ECE imaging development at W7-AS

S. Bäumel[1], M. Rodriguez[1,2], H. J. Hartfuß[1]
[1]Max-Planck-Institut für Plasmaphysik, EURATOM Ass., Boltzmannstr.2, 85748 Garching, Germany
[2]Institut für Hochfrequenztechnik, TU Darmstadt, 64283 Darmstadt, Germany

1. Introduction

Radiometry of electron cyclotron emission (ECE) is established as an electron temperature diagnostic in fusion plasmas since many years. By applying correlation techniques, also temperature fluctuations otherwise completely burried in thermal or wave noise of the ECE can be extracted. Crossed sightline correlation measurements were done on W7-AS, detecting electron temperature fluctuations with a level down to 0,1% of thermal noise [3]. With improved poloidal resolution parameter studies were performed [4]. The single sightline decorrelation, was used for temperature fluctuation measurements on TEXT [5]. These techniques proved the applicability of ECE diagnostics for measurements of electron temperature fluctuations. Both, crossed sightline and single sightline decorrelations, are proven to give the same results [6].
On the plasma edge two-dimensional (2D) characterisations of fluctuating structures are carried out by the use of 2D Langmuir probe arrays. Theoretical models were able to describe the measurements [7]. Recent development in mixer technology makes two-dimensional imaging also possible for the ECE. 2D arrays of microwave antennas are used to detect the fluctuating structures in both, the radial and the poloidal direction. Using specially designed millimeterwave optics, each antenna can detect different radial positions in the plasma core along its specific poloidal sightline. According to the principle of the diagnostic, it is called ECE imaging.
Two-dimensional measurements were successfully applied at TEXT-U [8]. The system was later installed at RTP [9]. Measurements of this kind are also planned for W7-AS. In the following an outline of the system planned for W7-AS and a characterisation of the system formerly used at RTP will be given.

2. Plans for an ECE imaging system setup for W7-AS

Before choosing the components of the system, a specification of the system performance has to be made.
In a first step it is planned to build an antenna array consisting of a four mixer array with integrated antennas with an intermediate frequency (IF) part made up by filter banks. The IF part is consisting of eight radial channels per antenna. The working frequency (RF) of the system is at 144 - 153 GHz, corresponding to the high field side of the electron temperature profile for 2,5 T. The intermediate frequency is chosen below 18 GHz to avoid additional complication with the detector array under development. To avoid the necessity, to sweep the local oscillator (LO) signal, and to be able to do measurements at different radial positions along a single sightline simultaneously, a wideband single sideband detection scheme with fixed LO signal is chosen. Therefore the local oscillator (LO) frequency is 135 GHz or 67,5 GHz for subharmonic mixing operation respectively. For the simultaneous detection seperate filter banks at the intermediate frequency (IF) will be used for each channel. In order to minimize losses by the optical system, it will be made up by elliptical mirrors. The location of the beam waist is in the plasma core. Since only a the circular port is available for the ECE imaging diagnostic at W7-AS, which is about 115 cm away from the plasma center, with only 10 cm in diameter, beam truncation would be the main problem for this diagnostic at W7-AS. The combination of these two concerns would

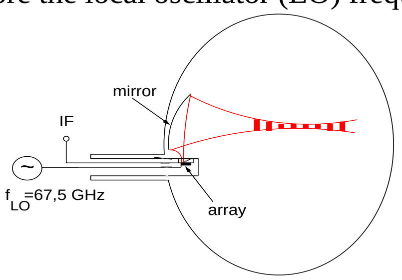

Fig. 1: Plasma vessel, elliptical mirror and immersion flange together with the LO source and the array can be seen. The beam of a single antenna is drawn in red.

make a refocussing of the Gaussian beam necessary, but is prohibited by the limited space at this part of the vessel. To overcome the problem of refocussing the Gaussian beam inside a small port towards the array outside the vessel, it is planned to place the array in an immersion flange. By a single focussing mirror inside the vessel, the radiation of the plasma will be focused onto the array, which is placed at atmospheric pressure together with another focussing lens. To ensure that only X-Mode radiation is detected, a polarizating grid is introduced into the sightline. LO power will be transmitted to the array by an oversized waveguide. The IF signal at the output of the array gets submitted to the IF section of the radiometer by coaxial cables. In Fig.1 a sketch of the setup together with a sightline of a single channel is shown.

