§11. Development of Microwave Imaging Technology

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Microwave imaging diagnostics has been proposed for three-dimensional observation of the local electron density and temperature in magnetically confined plasma. Microwave Imaging Reflectometry (MIR) and Electron Cyclotron Emission Imaging (ECEI) are improved as a combined system in Large Helical Device (LHD). The system development is expected to bring new findings to the plasma physics. The MIR basically need an optical system in order to capture the microwave pictures. Its spatial resolution is restricted by the optical system. An incident wave is reflected and scattered by the target and then it propagates and diverges to its peripheral space. In the absence of the optical system the microwave picture doesn't appear. The scattering wave keeps informations about the target's shape, size, location, its electrical parameters, and so on. Mathematical analysis can reconstruct the microwave picture without the optical system. This imaging technique is included in microwave Computer Tomography (CT). The conventional CT technique is applied to the transmission measurement as x-ray tomography for plasma and medical applications. The microwave tomography technique can be applied to the scattering measurement. In the scattering system the incident wave propagates to the target, many receivers are located around the target or a single receiver is scanned around the target. The spatial resolution is well enhanced as the scanning range is wide. This research develops the microwave CT system with quasi-plane incident wave. A corrugated horn antenna can launch the quasi-plane wave. The antenna has high gain, low loss and low cross-polarisation for wide frequency range. When the quasi-plane wave is used as the incident wave, the scattering analysis and the image reconstruction become easy and the calculation time can be reduced than the present level. The system development cost can be reduced by using a low-cost frequency converter and a quadrature mixer of the mobile phone and commercial Global Positioning System (GPS) devices. These low-cost circuits and improvement help us to develop microwave CT system for basic science and industrial applications.

The microwave CT system is similar to the heterodyne reflectometer with quadrature mixers as like MIR system in LHD and TPE-RX. The block diagram of the system is shown in Figure 1. A voltage controlled oscillator is used as the incident wave source. It outputs continuous microwave with the output power of +14 dBm at the frequency of 10 GHz. The frequency is tuned between 8.5 and 13.5 GHz by an external dc voltage, and the system can work as a frequency modulation reflectometer. The incident wave is launched from a corrugated horn antenna with the power of +10 dBm. The corrugated horn antenna was machined by a Numerical Controlled (NC) lathe in NIFS workshop. A crystal oscillator is used as a reference signal source with the precise frequency of 110 MHz. The reference signal is compared to an Intermediate Frequency (IF) signal of the scattering wave from the dielectric target. Local Oscillation (LO) signal is divided from the probe wave source, and its frequency is upconverted by 110 MHz by using a single-side upconverter IC. In the present setup the scattering wave is received by a waveguide aperture antenna for X-band (8 to 12 GHz) transfer. A linear array of 16 channel receivers is also under development for multichannel measurement. The quadrature mixer IC converts the IF signal to in-phase and quadrature signals. A power monitor measure the amplitude of the scattering wave. They calculate a complex amplitude of the scattering wave. These signals are recorded by a data acquisition system and a 1U rackmount workstation. The workstation can rotate the target by an auto-rotation table. It can also tune the probe wave frequency in frequency modulation mode.

For the system design and optimization the scattering wave is calculated by Finite-Difference Time-Domain (FDTD) method in C programing. Figure 2 shows the scattering pattern from a dielectric target. The cell size is 1 mm and the lattice is 500 x 500. The target is circular with the diameter of 12 mm and it is located at the center position of $(x, y) = (250, 250)$. The target is shown as the small circle in Figure 2. The relative permittivity of the target is set to $\varepsilon = 3.0$ for the incident frequency of 10 GHz. The wave source is set to be on the aperture of the corrugated horn antenna. The source is distributed as Gaussian from x = 155 to x = 245 on the x-axis. The quasi-plane wave propagates to the target in the y-direction and then it is scattered by the target or it passes through the target. Some interference between the incident wave and scattering wave appears behind the target. The FDTD result suggests that the angle interval of the receiver should be smaller than 5 degrees in order to measure the difference of the target size by some millimeters.

The work is supported by NIFS09KLEP001.

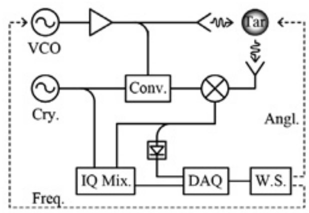

Fig. 1 Block diagram of microwave scattering CT system.

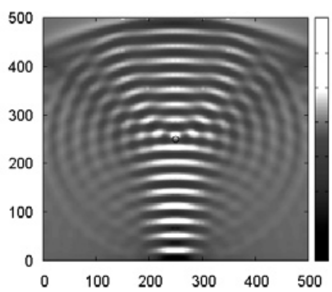

Fig 2. Scattering pattern calculated by FDTD method.