Proceedings of the 14th International Reflectometry Workshop - IRW14 (Lausanne) 22 – 24 May 2019

Editorial

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The 14th International Reflectometry Workshop for Fusion Plasma Diagnostics (IRW14) was held at the Ecole Polytechnique Fédérale de Lausanne (EPFL) and the Swiss Plasma Center (SPC) in Lausanne between the 22nd and 24th May 2019. The workshop was organized in collaboration with the International Atomic Energy Agency (IAEA).

The IRW series is the main biennial forum for the plasma fusion community to meet and discuss the latest technological and hardware developments, experimental results and advances in theoretical and numerical simulation codes as well as data analysis techniques applied to millimetre and microwave reflectometry for diagnosing high temperature fusion plasmas. The series has been running since 1992 when the first workshop was held as an IAEA Technical Committee Meeting at JET, England.

This was one of the largest workshops of the series with some 43 participants from across Europe, Asia, Russia, and the US. A total of 41 talks (20 minute duration plus 10 minutes for questions and discussions) were presented over a packed 3 days, covering theoretical, modelling, experimental and engineering aspects of microwave reflectometry and closely related subjects. Every participant has the opportunity to present a contributed oral paper. There are no review or invited papers. Allowing significant time for a rigorous discussion of each contribution is a particular feature of the workshop. Nevertheless, it is always a challenge, and in particular for this meeting, to balance a sufficient discussion period against the constraints of organisational planning and the desire for a late closing agenda. If, as anticipated, the current level of workshop participation is maintained then it will be necessary to extend the meeting length in future.

The workshop proceedings presented here contains 27 contributed papers covering the full range of topics of the workshop. The papers have been lightly refereed, but are otherwise in as-author-supplied manuscript form.

This workshop followed recent trends with both normal incidence density fluctuation reflectometry and oblique incidence Doppler reflectometry/backscatter (for plasma flow measurement) remaining strong topics with 7 and 12 papers respectively. However, a welcome surprise was a resurgence in the traditional area of density profile measurements (7 papers) - including the development of 1μs full-band profile sweep times on ASDEX Upgrade (AUG), and the reemergence of ultra-short pulse profile reflectometry on the TCV tokamak.

Diagnostic hardware developments are a main driver in our field and a particular highlight of this meeting was the dual Comb reflectometer development for LHD and JT-60SA. Here, two frequency comb generators are employed for the probing and receiving circuits forming a cost effective and robust multi-point measurement system. First results from LHD are impressive. An alternative comb system is also in development for AUG. Back in 2013/15 at the IRW11 & IRW12 workshops the design and development of two types (frequency keying and ganged phase shifter) of Phased Array Antenna (PAA) systems were introduced. Now, at this meeting first results from a bistatic, 32-element frequency-keyed PAA installed on the W7-X stellarator were presented, showing high quality Doppler flow measurements across the W7-X edge region.

Another form of phased array antenna Doppler reflectometer is the Synthetic Aperture Microwave Imaging (SAMI) system developed for MAST and NSTX. Since its introduction, also at the IRW12,

there has been significant technological development and a particular highlight of this meeting were the high-end technology presentations from the York plasma group on the SAMI-2 antenna and micro-strip based receiving circuits. These microwave technology developments offer a window on to the exciting area of compact heterodyne receivers and FMCW radar circuits now available on printed circuit boards for the automotive industries. It is only a matter of time before bespoke full-band FM reflectometers in the U to W-band become commercially viable. The availability of such compact, cost-effective reflectometers-on-a-chip, together with direct data acquisition at microwave frequencies may revolutionize the way we implement and use active microwave probing in the harsh fusion environment.

Together with the contributions on microwave scattering and the (reflectometer-ECE) nT-cross-phase measurements this continues a deliberate attempt started two meetings ago to broaden the traditional scope of the workshop. While retaining the core aspect of the workshop series, this development is not only appropriate, as it reflects the broader change of emphasis in the microwave fusion diagnostic community, it is also inevitable as technological developments evolve which are common across the various microwave diagnostic specialities. It is aimed to encourage more such cross-topic contributions in future meetings, in particular in the area of high-end microwave technology developments, applications and hardware innovations.

Full-wave (FDTD) numerical simulation codes are the primary tool for modelling the reflectometer diagnostic instrument response function and continue to form a large topic in all recent workshops (9 papers alone in these proceedings). Here, finally the discrepancy between experimental Doppler reflectometer wavenumber spectra measurements and simulations has been resolved with high resolution 2D full-wave simulations in X and O-mode revealing an underlying issue of numerical resolution. Despite the power of 2D and 3D numerical simulations they are not especially cost or time effective, hence the need for tractable theoretical and analytic models remains important. For example, while full-wave simulations continue to validate analytic theory for the behaviour of Doppler reflectometry, the "holy grail" of extracting calibrated density fluctuation $\delta n/n$ levels from standard normal incidence fluctuation reflectometer using analytic formulas remains difficult.

While AUG and TJ-II continue to be mainstays of the European reflectometry activity, there was a notable absence of the other "older" machines (JET, DIII-D) at this workshop. These were replaced by the welcome presence of new machines, notably W7-X stellarator (5 papers) which has recently completed its OP1.2b experimental campaign with new diagnostics and new physics, as well as the continuing presence of EAST, HL-2A and KSTAR. Several machines are currently undergoing upgrades, Tore Supra to WEST, as well as MAST and NSTX devices, hence only diagnostic design plans could be presented.

Also well represented at this workshop were reports on the developments in the ITER reflectometer systems (2 papers but 5 presentations) which are nearing their final design stages. Nevertheless, the recent cancellation of the ITER Plasma Position Reflectometer (PPR) system is a disappointment. This leaves just two reflectometer systems for ITER, the multi-antenna Low-Field-Side (US) and the High-Field-Side (RF) systems. Both system designs are progressing well, but severe technical challenges remain. ITER, of course, is still several years from operation. In the meantime, we look forward to many new results from the WEST, MAST-U, NSTX-U and JT-60SA devices.

Overall, the field remains very healthy with a strong diagnostic base continuing to deliver exciting new physics insights on plasma turbulence and flows. Together with the promise of significant new hardware developments and new machines coming online, this is a good time for reflectometry.

The next workshop, IRW15, is scheduled for late spring 2021 and is planned to be hosted at the ITER Organization headquarters based in St Paul Lez Durance (Cadarache), France.