Review of 2 reports from the Microwave diag. Specialists Working Group to the ITPA Diagnostics Topic Group

G.D.Conway, plus many co-authors

Part 1. “Requirements for calibration of ITER microwave based diagnostic front-end components” (May 2010)

Part 2. “Survey and assessment of ECE and Reflectometer calibration techniques” (April 2011)

Selected slides from:

Specialists Working Group on Microwave Diagnostics Report to ITPA TGD-18 (Oak Ridge)

G.D.Conway, M.E.Austin, V.S.Udintsev *et al.*

(14 May 2010)

Microwave diag. calibration & test requirements

G.D.Conway, G.Vayakis, G.Hanson, S.B.Korsholm, V.S.Udintsev, V.Petrov, M.E.Austin, W.A.Peebles & T.Estrada

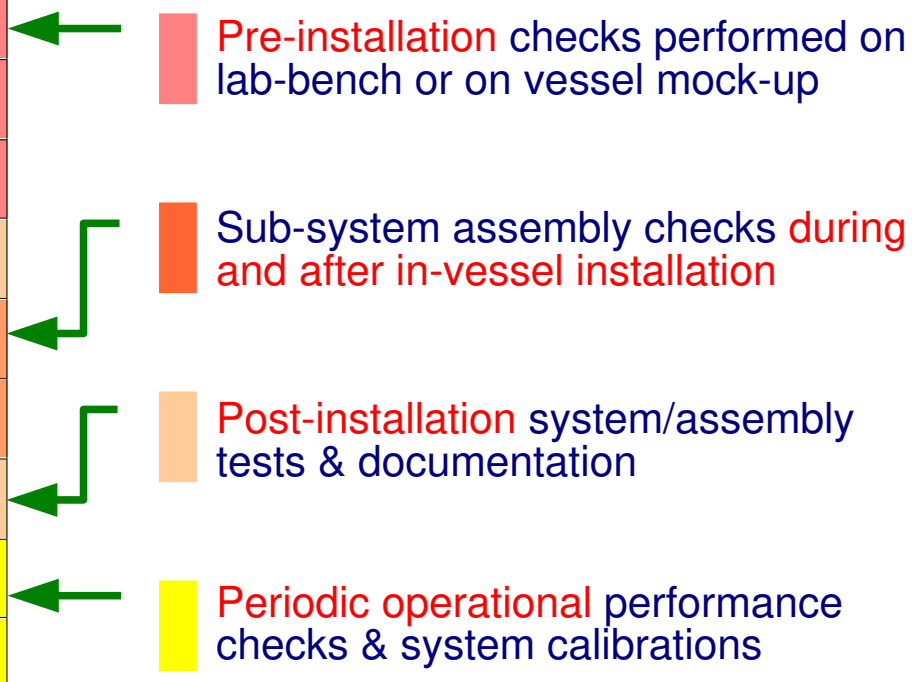
Action 16a312: Microwave Working Group to assess generic test/validation requirements of microwave transmission system and reflectometer/ECE diagnostic calibration needs.

- Established test & calibration procedures (before, during & after installation) are essential to ensure optimal operation of all diagnostics
- Microwave diags. (ECE, Reflectometry, Refractometry, CTS, ...) have many common features
- *Front-end* (metallic antennae & waveguides) + *Back-end* (transmitters, receivers & electronics)
- Front-end components are generic → common test requirements, but diagnostic back-ends are specific → individual test requirements
- Overall system performance depends on careful front-end installation & alignment → most critical testing
- Assessment of test procedures & calibration undertaken → Report prepared & distributed: "*Requirements for calibration & testing of ITER microwave based diagnostic front-end components*" *(May 2010) :* ***ITER_D_33ZRFR***

Test measurements – 1: Categories

- Series of test measurements identified & compiled (see table)
- System calibration requirements also considered

Test measurement	*Category*
1. Microwave component performance	pre
2. Antenna radiation pattern	pre
3. Antenna cross-coupling	pre/post
4. Antenna alignment	post
5. Electrical isolation / DC breaks	during
6. Waveguide continuity	during
7. Waveguide microwave performance	post
8. System protection	pre & op.
9. Calibration hardware	pre & op.



- (Component) manufacturing compliance (tolerance) checks are implicit

Test measurements – 2: Components

- *Front-end components* = antennas, oversized w/g, mitre-bends, swivel joints, vacuum windows, expansion joints, air-gaps, mode-filters, tapers, splitters, combiners, polarizers, QO couplers ...

Test measurement	*Category*
1. Microwave component performance	pre
2. Antenna radiation pattern	pre
3. Antenna cross-coupling	pre/post
4. Antenna alignment	post
5. Electrical isolation / DC breaks	during
6. Waveguide continuity	during
7. Waveguide microwave performance	post
8. System protection	pre & op.
9. Calibration hardware	pre & op.

- Lots of components – lots of things to go wrong!
- Insertion loss, reflection coefficient, mode conversion, …
- Must document individual component performances
- Check for faults + documentation allows subsequent identification of system degradation

- ECRH stray radiation protection: w/g filters, fast acting shutters, isolators, arc detectors, interlocks, …
- Test correct operation
- Establish test procedures: *like testing the fire-alarm bells!*

Test measurements – 3: Antennas

Test measurement	*Category*
1. Microwave component performance	pre
2. Antenna radiation pattern	pre
3. Antenna cross-coupling	pre/post
4. Antenna alignment	post
5. Electrical isolation / DC breaks	during
6. Waveguide continuity	during
7. Waveguide microwave performance	post
8. System protection	pre & op.
9. Calibration hardware	pre & op.

