§2. Numerical Study of Wave Propagation Near the OX Mode Conversion Region

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In this collaboration research program for the LHD experiments, we are developing numerical calculation code including the TASK/WF2DT code to analyze the mode conversion process between the electromagnetic modes and the electron Bernstein wave (EBW). If the density scale length is longer enough than the vacuum wavelength of the wave like the LHD, a part of the power of the ordinary (O) wave launched from the low magnetic field side that propagates obliquely to the external magnetic field can be mode converted to the extraordinary (X) wave after the tunneling through the evanescent region between the plasma cutoff (PC) and the left handed cutoff (LC). If the density scale length is similar or less than the vacuum wavelength like spherical tokamaks, a part of the power of the X wave launched from the low magnetic field side can tunnel through its evanescent layer between the upper hybrid resonance (UHR) and right handed cutoff (RC) and couples to the X wave in the high field (and density) side. The X wave in the high field side propagates toward the UHR and is mode converted to the EBW. In contrast to the ray-tracing calculation the TASK/WF2DT can treat the wave propagation near and inside the evanescent region directly where the O-X or X-X mode conversion occurs with taking into account a finite beam width. It solves the Maxwell's equation by finite elements method (FEM) in two dimensional (2D) space.

$$\nabla\times\nabla\times\boldsymbol{E} - \omega^2/c^2\vec{\boldsymbol{\varepsilon}}\cdot\boldsymbol{E} = i\omega\mu_0\boldsymbol{j}_{ext} \quad (1)$$

Now as the boundary condition, an arbitrary elliptically polarized incident wave that has Gaussian power distribution at the edge of a waveguide can be set for an arbitrary injection angle. Fig.1 shows the distribution of the real component of each electric field component when a linear polarized 5GHz wave is launched into an over-dense plasma obliquely to the uniform external magnetic field. Here, the electron density changes linearly along the R direction. In this case the X-mode component is dominant in the launched wave. To see the one-pass propagation of the wave easily, the power absorber is set to surround the calculation region. The distributions of the electric field components that is perpendicular to the external magnetic filed (E_R, E_Φ) indicate the reflection process of the X-mode at RC. A part of the launched power tunnels through the evanescent region between the upper hybrid resonance layer and the RC, then propagates almost parallel to the magnetic field direction and approaches the UHR. Here the collisional cold plasma model is applied to give the dielectric tensor in eq. (1), therefore the wave that reaches the UHR suffers the collisional damping.

Fig.2 shows an case of O-mode dominant launching. Also a linearly polarized wave was obliquely launched so that the parallel component of the refractive index $N_{//}$ is close to $N_{//opt} = (\Omega/(\omega+\Omega))^{1/2}$ where Ω is the electron cyclotron angular frequency and ω is the wave anglular frequency. The distribution of the E_Z component indicaes that the O-mode component propagates toward the plasma cutoff (PC) and a part of the power is reflected at PC and the rest propagates almost parallel to the external magnetic field and approaches the UHR layer.

To analyze the propagation of the wave launched as a Gaussian beam in the LHD, it is required in TASK/WF2DT to give an arbitrary distribution of the electric field at the calculation boundary that locates inside the plasma as one dimensional data. More, arbitrary 2D distributions of external magnetic field and electron density should be adopted. For this preparation, the distribution of the electric field components of the launched beam at the calculation boundaly has been able to be given with using the multi ray-tracing and interpolation by Krigging method.

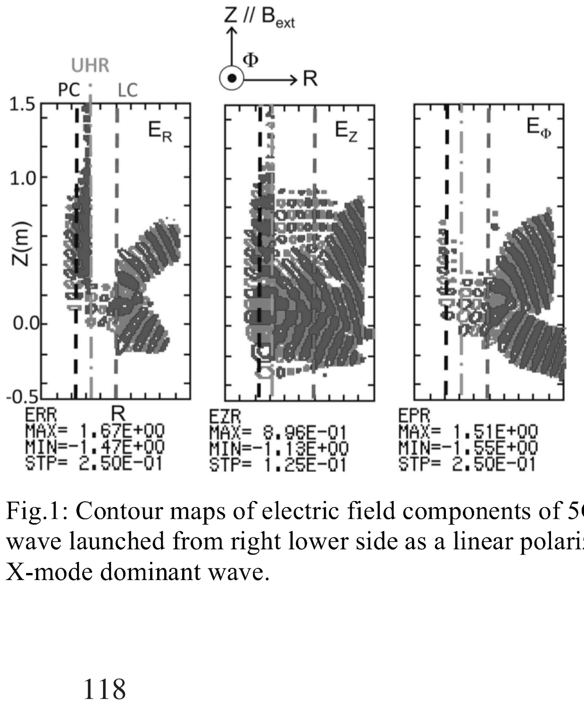

Fig.1: Contour maps of electric field components of 5GHz wave launched from right lower side as a linear polarized X-mode dominant wave.

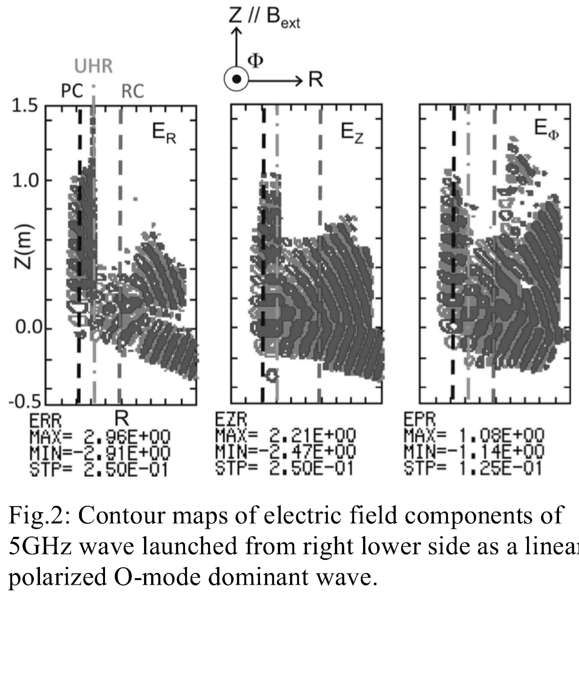

Fig.2: Contour maps of electric field components of 5GHz wave launched from right lower side as a linear polarized O-mode dominant wave.