

# ESTIMATION OF MULTIPLE COHERENT SOURCE LOCATIONS USING SIGNAL SUBSPACE FITTING TECHNIQUE COMBINED WITH SPM METHOD

Yuzo Yoshimoto<sup>\*1</sup>, Kazumasa Taira<sup>\*1</sup>, Kunio Sawaya<sup>\*1\*2</sup> and Risaburo Sato<sup>\*1</sup>

<sup>\*1</sup>Sendai EMC Research Center, Telecommunications Advancement Organization of Japan

<sup>\*2</sup>Department of Electrical Communications, Graduate School of Engineering, Tohoku University

E-mail: yosimoto@emc-rc.tao.go.jp

**Abstract:** An accurate estimation method of electromagnetic source location by combining the Weighted Subspace Fitting (WSF) method with the modified Sampled Pattern Matching (SPM) method, which has been proposed by the present authors, involves a problem to determine the phase reference. In order to overcome this problem, a calibration technique by using a reference antenna to obtain the phase reference and pattern of the receiving antenna is proposed. Experimental results show that the shapes of two half-wavelength dipole antennas fed with the same phase are visualized and source locations of these antennas are accurately estimated demonstrating the validity of the proposed method.

**Key words:** EMC, Electric Field, Estimation of Electromagnetic Source Location, SPM Method, WSF Method

## 1. Introduction

Visualization techniques are very important to find source locations of undesired electromagnetic emission from electric devices. The radio wave holography method [1] was applied to the imaging of the electromagnetic field distribution, where the phase distribution of emitted field is measured on a observation plane more than several wavelengths away from the electric device. However, the spatial resolution obtained by this technique is larger than a half-wavelength. Therefore, it is desired to improve the resolution of the source locations. Another imaging technique is the magnetoencephalogram (MEG), where the amplitude distribution is mainly employed because the observation frequency is less than several kHz. A method of the visualization of the

source locations based on the Sampled Pattern Matching (SPM) [2] method and the Weighted Subspace Fitting (WSF) [3] method, which are the methods used for the MEG, has been proposed by the present authors [4]. In this work, a modified SPM method and a combination of the SPM method and the WSF method are used. However, estimation of the source location has to be repeated to find the accurate phase of the received signal because the measured phase distribution is a relative value rather than an absolute value and the CPU time to find the absolute phase is not negligible.

In this report, a calibration technique to improve the estimation accuracy and reduce the CPU time by using a reference antenna to determine the phase reference is proposed to overcome the problem of the phase reference. Experimental results for the visualization of two dipole antennas are also presented to demonstrate the validity of the proposed method.

## 2. Estimation Method

### 2.1 Source and Measurement Model

The model for the estimation of the location of the electromagnetic wave source is shown in Fig.1, where the estimation region has almost the same size of the electronic equipment and the sources are located in the estimated region. It is assumed that the sources are composed of a lot of infinitesimal electric dipoles. The electric field emitted by the sources is measured on the observation plane located in  $xy$  plane of Cartesian coordinate system. The receiving dipole antennas parallel to  $x$  axis are placed on the observation plane. The number of the infinitesimal electric dipoles in the estimation region is  $M$  and the

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number of the receiving dipole antennas is  $J$ . The complex electric field  $E_{jm}$  ( $j = 1, 2, \dots, J$ ,  $m = 1, 2, \dots, M$ ) received by the dipole antenna # $j$  is expressed by

$$\tilde{E}_{jm} = \frac{e^{-jk r_{jm}}}{4\pi} \left( \frac{j\omega\mu_0}{r_{jm}} + \frac{k}{\omega\epsilon_0 r_{jm}^2} + \frac{1}{j\omega\epsilon_0 r_{jm}^3} \right) (\sin\theta_{jm})^2 \cos\phi_{jm} \quad (1)$$

where  $r_{jm}$  ( $j=1,2,\dots,J$ ,  $m=1,2,\dots,M$ ) is the distance between the infinitesimal electric dipole # $m$  and the receiving dipole antenna # $j$ ,  $\theta_{jm}$  is the angle between the direction of the source current and  $r_{jm}$ , and  $\phi_{jm}$  is the angle between the direction of source current and the direction of the receiving dipole antenna. The strength of each infinitesimal electric dipole is assumed to unity.

