Specialists Working Group on Microwave Diagnostics
Report to ITPA TGD-26 (Pohang)

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Group activity summary

- **EU** New reflectometer developments on AUG (Virtual Institute on Advanced Microwave Diagnostics) – report on UFS Refl. below
  - DTU & IST form consortium on ITER CTS – report below

- **KR** New results from MIR on KSTAR – report below

- **US** NSTX reflectometer under-going upgrades (ORNL)
  - ITER LFSR transmission line mock-up planned this summer (GA/UCLA)
  - No direct US activity on ITER ECE – waiting for next round of US-IOP contracts

- **RF** Prototyping ITER HFSR in-VV w/g, antennas + Mock-up built to simulate blankets/ in-VV environment (Kurchatov)

- **IO** HFSR: Work on in-vessel component interfaces (vacuum vessel, blankets..)
  - LFSR: Hybrid antenna solution in consideration, enabling both bi- & monostatic measurements
    Main challenge: integration in Eqp11 environment (front-end cooling in particular)
  - ECE: 2 papers: Eng. aspects (V.Udintsev) & Status (G.Taylor) @ EC-18 workshop in Japan

- **Misc** Action items
  - JEX DIAG-03 – report below
### Actions

- **Action 22a364:** Develop road map for escaping alpha measurement
  - Requested possible input from CTS experts
  - Nothing to report as yet

- **Action 22a365:** Develop JEX proposal for benchmarking of modelling codes of wall reflections
  - No new microwave modelling developments to report

- **Action 22a371:** Assess RE meas. capability (confined & escaped) by potential diags.
  - Completed from MWG side

- **Action 24a382:** Review IO’s document on PCS requirements
  - Completed from MWG side

- **Action 24a387:** Review IDD analysis (LA & MW)
  - Completed from MWG side

- **Action 25a392:** Compile monostatic test possibilities by adaption of present reflectometers
  - Tests planned for JET and AUG. Report results at next meeting
JEX: DIAG-03

JEX report update for 2014 – Anne White

for DIAG-03: “Resolving the discrepancy between ECE and TS at high Te”

Experimental Activities:

- **DIII-D**: Proposal for run time in support of JEX DIAG-03 was given low priority (Max Austin)
  - Proposal builds on past DIII-D expts. & includes TS-ECE comparisons in high Te plasmas (NBI and/or ECR heated) plus 2nd & 3rd harmonic ECE radiometer comparisons with Michelson data
  - Models for emission will be compared with measurements

- **JET**: Maybe opportunity to revisit JEX DIAG-03 at JET
  - Expts. to further probe role of fast ions would be useful; building on past work by E. de la Luna

- **ASDEX Upgrade**: Excellent ECE & TS profile systems are in place, plus AUG has planned ECRH and ICRH upgrades, and has substantial NBI heating capability
  - JEX DIAG-03 expts. could be conducted at AUG in the future – this possibility will be explored

- **TFTR**: Old data sets available and could be data mined to re-investigate TS - ECE discrepancy in NBI heated plasmas (no ICRH) and in plasmas with both NBI heating & ICRH

Suggestion: JET Scientist assume lead for JEX since JET is only outstanding machine seeing TS/ECE discrepancy
JEX: DIAG-03

JEX report update for 2014 – Anne White

for DIAG-03: “Resolving the discrepancy between ECE and TS at high Te”

Theory/Modeling Activities:

- Proposal submitted to US-DOE by MIT (A. White & P. Bonoli) to fund a theory/simulation study of the TS ECE discrepancy was declined

- Proposal would have focused on NBI & ICRH plasmas (e.g. C-Mod, JET, TFTR data sets & future possible work at ASDEX Upgrade and DIIID) using CQL3D code to model effects of fast ions on the electron distribution profile with 1 FTE (1 PPY) for 3 year time period

- Currently no plans for re-submission

- No further news from other machines or other modeling/theory groups
DTU and IST obtained the F4E CTS framework contract

- In February 2014 DTU and IST signed contract with F4E on:
  
  *Framework Partnership Agreement F4E-FPA-393 for Diagnostic Design and Development: Low Field Side Collective Thomson Scattering*

- DTU and IST-IFPN (Portugal) form a consortium with DTU Physics as administrator – and 2/3 of the budget & tasks

- DTU  Technical Responsible Person (TRP): Søren B Korsholm

- IST  TRP: Bruno S. Gonçalves and Paulo Varela

- F4E  TRO: Arcos Paco Sanchez

- Overall budget: 7.4 MEuro (~54 ppy) over 4 years

- F4E contribution: 3.4 MEuro
New microwave diagnostics on AUG

- Several new microwave diagnostics recently installed on ASDEX Upgrade as part of EU Helmholtz Virtual Institute on Advanced Microwave Diagnostics

  - New. Sec.2: FZJ Ka/U-band Poloidal Correlation Reflectometer

  - New. Sec.5: CEA V/W-band X-mode Ultra-Fast Swept reflectometer

  - Old. Sec.5: IST Multi-band profile & fluctuation reflectometers

  - Sec.13: IPP O & X-mode V-band Doppler reflectometers

  - New. LPP 3rd channel

  - Sec.11: IPP W-band X-mode Doppler refl.

