Electron Cyclotron Emission Diagnostics of the VASIMR Plasma Rocket

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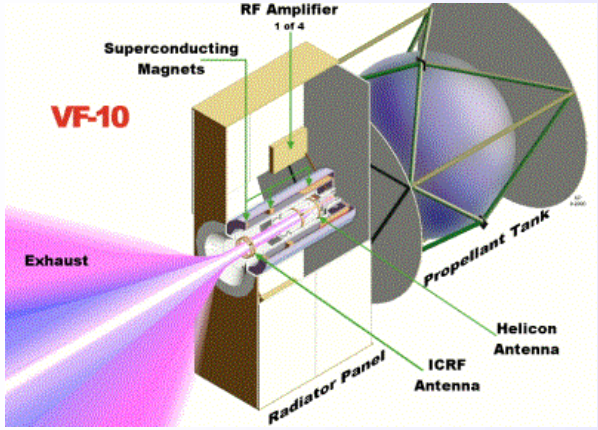
Abstract

Electron cyclotron emission diagnostics of the VASIMR plasma rocket concept. R. Munden (Stetson University, DeLand, FL 32720) F.W. Baity (Oak Ridge National Laboratory, Oak Ridge, TN 37831)

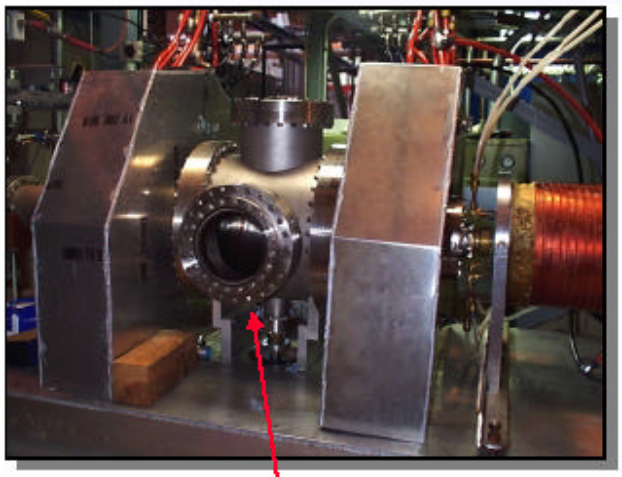
Advances in space exploration and sciences have led to great benefits for humankind. To continually enjoy those benefits and advances, it becomes necessary to improve the basic tool of space exploration, the rocket. Current chemical burn rockets are very useful for near-earth tasks and for breaking free of the Earth's gravitational field. The next step in space propulsion is a continuous burn, variable impulse rocket, which may be achieved through the VASIMR plasma rocket. The plasma rocket enables variable throttling of the propellant to maximize fuel efficiency. The plasma, an ionized gas, is created and accelerated by radio frequency (RF) fields launched with a helicon antenna. It attains much higher exhaust velocities enabling very rapid transit through space. By measuring the intensity and frequency of electron cyclotron emission in the plasma, a correlation to the electron temperature can be found. Preliminary tests with a helicon plasma source at Johnson Space Center showed promise that emission was in accordance with the predicted values based on the applied magnetic fields in the system. Continued tests on the Mini-RFTF helicon plasma system at ORNL have so far been inconclusive. Further testing with improved amplification and receivers is planned so that this diagnostic technique can be fruitfully applied to the VASIMR system. Determination of the electron temperature is important in developing models of the experiment.

