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Apparatus for investigating non-linear microwave interactions in magnetised plasma

K. Ronald[1], A.D.R. Phelps[1], R.A. Cairns[2,1], R. Bingham[3,1], B Eliasson[1], M.E. Koepke[4,1], A.W. Cross[1], D.C. Speirs[1], C.W. Robertson[1], and C.G. Whyte[1]

[1] *Department of Physics, SUPA, University of Strathclyde, Glasgow, G4 0NG, Scotland*

[2] *School of Mathematics and Statistics, University of St Andrews, KY16 9SS, Scotland*

[3]*STFC Rutherford Appleton Laboratory, Harwell, Oxford, Didcot, OX11 0QX, England*

[4]*Department of Physics, West Virginia University, Morgantown, WV 26506-6315, USA*

Plasma, as a non-linear medium supporting a rich and diverse range of electromagnetic and electrostatic oscillations, can enable a range of multi-wave interactions when excited by multiple injected propagating electromagnetic waves. Electromagnetic wave injection plays a dominant role in the introduction of energy in laser plasma interactions and in the heating of magnetically confined fusion reactors. In magnetically confined plasma, the EM waves tend to fall in the RF to microwave range, whilst in laser plasma interactions the signals are typically near the optical part of the spectrum.

Non-linear coupling enables energy to be transferred between one or more EM waves interacting in plasma. For example, plasma below one-quarter critical density allows for two injected EM waves to excite an electrostatic Langmuir oscillation, a process known as a Raman interaction, whereas plasma above one-quarter critical density still allows for an ion-acoustic oscillation to couple two EM modes, a process known as Brillouin scattering. Coupling of injected EM waves to Langmuir and ion acoustic waves is of interest for a number of laser plasma interactions and in ionospheric physics experiments. Long (and short) pulse signals with normalised intensities approaching those used in some recent laser plasma interactions can be generated using powerful and highly flexible microwave amplifiers. Understanding of the nonlinear electrodynamics will benefit from employing microwave sources and amplifiers to precisely launch and electronically control multiple EM signals. The relatively long lived, benign and accessible plasma relevant to coupling of microwave frequency signals will enable the use of insertion diagnostics in addition to analysing the EM signals.

