P5-12 Microwave Imaging Reflectometry in LHD

16th International Toki Conference - Advanced Imaging and Plasma Diagnostics –
Ceratopia Toki, Gifu, JAPAN December 5-8, 2006

Introduction

The fusion research requires understanding of the energy transport in the magnetically confined plasma.
- Radial energy transport via plasma microturbulences
- Complex theoretical models visualized in 3-D pictures.

Why the microwave imaging diagnostics ?
- Powerful tool for understanding complex transport processes
- Experimental verification of fluctuation based transport physics
- Recent advances and new ideas in *mm* wavelength technology enable 3-D imaging diagnostics for advanced fusion research.

Electron cyclotron emission imaging (ECEI)
- Electron temperature (T_e) profile / fluctuation
  (*KASTEC in Kyushu Univ.*)

Microwave imaging reflectometry (MIR)
- Electron density (n_e) fluctuation
  (*NIFS*)

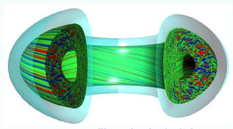
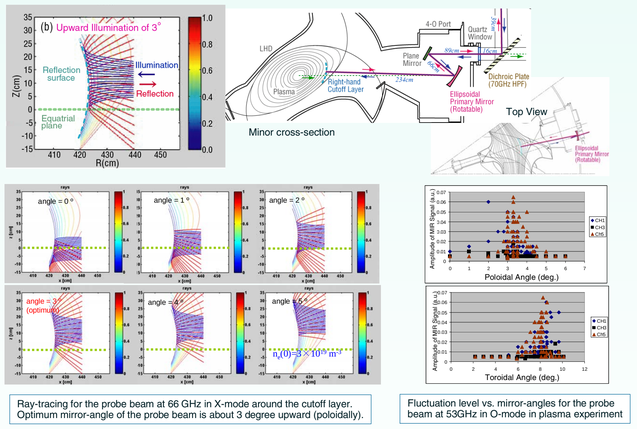


Figure is of calculations performed by GYRO-code

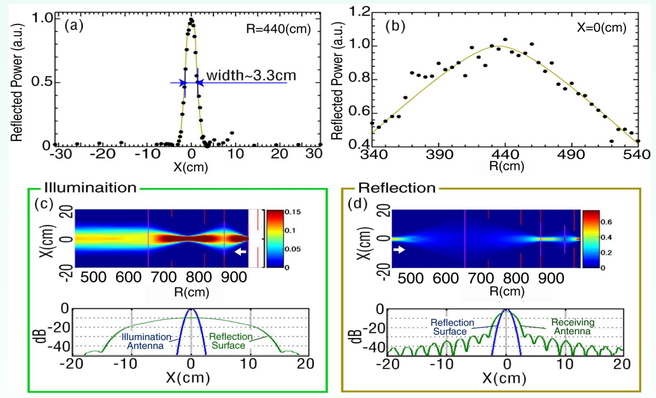
Ray-tracing and Optimum Mirror-Angles



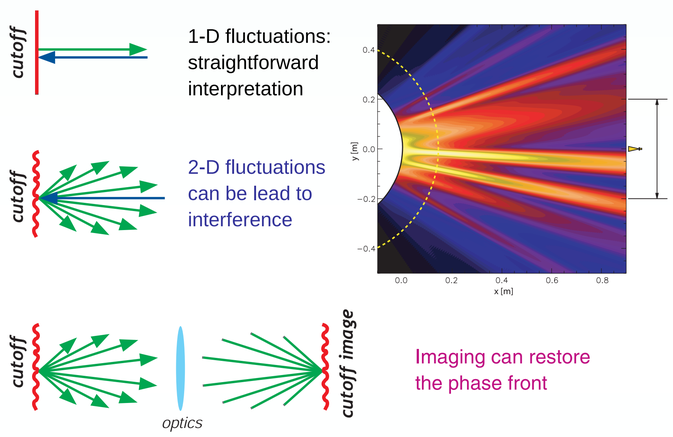
Ray-tracing for the probe beam at 66 GHz in X-mode around the cutoff layer. Optimum mirror-angle of the probe beam is about 3 degree upward (poloidally).