VASIMR Rocket

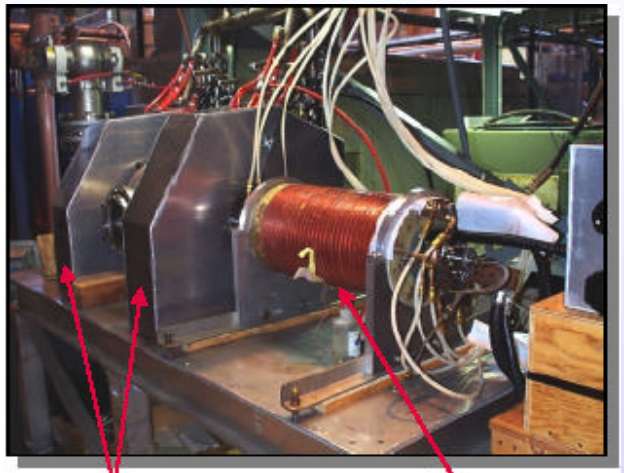


The VASIMR (Variable Specific Impulse Magnetoplasma Rocket) rocket concept developed by Dr. Franklin Chang-Diaz provides a variable throttle propulsion system for space travel. Rather than a burn-coast chemical design, the VASIMR thrust comes from a heated plasma or hot ionized gas. The light gas, ideally hydrogen, is accelerated to very high speed by radio frequency electromagnetic waves. The high speeds and fuel efficiency of the VASIMR concept make it an ideal choice for a manned mission to Mars. It would provide more maneuverability, and much shorter travel time.

