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Advanced Adaptive-array Technique for ECE Diagnostics in a Software Defined Radio System

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1. Introduction

Compact spherical tokamaks (STs) can attain efficiently higher beta and higher density plasmas than the conventional tokamak. However, the center solenoid (CS) fluxes for inductive Ohmic heating are inherently limited because the center stack area is very small. Non-inductive plasma current ramp-up using radio frequency (RF) waves has been explored on the QUEST spherical tokamak.

The high-density plasmas beyond the cutoff density cannot be heated, and no plasma current are ramped and maintained using RF waves, because the wave cannot propagate inside the plasmas. Electron Bernstein wave heating and current drive (EBWH/CD) is an attractive heating method for the high-density plasma. Electromagnetic waves would be expressed with eigen eXtra-ordinary and Ordinary (X/O) modes in the magnetized plasma. Electrostatic electron Bernstein wave (EBW) can propagate inside the high-density plasmas beyond the cutoff after mode conversion from the O/X modes. The electromagnetic waves, propagating obliquely to the external magnetic field at a specific angle, can convert into the EBW. There is a good mode conversion region around the oblique injection angle. This 2-dimensional conversion area is called mode conversion window. (see Figure 1). Electron cyclotron emission inside the high-density plasma might be detected after the mode conversion as a reversal process of the heating. The 2-dimension ECE measurement which is converted form EBW is effective to find the mode conversion window area.

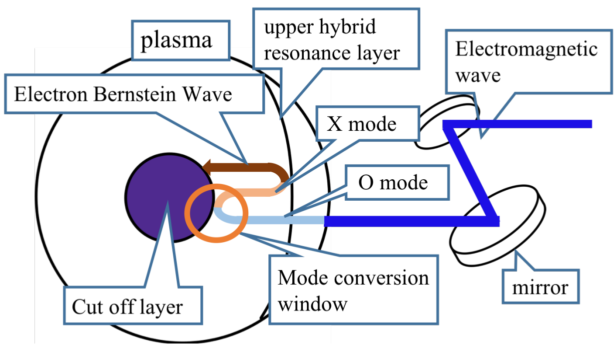


Figure 1: A schematic illustration of conversion scenario from O/X modes into EBW.

2. Adaptive-array analysis for thermal noise source

The phased array antenna has been developed to find the radiation source position with the adaptive-array technique. The thermal noise source (NS) is set as radiator to simulate the emission from mode conversion window. The radiations at the several antenna ports were measured with Software Defined Radio (SDR) system at heterodyne detections. (Figure 2). The NS position is at (x, y, z) = (-0.110 m, +0.110m, 0.483m). The origin of coordinates is at the array antenna center. In the previous work [1], the phases could correctly be detected with SDR system, and then the field intensity pattern was reconstructed with adaptive-array beam-forming technique (Figure 3A). The cross (+) and closed rectangle in the figure indicate the NS and phased array antenna positions, respectively. Since the number of antenna elements in the vertical direction is small (two), the vertical spatial-resolution is low.

To improve detected spatial-resolution, a Capon adaptive-array technique is introduced. The capon technique tries to find the main lobe and to minimize side lobs at same time. The result analyzed using the Capon technique is shown in Figure 3B. The spatial-resolution is improved drastically if the Capon technique is applied.

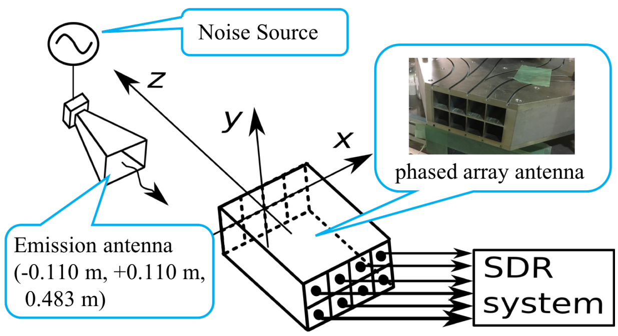
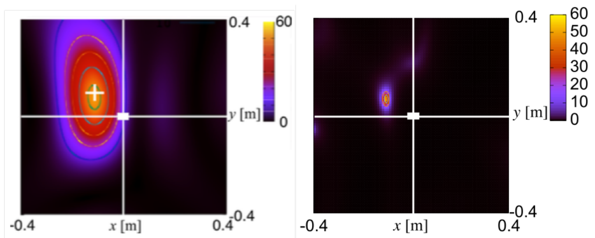


Figure 2: A schematic illustration of the experimentation.



A.experimental result (beamforming)

B.experimental result (Capon)

Figure 3: Field intensity pattern reconstructed using beamforming or capon analysis for NS radiation.

3. Adaptive-array analysis for two NS

The MUSIC (Multiple Signal Classification) technique is known as high estimation resolution of beam arrival direction. The MUSIC technique is introduced to find two NS radiator positions in the future.

References: [1] H.Idei *et al.*, Journal of Instrumentation, **11** (2016) C04010