Fluctuation level vs. mirror-angles for the probe beam at 53GHz in O-mode in plasma experiment

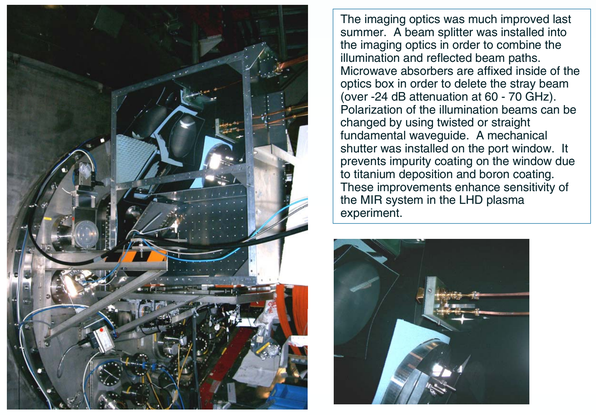
Measured and Calculated Beam Profiles



Microwave Imaging Reflectometry (MIR)

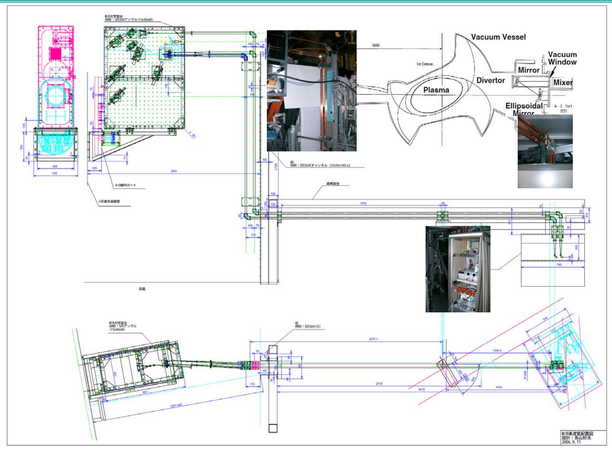


Imaging Optics

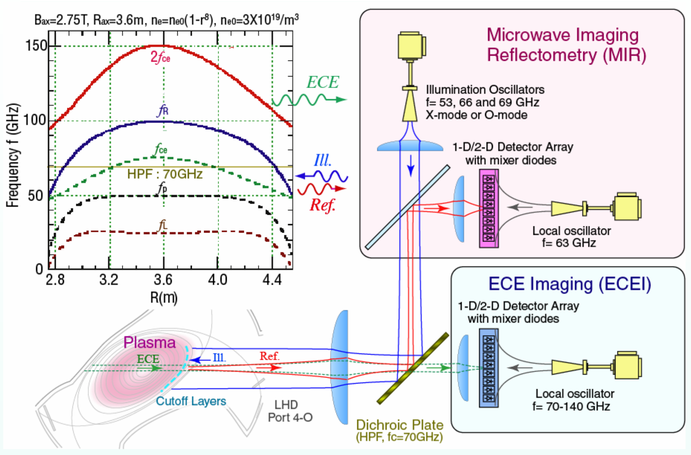


The imaging optics was much improved last summer. A beam splitter was installed into the imaging optics in order to combine the illumination and reflected beam paths. Microwave absorbers are affixed inside of the optics box in order to delete the stray beam (over -24 dB attenuation at 60 - 70 GHz). Polarization of the illumination beams can be changed by using twisted or straight fundamental waveguide. A mechanical shutter was installed on the port window. It prevents impurity coating on the window due to titanium deposition and boron coating. These improvements enhance sensitivity of the MIR system in the LHD plasma experiment.

