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Estimation of Equivalent Source of Modulated EM Radiation

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Abstract : In order to take the effective measures for the interference problem between electronic devices, it is important to estimate the radiation source position of the unnecessary electromagnetic waves inside of electronic devices. In the conventional researches, estimating the location of modulated electromagnetic waves has not been considered as its measurement is complicated. In this report, near-field measurement in time domain and matrix inversion, which are effective for the measurement of modulated signals, are applied to estimate the current distribution of radiation source. Moreover, the validity of this technique is demonstrated by experiment.
Keyword: Eigenmode, eigenvalue, equivalent source, matrix inversion, near-field measurement, time domain.

1. Introduction

The electromagnetic interference between electronic devices caused by not only the CW radiation but also the modulated electromagnetic radiation has become one of the major problems in the field of electromagnetic compatibility. Because the electronic devices are driven by higher and higher clock frequency as well as operate at a wider and wider bandwidth, the interference problem due to the radiation of modulated and incoherent signals has become more and more serious and has attracted lots of attention in researches. To solve this problem in practice, it is important to estimate the location or the distribution of the equivalent radiation source of the modulated electromagnetic wave radiated from the electronic devices. Consequently, a technique to estimate the distribution of the equivalent radiation source of the modulated electromagnetic wave is strongly required.

As one of the approaches to estimate the equivalent source of electromagnetic radiation, the method of estimating current distribution on the equivalent source in an area enclosing the source is well known [1]-[3], as shown in Fig. 1. This approach is effective even if the position and the structure of the real radiation source are unknown. Also, the inverse matrix method to estimate the current distribution on the equivalent source has been studied [4], [5]. However, it is very difficult to solve the problem when the radiation is composed of modulated signals. That is because it takes too much time to measure the modulated signals in frequency domain.

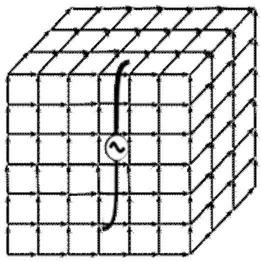

Fig. 1. Model of the equivalent source for estimation

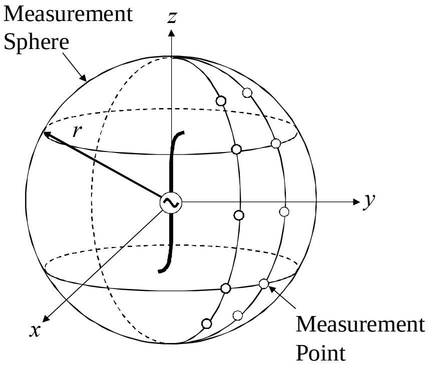

Fig. 2. Sphere for near-field measurement

Therefore, more effective measurement method to measure the modulated signals is required. A near-field measurement method in time domain was proposed for measuring the incoherent electromagnetic radiation [6], [7].

In this report, we propose a method to estimate the current distribution on the equivalent source for electromagnetic radiation of modulated signals. In this method, the near field from the modulated source is measured in time domain and the current distribution on the equivalent source is evaluated by using the eigenvalue and eigenmode of the correlation matrix generated from the measured near field.

At first, the proposed method is described and then experiment is performed to show how to estimate the current distribution on the equivalent source of dipole antennas.

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2. Theory

2.1 Near-Field Measurement in Time Domain

The near field of a radiation source with modulated signals is measured in time domain. Two probes are used to measure the near field simultaneously at different points. As shown in Fig. 2, on the field measurement point of N-point on the sphere of radius r enclosing the radiation source, the near field E^{θ}, E^{φ} (i=1, 2, é , N) are measured in time domain. Then, the correlation between each component of the electric field at each measurement point is calculated. As an example, the correlation of θ component to each other is calculated as (1),

$$C_{i,j}^{\theta,\varphi} = \frac{1}{T}\int_{t=0}^{T} E_i^{\theta}(t) E_j^{\varphi *}(t)\,dt \; (i, j = 1,2,\ldots,N) \quad (1)$$

where T is the measurement snapshot duration, and the subscript * denotes the complex conjugate. In (1), the signal must be stationary over the duration T, i.e., T must not be small with respect to the signal variation time. Each correlation $C^{\theta\theta}, C^{\varphi\theta}, C^{\varphi\varphi}$ component is calculated by the same way as well, and a correlation matrix **C** of $2N \times 2N$ is produced. After performing eigenvalue decomposition for the correlation matrix, the equation for **C** can be written as follows,

$$\mathbf{C} = \Phi_{\Sigma 1}\mathbf{\Lambda}\Phi_{\Sigma 1}^{H} + \sigma^2\mathbf{I}$$

where σ^2 is the spectral density of noise, **I** is the identity matrix, $\Phi_{\Sigma 1} = [\phi_1, \ldots, \phi_{2N}]$ is the matrix made of the eigenvectors ϕ_i which represent the eigenfunctions of the fields sampled at the N points for both θ and ϕ components, and Λ is the diagonal matrix of eigenvalues $\mathrm{diag}(\Lambda) = [\lambda_1, \lambda_2, \ldots, \lambda_{2N}]$. The eigenvalues are ordered in such a way that follows.