Mini-RFTF

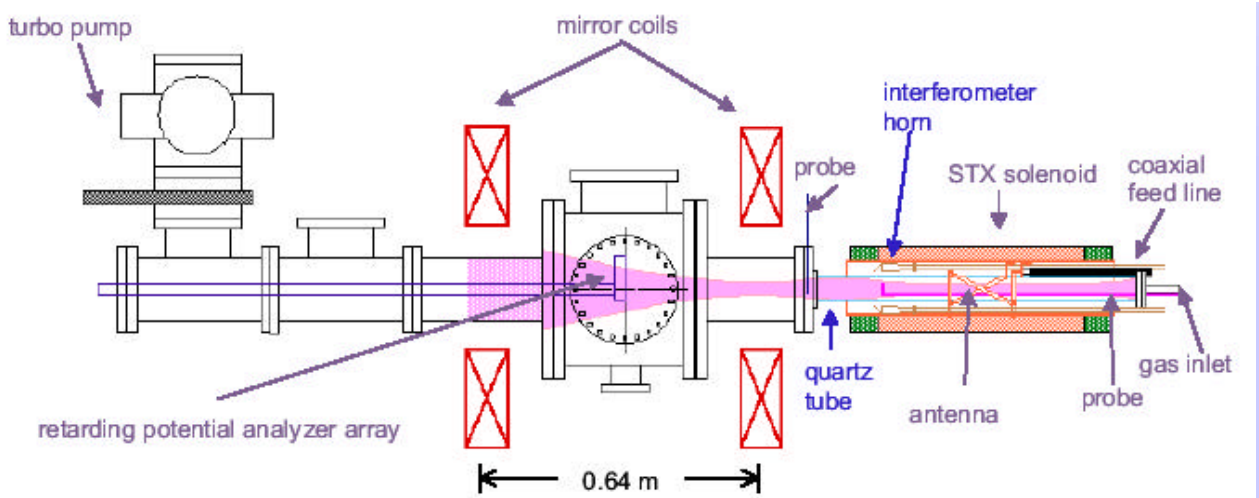


Mini-RFTF vacuum chamber



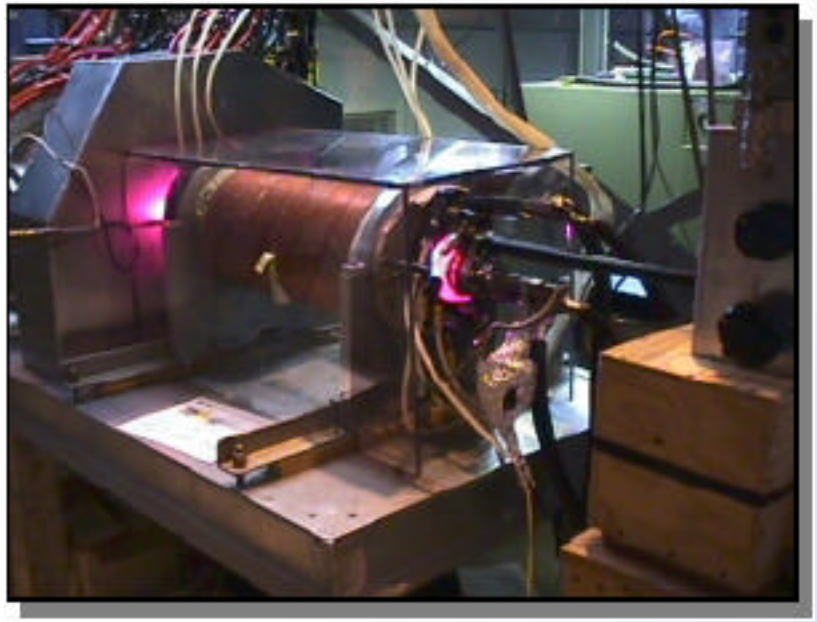
mirror coils

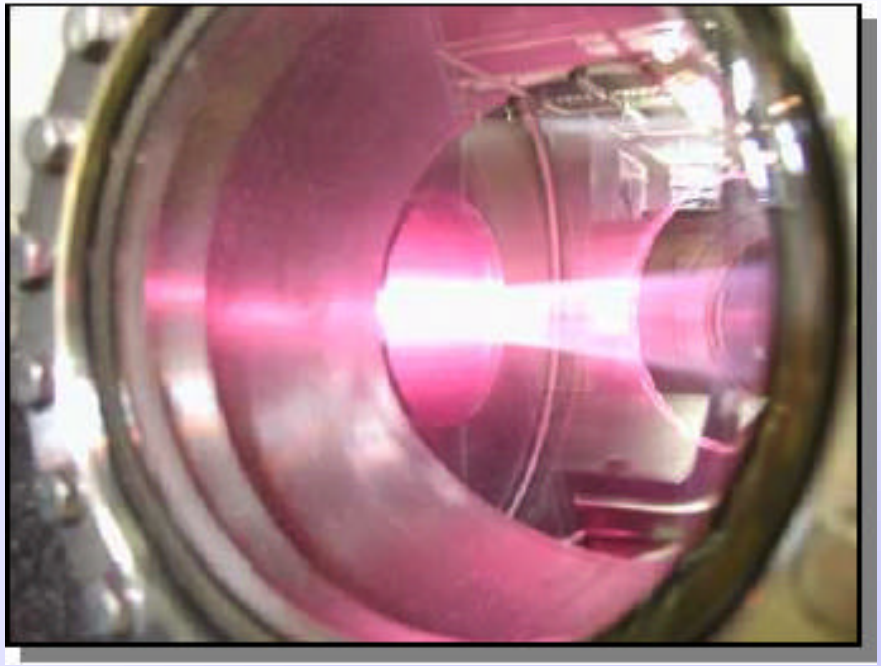
STX solenoid



The Mini-RFTF facility at ORNL provides a setup that allows study of the light ion plasmas useful in the VASIMR. The diagrams to the left show the setup of Mini-RFTF. A helicon antenna located inside of the STX solenoid creates the high density plasma from flowing hydrogen or helium. The mirror coils are critical in reaching high density modes.