3. Antenna/mixer array

In the following section the design of a fully MMIC (monolithic microwave integrated circuit) 150 GHz subharmonic mixer array is presented. As opposed to the receiver array described in [8], [9], which makes use of quasi-optical techniques, the circuit manufactured at the Technical University of Darmstadt (Germany) distributes the local oscillator power directly on the chip. The LO power gets fed to a 50 Ω microstrip line, thereby reducing significantly pumping power level requirements. The microstrip line acts as an LO filter and presents to the diodes a short circuit at IF and RF. Another structure on the other side acts as output filter. The RF antenna is also coupled to this structure. The antennas are printed on a 150 µm thick fused quartz substrate. Cross-talk between channels is reduced by physical substrate separation to prevent propagation of substrate modes. To increase channel isolation further, the patch antennas can also be isolated. The circuit is designed to have 9 GHz RF- and IF-bandwidths. Figure 2 describes the setup of all the four antennas integrated on a single chip. The diode pair has anti-parallel structure, a configuration with well-known advantages [10]. By reducing the pumping

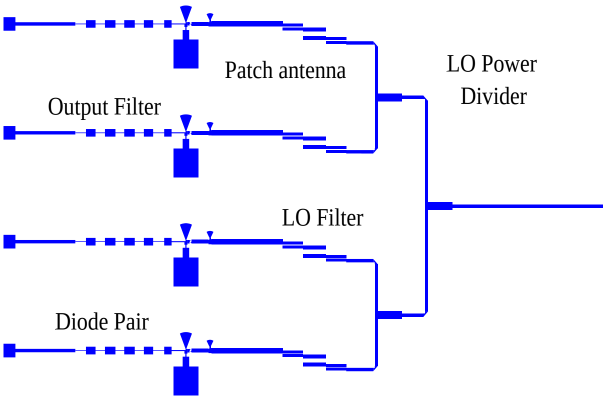

Fig. 2: Schematic view of the circuit. The LO signal gets fed towards the diode pair of each antenna from the right after passing the LO power dividers and the LO filters. The big square at each branch marks the patch antenna, followed by an output filter towards the IF part of the system.

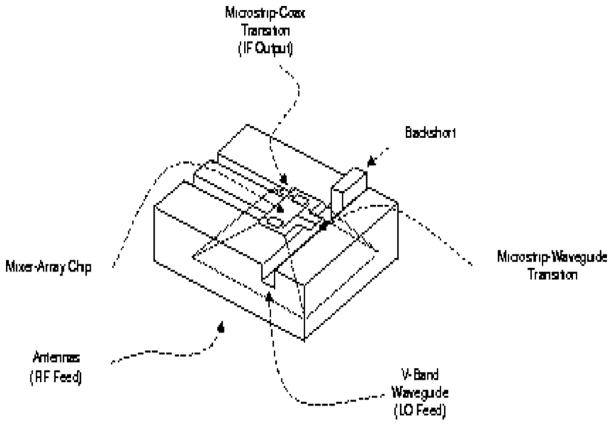

Fig. 3: Pricipal setup of two antennas mounted on a mixerblock. The RF signal from the plasma reaches the patch antennas, from below. The LO power is submitted to the patch antennas via a waveguide, which can be optimised by a backshort. The IF signal is released by a microstrip line to the IF part.

frequency to about 70 GHz, filtering is simplified, since the need to match an LO signal lying between RF and image bands is eliminated. This integrated circuit will be placed on the so called mixer block, which is shown in Fig. 3. The backshort in the LO waveguide allows to carry out an optimisation of LO power distribution to the microstrip lines.

