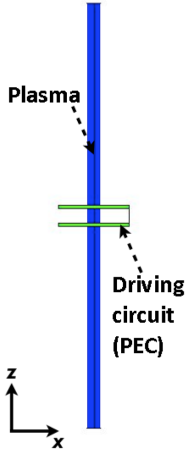
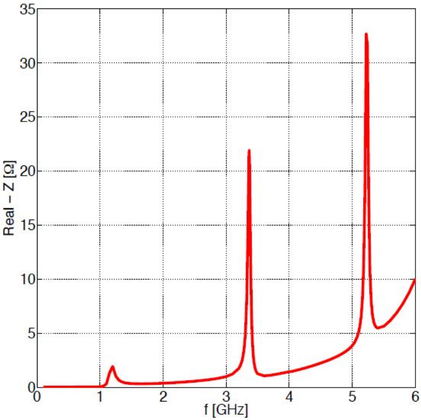


Where were we? II

First steps on numerical analysis on GPAs





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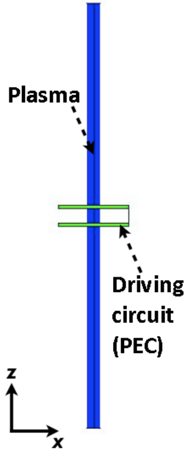

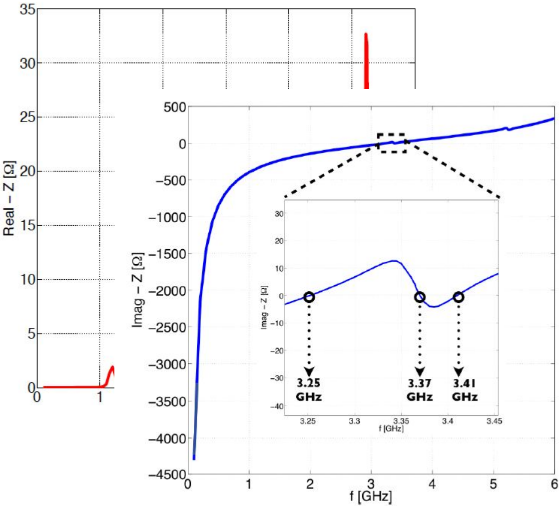

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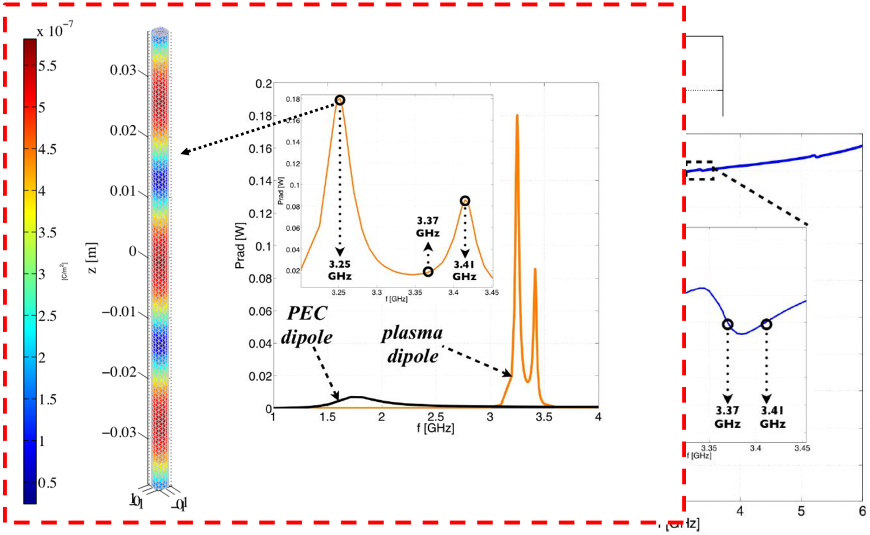
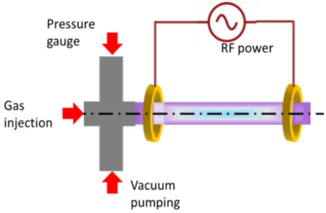


Where were we? III

First steps on experimental approach

- Pyrex glass vacuum vessel - high thermal and mechanical resistance, good dielectric, cheap and easy to manufacture
- Copper electrodes - easy manufacturing and soldering