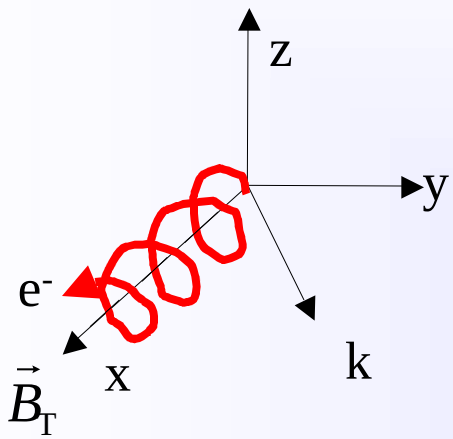
Plasma Source Diagnostics



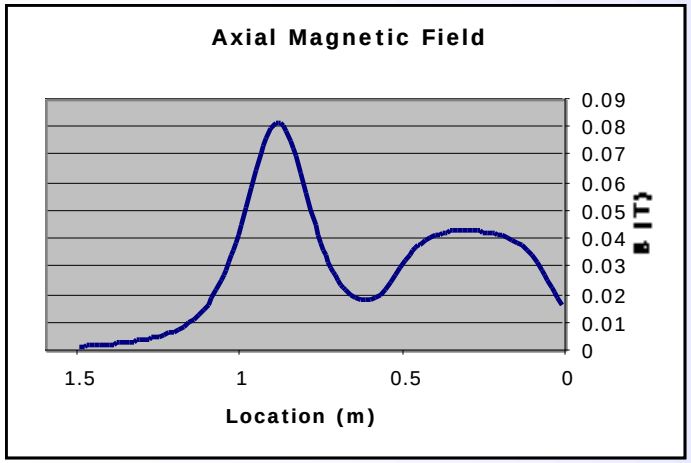


Several techniques are useful in determining the characteristics of the plasma. Measurements by microwave interferometry yield the electron density. By positioning a Retarding Potential Analyzer (RPA) in the beam of plasma the ion energies can be measured. Another useful quantity in analyzing the plasma is the electron temperature. Through Electron Cyclotron Emission experiments it is hoped that an approximate temperature can be determined. All of these quantities are necessary for further modelling and experimentation of the VASIMR concept.

Electron Cyclotron Emission



Electrons radiate at frequencies related to the magnetic field profile.



The free electrons present in the plasma orbit around the magnetic field lines in a helical motion. Charged particles (i.e. electrons) radiate at the corresponding cyclotron frequency:

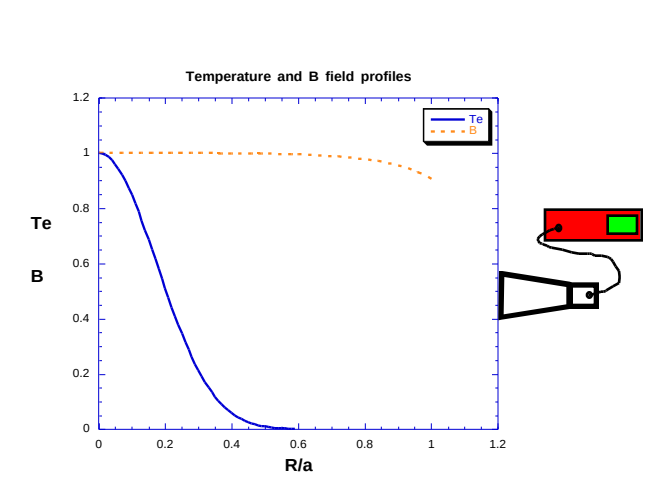
$$\omega_c = \frac{qB}{m}$$

The power emitted is found through the equation:

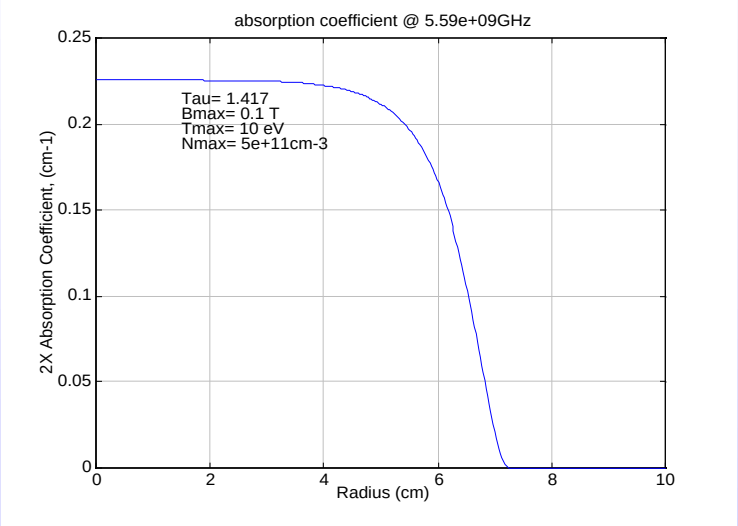
$$P = \frac{e^2 \omega^2 v^2}{6\pi\varepsilon_o c^3 (1-\beta^2)}$$