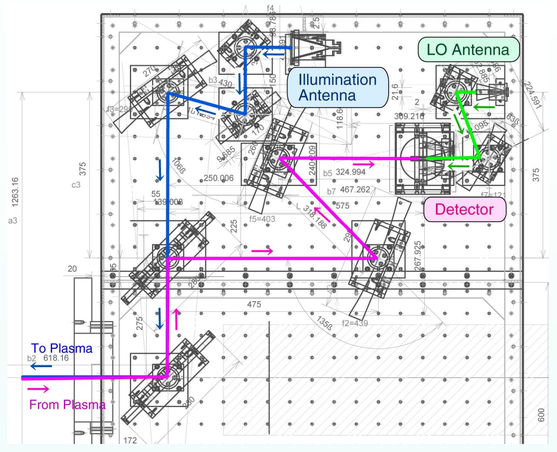
Oversize Waveguide System



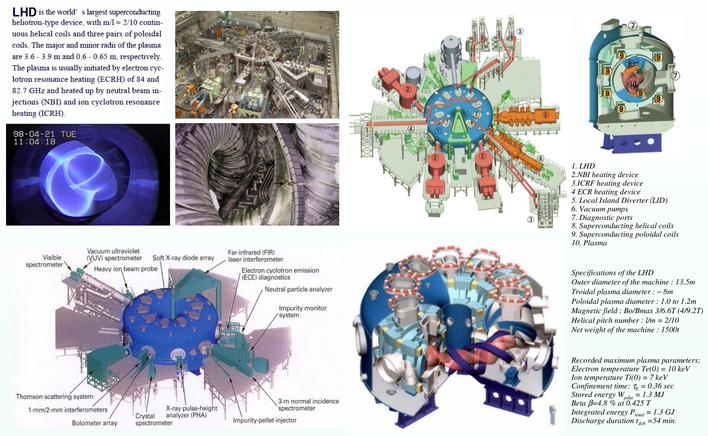
Overview of Microwave Imaging Diagnostics



MIR Imaging Optics (LHD 2006)



Large Helical Device (LHD)



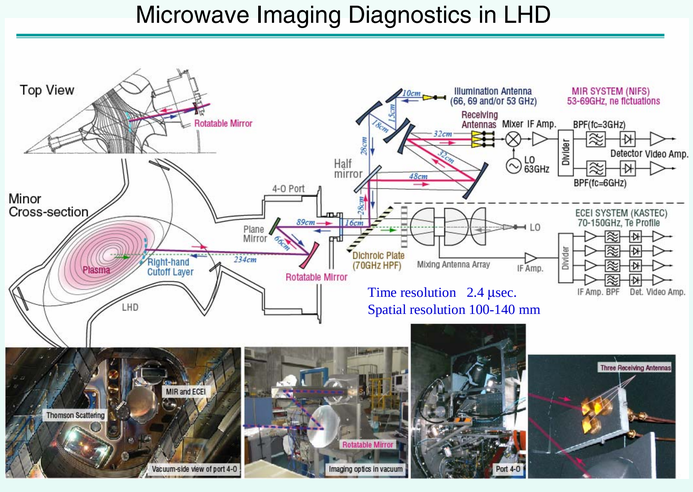
LHD is the world's largest superconducting heliotron-type device, with $m/l = 2/10$ continuous helical coils and three pairs of poloidal coils. The major and minor radii of the plasma are 3.6 - 3.9 m and 0.6 - 0.65 m, respectively. The plasma is usually initiated by electron cyclotron resonance heating (ECRH) of 84 and 82.7 GHz and heated up by neutral beam injections (NBI) and ion cyclotron resonance heating (ICRH).

1. LHD
2. NBI heating device
3. ICRF heating device
4. ECR heating device
5. Local Island Diverter (LID)
6. Vacuum pumps
7. Diagnostic ports
8. Superconducting helical coils
9. Superconducting poloidal coils
10. Plasma

Specifications of the LHD
Outer diameter of the machine : 13.5m
Toroidal plasma diameter : ~ 8m
Poloidal plasma diameter : 1.0 to 1.2m
Magnetic field : Bo/Bmax 3/6.6T (4/9.2T)
Helical pitch number : l/m = 2/10
Net weight of the machine : 1500t