The modified SPM method and the WSF method employ the complex electric field distribution on the observation plane calculated by equation (1). The procedure of estimation method is described as follows.

1. The complex electric field distribution on the observation plane is measured and sampled in an appropriate time duration. These data are stored as the spatio-temporal data.
2. The eigenvalue decomposition of the covariance matrix of the spatio-temporal data is performed.
3. The modified SPM method employs the eigenvector, which is referred as “reference data of the modified SPM method,” based on the maximum eigenvalue of the covariance matrix. By calculating the correlation between the “reference data” and the complex electric field distribution on the observation plane emitted by the infinitesimal electric dipole in the estimation region, the electromagnetic source is estimated as a set of a lot of infinitesimal electric dipoles.
4. The WSF method employs the signal subspace, which is referred as “reference data of the WSF method,” based on the number of the sources estimated by the modified SPM method. The source location of the largest current in the set of the infinitesimal electric dipoles estimated by the SPM method is estimated.

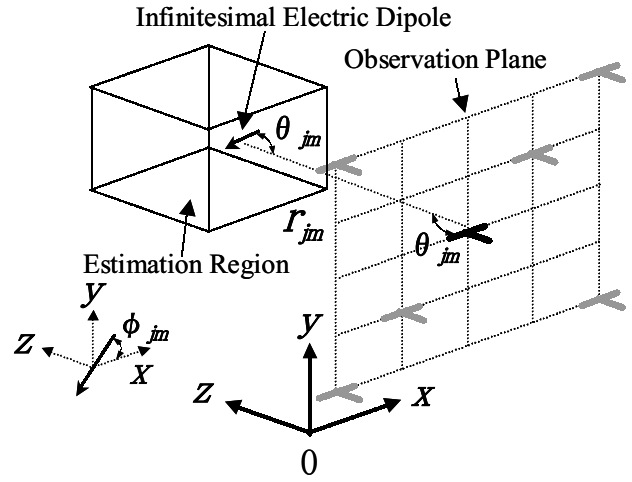


Fig.1 Source and measurement model.

### 2.2. Calibration Method

The phase distribution obtained by the measurement system is relative phase between the phase measured by the reference dipole antenna and that measured by each receiving dipole antenna. Therefore, it is necessary to repeat the estimation of the source locations to find adequate phase reference [4]. In order to remove this problem, a calibration technique using a transmitting reference antenna to obtain the phase reference and pattern of the receiving antenna is proposed. This calibration technique assumes that the distance between the observation plane and the estimation region is several wavelengths.

This calibration technique is described as follows.

1. A reference antenna for the calibration is placed at a reference point in the estimation region or in the vicinity of the estimation region. The continuous wave signal of the frequency same to the undesired electromagnetic wave is supplied to the reference antenna. The amplitude and the phase distributions of the electric field measured on the observation plane are expressed by

$$e_a = (e_{a_1}, e_{a_2}, \dots, e_{a_J})^T \quad (2)$$

$$\alpha_a = (\alpha_{a_1}, \alpha_{a_2}, \dots, \alpha_{a_J})^T \quad (3)$$

A half-wavelength dipole antenna is used for the reference antenna in the actual experiment.