  - New. LPP 2nd channel

  - New. Sec.9: MIT Correlation ECE Complements 1D ECE & 2D ECEI
Ultra-Fast Swept Reflectometer on AUG

- Report here first results from newly installed Ultra-Fast swept reflectometer (UFSR)
- Systems in V-band (50-75 GHz) & W-band (75-105 GHz) originally developed on Tore Supra now transferred to ASDEX Upgrade
- Diagnostic will allow study of radial & temporal dynamics of turbulence with 2 μs resolution
- Main objective is to take advantage of the UFSR capabilities to study density profile evolution & fast dynamics and density fluctuation characteristics

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Ultra-Fast Swept Reflectometer

- Former Doppler reflectometer location in Sec.5
- New in-vessel bistatic antennas installed
- Bug fixing: March – April 2014
Reflectometer Characteristics

- X-mode V & W frequency bands: (50 – 75GHz & 75 – 105GHz)
- Sweep time: 2 $\mu$s - Dead time: 1 $\mu$s
- 10000 profiles/shot (memory dependent)

**Standard mode**
Acquisition during the whole discharge

**Burst mode**
Acquisition at fast rate 2/1 $\mu$s

![Graphs showing standard and burst modes of operation](image)
First Results: Density Profiles

- X-mode UFS refl. = excellent agreement with other $n_e$ profile diagnostic
- LFS SOL to HFS coverage for opt. $B_T$ & $n_0$
- Exceptional time resolution → Profile dynamics
First Results: Density Fluctuations

- Burst mode: 1400 profiles $2\mu s/1\mu s$

Phase fluctuations of reflected signal
mode $q = 1$ (?) 2 kHz
Long-wavelength density turbulence measurements via microwave imaging reflectometry (MIR) system

W. Lee, J. Leem, G. S. Yun (POSTECH), and H. K. Park (UNIST)

Center for Fusion Plasma Diagnostic and Steady State Operation
Coherent & turbulent $n_e$ fluctuation meas. with MIR

1. Measurement of coherent fluctuations

- Detection channels: 2 by 16 (radial and poloidal)
- Detection poloidal wavenumber: $k_0 < 3 \text{ cm}^{-1}$
- Radial coverage: $0 < r/a < 0.8$
- Time resolution: 1 or 2 $\mu$s

2. Measurement of turbulent fluctuations
Ion-scale turbulent density fluctuations were measured in KSTAR ohmic & NBI L-mode plasmas

- Turbulent density fluctuations measured in ohmic & 1.4 MW NBI L-mode plasmas:
  - no coherent mode
  - clear cross phase for $k_\theta < 3 \text{ cm}^{-1}$
- $\rho_i \sim 0.23 \text{ cm} \ (T_i \sim 1 \text{ keV})$
- Normalized poloidal wave-number $k_\theta \rho_i < 0.6$
- ITG and/or TEM are most unstable in $k_\perp \rho_s = 0.1 - 0.4$
- Measured fluctuations are expected to be ITG or TEM
Turbulent density fluctuations with MIR

Apparent poloidal velocities $V_{\theta \text{Lab}}$ vs. poloidally projected toroidal fluid velocities $U_\phi \tan \alpha$

- $V_{\theta \text{Lab}}$ (by MIR) were compared with $U_\phi \tan \alpha$ (by CES and EFIT) in 1.4 MW NBI L-mode plasmas
- There are 2-3 km/s differences in some cases
- It is not clear yet whether it is due to:
  - finite contribution of the sum of $U_\theta$ and $V_{\phi h}$
  - or measurement uncertainty
- We need CES system for $U_\theta$ measurements
Apparent poloidal velocity of fluctuations in the lab. frame $V_{\theta\text{Lab}}$ using correlation methods

- Mean apparent poloidal velocities $V_{\theta\text{Lab}}$ of density fluctuations were obtained using two correlation methods:
  - Cross phase spectrum & dispersion with complex signals
    
    $$k_\theta(f) = \frac{\Delta \phi_{xy}(f)}{\Delta z}$$

  - Time delayed cross correlation with phase signals
    
    $$C_{xy}(\tau) = \frac{\sigma_{xy}(\tau)}{\sqrt{\sigma_{xx}(0)\sigma_{yy}(0)}} ,$$
    
    $$\sigma_{xy}(\tau) = \frac{1}{N-1} \sum_{i=1}^{N}(x_i - \bar{x})(y_{i+\tau} - \bar{y}).$$

- Two methods give similar velocities

W. Lee et al., NF 54, 023012 (2014)
Meaning of $V_{\theta \text{Lab}}$ measured by MIR system

- MIR system measures apparent poloidal velocities $V_{\theta \text{Lab}}$ of density fluctuations in the lab. frame which is given by

$$v_{\theta \text{Lab}} = u_{\theta} - u_{\phi} \tan \alpha + \frac{V_{\text{ph}}}{\cos \alpha},$$

- where $U_{\theta}$ & $U_{\phi}$ are the poloidal & toroidal plasma flow velocities, $\alpha$ is the magnetic field pitch angle, and $V_{\text{ph}}$ is the phase velocity of turbulence in the plasma (ion fluid) frame.

- Note $V_{\theta \text{Lab}}$ is not the poloidal fluid velocity $U_{\theta}$.

- We need CES for $U_{\theta}$ measurements.