4. Simulated properties of the antennas/mixers

Simulations of the MMIC by using the method of moments predict excellent electrical attributes (Fig. 4, Fig. 5). LO distribution loss includes 2 dB conductor and dielectric loss (3 dB/cm at 67,5 GHz) and 2 dB from the LO filter. The calculated conversion loss versus the output frequency for different values of pumping power available per channel indicates, that e.g. for a LO power of 8 dBm the conversion loss varies between 6 dB and 10 dB (Fig. 4). Typical values of isolation between ports were also estimated. The LO-IF isolation is 31 dB. The LO power flowing towards the RF antenna is 41 dB below the injected LO level. The RF-IF isolation is 50 dB. Undesired down converted image signal at the IF port is between 10 and 30 dB below the desired IF frequency. This is due to the antenna acting as an image filter and to additional intended mismatching.

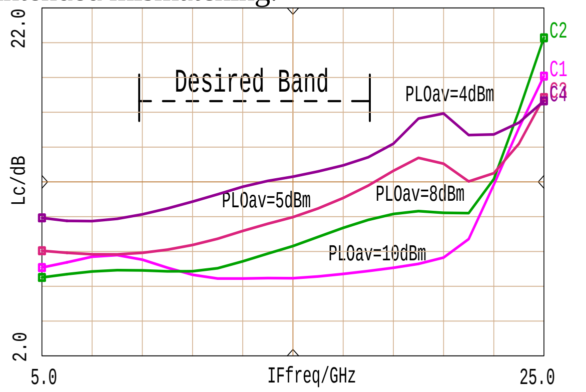

Fig. 4: Calculated conversion loss versus output frequency. The ripple of the conversion loss for an LO power of 8 dBm is less than 4 dB in the desired band.

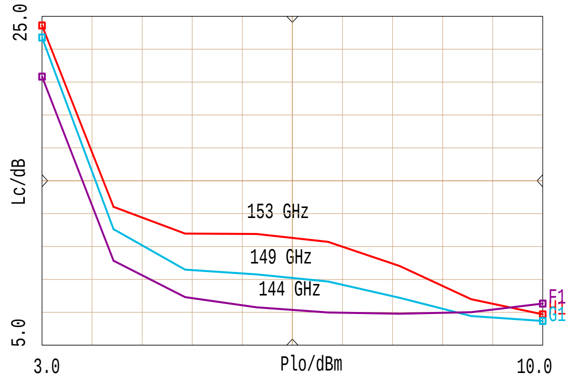

Fig. 5: Simulated conversion loss depending on different RF frequencies and LO power.

5. IF-Part of the system

The IF part of the system consists of eight radial channels for each poloidal antenna, which results in 32 radial channels of the whole ECE imaging system. In Fig. 6 an outline drawing of the planned IF-part is shown.The signal from the IF output of each branch of the array towards the IF part of the system is in the frequency range of 9-18 GHz. The first IF stage uses an amplifier with low noise figure (1.3 dB). After the next amplification step, the signal gets split up into two branches and after another amplification into four branches. After IF amplification and signal splitting, the total signal bandwidth is reduced to 400 MHz by the bandpass filters which comprise the filter banks. Each center frequency of a filter marks a radial position along the sightline of the corresponding poloidal antenna in the plasma. The bandwidth and the center frequencies of the filters determine the radial section along the chord. Finally the signal is detected with a zero bias Schottky diode detector and the output voltage of each video-channel is applied to the data aquisition.

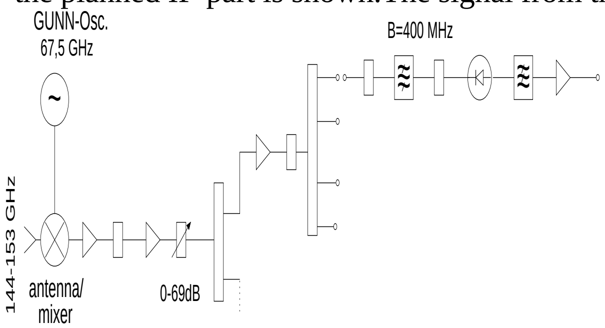

Fig. 6: IF part of the ECE imaging system planned for W7-AS. After mixing, the signal gets amplified and filtered. Each antenna provides a signal for eight channels, corresponding to eight radial sections in the plasma along the sightline of each of the four poloidal antennas.

