Apparatus for investigating non-linear microwave interactions in magnetised plasma

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In many plasma applications, electromagnetic (EM) waves are key to providing energy. Plasmas can demonstrate complex dynamics when exposed to multiple EM signals. Raman coupling (by Langmuir oscillation) in plasmas below one quarter critical density and Brillouin scattering (through ion-acoustic waves) for all plasmas below critical density are important in laser plasma interactions [1-4] and ionospheric situations. Microwave beams can be formed at normalised intensities comparable to those used for some laser plasma interactions, and can interact in tenuous, cool and accessible plasmas potentially enhancing insight into the non-linear plasma dynamics.

Magnetic confinement fusion physics may directly benefit from developing the understanding of multifrequency microwave interaction in plasma. This is particularly relevant to future fusion experiments and reactors where it is expected to be more difficult to directly heat the ions with EM waves, whilst access to the lower cyclotron harmonics of the electrons is difficult in the dense plasmas seen in spherical aspect ratio tokamaks. Coupling of two higher frequency waves to cyclotron and hybrid resonances in dense plasma, either for heating or current drive may mitigate these issues [5,6].

Building on earlier research investigating geophysical cyclotron wave emissions [7,8], a new “linear plasma” experiment is under construction to test multifrequency microwave interactions in magnetised plasma. Figure 1 illustrates the configuration of the vacuum vessel with six magnet coils generating a primarily axial bias magnetic field having a high degree of uniformity over a volume 2m in length and 0.5m in diameter. The expected field map is illustrated in figure 2.

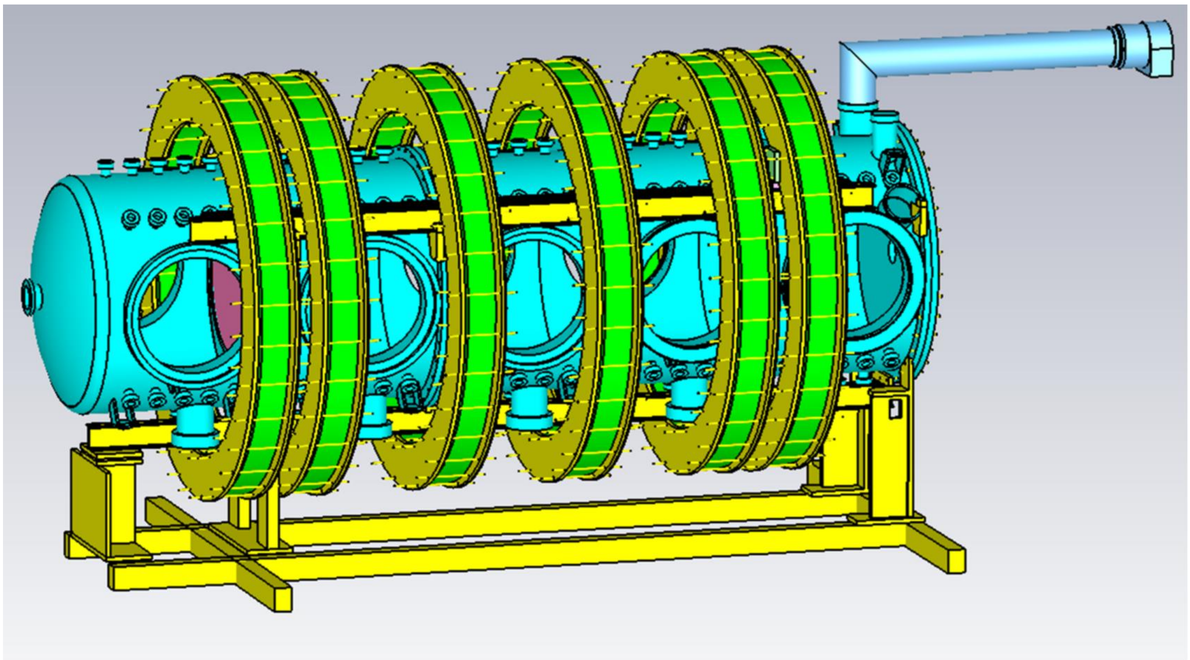

Figure 1: The vacuum vessel is 1m in diameter and 3m in length with a range of ports. Half meter diameter ports are spaced at 0.75m along the axis. Large ports around 200mm diameter are used to evacuate the vessel (base pressure 10^{-7}mB). Gases can be admitted (primarily noble gases will be used). Multiple ports 25mm in diameter provide flexible diagnostic access.

