Microwave Imaging in the Large Helical Device

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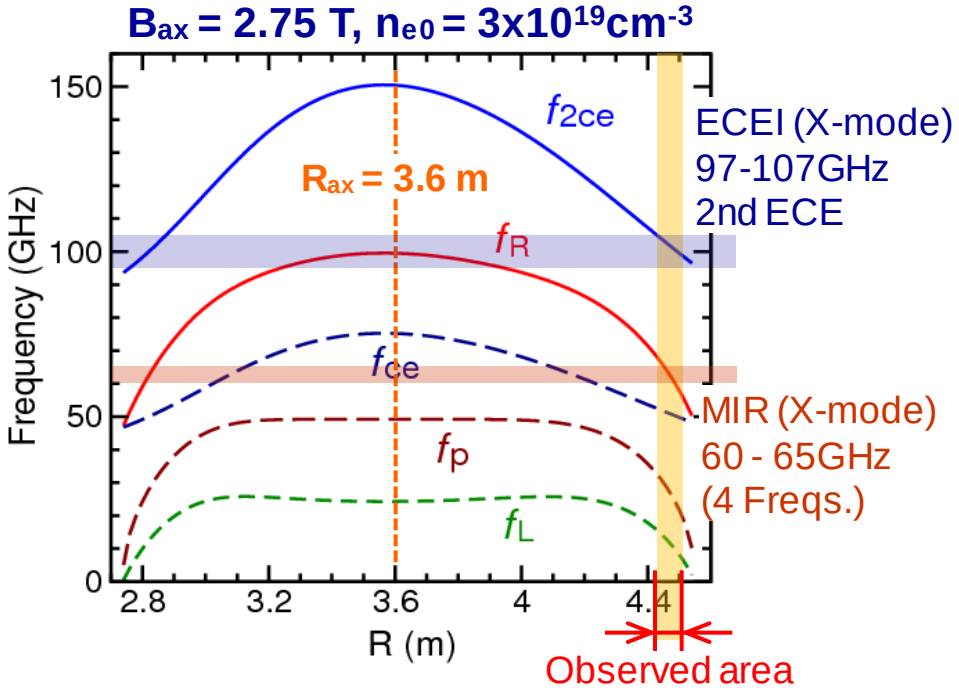
Introduction

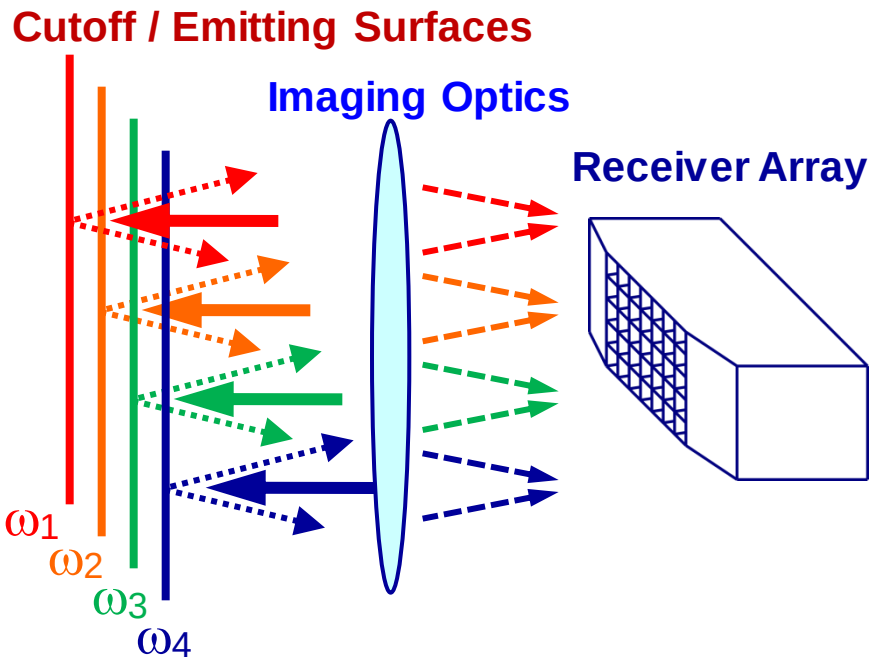
- The objective of **Microwave Imaging Reflectometry (MIR)** and **Electron Cyclotron Emission Imaging (ECEI)** in LHD is to observe and reconstruct **3-D** structures of n_e / T_e fluctuations.
- Simultaneous observation of local n_e / T_e fluctuations may be realized by using MIR and ECEI.
- The final goal is to observe turbulence structures.

MIR and ECEI observe the edge region under a typical configuration in LHD.



Principles of MIR / ECEI

- MIR enables 3-D observation of n_e fluctuations by
  1. Two-dimensional receiver array (toroidal and poloidal profile),
  2. Different frequency projection (radial profile),
  3. Imaging Optics (focusing).
- ECEI visualizes 2-D (poloidal) T_e profile by detecting ECE with arrayed receivers.



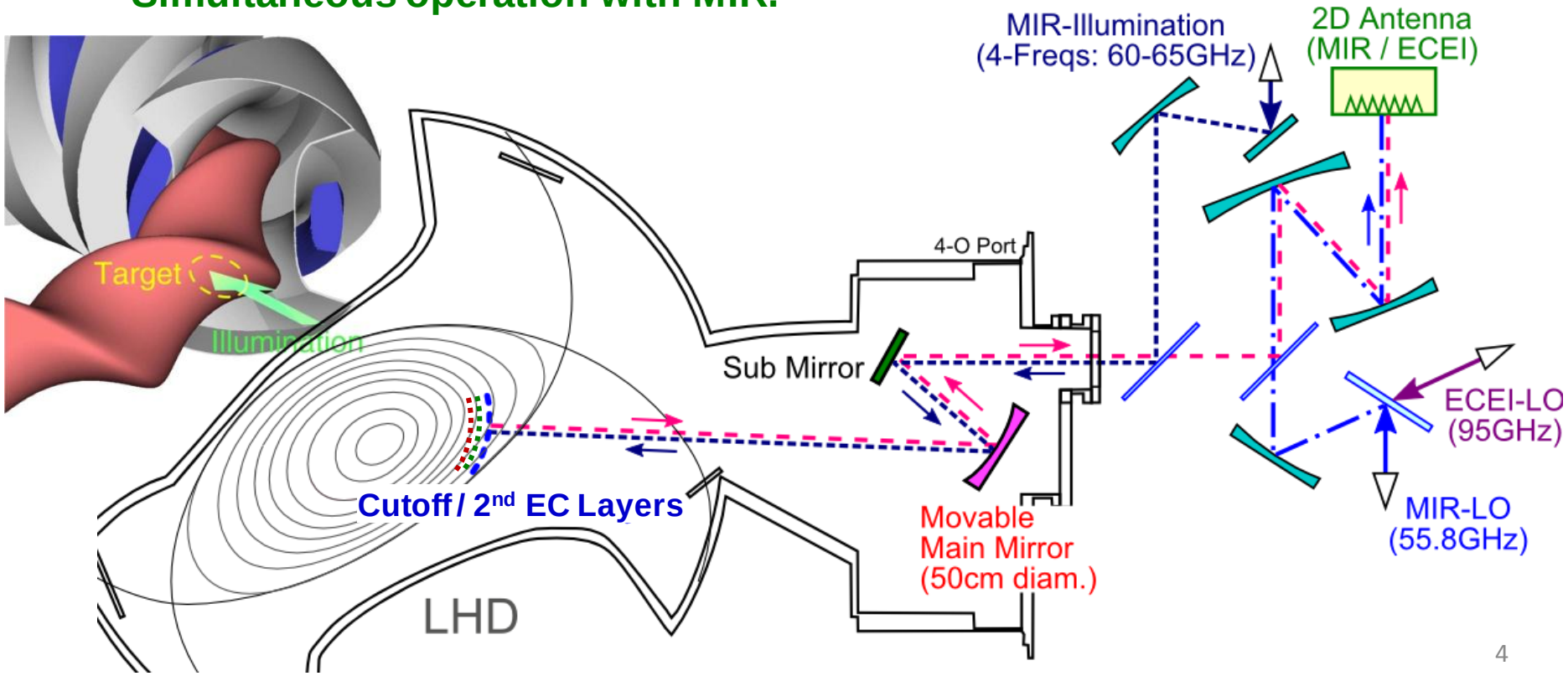
MIR / ECEI System in LHD

MIR:

- **Simultaneous projection of 4 frequencies (60.4, 61.8, 63.0, 64.6 GHz).**
- **2-D horn antenna array (poloidally 7 ch x toroidally 5 ch).**
- **Movable main-mirror.**

ECEI:

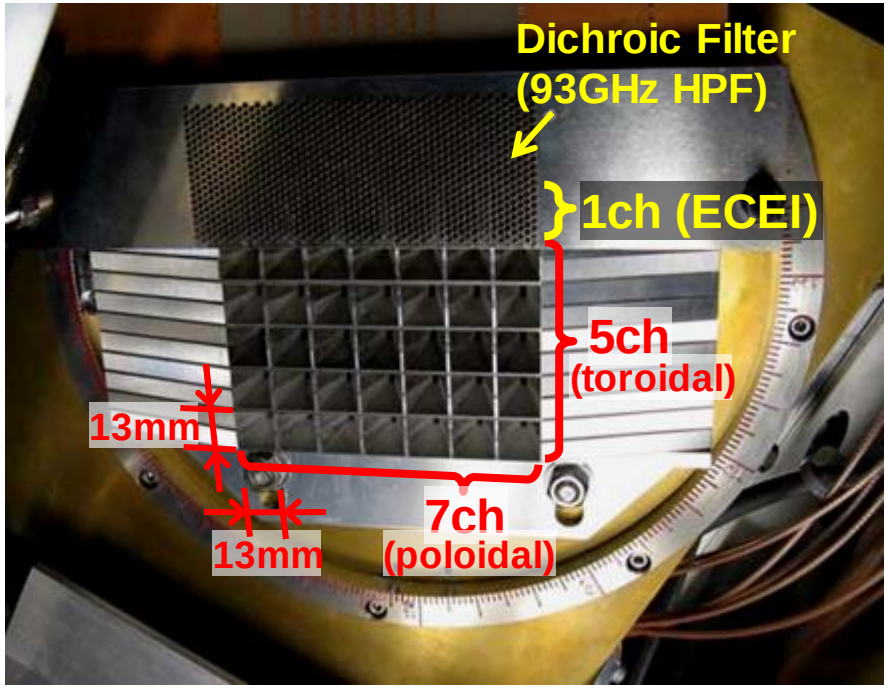
- **Resolve 11 frequencies (97 - 107 GHz, 1GHz step) for radial profile.**
- **1-D horn antenna array (poloidally 7 ch).**
- **Simultaneous operation with MIR.**

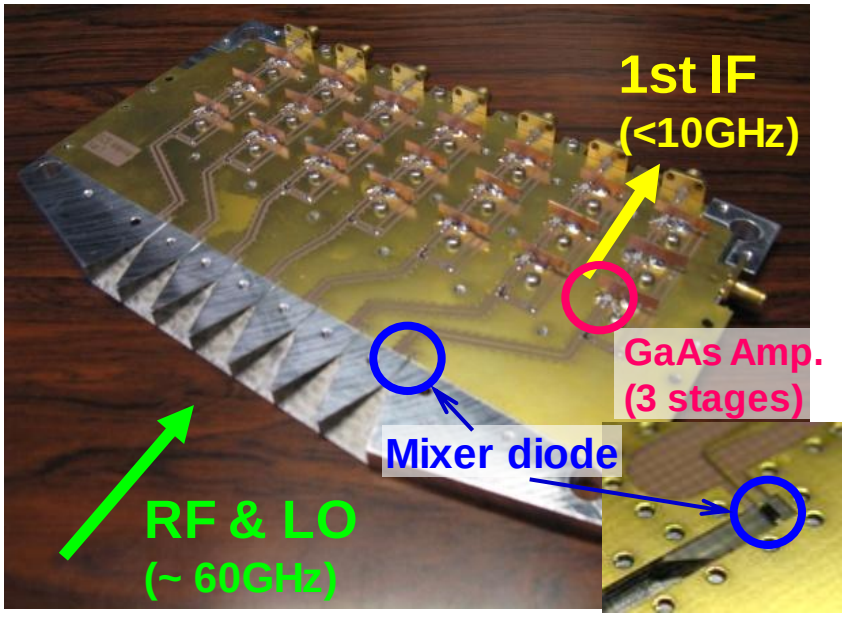


1. Key Devices for MIR

1. 2-D Receiver Antenna
   - Imaging Optics
2. 4-Frequency Separator
3. 110MHz IF Detection Circuits