This allows a relationship between the intensity of the emission and the temperature of the electrons to be found since the velocity (v) is the thermal velocity of the electrons perpendicular to the magnetic field lines.

Methods

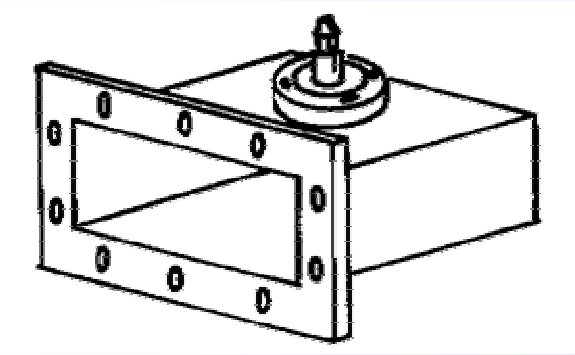


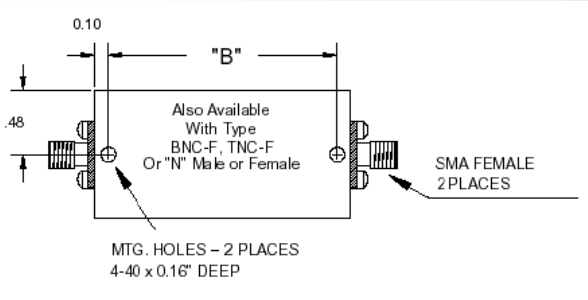
Normalized radial profiles of the temperature and magnetic fields in the plasma. ECE is detected looking radially in to the plasma with a microwave horn. Any signals seen must be able to escape from the side of the plasma. Those signals are then displayed on a spectrum analyzer. The microwave horn showed good results at ASPL, but was less effective on Mini-RFTF.



Initial calculations showed the plasma far to dense to allow ECE emissions to escape from the plasma, however they also show that inside the plasma there is still a chance of seeing ECE. The langmuir probe enabled us to search for ECE in the interior of the plasma. This also overcame problems arising from the cutoff of the windows in the vacuum system. This was much more suited to Mini-RFTF.