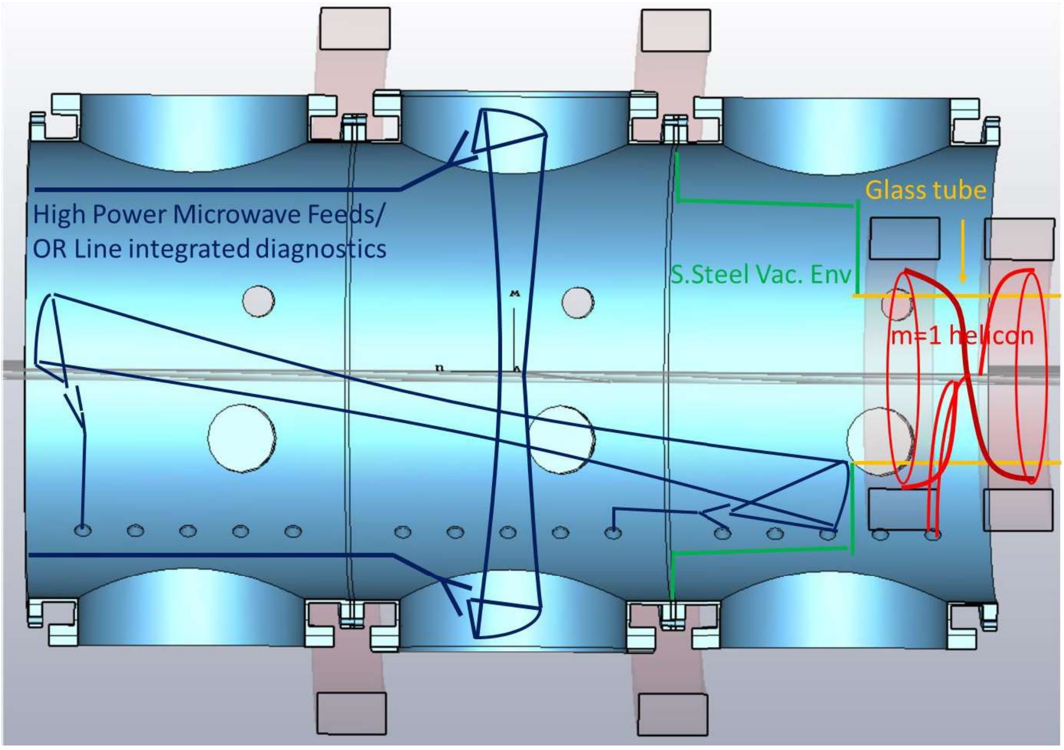

Figure 1: Illustration of apparatus showing vacuum vessel, microwave feeds and magnet coils

Other multi-wave interactions can overcome challenges in the delivery of heating and current drive in future magnetic confinement fusion (MCF) reactors. For example, direct heating of the ions may become problematic in future MCF reactors, whilst, in the case of spherical aspect ratio tokamaks, poor access to low cyclotron harmonics of the electrons complicates the delivery of EC heating and current drive. The promise of beat-wave interactions between two microwave signals and the cyclotron motion of the ions and electrons will be investigated, as will the potential for current drive by exciting lower hybrid oscillations by beat-wave interactions and via helicon waves.

To undertake this research a medium-scale linear plasma experiment is being designed, approximately 1m in diameter and several meters in length, figure 1. This apparatus builds on the authors experience in developing a series of experiments [1-3] and simulations [4] of natural plasma [5]. The main section of the plasma, around 1m long and 0.5m in diameter, will be magnetised at up to 0.08T using a set of magnet coils, figure 2 and 3. The plasma will be created by an RF helicon source, using a whistler wave injected from a high-field region near (or, in inductive mode, below) the lower hybrid resonance, to generate a dense, large, cool plasma with high ionisation fraction (electron number densities up to $10^{19}m^{-3}$ may be possible). Helicon sources have attracted interest as a method of generating plasma for industrial processing applications besides their use in fundamental physics research.

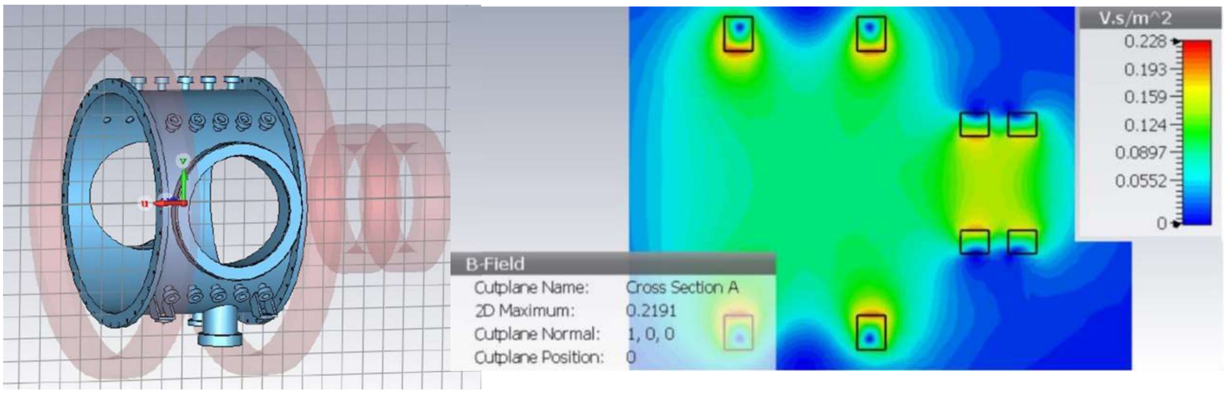

Figure 2: Preliminary illustration of magnet configuration and predictions of magnetic field profiles.