$$\lambda_1 > \lambda_2 > \ldots > \lambda_p > \sigma^2 > \lambda_{p+1} > \ldots > \lambda_{2N}$$

The p highest eigenvalues are considered whereas the others corresponding to noise are discarded. Therefore, p eigenvalues ($\lambda_1 \sim \lambda_p$) and eigenvectors ($\phi_1 \sim \phi_p$) corresponding to them are picked out to generate equivalent eigenmode ($\sqrt{\lambda_1}\phi_1 \sim \sqrt{\lambda_p}\phi_p$) which are considered coherent and orthogonal to each other [6], [7].

2.2 Matrix Inversion

The unknown current of radiation source is obtained by solving the matrix equation,

$$\mathbf{V} = \mathbf{ZI} \quad (2)$$

where **V** vector is radiation field distribution of the radiation source, **Z** matrix is the mutual impedance between the equivalent source and the measurement probes. Assuming **I** vector is the unknown current coefficient on the equivalent source. **V** vector is obtained as the product of the equivalent eigenmode and eigenvalues which are obtained from the previous measurement steps. By solving the equation (3), the current coefficients on the equivalent source are obtained.

$$[\mathbf{I}] = [\mathbf{Z}^{\mathbf{H}}\mathbf{Z}]^{-1}[\mathbf{Z}^{\mathbf{H}}\mathbf{V}] \quad (3)$$

As each eigenmode is orthogonal to each other, each current coefficient on the equivalent source corresponding to each eigenvalue also can be considered as coherent. Consequently, it is possible to estimate the equivalent current of the radiation source by adding together the components of |**I**|.

3. Experiment

3.1 Experimental Setup

The experiment system is illustrated in Fig. 3. To make the correlation matrix **C**, near-field measurement must be simultaneously performed at the reference point and the measurement point. The reference probe Rx1 must remain fixed, whereas the measurement probe Rx2 scans the sample points taking into account both x and y polarizations. The measurement area is aligned in the x-y plane. The radiation sources are two half-wavelength dipole antennas which are set vertically in y-direction, and estimation for known source locations are carried out to check the performance of the proposed method. The analysis model for the source location is shown in Fig. 4. The distance between the estimation plane and measurement plane must be small enough to obtain a high signal-to-noise ratio (SNR) in order to give an accurate estimation results. Parameters for the experiment model are summarized in Table I.