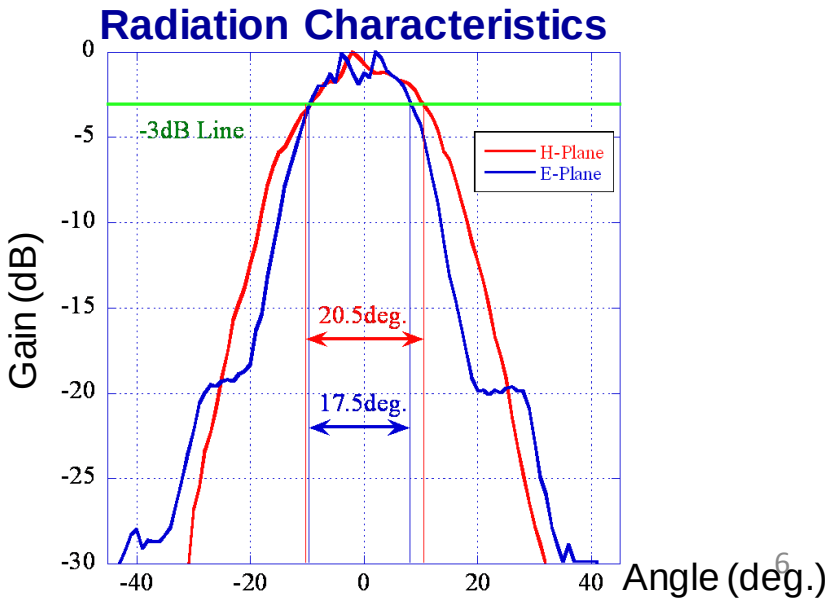
1: 2-Dimensional Horn Antenna Array



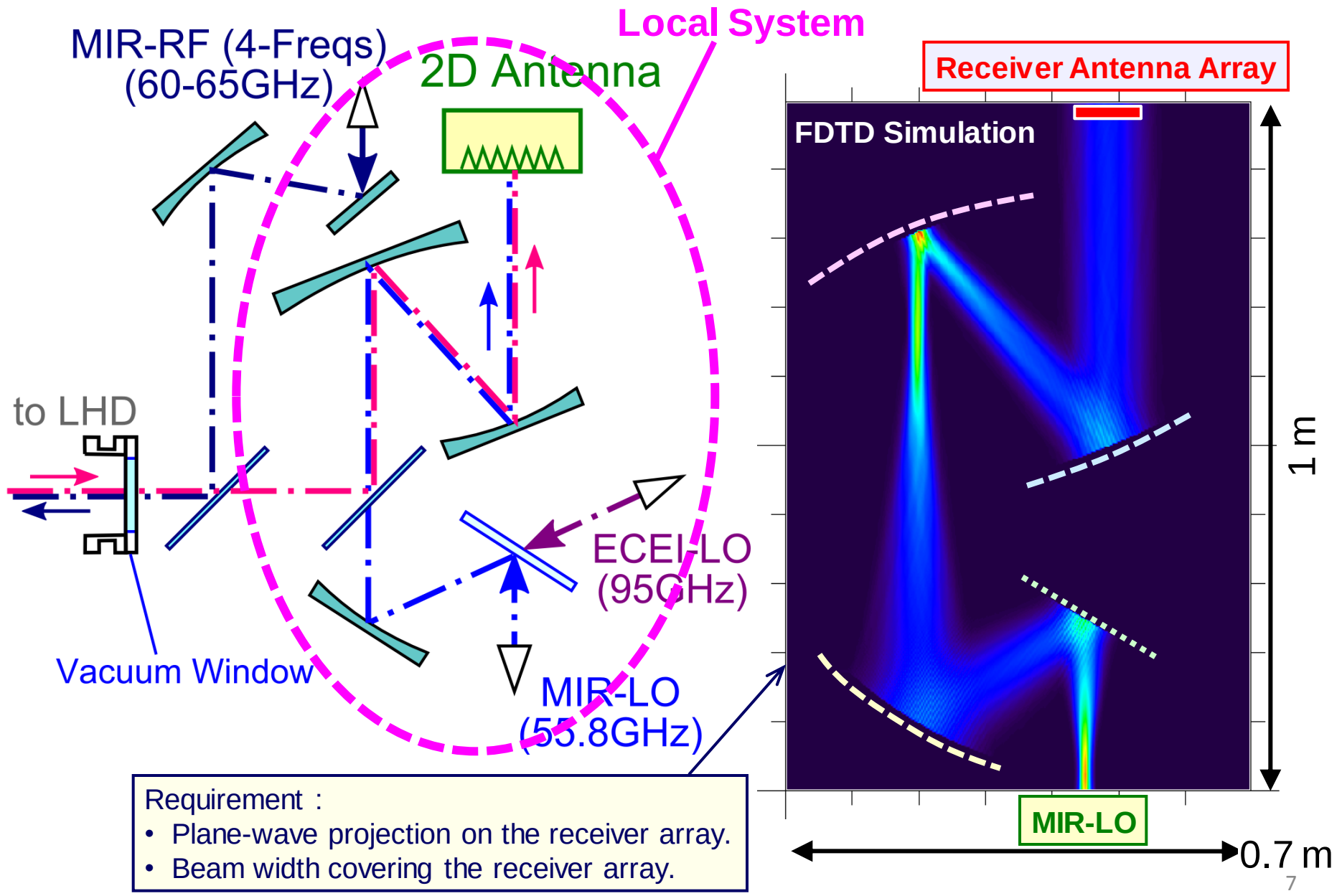


Printed-circuit-board, on which the mixer diode and GaAs amplifiers are mounted, is sandwiched by Al frame to form the horn antenna array.

The use of high-gain horn antenna array can be enabled by the projection of LO-wave from the front-side of the antenna aperture.

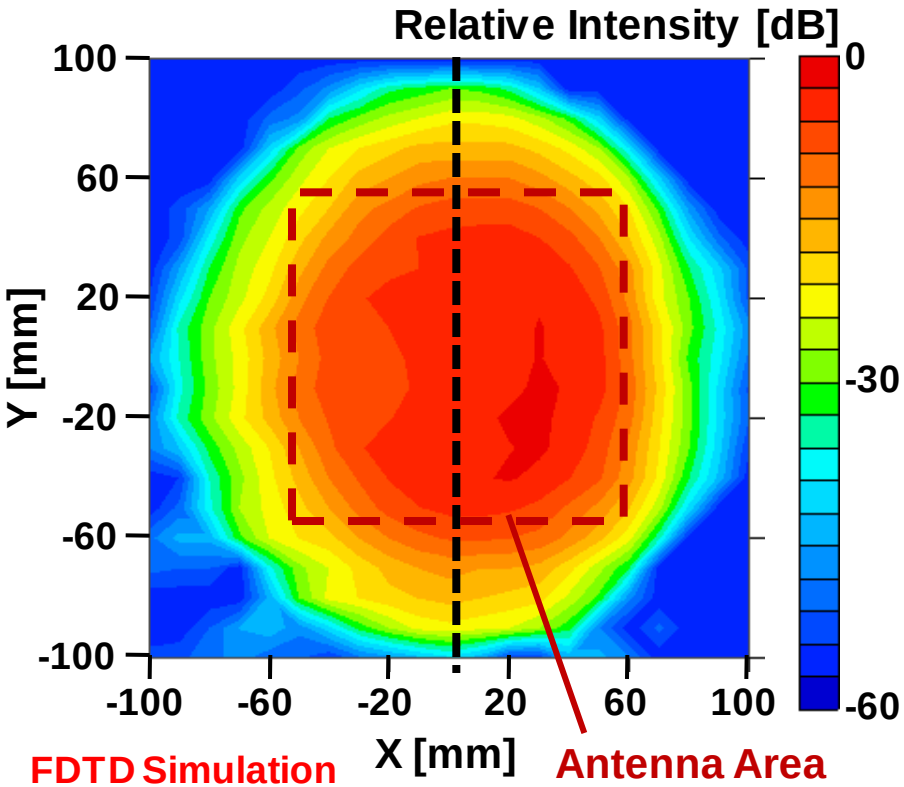


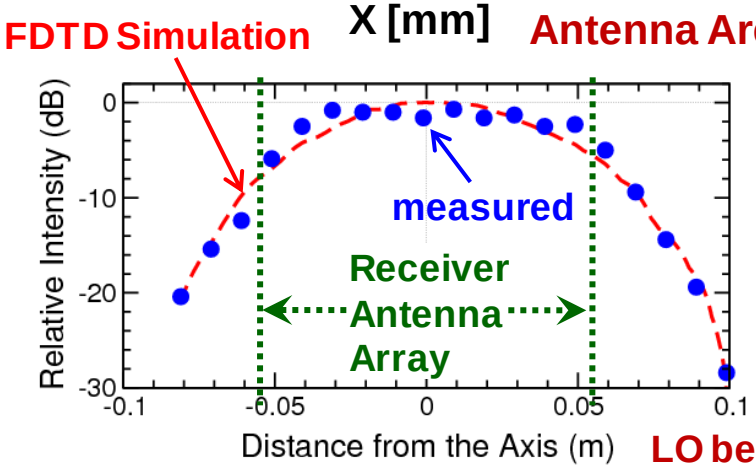
Optimization of LO Wave Projection onto 2D Receiver

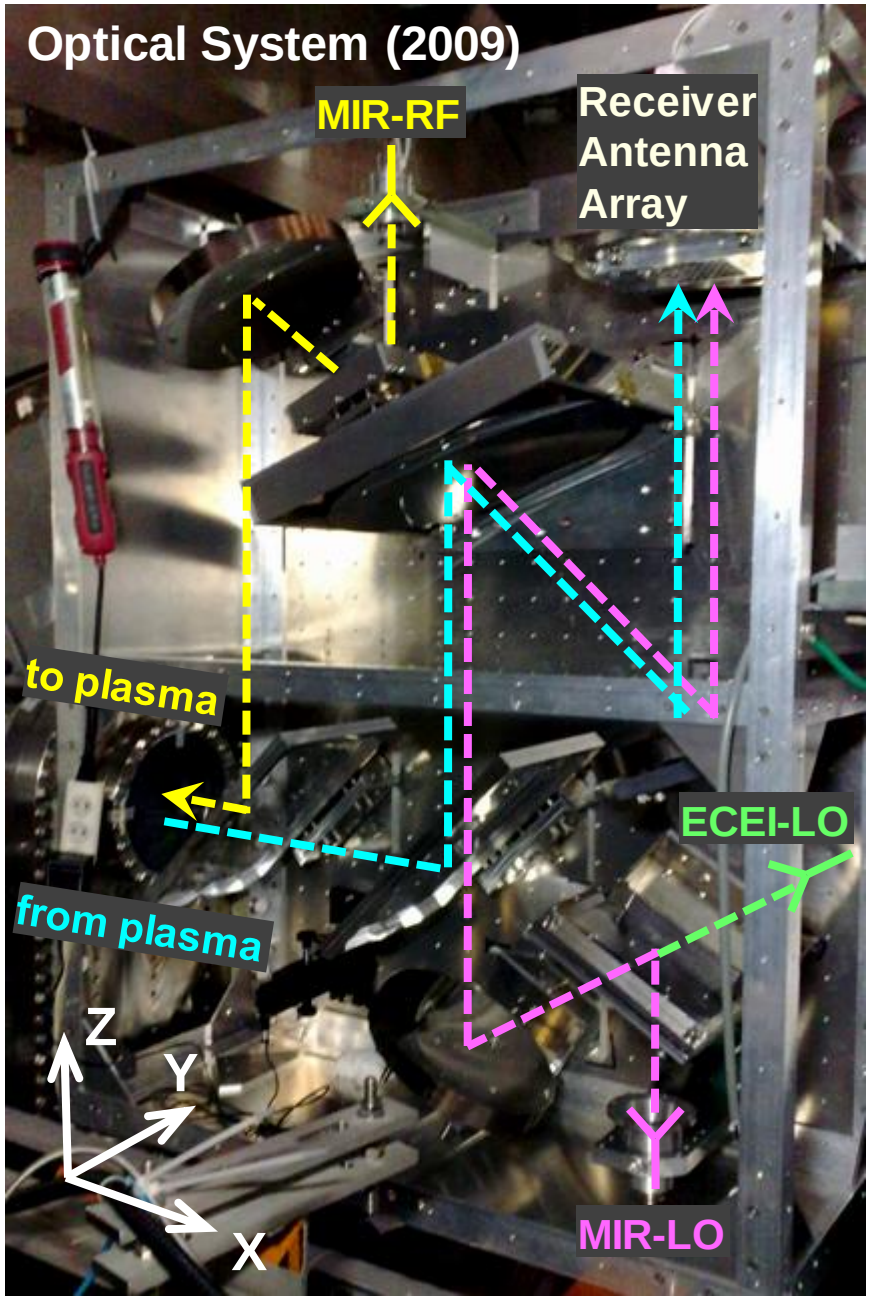


Requirement :
- Plane-wave projection on the receiver array.
- Beam width covering the receiver array.

