§21. Development of High Resolution Microwave Imaging System for Plasma and Dielectric Object Observations

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The microwave imaging reflectometer (MIR) and the electron cyclotron emission (ECE) measurement systems are acquiring valuable data on LHD plasma with well-designed systems of high spatial-temporal resolution antenna array. The measured raw data posses rich information about 3-dimensional (3D) fluctuations of density and temperature of LHD plasma and is waiting for effective 3D image analysis. Meanwhile, on the basis of experiences that we got through construction of these systems, we built a new diffraction microwave imaging system [1, 2] for the purpose of breast cancer diagnostics. This imaging system is expected to have a capability of getting information on the shapes of tumors that are less than 5 mm in diameter at the early stage of cancer.

Firstly, we have started to develop a new software for spectral analysis of MIR and ECE signals [3]. After obtaining the spatial cross correlation among multi-channel signals for a particular frequency, the software intends to estimate the 3D wavenumber spectrum from the obtained cross correlation values by iteratively solving an inverse problem [2] with a Hopfield neural network. This inversion approach to wavenumber spectral estimation allows to get a super resolution in the sense that the estimator will give a higher resolution than the spatial Fourier transform of the cross correlation series that is obtained among a few channels.

The inversion approach was tested for both simulational and LHD data in one-dimensional estimation. A simulation with a sinusoidal wave gave a super resolution of wavenumber as expected. With respect to MIR data, an estimate of the wavenumber spectrum is shown in Fig. 1 (a). This result was obtained from six neighboring channels with equal spaces of 2cm. This result is examined in recovering the cross correlation in Fig.1 (b). Extensions to 2D and 3D spectral estimations is progressing.

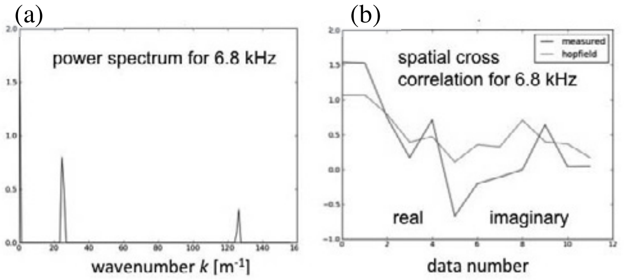

Fig. 1 Results of 1D wavenumber spectrum estimation of MIR for 6.8 kHz component: (a) an estimate of wavenumber power spectrum, (b) recovered and measured cross correlations.

Secondarily, we have developed a diffraction tomography subsystem of the microwave imaging system for breast cancers. The tomography subsystem is the following part of the preprocessing pulse radar subsystem which had already tested by the FDTD simulation in the former fiscal year. The tomography subsystem reconstructs relative permittivity as the contrast of the object and the background, by using amplitude and phase information of the diffracted microwave. For the fast reconstruction, we solve the inversion problem directly by using the Extended Born Approximation (EBA), that extends the original Born Approximation to the secondary scattered waves. We also arranged the EBA for strong scattering objects like breast cancers, by using the Modified Quasi Linear Approximation (MQLA). We had validated the reconstruction capabilities of the MQLA with our transmitting/receiving antenna, by the FDTD simulation.

An imaging experiment for an acryl pillar phantom with 20mm diameter reconstructed successfully the object contrast, only using front-scattered microwave. By using amplitude and phase data of the measured receiving microwaves at 16 locations, the system reconstructed the relative permittivity image in the reconstruction area consists of 4 x 4, 10mm-squared pixels(Fig. 2). The measured amplitude and phase values of the received microwaves are agree well with those of FDTD simulation. Though the values of the reconstructed relative permittivity of the object are little lower than the assumed ones, they have enough contrast against the background. Spatial resolution of the reconstructed image can be improved by adding back and side scattered wave data. The modification of the MQLA to introduce above two kinds of scattered waves is remained as a further work.

1) Yamaguchi, S. et al.: Ann. Rep. NIFS 2012, p.149.
2) Teranishi, M. et al.: Ann. Rep. NIFS 2012, p.444.
3) Emoto, M. et al.: 22nd Int'l Toki Conf., p4-46 (2012).

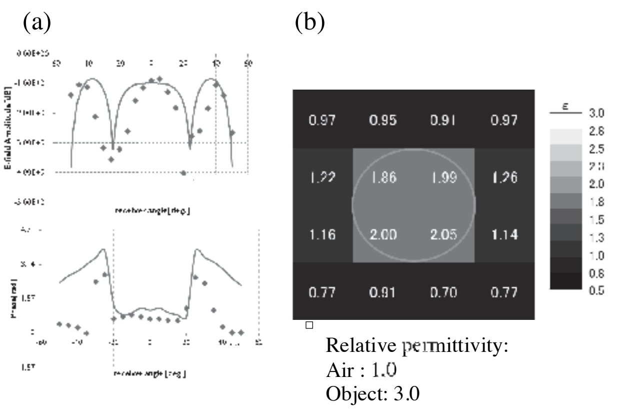

Fig. 2 Result of an microwave imaging experiment for acryl pillar phantom: (a) Simulated (lines) and measured (dots) front scattered microwave, (b) reconstructed relative permittivity of the object.