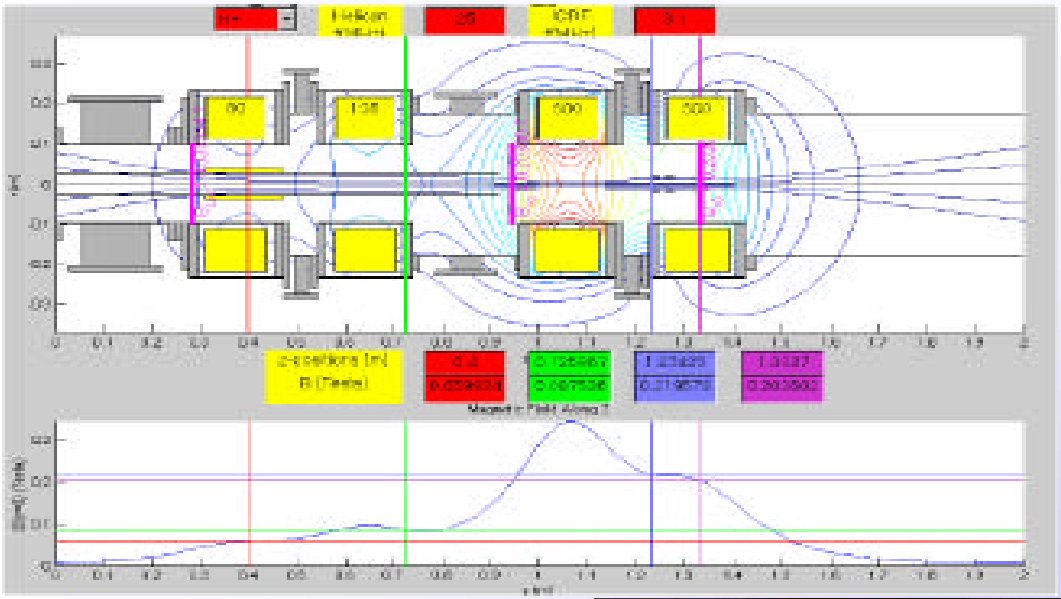
Equipment and Amplifiers

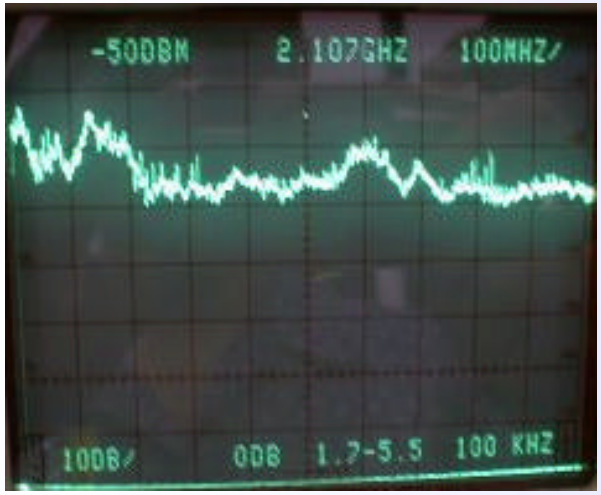


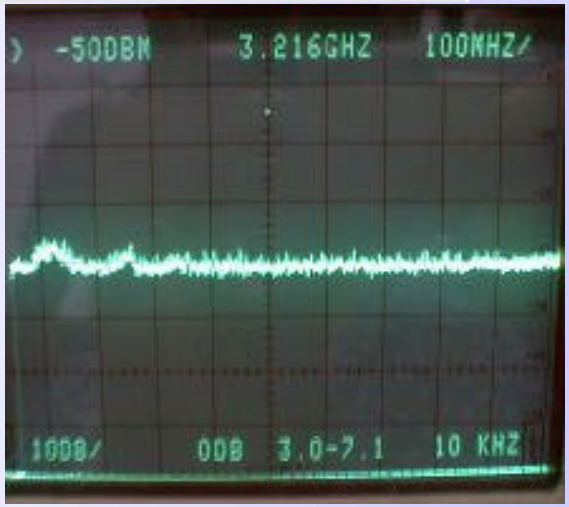


- **Analyzer: Tektronix Spectrum Analyzer 492. The spectrum analyzer is able to detect RF signals and display the relative contributions of each frequency.**
- **Antenna: The antenna detects the signal, either the Mega Ind. WR975 waveguide-to-coax transition (outside the vacuum), or the langmuir probe (inside).**
- **Amplification: provided by a Miteq bipolar amplifier in the .5-2 GHz range, and Trontech 500 amplifier in series for a total gain of ~60 dB.**
- **Filter: 400 MHz high pass filter cuts out low frequencies to clean up the signal.**