2. The amplitude and the phase distributions of electric field emitted by the reference antenna are analyzed numerically by using the method of moments (MOM). The calculated data are given by

$$e_b = (e_{b_1}, e_{b_2}, \dots, e_{b_J})^T \quad (4)$$

$$\alpha_b = (\alpha_{b_1}, \alpha_{b_2}, \dots, \alpha_{b_J})^T \quad (5)$$

3. The infinitesimal electric dipoles is assumed placed at each estimation point # $m$  ( $m=1, 2, \dots, M$ ). The amplitude and the phase distributions of electric field emitted by each infinitesimal electric dipole are calculated numerically. These data are expressed by

$$E = \begin{bmatrix} e_{11} & e_{12} & \dots & e_{1M} \\ e_{21} & e_{22} & \dots & e_{2M} \\ \cdot & \cdot & \dots & \cdot \\ e_{J1} & e_{J2} & \dots & e_{JM} \end{bmatrix} \quad (6)$$

$$A = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \dots & \alpha_{1M} \\ \alpha_{21} & \alpha_{22} & \dots & \alpha_{2M} \\ \cdot & \cdot & \dots & \cdot \\ \alpha_{J1} & \alpha_{J2} & \dots & \alpha_{JM} \end{bmatrix}. \quad (7)$$

The phase of each infinitesimal electric dipole numerically obtained is corresponding to the phase of the reference antenna.

4. The calibrated amplitude and phase distributions of the electric field are expressed by using equations (6), (7) and the calibration data given by equations (2)-(5) as

$$E_{cal} = \begin{bmatrix} ea_1 \times (e_{11}/eb_1) & ea_1 \times (e_{12}/eb_1) & \dots & ea_1 \times (e_{1M}/eb_1) \\ ea_2 \times (e_{21}/eb_2) & ea_2 \times (e_{22}/eb_2) & \dots & ea_2 \times (e_{2M}/eb_2) \\ \cdot & \cdot & \dots & \cdot \\ ea_J \times (e_{J1}/eb_J) & ea_J \times (e_{J2}/eb_J) & \dots & ea_J \times (e_{JM}/eb_J) \end{bmatrix} \quad (8)$$

$$A_{cal} = \begin{bmatrix} \alpha_{a1} - (\alpha_{b1} - \alpha_{11}) & \alpha_{a1} - (\alpha_{b1} - \alpha_{12}) & \dots & \alpha_{a1} - (\alpha_{b1} - \alpha_{1M}) \\ \alpha_{a2} - (\alpha_{b2} - \alpha_{21}) & \alpha_{a2} - (\alpha_{b2} - \alpha_{22}) & \dots & \alpha_{a2} - (\alpha_{b2} - \alpha_{2M}) \\ \cdot & \cdot & \dots & \cdot \\ \alpha_{aJ} - (\alpha_{bJ} - \alpha_{J1}) & \alpha_{aJ} - (\alpha_{bJ} - \alpha_{JM}) & \dots & \alpha_{aJ} - (\alpha_{bJ} - \alpha_{JM}) \end{bmatrix} \quad (9)$$

The complex electric field obtained by equations (8) and (9) is used for the calculation of the correlation with the “reference data of the modified SPM method” in step 3 of Chapter 2.1 in stead of equation (6) and (7).

### 3. Experimental Investigation

In order to demonstrate the validity of the proposed estimation method, experimental investigation was performed. Table 1 shows the parameters of the

sources and observation points. Figure 2 shows the experimental setup. The polarization of the current source was assumed to be known. The experiment was carried out in an anechoic chamber. The target sources for the estimation were two half-wavelength dipole antennas fixed on an acrylic board. Each source was placed at a distance  $2\lambda$  (248 mm) from the observation plane and the spacing of two sources was  $0.8\lambda$  (100 mm). The continuous wave signal of 2.42 GHz and  $-20$  dBm generated by a signal generator was fed to two sources. Two sources were coherent sources without the phase difference.

The amplitude and the phase distributions of electric field were measured by scanning a single dipole antenna fixed on the  $xy$  positioner on the observation plane. The signal received by the dipole antenna was delivered to the network analyzer. The reference signal to the network analyzer was supplied by the same signal generator. The spatio-temporal data of the complex electric field on the observation plane were obtained by measuring the amplitude and the phase distributions at  $8 \times 8$  observation points and 77 time samples. The measured the amplitude and the phase distributions of electric field from the reference dipole antenna were averaged over 20 time samples are referred as “standard data” for this calibration.

Figure 3 shows the experimental results obtained by the modified SPM method. Estimation points with strong correlation are distributed along the source dipole antenna. The shapes of two dipole antennas are visualized as sets of the estimation points.

