§27. Data Analysis Study for Microwave Tomography System Implementation

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The purpose of study is to develop the image reconstruction method for the microwave computerized tomography (microwave CT) with high space resolution. A new microwave imaging system is under development on the basis of the advanced measurement technology that has been built up for the microwave imaging reflectometry (MIR) of high temperature plasma. The system will serve purposes of practical imaging such as the breast cancer detection and the concrete pillar diagnostics. The system will be able to emit microwaves to objects with frequency variable and higher than those of the conventional practical imaging systems, and receive the scattered waves with phase information.

After assemblage of the fundamental measurement components (a transmitter and a receiver antenna array, a data acquisition system) of our microwave imaging system, a function of measuring scattered microwave was tested for a dielectric cylindrical phantom (Fig. 1). By sweeping the microwave frequency in the range from 8.0 to 9.4 GHz, scattered microwaves were received in the form of complex signal by a quadrature detection circuit at 4 channels out of 16 channels of the receiver antenna array (Fig. 2).

From the aspect of data analysis study, furthermore, recent works of microwave imaging such as the distorted Born iterative method (DBIM)[1], a frequency-domain inversion with 3D series expansion[2] and the time-domain inversion[3] were reviewed to frame our concept towards good methods of image reconstruction.

When an object is illuminated in the two-dimensional scheme by a TM incident wave $e^i(\boldsymbol{r})$ with time dependence of $\exp(-i\omega t)$, the electric fields $e(\boldsymbol{r})$ in the object and $e(\boldsymbol{s})$ at a receiver are expressed as

$$e(\boldsymbol{r}) = e^i(\boldsymbol{r}) + \iint_S k_0^2 c(\boldsymbol{r}')e(\boldsymbol{r}')G(\boldsymbol{r},\boldsymbol{r}')d\boldsymbol{r}' \qquad (1)$$

and

$$e(\boldsymbol{s}) = \iint_S k_0^2 c(\boldsymbol{r}')e(\boldsymbol{r}')G(\boldsymbol{s},\boldsymbol{r}')d\boldsymbol{r}' \,. \qquad (2)$$

Here, $c(\boldsymbol{r})$ and $G(\boldsymbol{r}, \boldsymbol{r}')$ denote the contrast function of complex permittivity and the Green function, respectively, and k_0 is the wavenumber in free space. When $e(\boldsymbol{s})$ is observed at several points in a multi-transmitter configuration, determining $c(\boldsymbol{r})$ from the acquired data is a nonlinear problem of image reconstruction. After pixellating the object region, the problem can be written in an algebraic equation

$$A(\boldsymbol{c})\boldsymbol{c} = \boldsymbol{e}^s \qquad (3)$$

in order to determine the unknown image vector $\boldsymbol{c}$ from the data vector $\boldsymbol{e}^s$ of the whole receiving system. The coefficient matrix $A(\boldsymbol{c})$ is calculated depend on the solution vector $\boldsymbol{c}$, the inversion of Eq. (3) has strong ill-posedness.

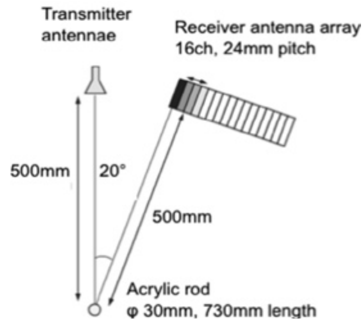

Fig. 1 Experimental setup of microwave measurement test.

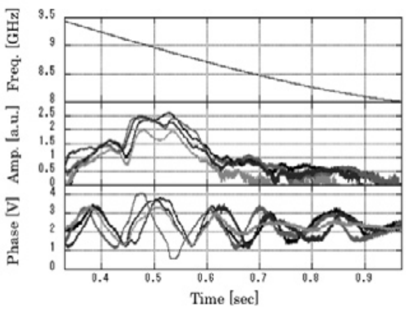

Fig. 2 Result of frequency sweeping test.

The DBIM solves this nonlinear inversion problem iteratively by solving linear approximate equations, whose coefficients are modified by forward calculation of the scattered field with the finite difference time domain (FDTD) analysis. This DBIM with FDTD is equivalent to the least square minimizing method that solves this nonlinear problem directly by using a Newton type minimizing technique[4]. Due to massive computational cost of FDTD, hardware accelerators are used to reduce the imaging time to a reasonable level. Effective reduction is obtained moreover by introducing an orthogonal series expansion on the inside of object with a matrix decomposition technique[2]. The geometrical knowledge of object boundary leads to a notable image improvement also in the time domain inversion[3] that is based on fitting to the waveforms of pulsed scattering signals and properly involves the multi-frequency stabilizing effect.

The possibility of reducing the computing time with higher resolution was investigated on the usage of new methods of matrix decomposition and of solving ill-conditioned linear equations of large size. The preparation of microwave imaging experiment was well progressed.

1) W.C. Chew and Y.M. Wang: IEEE Trans. Medical Imag., **MI-9** (1990) 218.
2) D.W. Winters, J.D. Shea, P. Kosmas, B.D. Van Veen, and S.C. Hagness: IEEE Trans. Medical Imag., **MI-28** (2009) 969.
3) J.E. Johnson, T. Takenaka *et al.*: IEEE Trans. Biomed. Eng., **BE-55** (2008) 1941; **BE-56** (2009) 2232.
4) A. Franchois and C. Pichot: IEEE Trans. Antennas Propagat., **AP-45** (1997) 203.