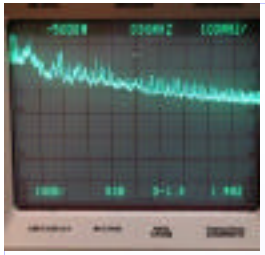
Results ASPL



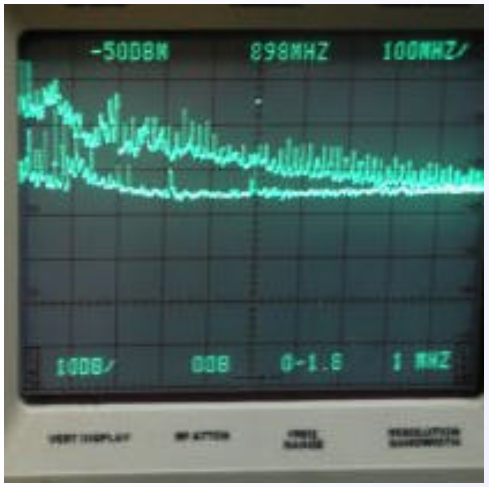


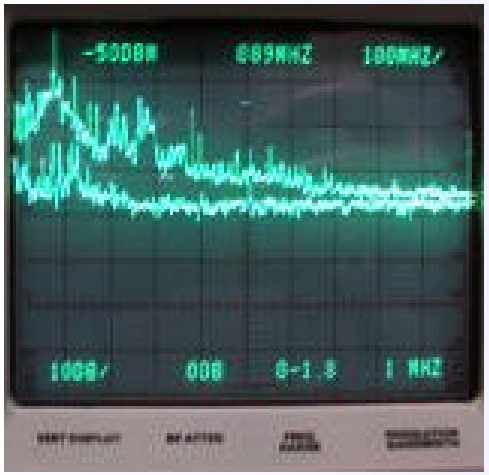


Initial testing for ECE was performed on the VASIMR system at ASPL. The results were promising, showing that emission detected above the helicon source did correlate to the magnetic fields present in the system. Emission was most likely detected from points upstream from the mirror coil. High densities and high magnetic fields, as well as RF baffles would prevent detection of ECE from downstream in the plasma.

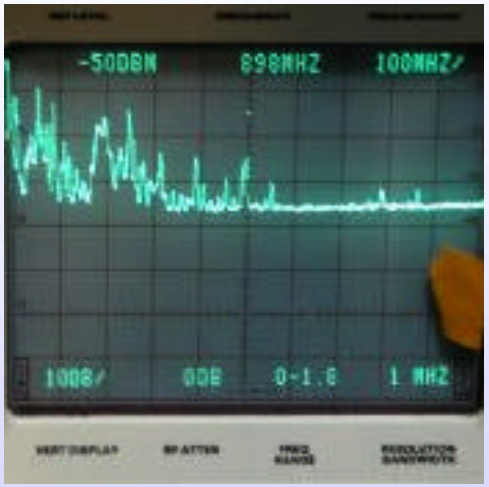


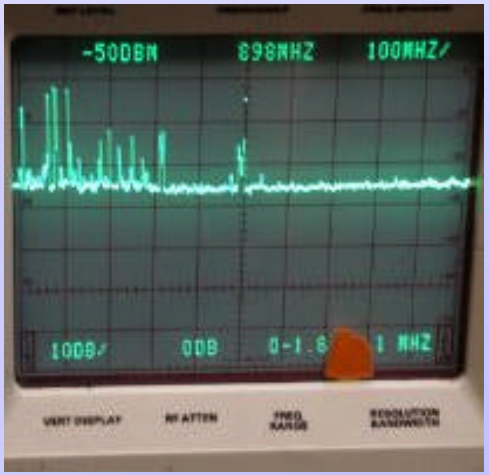
Results Mini-RFTF





Screen shots to the left show signals detected with the langmuir probe inside of the plasma radius. To the right are screen shots of signals detected by a WR975 microwave horn. Shown is the signal (top) and noise (bottom). From outside the vacuum chamber is is very difficult to detect clear signals. The langmuir probe data (to left) shows very strong signal to noise ratios, showing clear detection of ECE. Obtaining results on the Mini-RFTF required very high amplification (>60 dB).



