THEORETICAL AND EXPERIMENTAL STUDIES ON PASSIVE IMAGING OF ELECTROMAGNETIC SOURCES

Toru UNO*, Shin-ichiro HOSOYA*, Yiwei HE** and Saburo ADACHI***
*Department of Electrical and Computer Engineering
Tokyo University of Agriculture and Technology
Koganei, Tokyo 184, Japan
**Department of Computer Science and Communication Engineering
Kyushu University
Higashi-ku, Fukuoka 812, Japan
***Department of Communication Engineering
Tohoku Institute of Technology
Taihaku-ku, Sendai 980, Japan

1. INTRODUCTION

In radar and geophysical researches, or in electromagnetic spurious source searching, a main objective is to localize and characterize the radiating sources, i.e., the primary sources, and/or the secondary sources, from observed electromagnetic field. Until now, acoustic or electromagnetic source localization problem has been investigated by using several techniques, for example, the root mean square error evaluation, the synthetic aperture techniques, the maximum entropy method, and their modified versions[1]~[10]. However, most of the work done has treated under the approximation of scalar wave in far zone or in Fresnel zone. The present authors has implemented a time-domain exact inverse procedure for searching the electromagnetic radiation sources located in an arbitrary region[11]. To illustrate the concept we dealt with a highly idealized situation. However, the analysis was a full-wave treatment, and the solution of the inverse problem was mathematically exact. In this paper we study a frequency domain passive imaging of three dimensional electric and magnetic currents. The validity of the method is confirmed by an experiment.

2. 3-D PASSIVE IMAGING THEORY AND NUMERICAL EXAMPLE

The geometry of the problem is shown in Fig.1. The electric or magnetic short dipoles are located arbitrarily in free space. Radiated field is observed in flat plane parallel to y-z plane.

First we consider the imaging problem for electric short dipole distribution which is expressed by

$$J(\omega, R) = \sum_{n=1}^{N} P_n(\omega)\, m_n \delta(R - R_n) \qquad (1)$$

where m_n is a unit vector indicating the direction of each dipole.

Radiated electric field is expressed by

$$E = \nabla\nabla\cdot\Pi + k_0^2\Pi \qquad (2)$$

$$\Pi = \frac{1}{j\omega\varepsilon_0}\sum_{n=1}^{N} P_n(\omega)\, m_n\, G_3(k_0, R\,; R_n) \qquad (3)$$

where $G_3(k_0, R\,; R_n)$ is a free space Green's function. Multiplying (2) by $e^{jk_0 \hat{s}\cdot R}$ and integrating with respect to y and z, we obtain the following relation.

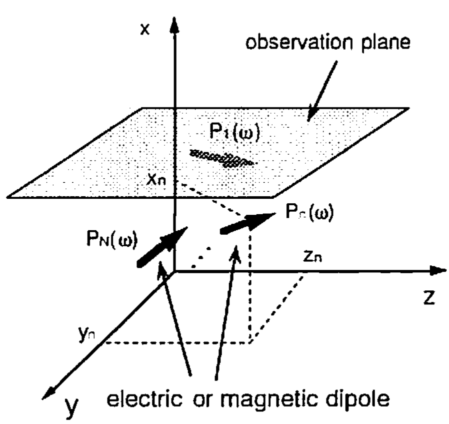

Fig.1 Geometry of the problem

$$\hat{s} \times \left\{ \left(\sum_{n=1}^{N} P_n(\omega)\, m_n\, e^{jk_0 \hat{s}\cdot R_n} \right) \times \hat{s} \right\} = -\frac{2 \sin\theta \cos\phi}{\eta_0} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} E(R)\, e^{jk_0 \hat{s}\cdot R}\, dy\, dz \qquad (4)$$

where η_0 is a free space characteristic impedance, and

$$\hat{s} = \sin\theta \cos\phi\, \hat{x} + \sin\theta \sin\phi\, \hat{y} + \cos\theta\, \hat{z} \qquad (5)$$

is an arbitrary unit vector. Furthermore, multiplying (4) by $e^{jk_0 \hat{s}\cdot R'}$ and integrating over the total solid angle, we have

$$\begin{aligned} &\nabla' \times \nabla' \times \left\{ \sum_{n=1}^{N} P_n(\omega)\, m_n\, j_0(k_0 |R_n - R'|) \right\} \\ &= -2 \frac{j k_0}{\eta_0} \frac{\partial}{\partial x'} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} E(R)\, j_0(k_0 |R - R'|)\, dy\, dz \end{aligned} \qquad (6)$$

where $j_0(\cdot)$ is the zero-th order spherical Bessel function. The left-hand side of (6) has a peak value at $R' = R_n$ and vanishes very rapidly at the other point. Therefore, the right-hand side of (6), that is, the synthesis of the radiated field has an image of the dipole.
In the case of magnetic dipole, replacing E/η_0 in (6) to $\eta_0 H$, the similar relation can be obtained.

