Contribution ID: **27** Type: **Short Contributed Oral**

Development of fast and scalable hybrid profile reflectometry for real-time plasma control

On the pathway to delivering net-energy power plants, microwave diagnostics offer a promising solution for real-time control of several parameters related to electron temperature and density profiles, as well as magnetic-field pitch angle. Microwave diagnostics are promising because the wavelength range is at a sweet spot between a few millimetres and a few centimetres, providing excellent robustness and potential for cm to sub-cm precision; and their measurement speed is compatible with real-time control.

One critical application foreseen via microwave reflectometry is the real-time control of plasma position and shape. As an example, the implementation foreseen for DEMO[1] encompasses two poloidal arrays of 16 lines-of-sight each, with a similar approach being assessed for STEP. Some challenges in developing such systems include the real-time frequency calibration of frequency-swept oscillators, the challenge with out-of-the-midplane lines-of-sight where cut-off layer curvature can potentially play a role, the cooling of the front plasma-facing elements, the space available for testing multi line-of-sight prototypes in operating experiments, the complexity and associated prototyping cost for a large number of reflectometers, and the reliable evaluation of the accuracy and precision that will be achieved.

A multi-line-of-sight prototype is being developed for deployment on MAST-U, starting with a single line-of-sight at the midplane, to mitigate some of the aforementioned challenges and also likely uncover unforeseen obstacles in real-time operation. The implementation on MAST-U at first minimizes the use of waveguides and plasma-facing components, as these challenges should be tackled on a harsher environment. The focus is rather on developing scalable solutions for the backend electronics, which encompasses deploying the fastest cost-effective ADC/DACs and host FPGAs, as well as modular surface-mount drop-in RF components for rapid prototyping and reduced footprint and overall overhead. Because of the reduced cost and footprint, high signal generation flexibility and high speed that these systems provide, they will also enable us to explore a combination of multiple operational modes. The first candidate to be tested is the use of short pulse reflectometry to constrain the initialization of profile reconstruction from FMCW (Frequency-Modulated Continuous Wave) measurements, be it from X-mode first-fringe detection and/or O-mode estimated non-probed density profile.

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Track Classification: withdrawn