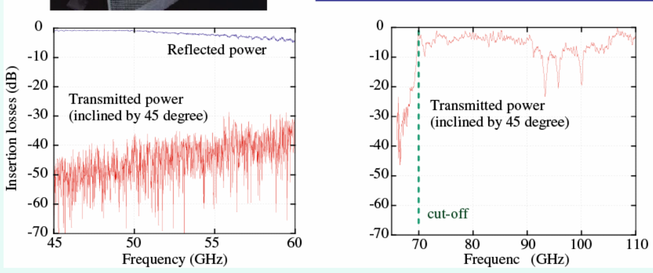
Recorded maximum plasma parameters:
Electron temperature Te(0) = 10 keV
Ion temperature Ti(0) = 7 keV
Confinement time: τ_E = 0.36 sec
Stored energy W_{dia} = 1.3 MJ
Beta Bo=4.8 % at 0.425 T
Integrated energy E_{total} = 1.3 GJ
Discharge duration t_{dis}=54 min.

Microwave Imaging Diagnostics in LHD

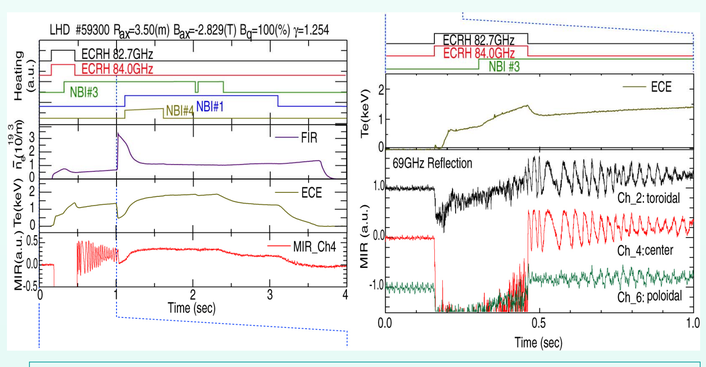


Dichroic Plate (Quasi-Optical High-Pass Filter)

- Tested Dichroic Plate shows good properties: clear "sharp" cut-off at 70 GHz was observed.
- It could be used as power splitter between ECEI and MIR parts of the system, for the illumination (or reflected) radiation to (or from) the LHD plasmas in the range of 40-90GHz.



Low Frequency Oscillation in MIR signals



A low frequency oscillation due to density fluctuation was observed by using MIR for the first time in LHD plasma experiment.

S. Yamaguchi[1], *Y. Nagayama*[1], *R. Pavlichenko*[1], *S. Inagaki*[1], *Y. Kogi*[2] *and A. Mase*[2]
[1]*National Institute for Fusion Science, Toki 509-5292, Japan*
[2]*Art Science and Technology Center for Cooperative Research, Kyushu Univ., Kasuga 816-8580, Japan*

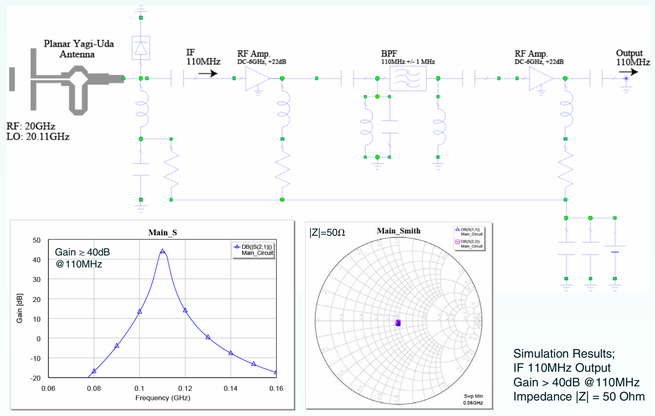
Recent Development and Future Plan

Two MIR system for
LHD (66, 69GHz) and Test Bench (20GHz)

Multi-channel phase measurement system

- Phase Measurement System
  Quadrature Demodulator
- 2-D Imaging Antenna Array
  Yagi-Uda Antenna (End-fire type)
  Bow Tie Antenna
- Imaging Optics
  2-D Imaging Antenna Array

Detector circuit



Simulation Results;
IF 110MHz Output
Gain > 40dB @110MHz
Impedance |Z| = 50 Ohm

Phase Measurement System (LHD 2006)