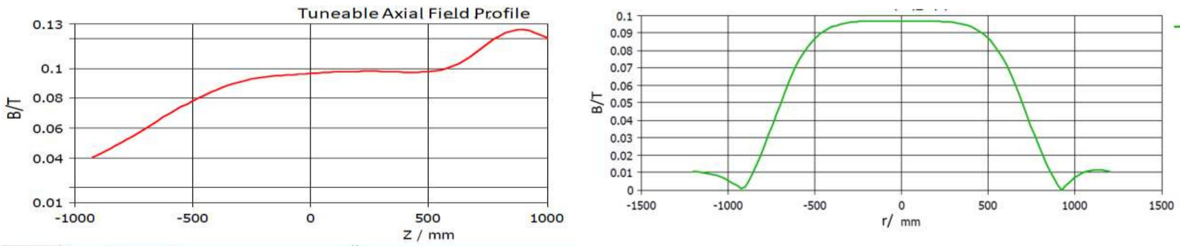

Figure 3: Axial and radial profiles of the predicted magnetic field

A range of fixed and flexible frequency microwave sources will provide beams to enable multi-wave coupling experiments. Sources available in the first instance include X-band (8.4-12.4GHz) magnetron oscillators, figure 4, (up to 25kW) to produce powerful pulses at fixed frequencies which will be combined with the signals from wideband TWT amplifiers (up to 7kW). The TWT's can boost a precisely controlled microwave signal from programmable synthesised oscillators, with programmed steps and chirps created by arbitrary wave generators at frequencies close to the magnetrons. Combined with dispersive pulse compressors [6], these enable signals of up to 140kW to be generated. Unique amplifier technology developed at Strathclyde will enable these signals to be further enhanced by up to two orders of magnitude [7,8], whilst longer term, relativistic backward wave oscillators can deliver 100's MW in the same spectral range. These signals can be formed into beams with parameters which become relevant to relativistic plasma conditions. The paper will present the proposed apparatus and will outline the envisioned research programme.

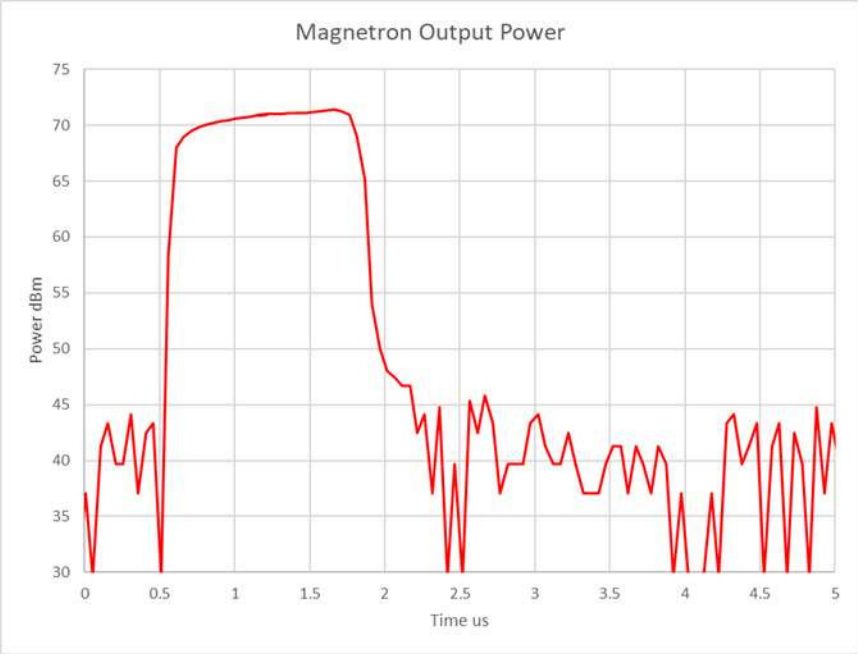

Figure 4: Output pulse from one of the high power microwave sources to be used as initial drivers for the experiments

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