Figure 4 shows the experimental results obtained by combining the WSF method with the modified SPM method. As a result of the experiment, locations of feed points of each dipole sources are estimated within the errors of 7.5 mm and 4.9 mm, respectively.

### 4. Conclusion

A calibration technique by using a reference antenna to obtain the phase reference and pattern of the receiving antenna has been proposed. The shape of the entire source has been visualized as a set of infinitesimal electric dipoles by using the modified SPM method. The source location of the maximum current strength has been also estimated by using the WSF method. The proposed estimation method is considered to be valid for the EMC countermeasure.

In the future work, validity of this estimation method for various sources of undesired electromagnetic wave should be confirmed.

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Table 1 Parameters of sources and observation points.

Source $S_1$	Source $S_2$	Current Direction	Frequency
$x=676\text{mm}$ $y=611\text{mm}$ $z=248\text{mm}$	$x=676\text{mm}$ $y=711\text{mm}$ $z=248\text{mm}$	$x$ axis	2.42 GHz
Measurement Distance	Observation Plane	Number of Measurement Points	Estimation Area
$2\lambda$	$3.5\lambda \times 3.5\lambda$	$8 \times 8 = 64$	$1\lambda \times 1\lambda \times 1\lambda$

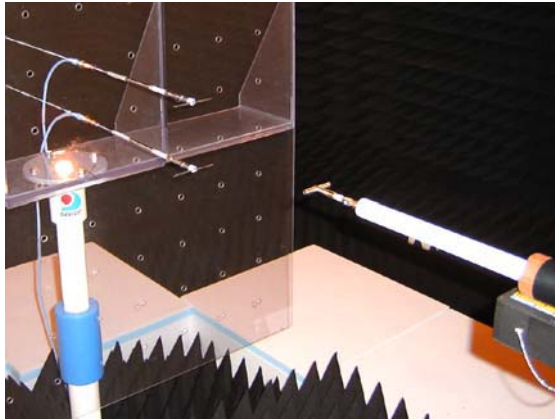


Fig.2 Experimental setup.

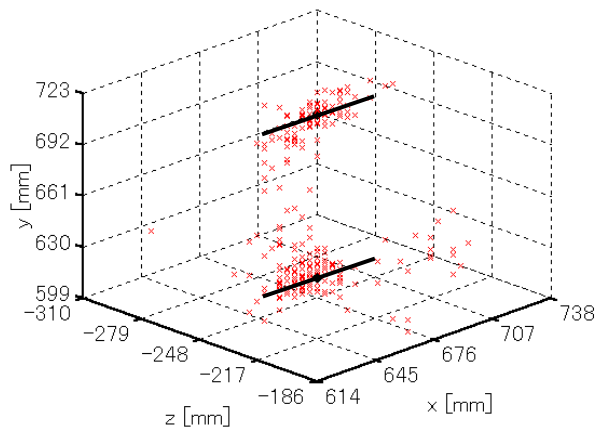


Fig.3 Experimental results by modified SPM method.

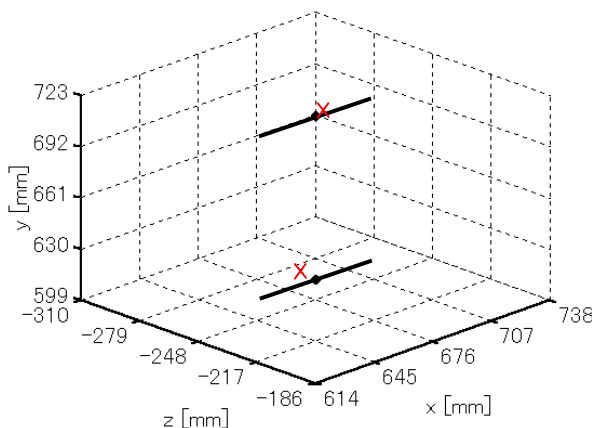


Fig.4 Experimental results by modified SPM method and WSF method.

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