Fig.2 shows the geometry of the numerical example. Three dipoles are arranged as P_1 : (0, -3, 0), $m_1 = \hat{x}$, P_2 : (0, 0, 5), $m_2 = \hat{y}$, P_3 : (2, 0, 0), $m_3 = \hat{z}$. Amplitudes of their dipoles are assumed as $P_1 = P_2 = P_3 = 1$. All components of the radiated electric field are observed over the observation plane at x=7m.

The resultant images on y-z plane at x=0 which is synthesized from the noise free data using eq.(6), are shown in Fig.3. It is found that the positions and the directions of the dipoles are well reconstructed. Weak image is observed at the z-component. This image is the contribution from the near-field of P_3.

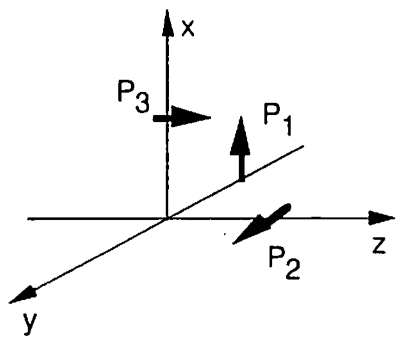

Fig.2 Geometry of electric dipoles for numerical example

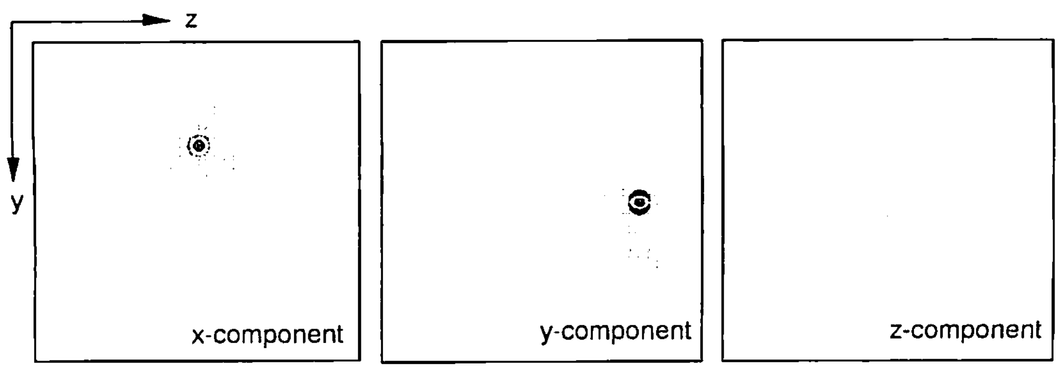

Fig.3 Reconstructed images on x=0 plane

3. EXPERIMENT

In order to confirm the validity of the above theory, an experiment was performed. An experimental setup is shown in Fig.4.

Two loop antennas #1 and #2 are located above a plotter. The loop antenna #1 moves over the plane of plotter, and #2 is supported in the air. The scattering parameters are measured by the network analyzer. The personal computer controls all of the measurement system. This experiment corresponds to the imaging of the magnetic dipole by measuring the magnetic field. The parameters of the experiment are shown below.

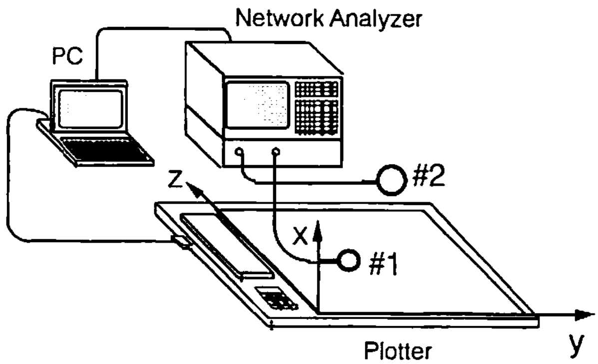

Fig.4 Experimental setup

- Antenna diameters;
  #1: 1.7cm #2: 4cm
- Measurement range and number of points;
  80cm x 55cm, 204 points
- Frequency range;
  2.4GHz to 2.8GHz, 11points
- Height of #2;
  x=20cm

Images calculated using (6) is shown in Fig.5. First column is the images on y-z plane and the second is on x-y plane. z-component magnetic current is well reconstructed, however, relatively large y-component image appears in y-z plane. This image may correspond to electric current caused by the electric field component contained in the measured data, because the loop antennas are relatively large in this frequency range.

4. CONCLUSIONS

In this paper we implemented the frequency domain inverse procedure for searching the electromagnetic radiation sources located in an arbitrary region. In the passive imaging theory, we treated the small dipole currents for simplicity, but the analysis was a full-wave and the solution is mathematically exact. The validity of the imaging method was confirmed by the experiment.

REFERENCES

[1] F. C. Schweppe, "Sensor array data processing for multiple signal sources," IEEE Trans. Inform. Theory, vol.IT-14, pp.294-305, 1968.

[2] C. H. Knapp and G. C. Carter, "The generalized correlation method for estimating of time delay," IEEE Trans. Acoust., Speech, Signal Process., vol.ASSP-24, pp.320-327, 1976.