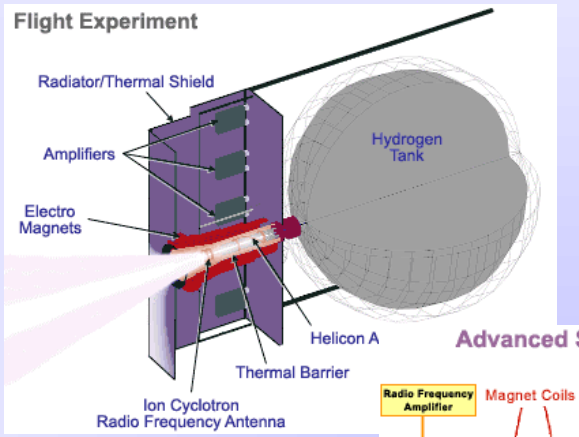


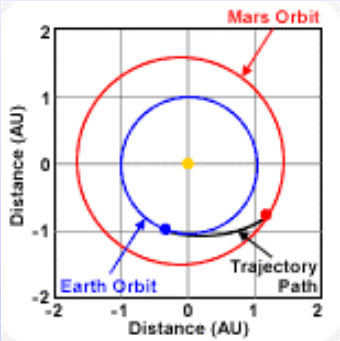
Discussion and Conclusions

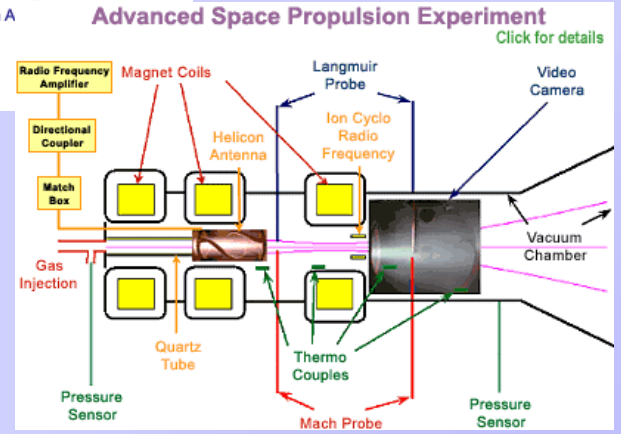
- Initial results at ASPL showed reasonable correlation between the signals received and the expected emission based on the magnetic field profile.
- Further testing on the Mini-RFTF system were unsuccessful initially. The plasma was too dense for the emission to escape from the bulk of the plasma. Therefore external detectors were unable to measure sufficient signal through the windows of the vacuum chamber.
- Internal measurements using the langmuir probe as an antenna and higher amplification yielded believable signals on the Mini-RFTF system.
- From apparent signal to noise ratios, especially at ASPL, it is expected that the electron temperatures are in the 5 – 10 eV range.
- It is still unclear as to why there is signal decline as the frequency is increased. There is no apparent reason, though perhaps the langmuir probe is cutting off the signal.

Future Work

- Further testing for optimal reception of the ECE signal is necessary.
- Calibration of the antennae (Langmuir probe and waveguide) against a black body noise source will be needed to extract quantitative results for electron temperature.
- Further optimization of the VASIMR system will be done to maximize thrust and efficiency.
- Earthlings will go to Mars.







Summary

- The VASIMR plasma rocket provides an alternative propulsion system using light ion plasma as a highly efficienty propellant.
- Diagnostics of the plasma are necessary to enable future experiments to progress toward a space test of the thruster in preparation for full-scale use.
- Electron Cyclotron Emission (ECE) diagnostics are a useful tool in determining the temperature of the electrons in the plasma.
- Langmuir probes are more effective receivers of ECE in the Mini-RFTF system.
- Many difficulties in the system must be overcome to enable solid quantitative measurements of temperature to be made.

Acknowledgements and References

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Thanks to G.L. Bell and M.D. Carter for their computation and theory input, that stuff that it's always better to have someone else doing.

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