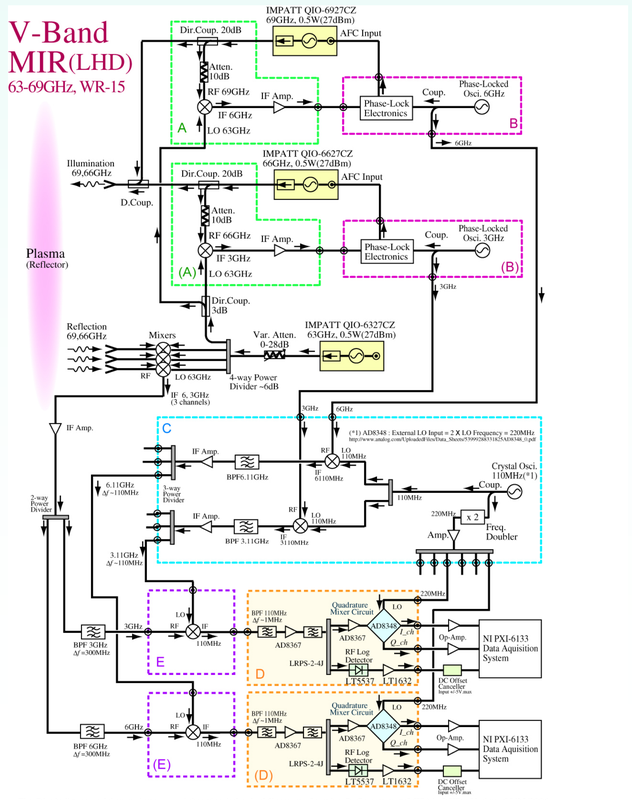


Fig. Block diagram of the quadrature receiving circuit for the Microwave Imaging Reflectometry (MIR) in LHD. Update :08/25/2006

Phase Measurement System (Test Bench 2006)

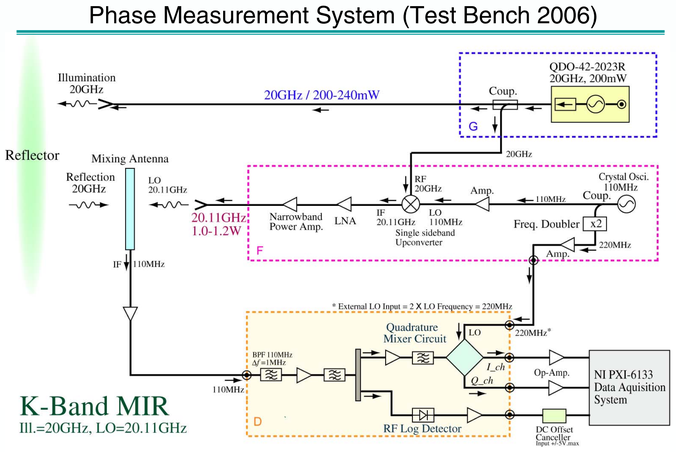
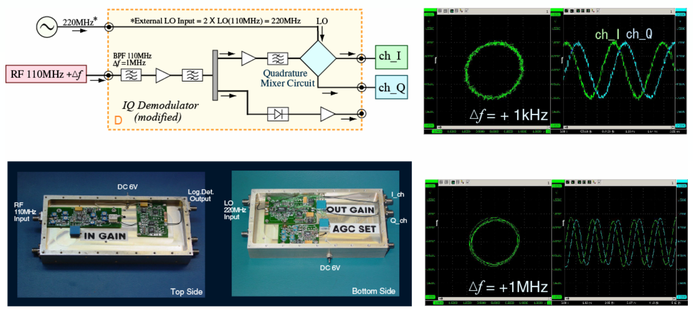


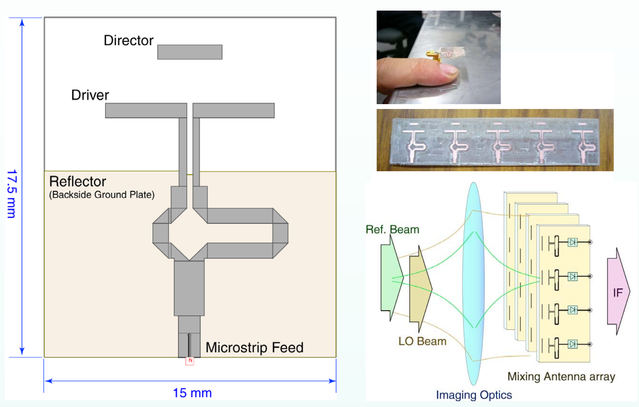
Fig. Block diagram of the heterodyne and quadrature receiver for the microwave imaging reflectometry. Update :08/04/2006