Power profile of Local wave at 2-D Receiver Antenna Array



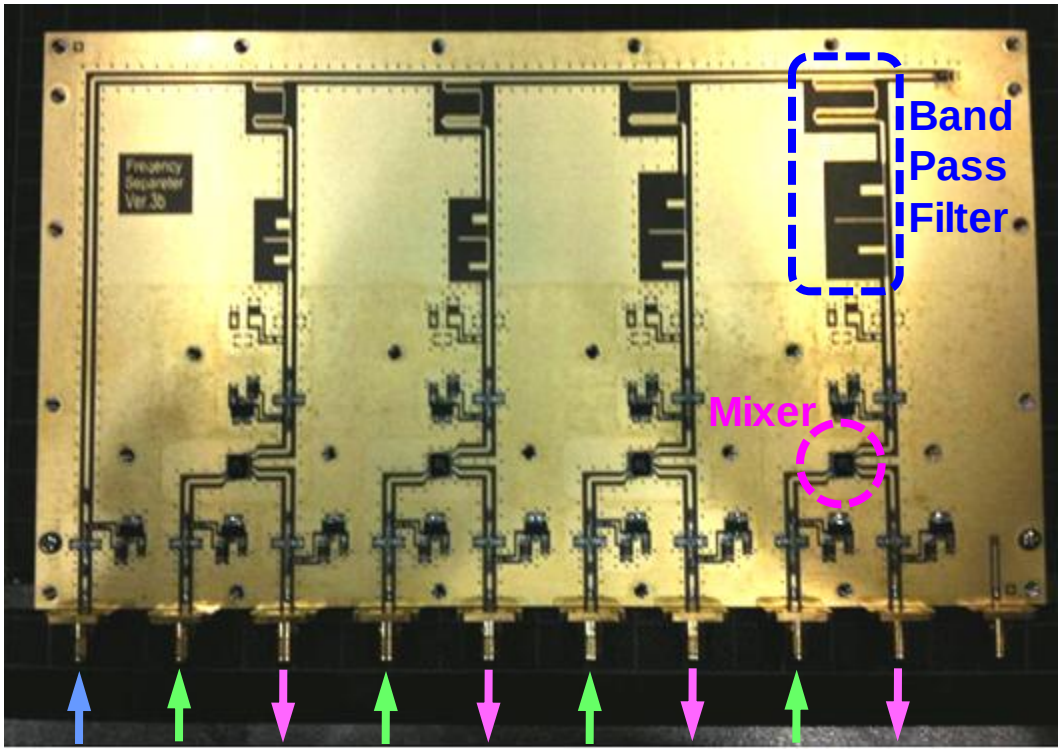




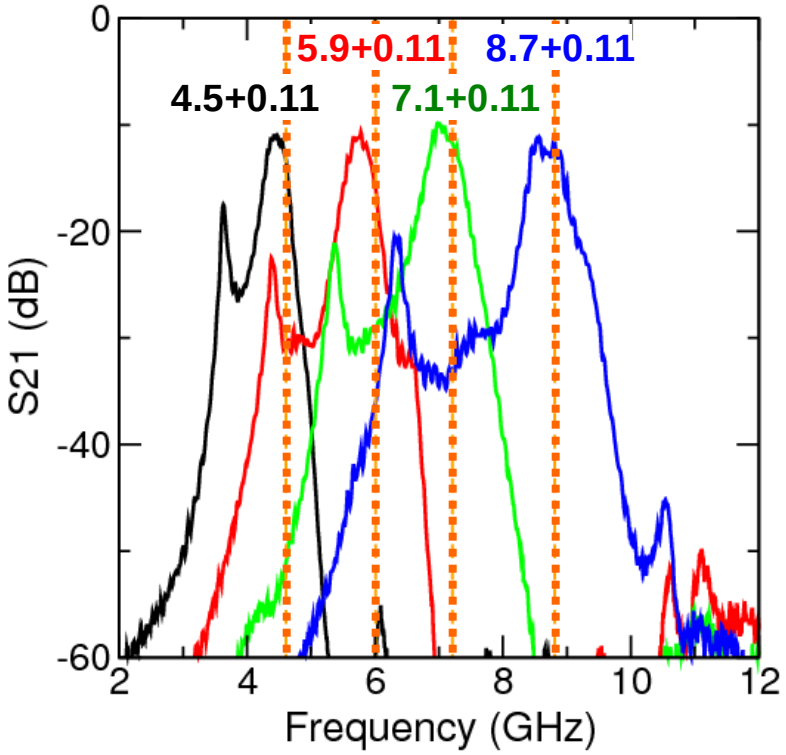
LO beam is confirmed to cover the receiver area.

2: 4 Frequency Separator + Down-Converter

First IF signal from the 2-D receiver array at 4 frequencies (4.61, 6.01, 7.21, 8.81GHz) are separated and down-converted into 110 MHz second IF signals.

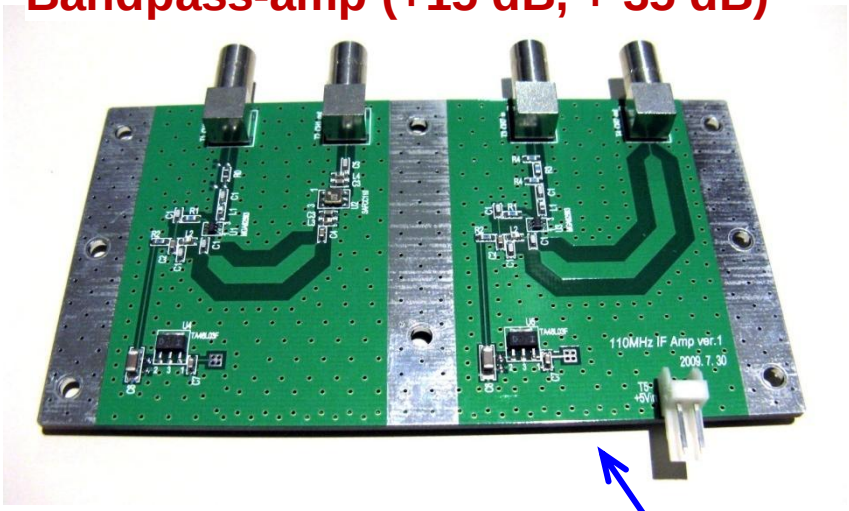


Filter characteristics of each BPF section.

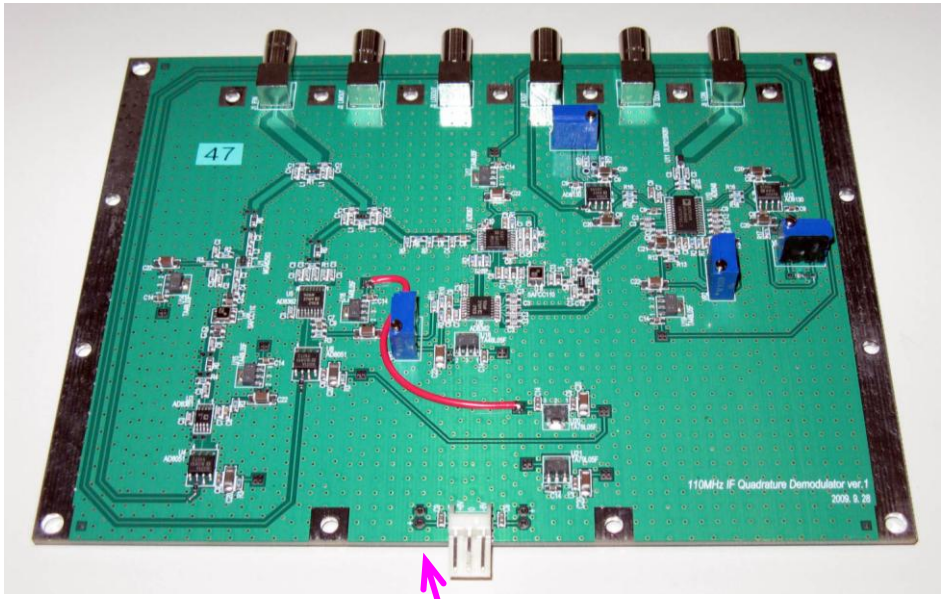


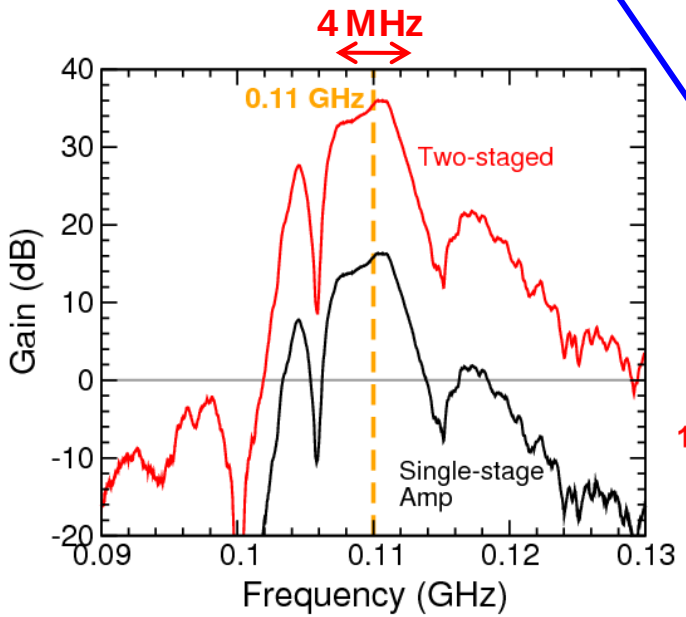
3: 110MHz 2nd IF Signal Detectors

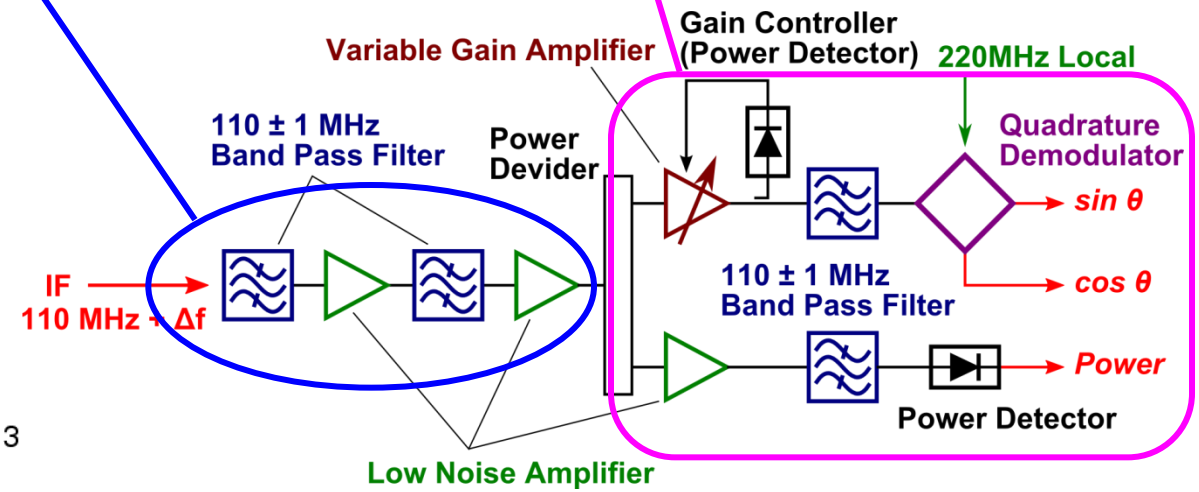
Bandpass-amp (+15 dB, + 35 dB)