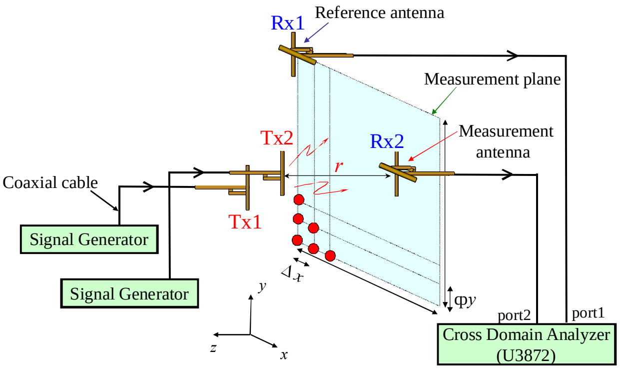

Fig. 3. Experimental system

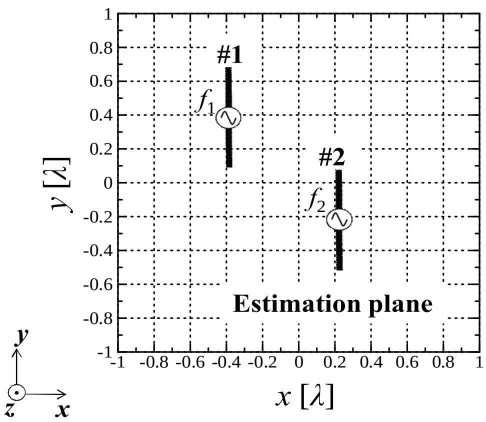

Fig. 4. Source location

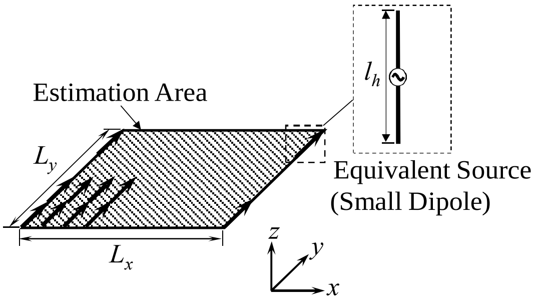

Fig. 5. Model of the equivalent source

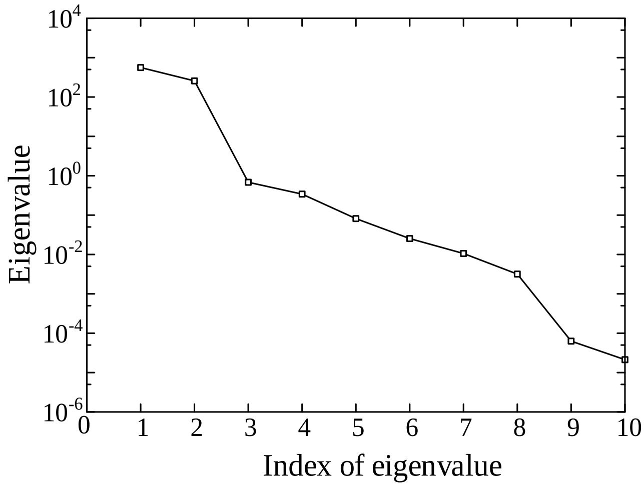

Fig. 6. Eigenvalues

TABLE I

PARAMETERS FOR NEAR-FIELD MEASUREMENT

Sources	Half-wavelength dipoles
Source location	$P_1 = (-0.4\lambda, 0.4\lambda)$ $P_2 = (0.2\lambda, -0.2\lambda)$
Frequency	$f_1 = 1$ GHz (3 dBm) $f_2 = 1.0005$ GHz (3 dBm)
Frequency difference	$\Delta f = \lvert f_1 - f_2 \rvert = 500$ kHz
Measurement area	$(2\lambda, 2\lambda)$
Total number of measurement points	$N = 625$ (25×25)
Distance between the measurement plane and the source plane	$r = 0.2\lambda$
Space between measurement points	$\Delta x = 0.08\lambda$ $\Delta y = 0.08\lambda$
Sampling point in time domain	1001
Acquisition time	20 ms
Capture bandwidth	BW = 1 MHz

TABLE II

PARAMETERS OF THE EQUIVALENT SOURCE

Equivalent source	Small dipole
Frequency	$f_h = 1$ GHz
Length of equivalent source	$l_h = 0.1\lambda$
Total number of equivalent source	M

3.1 Equivalent Source

Equivalent source is composed of 0.1 λ dipole antennas of three polarizations. These small dipoles are arranged in a grid as shown in Fig. 5. Parameters of the equivalent source are shown in Table II.

3.2 Eigenvalue Decomposition

Applying the eigenvalue decomposition to the correlation matrix $\mathbf{C}$ generated by the near-field measurement, eigenvalues are obtained as shown in Fig. 6. The first eigenvalue and second one can be regarded as signal components generated by the modulated radiation sources as they are much larger than those of the third and subsequent.

3.3 Current Distribution by Matrix Inversion

By solving the matrix equation, $\mathbf{I}_1$, $\mathbf{I}_2$ representing the current distribution on the equivalent source are obtained.

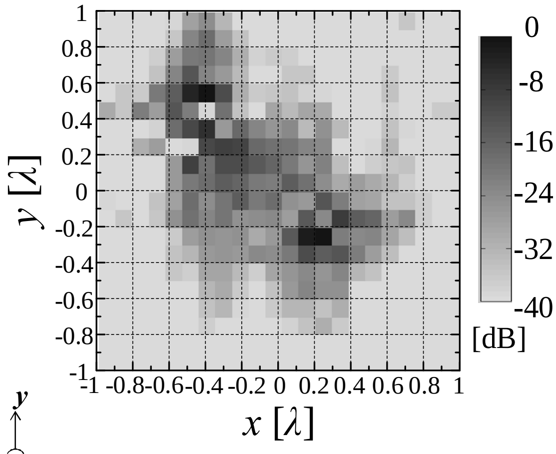

Fig. 7. Current distribution

The estimation result of current distribution on the equivalent source obtained by near-field measurement and the matrix inversion is shown in Fig. 7. It is found that the estimated location of radiation source by using the proposed method coincident with the location of real sources in Fig. 4. Therefore, the validity of the proposed method for modulated radiation signals is demonstrated by experiment.

4. Conclusion

In this report, a method to estimate the position of the modulated radiation source was proposed. In this method, the near field of the source was measured in time domain, and then the measured near field was applied to construction of the modulated EM radiation source by using the inverse matrix method. The current distribution source model composed of two dipole antennas was estimated experimentally, confirming the validity of the proposed method. It can be said that the proposed method is effective for the estimation of the current distribution of the modulated radiation source.

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