- Antenna rad. pattern is fundamental
- Must characterize all antennas
- Measure pattern in far-field @ 3 freq. in O & X-mode polarization
- 3 dB half-width vs distance from ant.

- For antenna clusters, coupling causes unwanted signal cross-talk / leakage
- Measure coupling
- Measure *Tx/Rx* coupling vs distance with plate reflector

- Alignment = Line-of-Sight is crucial for Doppler refl. & CTS
- Document absolute antenna position & orientation
- Use in-vessel CMM (coord. measuring machine)

Test measurements – 4: Waveguides

Test measurement	*Category*
1. Microwave component performance	pre
2. Antenna radiation pattern	pre
3. Antenna cross-coupling	pre/post
4. Antenna alignment	post
5. Electrical isolation / DC breaks	during
6. Waveguide continuity	during
7. Waveguide microwave performance	post
8. System protection	pre & op.
9. Calibration hardware	pre & op.

- Halo currents etc. induce $j \times B$ forces → distort / damage in-vessel w/g
- DC breaks + guide-vessel isolation prevent ground loops & arcs
- Perform high voltage isolation testing

- Waveguide breaks/flange discontinuity create reflections + leakage
- Check inter-guide leakage/ isolation
- Check w/g alignment + straightness
- Measure & mitigate w/g reflections

- Oversized w/g prone to high order modes → power loss & freq. Holes
- Measure system w/g performance: losses, power trans. curve (holes & resonances) + polarization rotation
- Check operation of passive w/g comp. splitters, tapers, QO-couplers, ..

Test measurements – 5: System calibration issues

- System calibration is diagnostic specific → generally require temporary additional hardware
- Generate calibrated reference signal → obtain signal correction or conversion factor

Test measurement	*Category*
1. Microwave component performance	pre
2. Antenna radiation pattern	pre
3. Antenna cross-coupling	pre/post
4. Antenna alignment	post
5. Electrical isolation / DC breaks	during
6. Waveguide continuity	during
7. Waveguide microwave performance	post
8. System protection	pre & op.
9. Calibration hardware	pre & op.

- **Calibration requirements**
- **ECE:** Hot & Cold source
- **Reflectometry:** Line length meas.
- **CTS:** Similar issues & requirements as ECE

- Thermal expansion, mechanical dislocation + component degradation → regular re-calibration
- Calibration hardware must be tested and test procedures established !

- Diagnostic protection issues discussed in report *"Stray radiation protection of ITER microwave based diagnostics" (April 2010) :* ***ITER_D_33PKHG***

Selected slides from:

Specialists Working Group on Microwave Diagnostics Report to ITPA TGD-20 (Noordwijk)

G.D.Conway, M.E.Austin, V.S.Udintsev

(26 May 2011)

ECE & Reflectometer calibration survey – 1

Action 18a335: Microwave Working Group to collate the history and actual performance of in-situ calibration for ECE and reflectometry across machines

Many contributors ,..

- Aim is to collate the history and actual performance of in-situ calibration for ECE and reflectometry from all the experts from various machines - before they retire and the information is lost!
- Systematically document:
  - Calibration techniques (what methods actually used and tried)
  - Long & short term calibration performance – drifts etc
  - How robust is the calibration – ie. reliability of calibration & how to check the calibration of the calibration method/source
  - Associated problems, tricks and successes
  - Other issues such as known discrepancies, eg. between ECE and Lidar and impact of non-Maxwellian distributions
- Contributions solicited – 19 ECE & 10 Refl. responses to-date.
- Rreport prepared: *"Survey and assessment of ECE and reflectometer calaibration techniques" (April 2011)* ***ITER_D_3622CE***
- Should lead to a "best procedure" for ITER diagnostics

ECE & Reflectometer calibration survey – 2

Reflectometry

- Several parameters to calibrate depending on reflectometer type:
  - Profile - Swept frequency (probe frequency, source freq. linearity, group delay)
  - Fluctuation (probe freq., I & Q offsets, phase)
  - Doppler (probe, freq., antenna alignment, receiver power, Doppler shift)
- Calibration techniques are performed mostly in lab. Few are in-situ.
  - Probe freq. calibration & stability → Frequency meters. Note growing use of synthesizers
  - Signal phase calibration → Use of known reflections, in-vessel mirrors etc.
  - Receiver power, line losses etc. → Power meters (necessary only for Doppler *k*-spectrum)
  - Antenna alignment → In-vessel Measurement Coordinate Machine + accurate drawings (critical parameter for Doppler – determines *k* probed)
  - Doppler frequency shift → Rotating grating wheel
- Issues
  - Dominant error is cutoff position – depends on n_e profile & *B*-field from other diagnostics
  - Even if poorly or un-calibrated, fluctuation refl. can provide useful physics

ECE & Reflectometer calibration survey – 3

ECE calibration issues

- Principally need to convert emission intensity (receiver power) to T_e
- Type of calibration and issues depends on measurement hardware (each pros & cons):
  - Michelson interferometer – baseline technique
  - Multichannel heterodyne radiometer – cheapest & most popular
  - Multichannel polychromator – less popular & mostly surpassed by radiometers
- Calibration approaches – in order of popularity
  - Absolute blackbody hot & cold source
  - Cross-calibration with other diagnostics – i.e. Thomson Scattering
  - Relative channel calibration using *B*-field ramps
  - Absolute calibrated microwave source (klystron or noise source)
- Issues
  - Instrumentation: SNR, w/g emission, source alignment and QO ant. replication etc.
  - Stability of calibration source is important (crucial for ITER in-vessel source)
  - Correct handling and propagation of errors → Bayesian approach proposed
  - Long term calibration is often remarkably stable, < 10% over years
- Survey provided wealth of technical information and details → Define best practise