Power Detector / Quadrature Demodulator

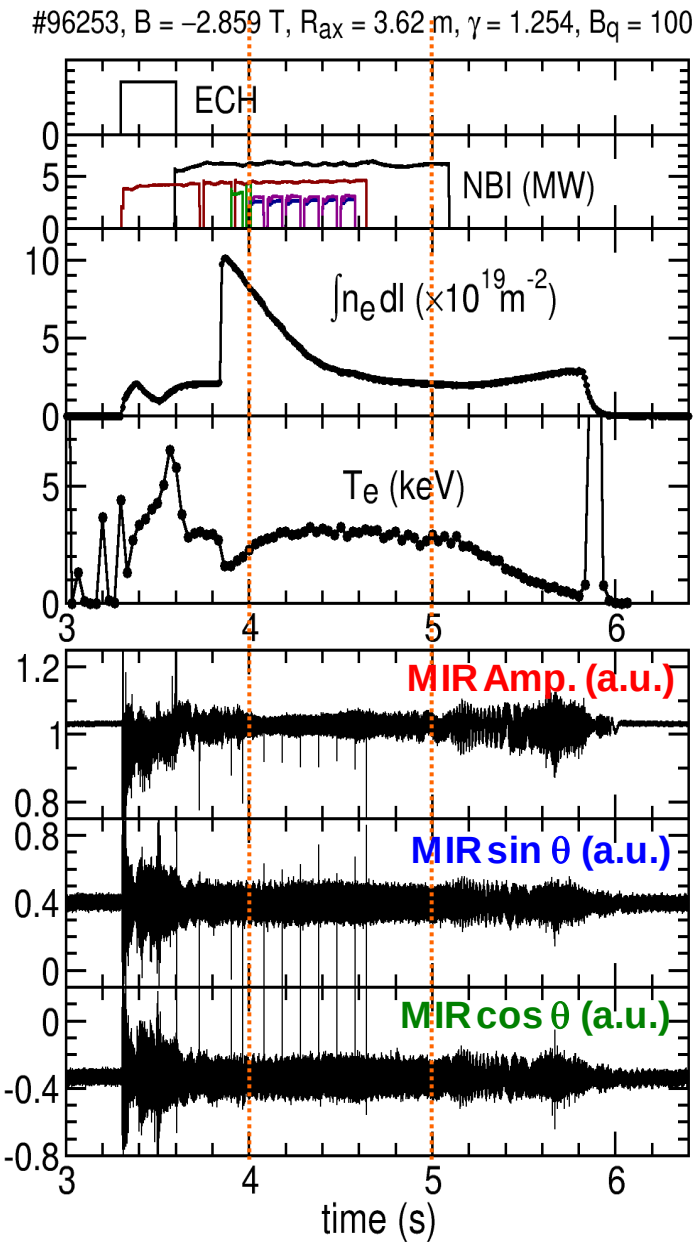




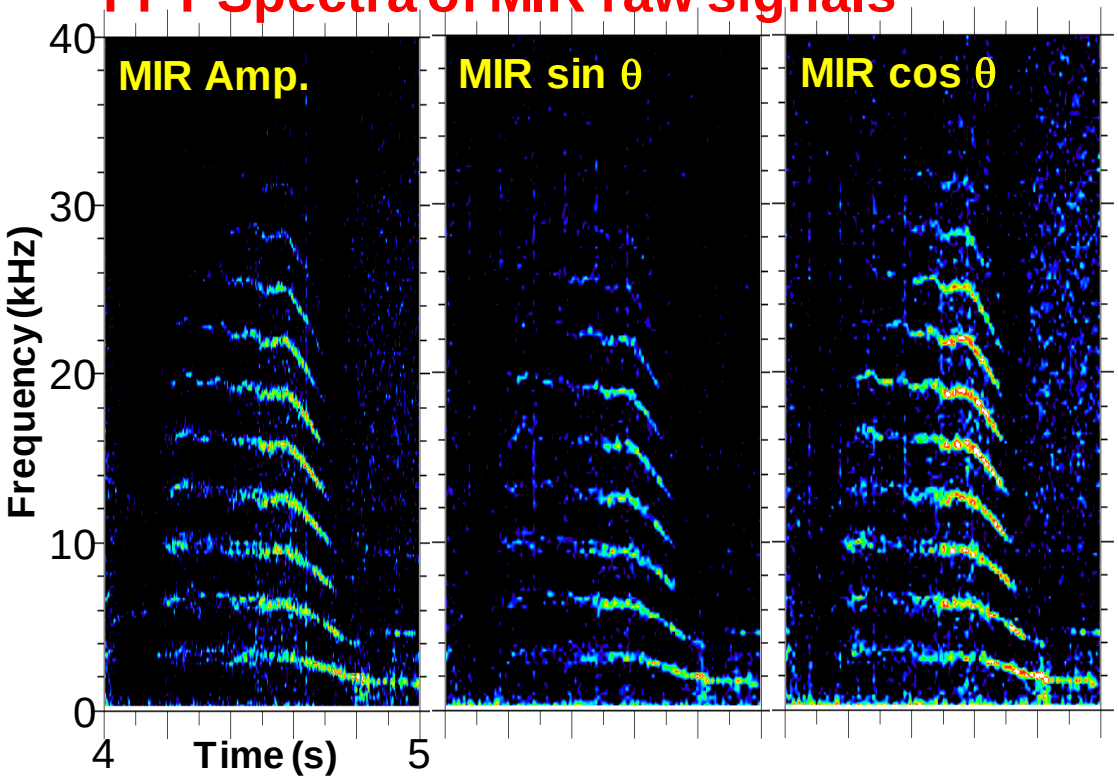


Narrow-band (~4MHz) BPF reduces noises.

Observation of MHD Oscillations in Edge Region



FFT Spectra of MIR raw signals

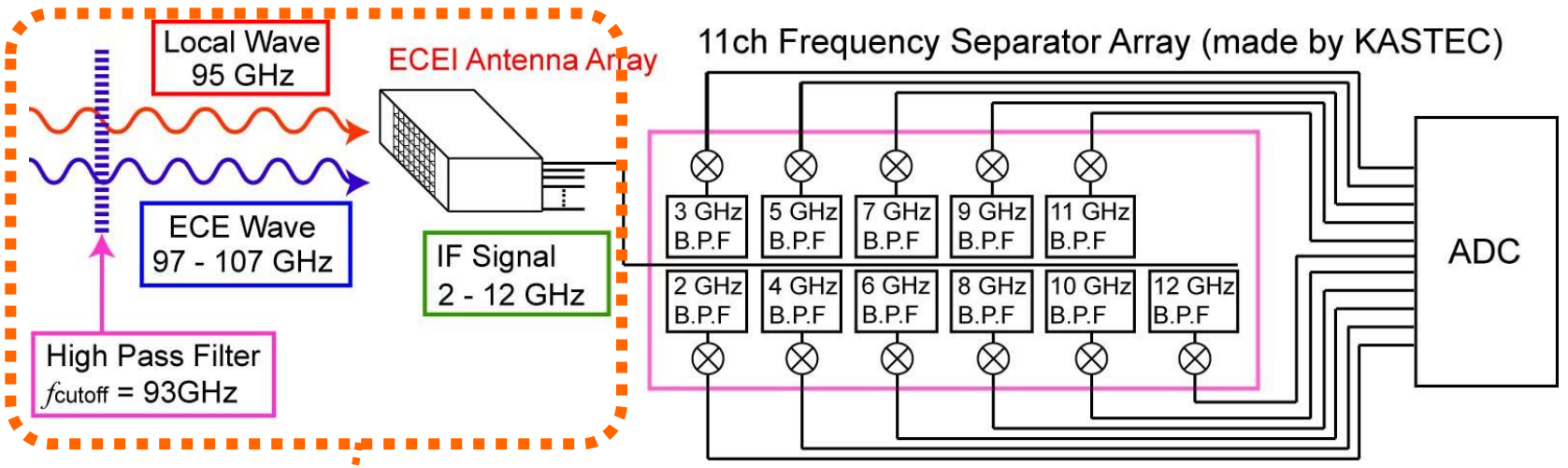


Oscillations which accompany many harmonics were observed in the edge plasma region.

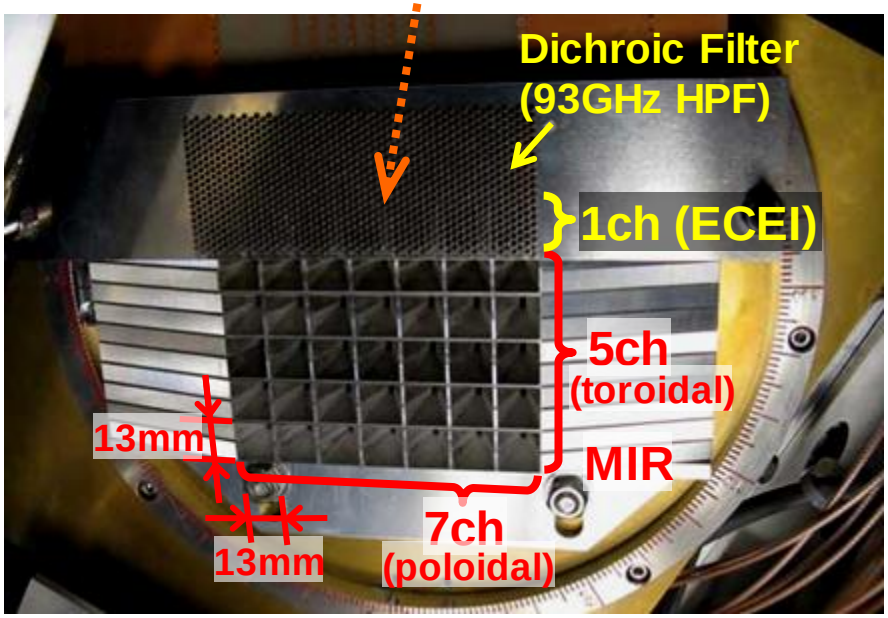
- The modulations can be found all in the amplitude and the phase signals.
- Fundamental frequency is ~ 2-3 kHz.

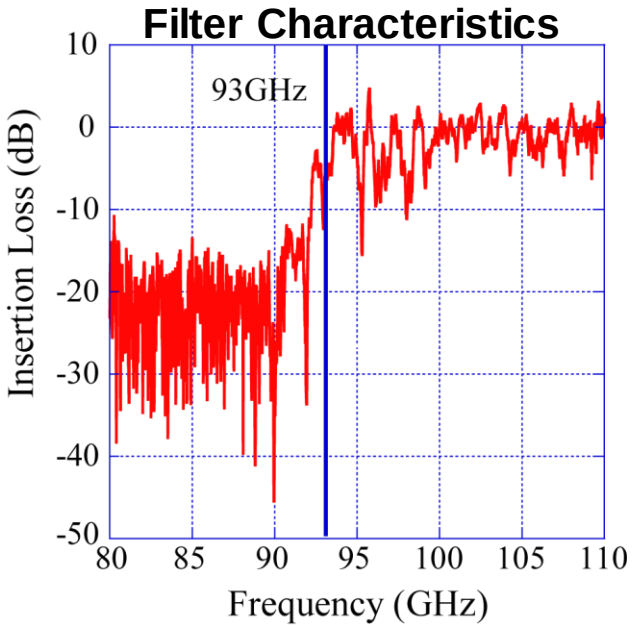
2. ECEI System

7ch x 11 Freq. ECEI System



The same receiver array with MIR is used for ECEI except the high-pass-filter. The high-pass-filter rejects frequency at lower than 93 GHz.