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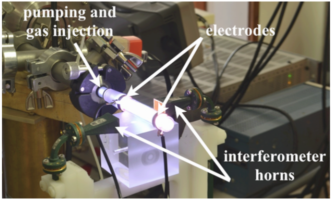
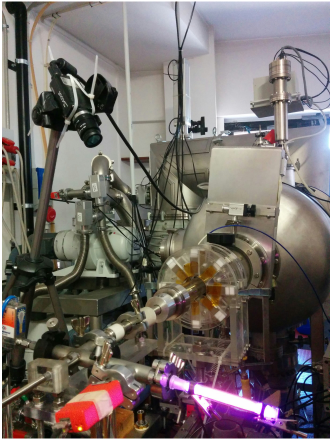
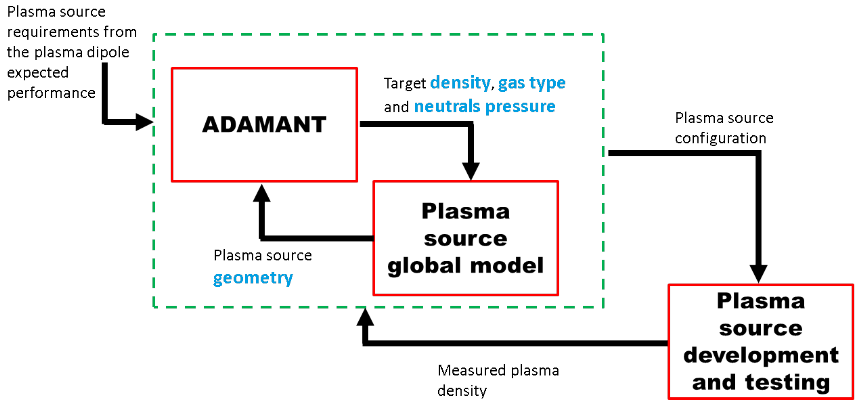




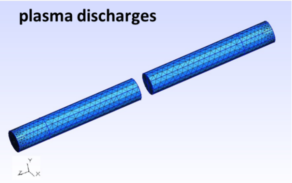
Numerical and Experimental Approach

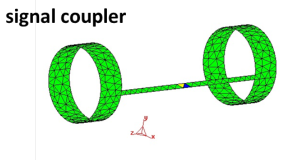


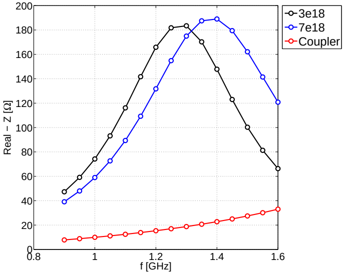
Numerical Work

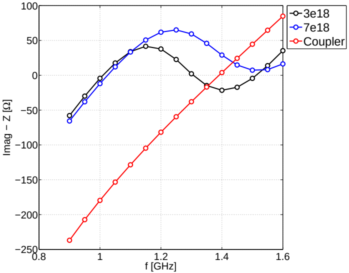
We worked on the coupler, and the plasma discharge geometries to move resonances on a more suitable range of frequencies

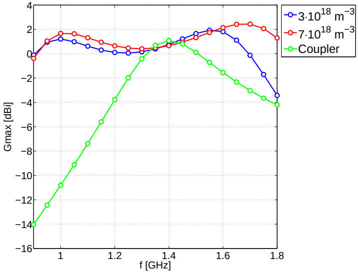
Plasma Φ	10 mm
Column length	60 mm
Column distance	6 mm
Neutral gas	Ar, He, Ne
Metal-coupler length	42 mm
Metal-coupler Φ	14 mm
Electron temperature	3 eV
Neutral pressure	1 mbar
Plasma density	$10^{18} - 10^{19}$ m^{-3}
Working frequency	0.8 – 1.8 GHz
Voltage	1 V

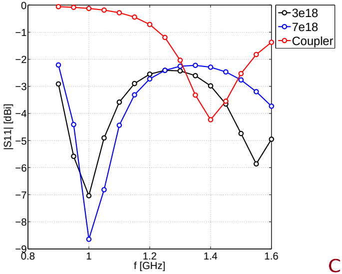





3e18
7e18
Coupler
Real – Z [Ω]
f [GHz]
0.8 1 1.2 1.4 1.6
0 20 40 60 80 100 120 140 160 180 200