1st Prototype of I/Q Demodulator

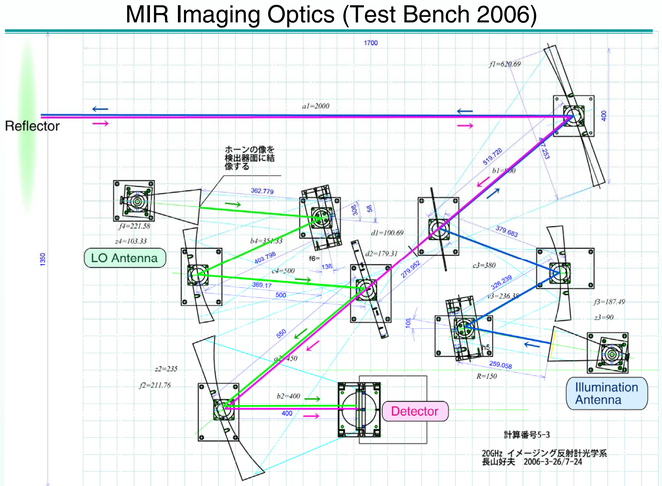


I/Q demodulator for multi-channel phase measurement.
Frequency : DC to 1 MHz

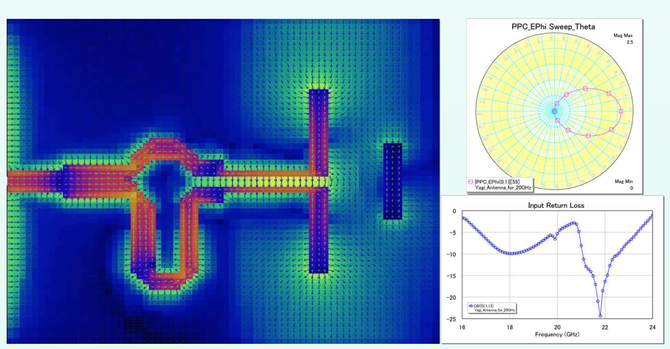
End-fire Array of Yagi-Antenna



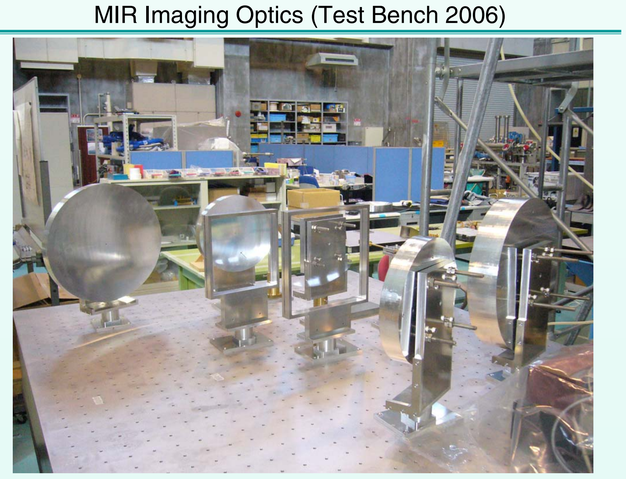
MIR Imaging Optics (Test Bench 2006)



Performance Simulation



MIR Imaging Optics (Test Bench 2006)



Summary

1. The Microwave imaging reflectometry is under development in LHD to observe the electron density fluctuations in magnetically confined plasma.
2. The rotating mirror is installed in vacuum in order to control the illumination angle for the wider range of plasma parameters.
3. The beam paths near the reflection surface are calculated with the ray tracing code, and the beam patterns are numerically calculated by using the FDTD method.
4. A slow oscillation due to density fluctuation was observed by using MIR for the first time in LHD plasma experiment.