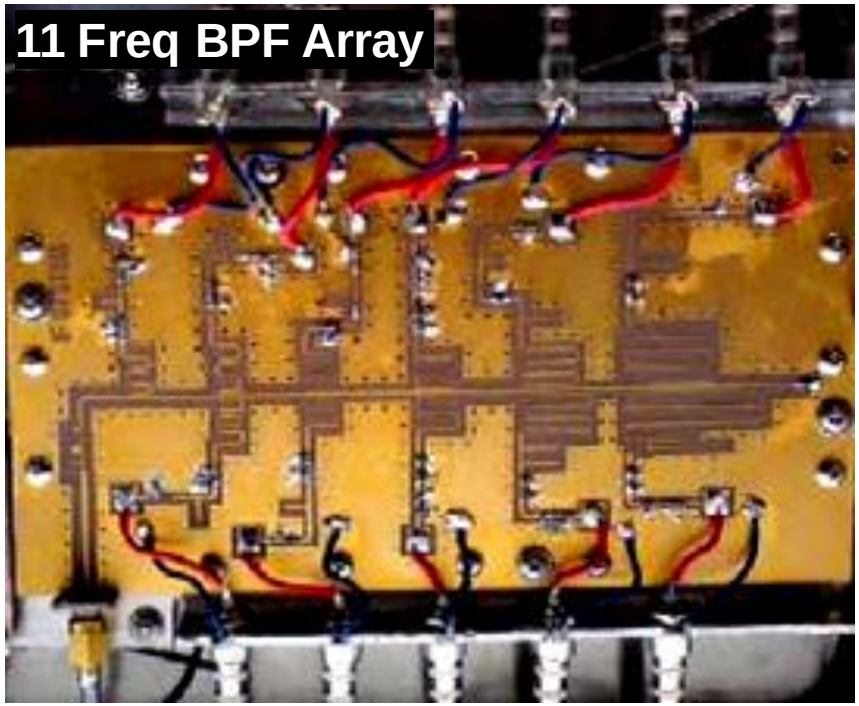


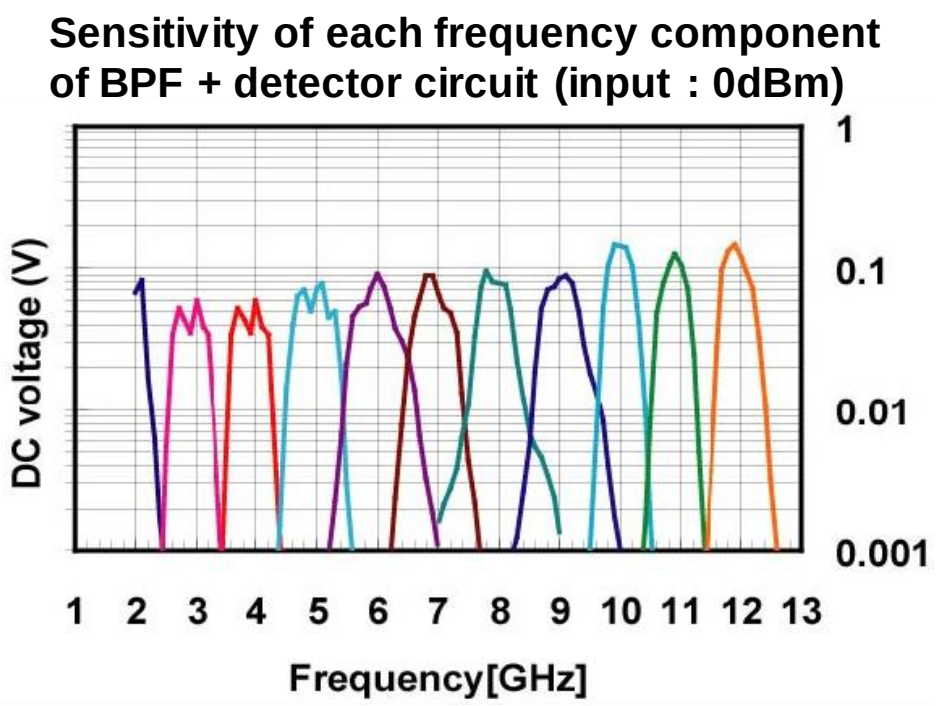


11 Freq. IF Detection in ECEI

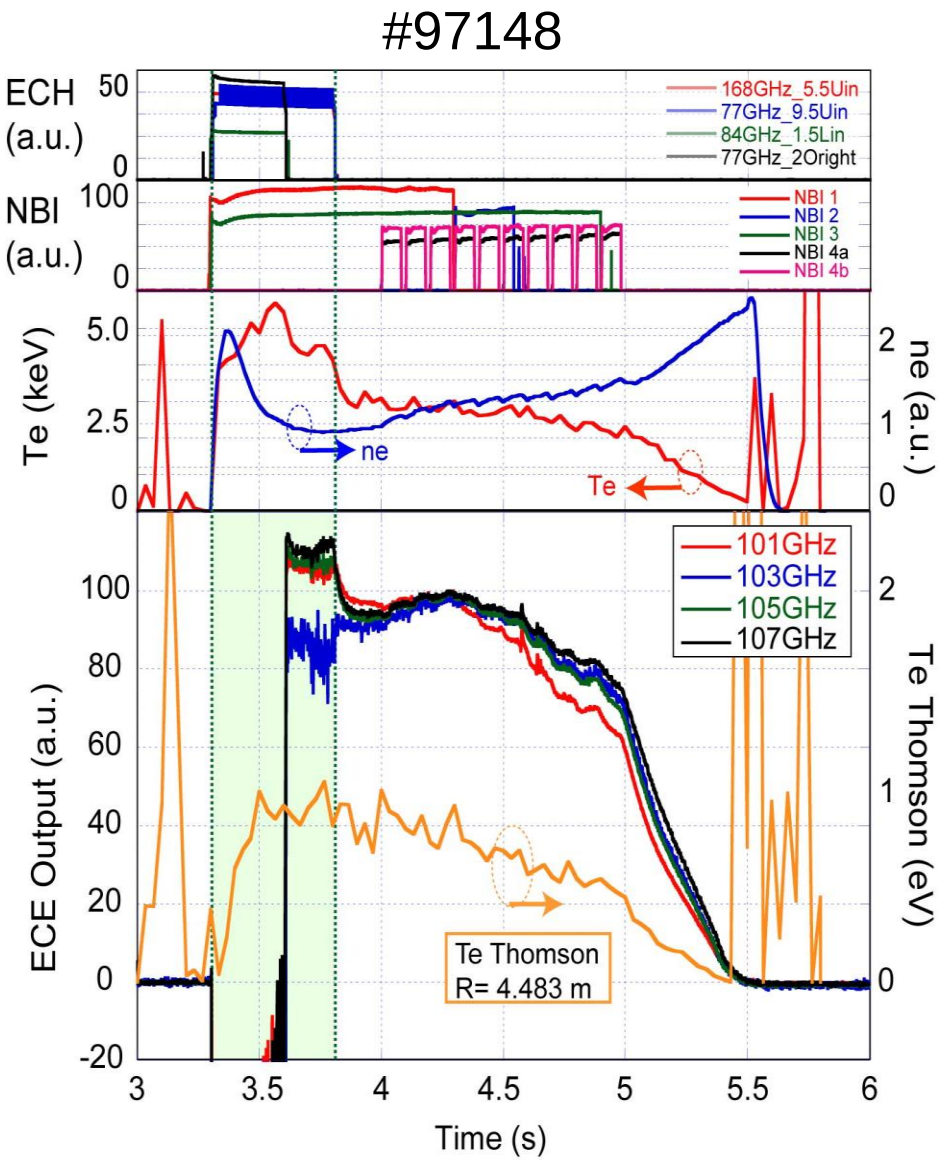
11ch BPF Array is fabricated by micro-strip-line technique in a low-cost.

- IF signals at 2-12GHz are resolved into 11 components with 1GHz step.
- BPFs and power detectors are placed on the PCB.





Initial Result of ECEI



R_{ax}=3.6m, B_t=-2.75T, γ=1.2538, B_q=100%

ECE Freq. : 101, 103, 105, 107 GHz
IF Freq. : 6, 8, 10, 12 GHz

ECEI signals are disturbed during EC-Heated phase.

Without EC injection, ECEI signals seems to reflect time-evolution of T_e observed by the Thomson scattering.

Summary

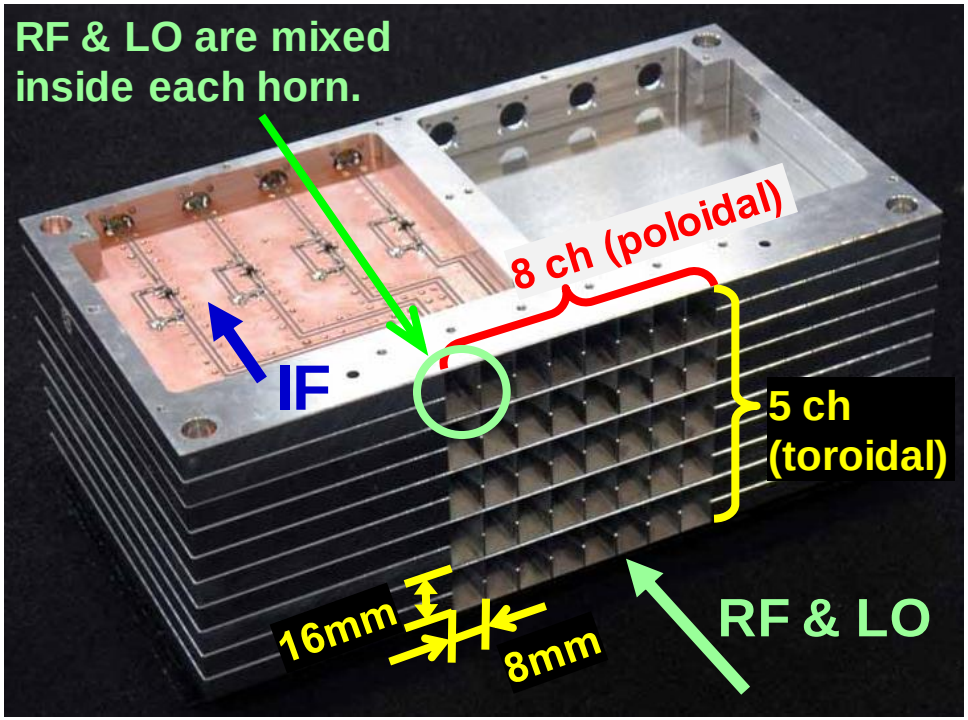
MIR system has been developed to observe 3-D structure of fluctuations in LHD and started operation.

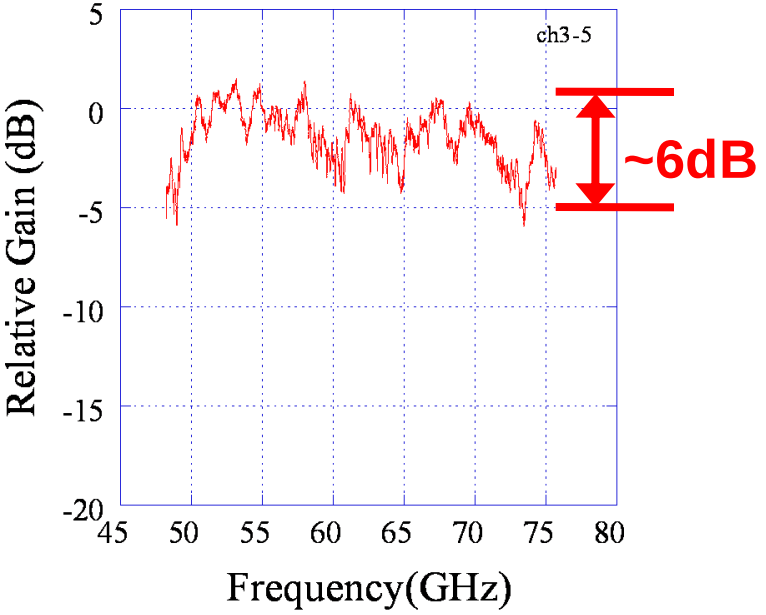
- Simultaneous projection system of 4 frequencies (60.4, 61.8, 63.0, 64.6 GHz).
- 2-D receiver array (7ch x 5ch).
- Optics for LO projection on 2-D receiver array.
- First IF 4-frequency separators.
- 110 MHz 2nd IF detectors / quadrature demodulators.

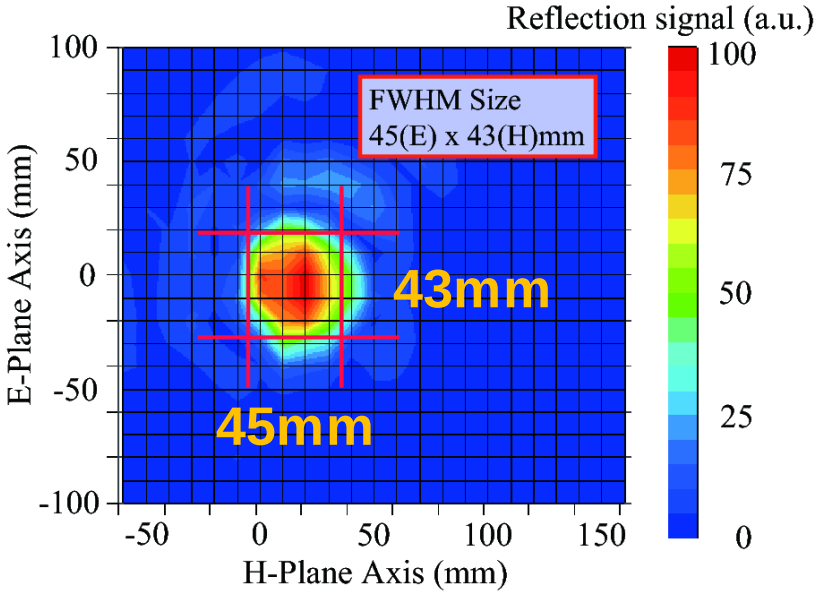
ECEI system was developed for the observation of 2-D Te profile.

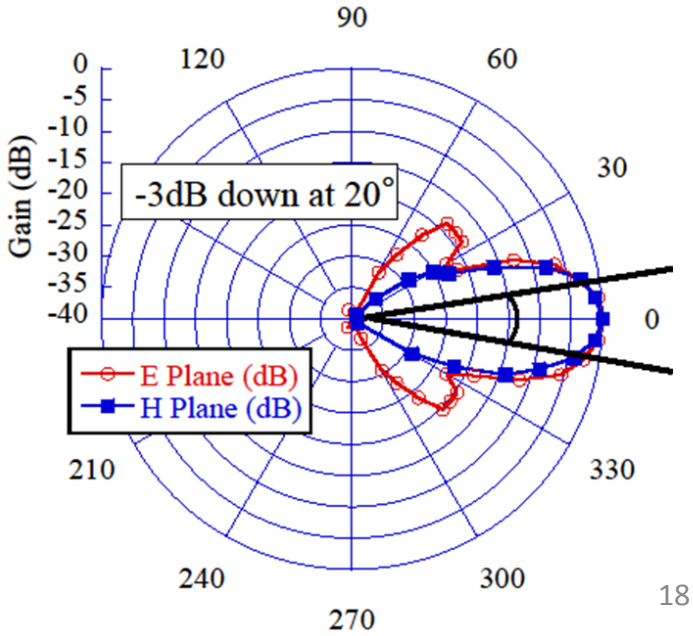
- Detect frequency at 97 GHz – 107 GHz.
- The same 1-D receiver array (7ch) with MIR system is used except high-pass-filter plate placed on the antenna aperture.
- BPF arrays resolve IF signals into 11 frequency components.