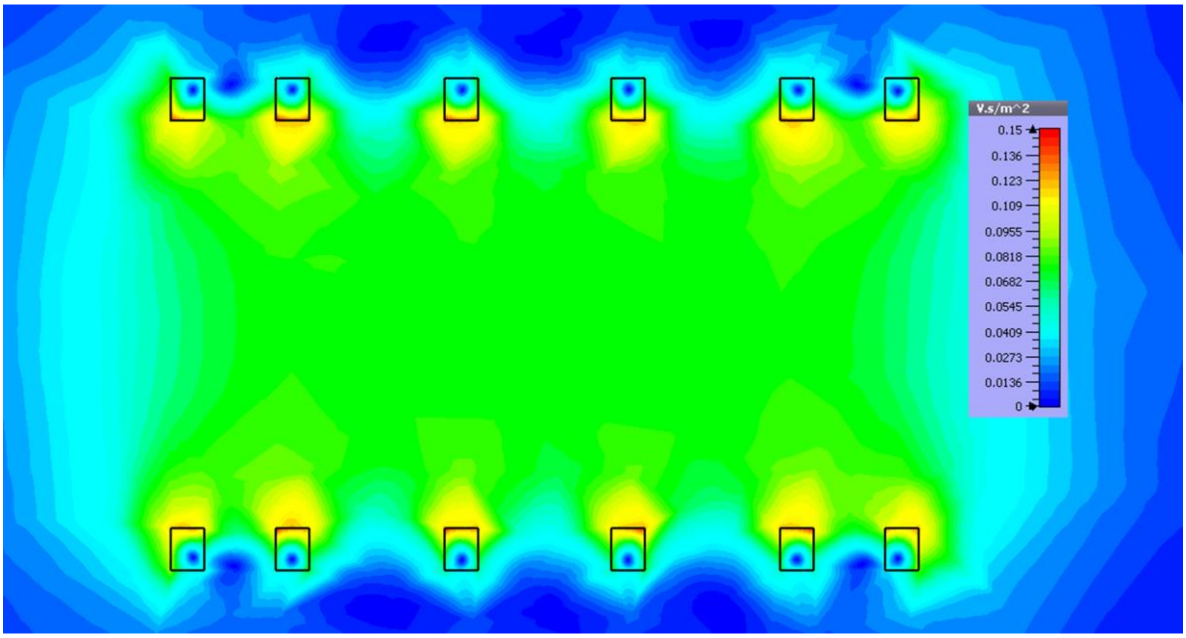

Figure 2: Illustration of the predicted magnetic field generated by 6 magnet coils operating at 250A. The length of the magnet array is ~2.5m

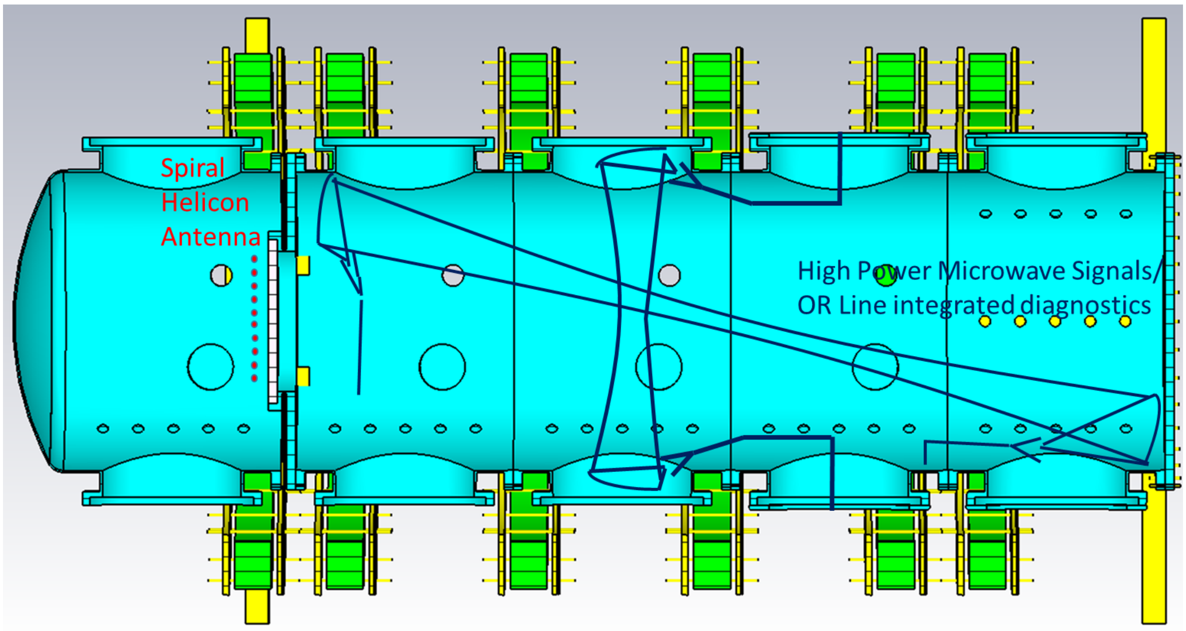

Figure 3: Illustrates the distribution of the ports and their alignment with the magnet coils and helicon antenna. Microwave beams may be directed both across and along the apparatus to study parametric scattering of O, X, R and L modes with plasma oscillations subject to differing degrees of magnetisation.

Figure 3 illustrates the planned configuration of the apparatus. The magnetic field will be adjustable up to 0.085 T with magnet currents of up to 300A, allowing effective additional heating with 2.45 GHz microwaves where required. The primary source of the plasma will be a helicon antenna [9-11] of the 'flat-spiral' configuration secured to the airside of a borosilicate glass window enclosed in a Faraday cage. The antenna will be driven by a tuneable 2-30 MHz RF source boosted by an amplifier to several kW average power via an RF matching network in either pulsed or CW modes. Target parameters are a large 0.2-0.3 m^3, dense (up to $10^{19}m^{-3}$), cool $T_i << T_e$ ~ eV plasma having a potentially high ionisation fraction ~10%.

Microwave sources and amplifiers will be used to generate pump-probe signal pairs around 9-10 GHz with a very high degree of spectral and temporal control. Up to 7 kW can be provided at a precisely controlled frequency in pulses of up to 20μs in duration by TWT amplifiers. The output from such an amplifier can be configured to be single tone over the range 9-10 GHz, either a chirp over this bandwidth, or a transform limited microwave pulse driven by an arbitrary waveform generator. In due course higher microwave power may be provided in the same spectral range with signals of ~1MW from fast wave amplifiers with similar frequency flexibility. Dispersive pulse compressors can be used to raise the peak power of the amplifiers by up to a factor of 25. The signals from the amplifiers can be offset to signals ~25kW from pulsed fixed frequency magnetron oscillators (available at several fixed frequencies in this range) to excite plasma oscillations. It will be possible to launch such waves across the magnetic field in both the X and O modes, and along the magnetic field in the R and L modes to study the parametric scattering processes between modes subject to various degrees of magnetisation.

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