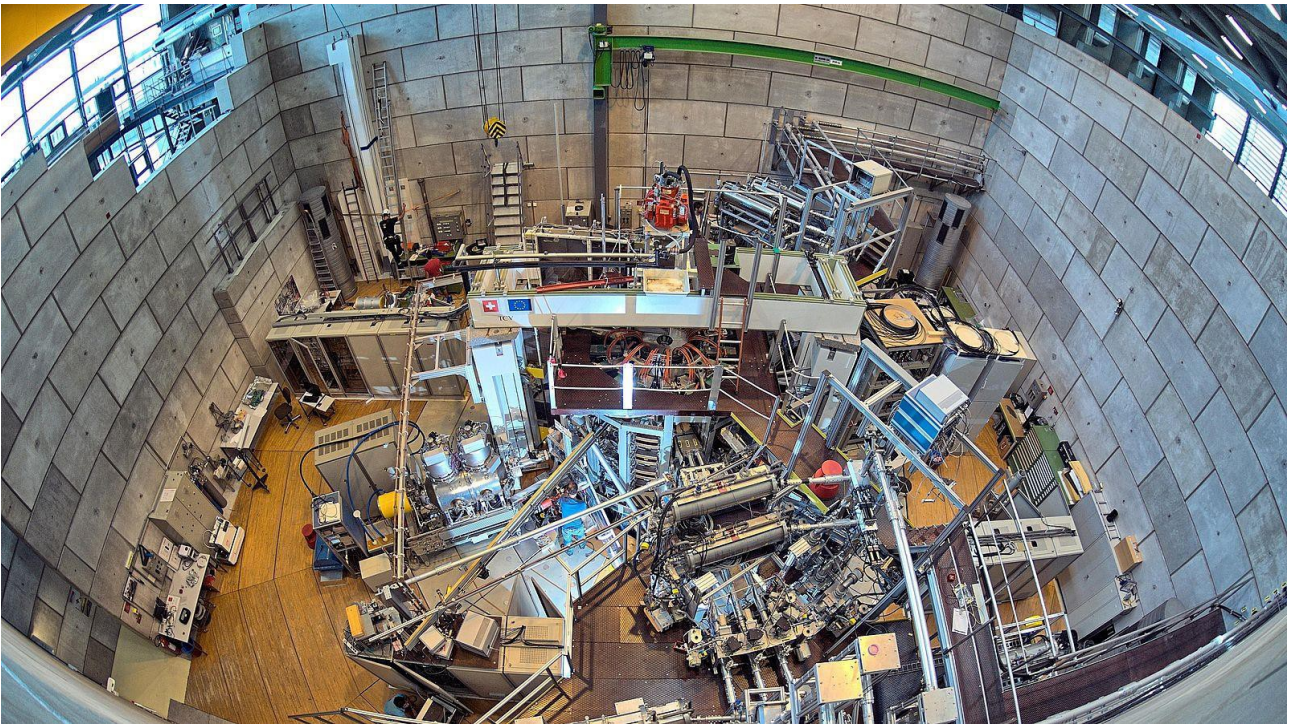


# EPFL



## **Proceedings of the 14th International Reflectometry Workshop for Fusion Plasma Diagnostics (IRW14)**

**Swiss Plasma Center  
Ecole Polytechnique Fédérale de Lausanne  
22 – 24 May 2019**

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IRW14

# Proceedings of the 14th International Reflectometry Workshop for Fusion Plasma Diagnostics (IRW14)

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22 – 24 May 2019

Organized in co-operation with the  
International Atomic Energy Agency (IAEA)

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

## **Editorial**

G.D.Conway (IPP) - October 2019

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 1 $\mu$ s 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.



## IRW14 Workshop participants

ALLEN, Joe	University of York, UK
BIANCHETTI MORALES, Rennan	CCFE, UK
CARRALERO, Daniel	CIEMAT, Spain
CLAIRET, Frederic	CEA - Cadarache, France
CODA, Stefano	EPFL - SPC, Switzerland
CONWAY, Garrard	IPP Garching, Germany
ESTRADA, Teresa	CIEMAT, Spain
FREETHY, Simon	CCFE, UK
GUSAKOV, Evgeniy	Ioffe institute, Russia
HALL-CHEN, Valerian	University of Oxford / CCFE, UK
HAN, Xiang	Forschungszentrum Juelich GmbH, Germany
HAPPEL, Tim	IPP Garching, Germany
HEURAUX, Stephane	IJL-CNRS-Univ of Lorraine, France
HOEFLER, Klara	IPP Garching, Germany
KRAMER, Gerrit J.	PPPL, Princeton University, USA
KRÄMER-FLECKEN, Andreas	Forschungszentrum Juelich GmbH, Germany
LECHTE, Carsten	IGVP, Stuttgart, Germany
LEE, DongJae	National Fusion Research Institute, South Korea
LEE, Woochang	National Fusion Research Institute, South Korea
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MEDVEDEVA, Anna	CEA Cadarache, France
MOLINA CABRERA, Pedro	EPFL - SPC, Switzerland
MUSCATELLO, Christopher	General Atomics, USA
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PORTE, Laurie	EPFL - SPC, Switzerland
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SIRINELLI, Antoine	ITER Organization, France

TEPLOVA, Natalia	Ioffe Institute, Russia
TOKUZAWA, Tokihiko	NIFS, Japan
TRIER, Elisee	IPP Garching, Germany
VANN, Roddy	University of York, UK
VERMARE, Laure	LPP, Ecole Polytechnique, France
VERSHKOV, Vladimir	NRC "Kurchatov institute", Russia
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WANG, Yumin	Institute of Plasma Physics, Hefei, China
WINDISCH, Thomas	IPP Greifswald, Germany
WOODWARD, David	University of Strathclyde, UK
ZADVITSKIY, Georgiy	Universite de Lorraine, France