Main Characteristics of 2-D Receiver Array



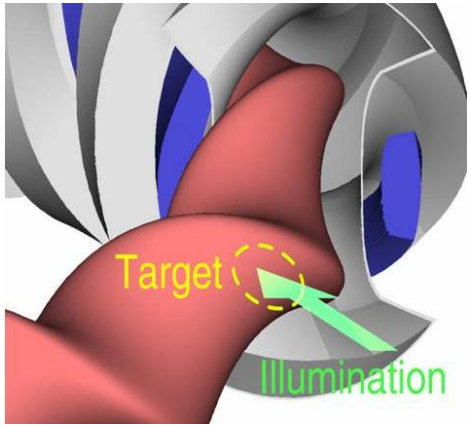


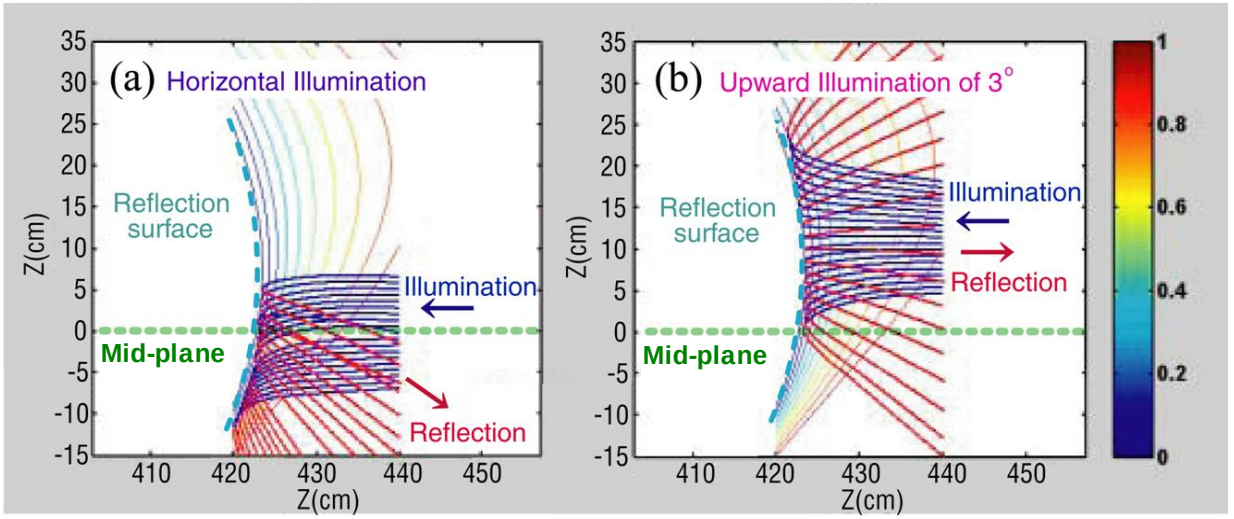


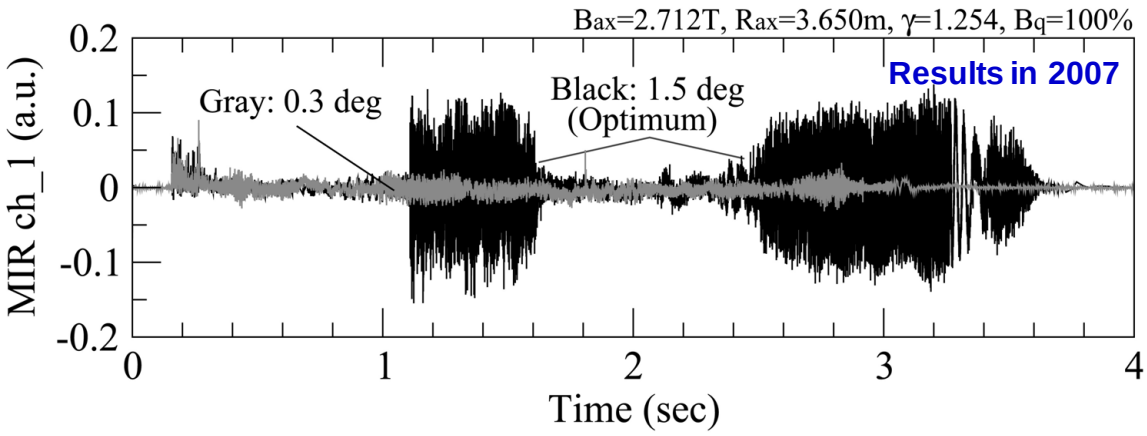


Optimization of Injection Angle is Indispensable

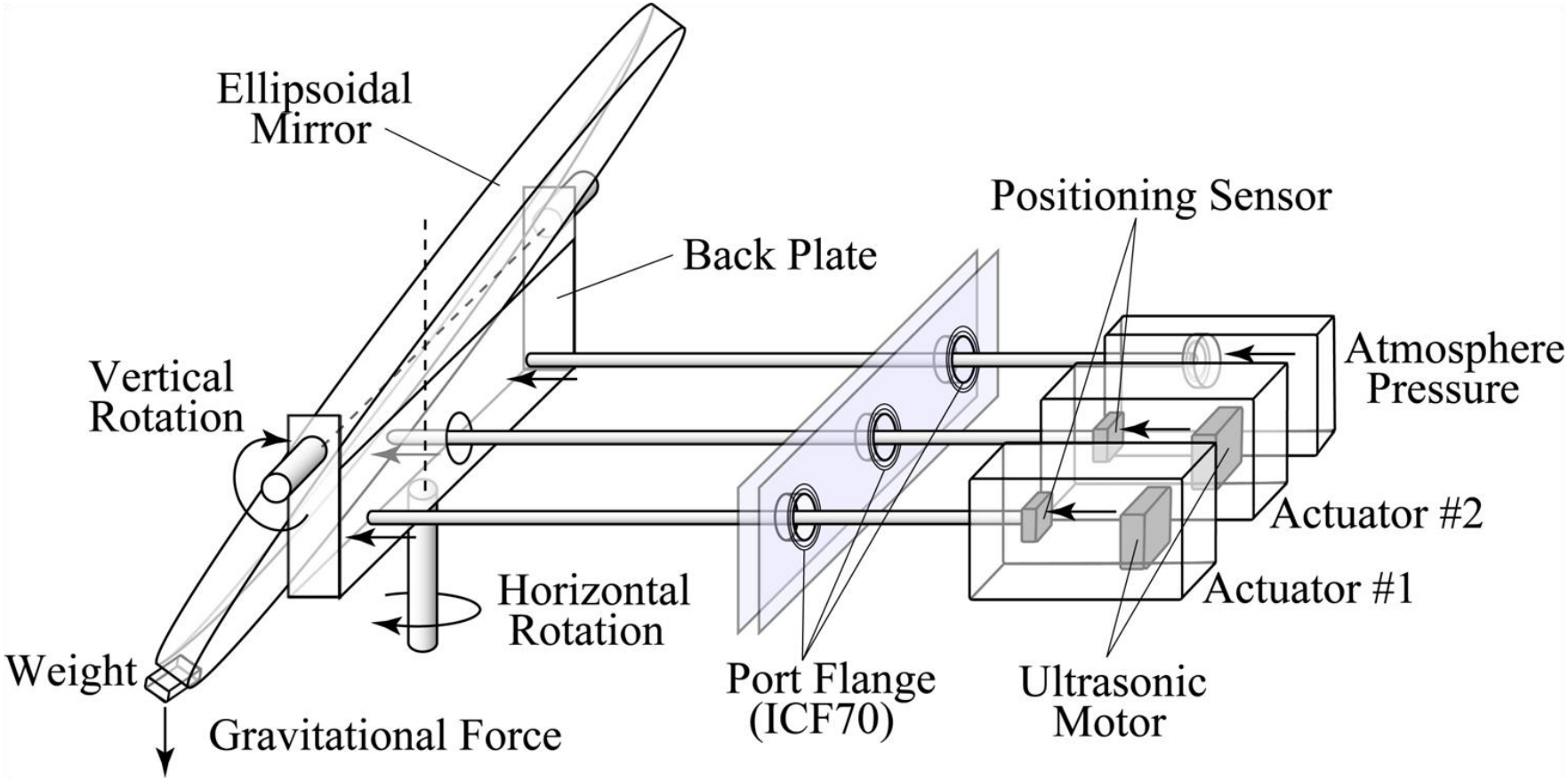
Main-mirror angle must be adjusted so that the injection angle of illumination-wave matches the cutoff surface of the twisted plasma in LHD.





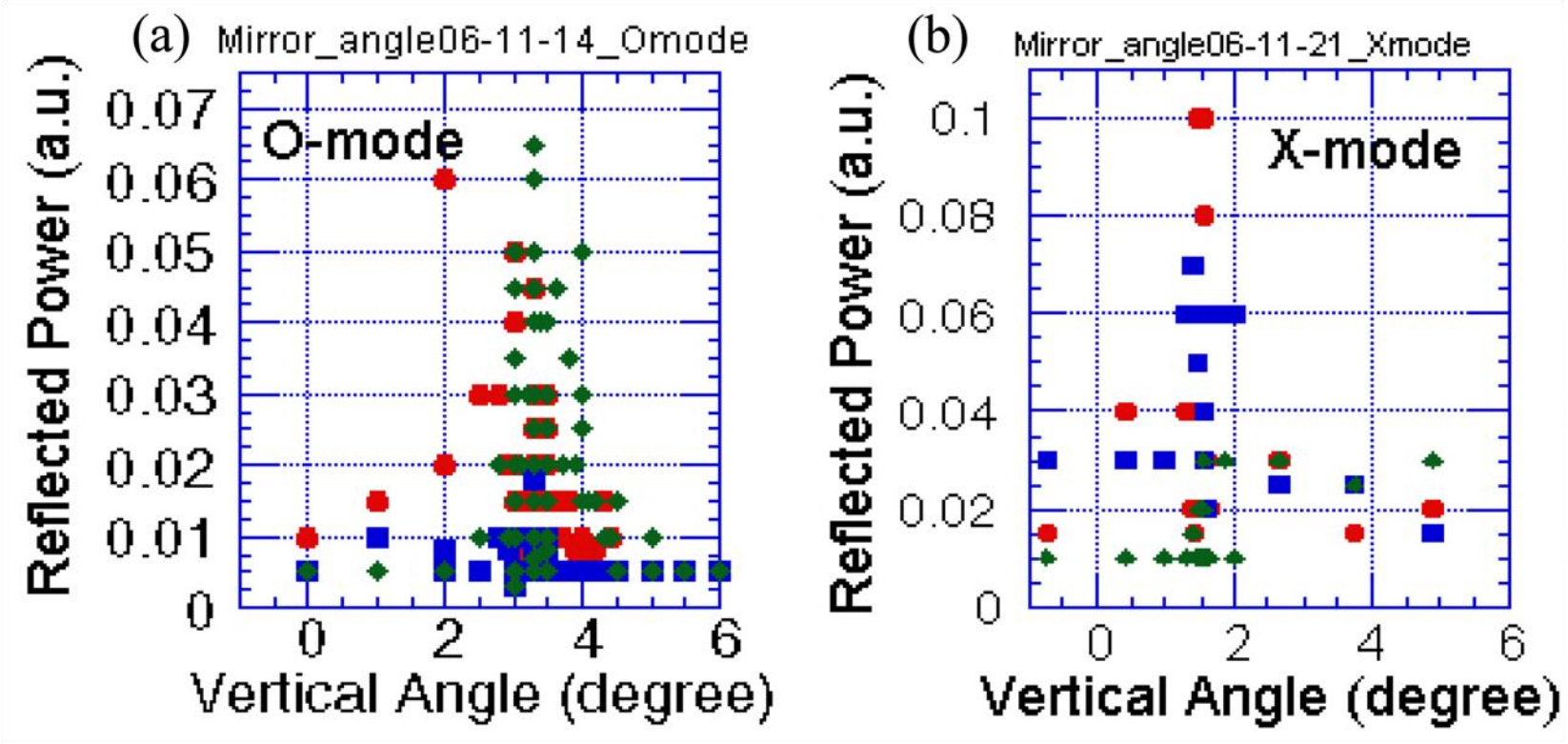


Movable Main Mirror System



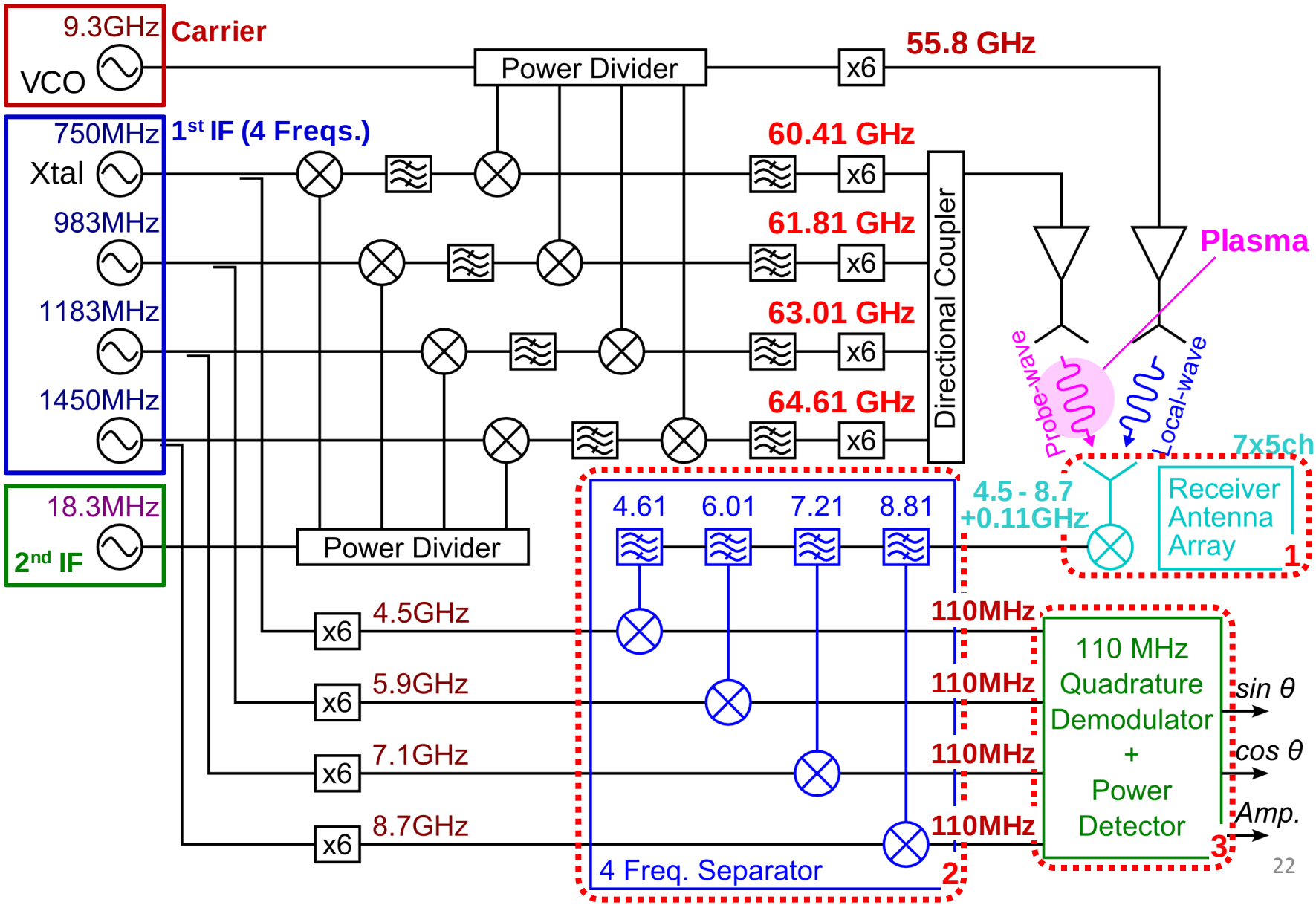
Dependences of Reflection on Injection Angle