3e18
7e18
Coupler
Imag – Z [Ω]
f [GHz]
0.8 1 1.2 1.4 1.6
−250 −200 −150 −100 −50 0 50 100


3·10^18 m^−3
7·10^18 m^−3
Coupler
Gmax [dBi]
f [GHz]
1 1.2 1.4 1.6 1.8
−16 −14 −12 −10 −8 −6 −4 −2 0 2 4


3e18
7e18
Coupler
|S11| [dBi]
f [GHz]
0.8 1 1.2 1.4 1.6
−9 −8 −7 −6 −5 −4 −3 −2 −1 0

Experimental approach

GPA

Evaluate:

- Bandwidth
- Gain
- Radiated fields

with different

- gas types
- plasma densities
- excitation circuit geometries

Diagnostics

Plasma characterization

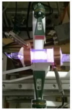
- Microwave interferometer
- CCD Cameras with band-pass filters (488BP10 and 751BP10)

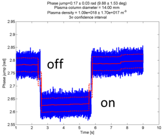
GPA performances

- Spectrum analyzer
- Vector Network Analyzer

Experimental approach

Plasma characterization





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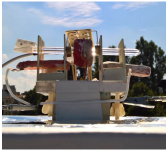

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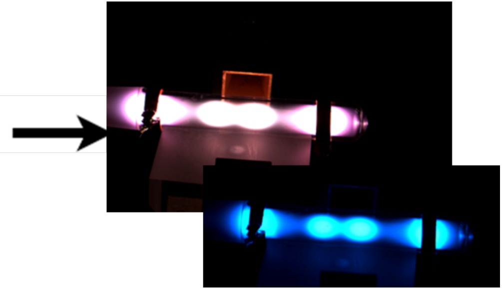
Experimental work

Electrodes Optimization

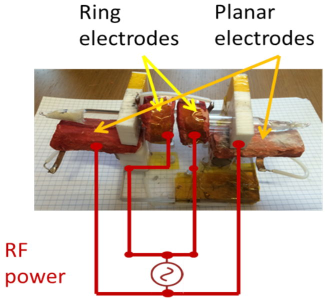
First prototype led to inhomogeneous plasma discharges

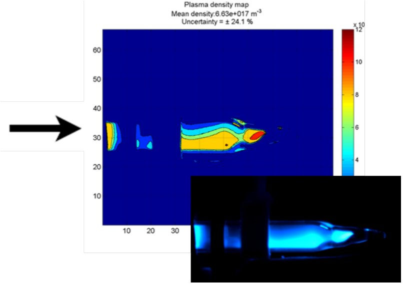


Experimental work

Electrodes Optimization

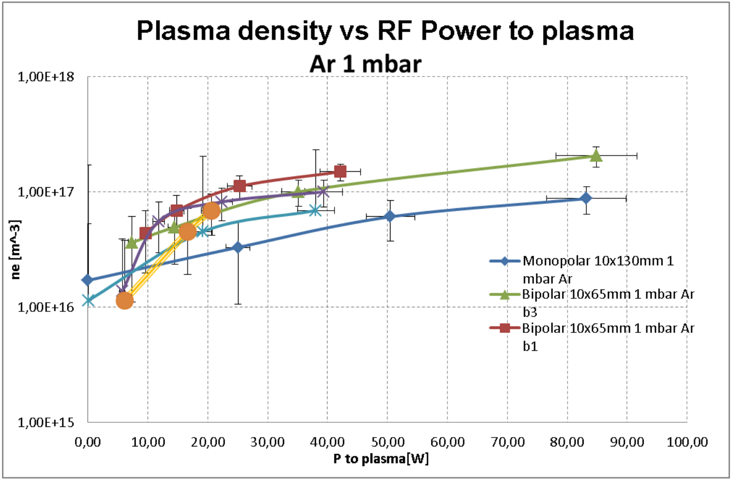
New electrodes enhance plasma homogeneity





Experimental work

Plasma characterization



Experimental work

Antenna Measurements

Power received measurements using a well known LOG-HALLO antenna as transmitter

By means of Friis Transmission Equation we can calculate antenna gain:

$$G_r = P_r - P_t - G_t - 10\log_{10}\left(\frac{\lambda}{4\pi R}\right)^2$$

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Future work

- Numerical analysis on GPA, and on Helicon sources
- Tests on GPA
- Experimental validation of the codes
- Design of a plasma source for GPA, and of a Helicon plasma source for space applications

Thanks for your attention