[3] M. Wax and T.Kailath, "Optimum localization of multiple sources by passive arrays," IEEE Trans. Acoust., Speech, Signal Processing, vol.ASSP-31, pp.1210-1217, 1983.

[4] R. O. Schmidt, "Multiple emitter location and signal parameter estimation," IEEE Trans. Antennas Propagat., vol.AP-34, pp.276-280, 1986.

[5] R. Kumaresan and D. W. Tufts, "Estimation source location - A digital approach," IEEE Trans. Aeros. Electron. Syst., vol.AES-19, pp.134-139, 1983.

[6] Y. Rockah and P. M. Schltheiss, "Array shape calibration using sources in unknown location- Part II: Near-field sources and estimator implementation," IEEE Trans. Acoust.

Speech, Signal Process., vol.ASSP-35, pp.724-735, 1987.
[7] J. Kikuchi, M. Sato, Y. Nagasawa and R. Sato, "A proposal for searching for electromagnetic wave sources by using a synthetic aperture technique," Trans. IECE Japan, vol.J68-B, pp.1194-1201, Oct. 1985.
[8] J. Kikuchi, Y. Nagasawa, "Search for electromagnetic wave sources by using the maximum entropy method," Trans. IECE Japan, vol.J69-B, pp.949-957, Sept. 1986.
[9] Y-D. Huang and M. Barkat, "Near-field multiple source localization by passive sensor array," IEEE Trans. Antennas Propagat., vol.39, pp.968-975, July 1991.
[10] T. Uno, Y. He and S. Adachi, "Electromagnetic Imaging Method for Line Sources Buried in a Dielectric Half-Space," North Amer. Radio Sci. Meeting, p.678, June 1991.
[11] T. Uno, Y. He, S. Adachi and J. Tada, "Two and Three Dimensional Passive Imagings of Electromagnetic Radiation Sources," Proc. 1994 Int. Symp. Electromagn. Compat., pp.666-669, May 1994.

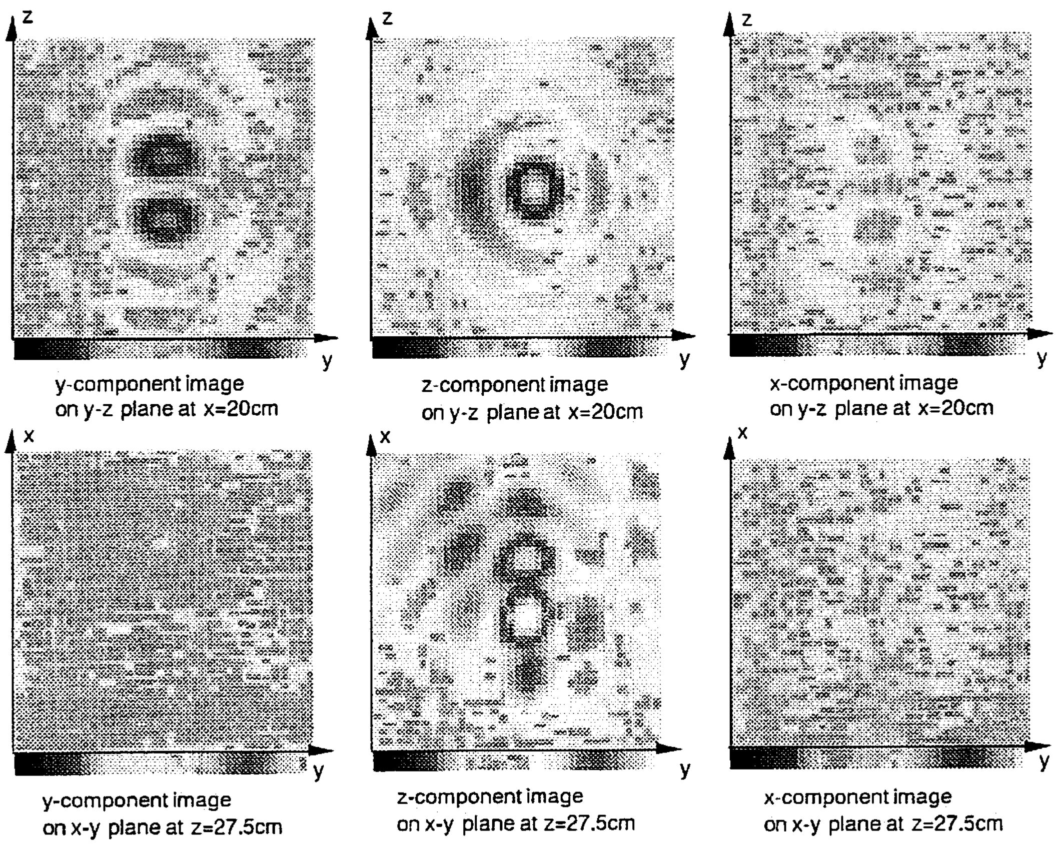

Fig.5 Reconstructed images of a magnetic dipole