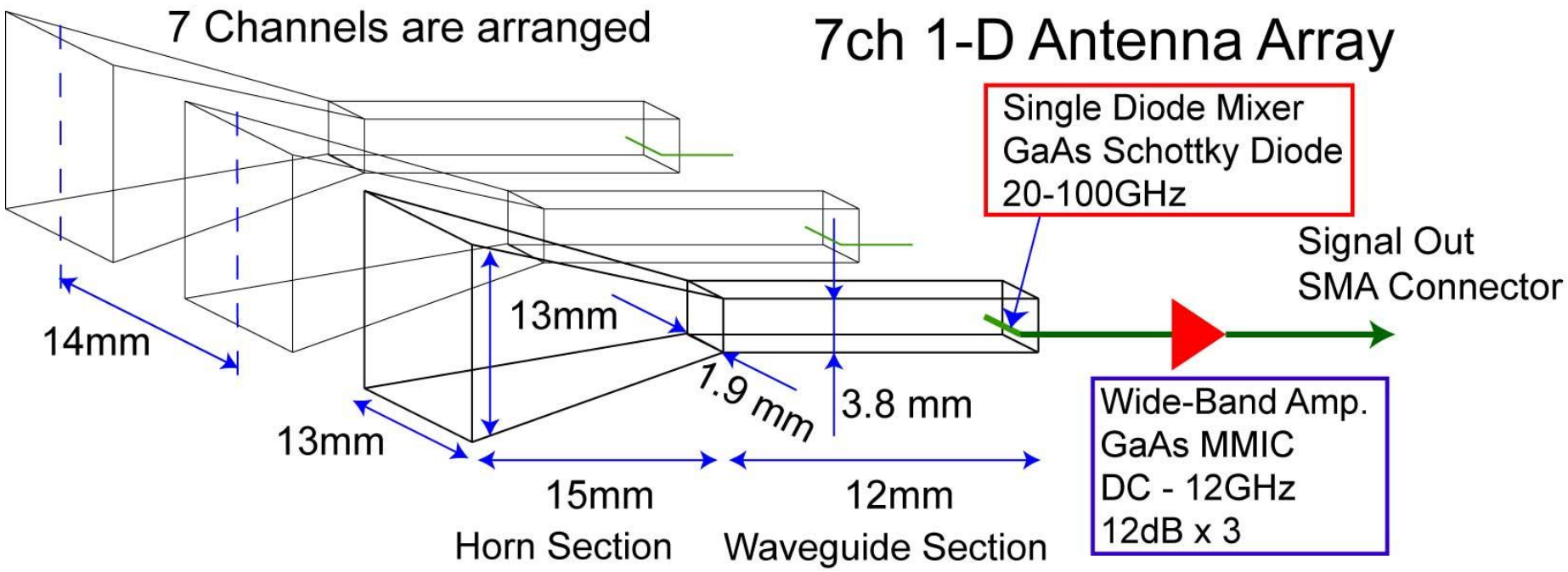
Very narrow range of injection angle (mirror setting) is allowed.



Simultaneous Projection / Detection Scheme of MIR

Four different frequencies are projected to the plasma simultaneously.



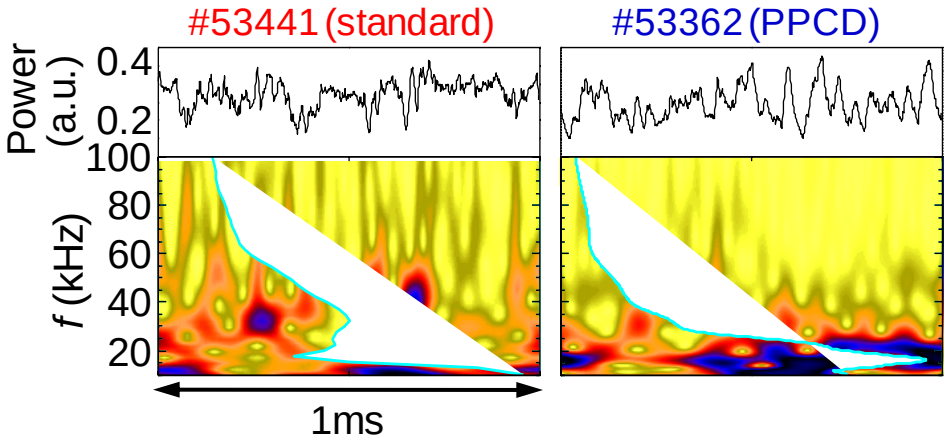

7 Channels are arranged
7ch 1-D Antenna Array
Single Diode Mixer
GaAs Schottky Diode
20-100GHz
Signal Out
SMA Connector
14mm
13mm
1.9 mm
3.8 mm
13mm
15mm
Horn Section
12mm
Waveguide Section
Wide-Band Amp.
GaAs MMIC
DC - 12GHz
12dB x 3

Goal of MIR Diagnostics [Results in TPE-RX (2007)]

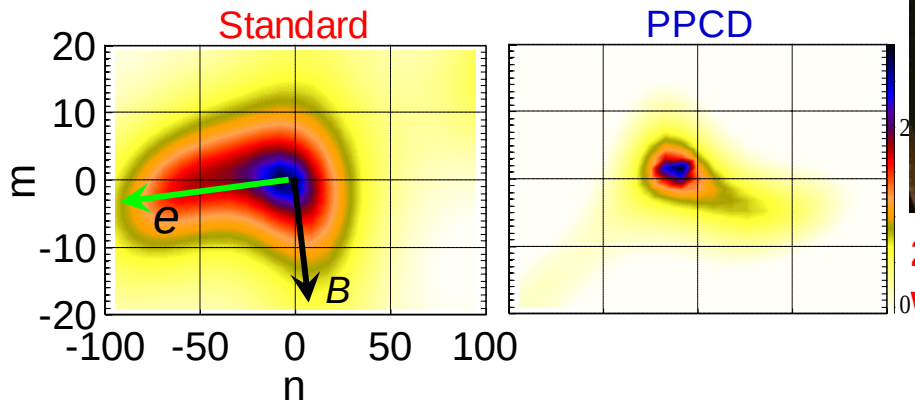
Shi Z.B. Ph.D Thesis

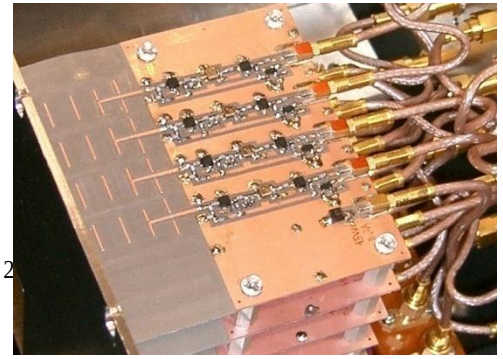
MIR in TPE-RX (worked at ~20GHz) confirmed that the fluctuations with high-frequency and large-*k* was suppressed in PPCD (Pulsed Poloidal Current Drive) operation.

High-freq. component is suppressed in PPCD.



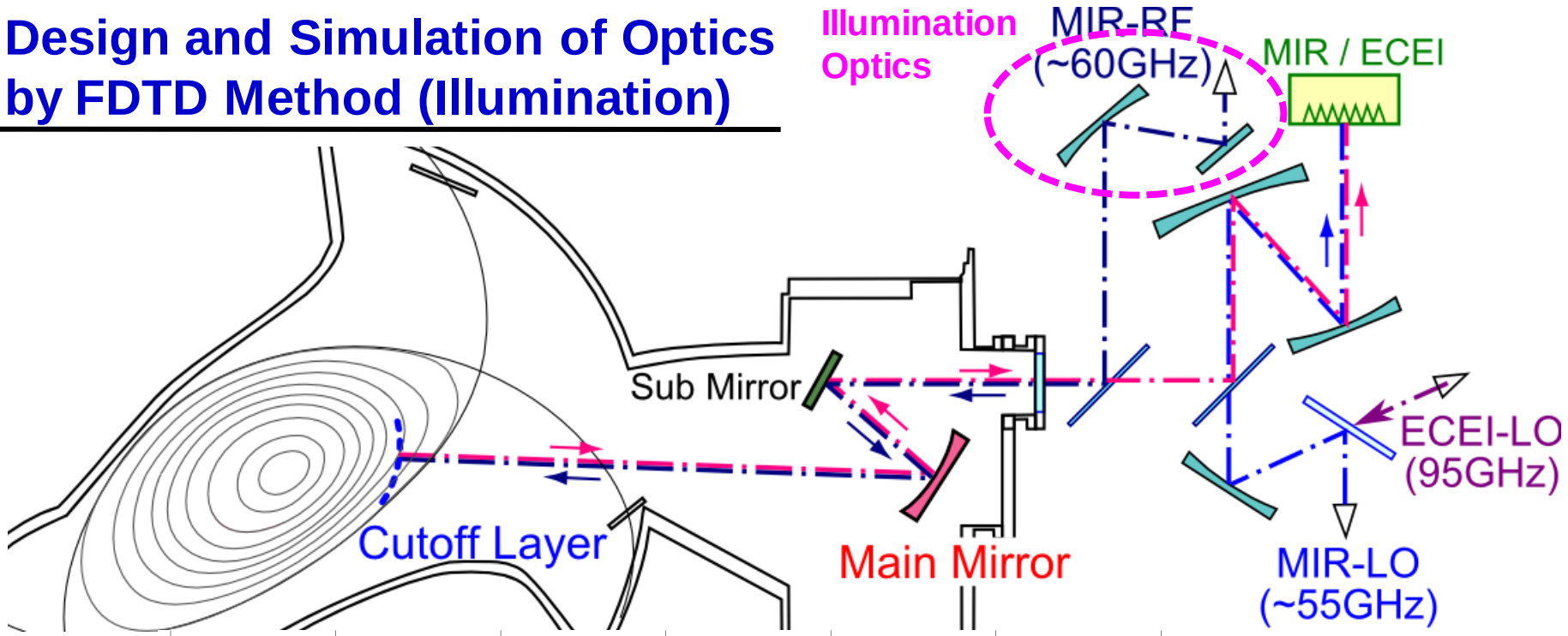
Large-*k* component is suppressed in PPCD.