6. Characterisation of the RTP ECEI system

Preliminary experiments were planned at W7-AS using the RTP ECEI system [9],[11] designed and constructed at UC Davis. Since the array was originally designed for signal frequencies (RF) between 100 and 125 GHz, it was necessary to characterise the system at 150 GHz, in order to prove its applicability to W7-AS. The system consists of a planar Schottky diode mixer array with an attached lens and four focusing lenses. The 20 antennas are arranged in two displaced columns and the local oscillator frequency is quasi-optically coupled into the array through the backside.

The double sideband receivers have intermediate frequencies within 25 to 300 MHz. In the frame of test measurements the antenna array characteristics were measured in both, the radial direction and in the poloidal plane. A signal source (GUNN oscillator) was moved along every single chord to determine the plane of the Gaussian waist along this chord of the system. Afterwards each antenna pattern was determined by moving the oscillator in the focal plane.

In Fig. 7 the beam pattern of a single antenna in its focal plane is shown. In Fig. 8 ten antennas of the array are plotted altogether. In both figures the detected IF output voltage is plotted normalized to the maximum of each antenna. The vertical distance between adjacent channels averages to about 1.2 cm; the horizontal distance is roughly 3.2 cm and the 3 dB spot in the focal plane averages to about 1.1 cm. The side lobes of each antenna increase in power as one moves away from the center channels due to the increasing diffraction caused by the finite size of the lenses. Unfortunately some of the minor lobes of one antenna coincide with the main lobe of the adjacent antenna at an RF frequency of 150 GHz. At this RF frequency the side wlobes can reach up to 25% in power of the maximum signal at a center channel. Fig. 8 gives only the main lobes, the side lobes are suppressed for clarity.

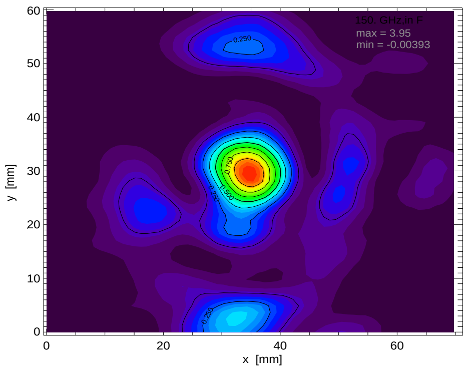

Fig.7: Beam pattern of a single detector of the RTP imaging array in its focal plane at a signal frequency of 150 GHz. Plotted is the power detected at the IF output.

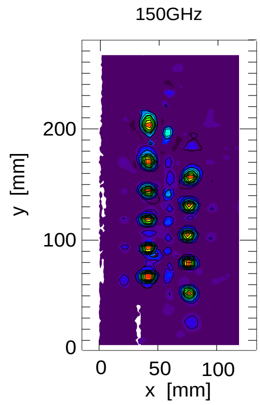

Fig.8: Beam pattern of ten detectors of the RTP imaging array at a signal frequency of 150 GHz in the focal plane. Each pattern was measured separately. For clarity the side lobes are suppressed.

Measurements show, that the system could successfully be used at about 150 GHz too. But an adaption to W7-AS is not possible without any refocussing lenses inside the vessel. The reasons are beam truncation and limited space as already mentioned before.

7. Acknowledgements

The authors would like to thank A.J.H. Donné, B.H. Deng, C. W. Domier and N.C. Luhmann, Jr. for loaning their ECEI system. Special thanks to M. van de Pol from RTP, who gratefully helped making the array ready for shipping.

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