## IRW14 Workshop agenda

	Wednesday 22 May 2019	Thursday 23 May 2019	Friday 24 May 2019
08:30	Introduction	<b>S. Heuraux</b> : Full-Wave simulation of the enhanced Upper-Hybrid Resonance Scattering (UHRS)	<b>L. Vermare</b> : Perpendicular flows in Tore Supra plasmas
09:00	<b>P. Molina-Cabrera</b> : AWG-driven short pulse reflectometer diagnostic in the TCV tokamak	<b>J. Vicente</b> : Full-wave simulations of conventional O-mode fixed frequency probing of plasma turbulence with REF MUL/GEMR codes	<b>M. Peret</b> : Perpendicular velocity evolution in the first plasmas of the WEST tokamak
09:30	<b>Y.M. Wang</b> : Recent status of the electron density profile and fluctuation reflectometer on EAST tokamak	<b>P. Molina-Cabrera</b> : Doppler back-scattering diagnostic in the TCV tokamak	<b>T. Estrada</b> : Turbulence k-perp spectrum & perpendicular plasma flow asymmetries measured using Doppler reflectometry at TJ-II plasmas
	coffee break	coffee break	coffee break
10:30	<b>F. Claret</b> : 1msec broadband frequency sweeping reflectometry for plasma density and fluctuation profile measurements	<b>T. Tokuzawa</b> : Dual-comb microwave Doppler reflectometer system in LHD & feasibility study for JT-60SA Doppler reflectometer	<b>K. Höfler</b> : Study of poloidal asymmetries in the flow perpendicular to the magnetic field of the ASDEX Upgrade tokamak
11:00	<b>A. Medvedeva</b> : Development of the synthetic diagnostic for the ultra-fast swept reflectometer	<b>Z.B. Shi</b> : Development of multi-channel Doppler reflectometer for MAST-U and HL-2A	<b>S.J. Freethy</b> : Measurements of the density-temperature cross-phase angle of turbulent fluctuations at ASDEX Upgrade and comparison to theory
11:30	<b>R.B. Morales</b> : The reconstruction of hollow areas in the density profiles from frequency-swept reflectometry	<b>R. Vann</b> : SAMI-2 ; 2-D microwave Doppler backscattering at MAST-U	<b>R. Sabot</b> : Trends emerging from a systematic analysis of a decade of fluctuation reflectometry measurements on Tore Supra
	lunch	lunch	lunch
13:30	<b>T. Happel</b> : Design of a variable frequency comb reflectometer system for the ASDEX Upgrade tokamak	<b>J.O. Allen</b> : Dual-polarisation broadband sinuous antenna and RF downconverter design for the Synthetic Aperture Microwave Imager-2 diagnostic	<b>W. Lee</b> : Effect of the quasi-coherent mode on the intrinsic rotation of ohmic plasmas in KSTAR
14:00	<b>S-H. Seo</b> : Precise density profile reconstruction of FMCW reflectometer	<b>T. Windisch</b> : Doppler Reflectometry at Wendelstein 7-X	<b>E. Trier</b> : Comparison of poloidal correlation reflectometry measurements in W7-X and ASDEX Upgrade plasmas
14:30	<b>X. Han</b> : Development of a dual band X-mode reflectometer for the density profile measurement at the ICRF antenna in W7-X	<b>D. Carralero</b> : First V-band Doppler reflectometer results from the OP1.2b campaign in Wendelstein 7-X	<b>V.A. Vershkov</b> : Spatial structure of density fluctuations in T-10 tokamak
15:00	<b>J.W. Oosterbeek</b> : Edge electron density profile reflectometer study W7-X	<b>D. Woodward</b> : Full wave numerical simulations of cross polarization Doppler backscattering	<b>A. Krämer-Flecken</b> : Effects of the magnetic topology on turbulence in the SOL and plasma edge of W7-X
15:30	coffee break	coffee break	<b>G.V. Zadivitskiy</b> : Modelling of simultaneous measurements of turbulence correlation lengths and turbulence amplitudes using multichannel radial reflectometry

16:00	<b>A. Sirinelli</b> : Update on ITER construction and integration of reflectometry systems	<b>V.H. Hall-Chen</b> : Modelling the effects of misaligning the probe beam and magnetic field in Doppler backscattering measurements	
16:30	<b>J. Martinez</b> : In-port-plug transmission line design of the ITER plasma position reflectometer	<b>E.Z. Gusakov</b> : Validation of full-f global gyrokinetic modelling results against the FT-2 tokamak Doppler reflectometry data using different synthetic diagnostics	
17:00	<b>D.A. Shelukhin</b> : Findings on the way towards ITER HFS reflectometry	<b>N. Teplova (V. Bulanin)</b> : Full wave modelling of Doppler backscattering from filaments	
17:30	<b>C.M. Muscatello</b> : Preliminary design overview and performance assessment of the low-field-side reflectometer for ITER	<b>G.D. Conway</b> : Recent progress in modelling the resolution and localization of Doppler reflectometry measurements	
18:00	<b>G.J. Kramer</b> : Simulation of the antenna-plasma coupling for the ITER low-field-side reflectometer system	<b>C. Lechte</b> : Fullwave Doppler Reflectometry Simulations for Turbulence Spectra Using GENE and IPF-FD3D	
18:30	<b>D.J. Lee</b> : Collective Scattering system developed for high-k turbulence study in KSTAR	Tour of TCV & SPC	