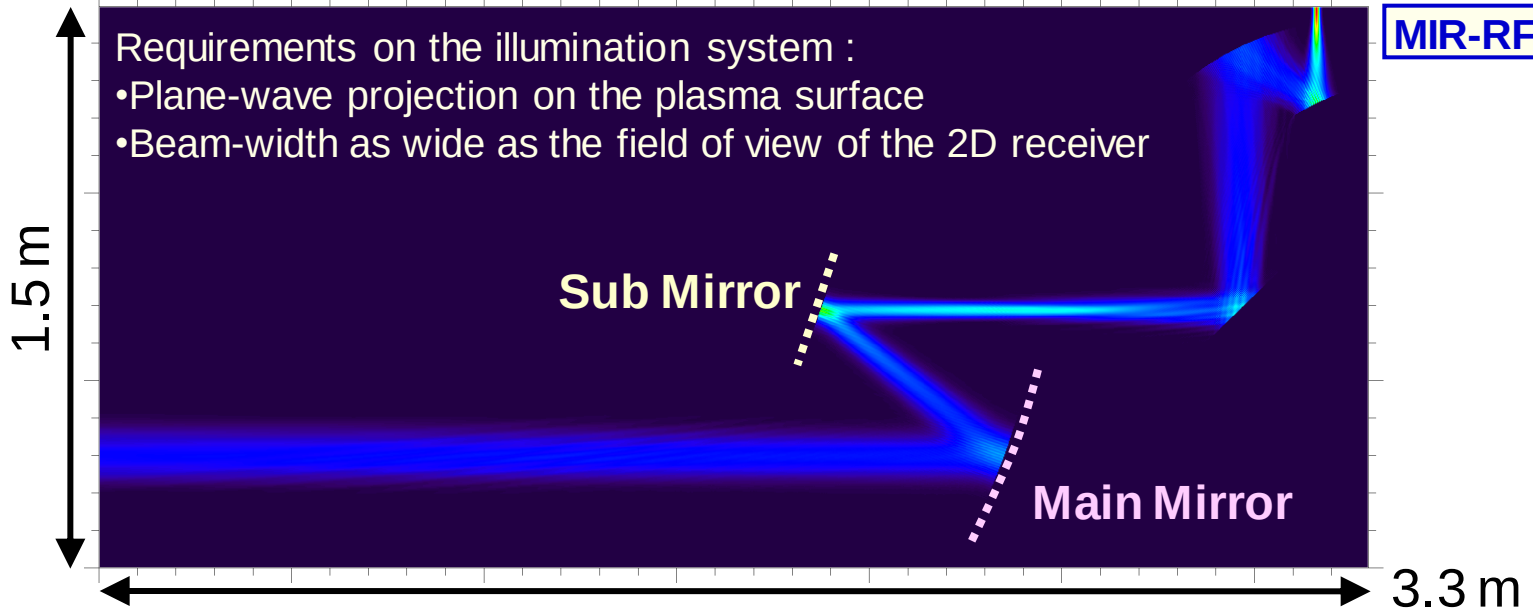




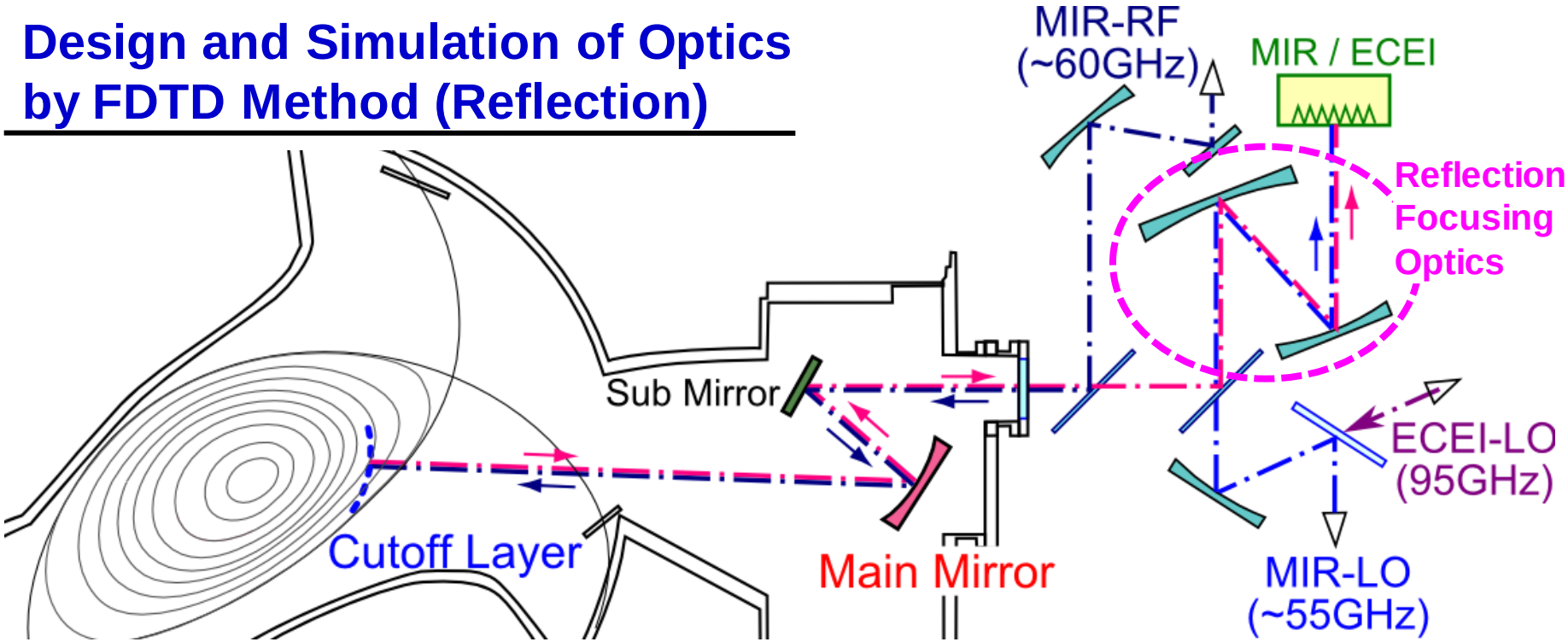
20GHz Receiver Antenna Array with 4x4ch Yagi-Uda Antenna

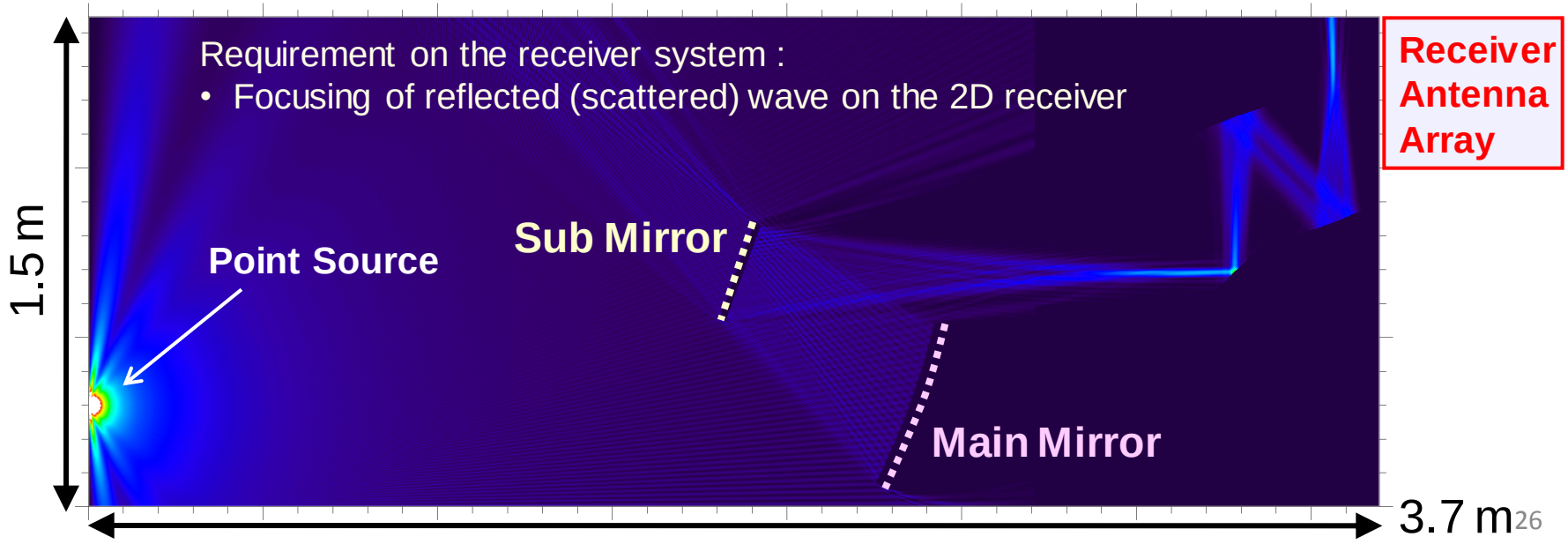
Design and Simulation of Optics by FDTD Method (Illumination)

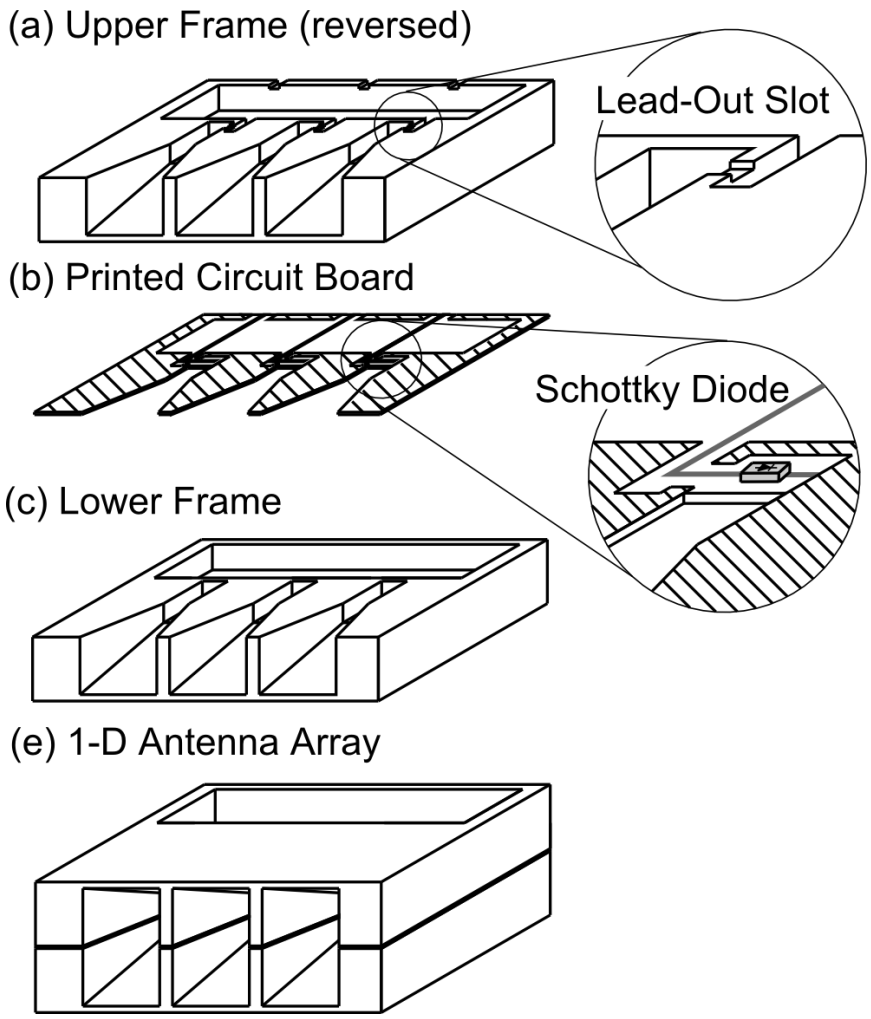




Design and Simulation of Optics by FDTD Method (Reflection)







1-D horn antenna array consists of 3 parts.

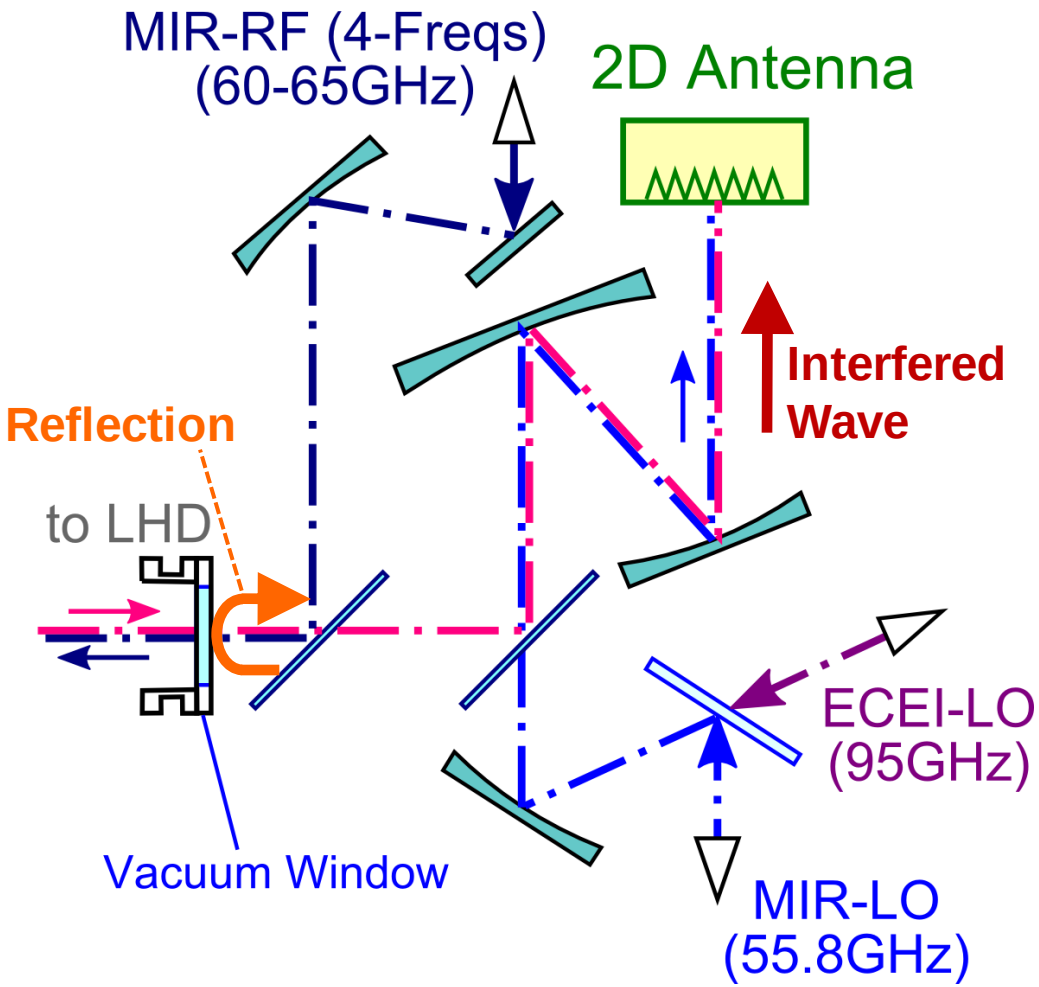
The upper and lower structures are made of aluminum alloy. A half of horn shapes and waveguide slots are made by electrical discharge machining. By attaching these slots, a horn antenna shape is formed.

The single diode mixer is mounted on P.C.B. at wave guide slot position. And wide-band IF amplifiers are mounted behind the antenna element.

Remaining Problems

Reflection from the vacuum window may be interfering with the wave from the plasma.

Tilting vacuum window will be one of the solution.



Cutoff density (MIR : ～60GHz)
O-mode : 4.5 x 10^{19} m^{-3}
X-mode : 1T → 2.4 x 10^{19} m^{-3}
2T → 3.0 x 10^{18} m^{-3}