PROCEEDINGS OF ISAP '96, CHIBA, JAPAN

A PROPOSAL ON THE DIRECTION FINDING FOR MAN-MADE RADIO NOISE SOURCES: SIMULATION EXPERIMENTS

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1.Introduction

With the increase in the information communication and also with the popularization of electric and electronic equipments, our daily life is becoming very comfortable. Instead, there is a tendency of enhanced radio interference problems arising from such equipments. Any equipments using electrical energy, radiate unwanted waves in any form, and their spectrum covers a wide frequency range. The most essential problem in this situation is to locate the multiple radio noise sources(i.e., this is called, "Direction finding (DF)"). There have been proposed a few methods of DF for man-made radio noise sources: (1) scanning method, (2) synthetic aperture method (Kikuchi et al, 1985 ; Nagasawa et al., 1986) and (3) MUSIC method (Schmidt, 1986). When we use the scanning method, we will face with the serious situation such that the parameters of the noise source(s) (such as position, frequency, polarization etc.) will change during the scanning. Hence, the noise distribution at any particular time is desirable; the first requirement is the so-called "snapshot" distribution. Another requirement for the DF is that the number of antennas (or sensors) should be as smaller as possible. That is, the number of sensors in both the synthetic aperture and MUSIC methods is rather large because of an array system. In this paper we propose a new method of DF for man-made noise sources satisfying the above requirements by means of the use of inversion method based on the simultaneous measurement of multiple field components at a single observation point.

2.Principle of the proposed method

Figure 1 illustrates the statement of the problem in which the observing sensors are located at a point located at the origin ($x = y = z = 0$). Also, we are going to measure the multiple field components simultaneously: that is, at maximum, three electric field components (E_x, E_y, E_z) and three magnetic field components (B_x, B_y, B_z) . For example, x is taken as North, y, East and z , Zenith. Then, the noise sources are imagined in one hemisphere with positive z . Due to the advance in electrical and electronic equipments, the noise sources become very complicated such that the noises are coming from different areas (i.e., a few simultaneous sources as a general case) and their polarization becomes extremely complicated. Hence, the signals observed by the sensors at the origin, are assumed to be a sum (a continuum) of infinitesimal plane waves with different direction of arrival, with different frequencies, with their phase relationship being random. In the following we will concentrate ourselves to the simultaneous measurement of three electric field components (E_x, E_y, E_z). These electric field components observed at the origin, O in Fig.1 are expressed as follows,

$$\begin{pmatrix} E_1 \\ E_2 \\ E_3 \end{pmatrix} = \begin{pmatrix} \sin\phi & \cos\theta\cos\phi \\ -\cos\phi & \cos\theta\sin\phi \\ 0 & -\sin\theta \end{pmatrix} \begin{pmatrix} E_\perp \\ E_\parallel \end{pmatrix} = \begin{pmatrix} P_0\sin\phi & \cos\theta\cos\phi \\ -P_0\cos\phi & \cos\theta\sin\phi \\ 0 & -\sin\theta \end{pmatrix} E_\parallel \qquad (1)$$

where $E_1 = E_x, E_2 = E_y$, and $E_3 = E_z$. An incident wave is generally assumed to be elliptically polarized and it is decomposed into the transverse electric (TE) and TM mode components. In Eq.1 the polarization is defined as the ratio of electric field components of the two modes($P_0 = E_\perp / E_\parallel (\equiv B_\parallel / B_\perp)$). Due to our hypothesis of signal randomness, the measured quantities should be described by statistical quantities. We try to obtain the spectral matrix. The auto- and cross-power spectra by using the different field components will be the elements of spectral matrix $S_{ij}(\omega)$. As mentioned in the introduction, we have much more complicated situation such taht we have a few simultaneous radio noise sources and the polarization is expected to vary from one source to another. So that, we have to explore a DF system effective even for this situation, which is a further extension of our above magnetospheric DF system (Shimakura et al., 1992: Hayakawa et al., 1993). A new DF method we are going to propose. is to estimate simultaneously the wave distribution functions for right- and left-handed circularly polarized components in the case of multiple man-made radio noise sources. The received field components with an incident angle θ and azimuthal angle ϕ, can be written as follows.

$$\begin{pmatrix} E_1 \\ E_2 \\ E_3 \end{pmatrix} = T_R(\theta,\phi)R + T_L(\theta,\phi)L \tag{2}$$

where

$$T_R(\theta,\phi) = \begin{pmatrix} \cos\theta\cos\phi - i\sin\phi \\ \cos\theta\sin\phi + i\cos\phi \\ -\sin\theta \end{pmatrix}, T_L(\theta,\phi) = \begin{pmatrix} \cos\theta + i\sin\phi \\ \cos\theta - i\cos\phi \\ -\sin\theta \end{pmatrix} \tag{3}$$

$R = (E_{\|} + iE_{\perp})/2$ is the electric field component of the right-handed (RH) circularly polarized mode, while $L = (E_{\|} - iE_{\perp})/2$, the left-handed (LH) circularly polarized mode. The elements of spectral matrix for each mode can be expressed as follows:

$$\begin{aligned} S_{ij}^R(\omega) &= \frac{\pi}{2}\int_{-1}^{1}\int_{0}^{\pi} a_{ij}^R(\omega,\theta,\phi)F^R(\omega,\theta,\phi)d(\cos\theta)d\phi \\ S_{ij}^L(\omega) &= \frac{\pi}{2}\int_{-1}^{1}\int_{0}^{\pi} a_{ij}^L(\omega,\theta,\phi)F^L(\omega,\theta,\phi)d(\cos\theta)d\phi \end{aligned} \tag{4}$$

and

$$\begin{aligned} a_{ij}^R(\omega,\theta,\phi) &= T_R(\theta,\phi)T_R^\dagger(\theta,\phi) \\ a_{ij}^L(\omega,\theta,\phi) &= T_L(\theta,\phi)T_L^\dagger(\theta,\phi) \end{aligned} \tag{5}$$

a_{ij}^R is the integration kerenel for RH circularly polarized mode wave, while a_{ij}^L is LH circularly polarized mode wave. $\dagger$ in the above equations means conjugate transpose. As is understood from the expressions for the integration kernels. the elements are independent of wave frequency because of the absence of frequency terms in the elements. and also we assume the radiation field. So that we have to choose the frequency at which this assumption is valid by taking into account of both a wavelength and the observer-noise source distance. By using the observed field components. we can get the R and L such that we can estimate the spectral matrix for both modes separately. Then. we define the entropy H of the wave distribution function in the following way:

$$H = -\int_{0}^{\pi}\int_{0}^{2\pi} F(\theta,\phi)\ln F(\theta,\phi)d\theta d\phi \tag{6}$$

We try to obtain the wave distribution funciton such that the entropy is maximized (so. this method is called. "Maximum entropy method (MEM)").

3.Application of the proposed MEM to the simulated data

3.1 How to make the assumed source: simulated data

The observed signal considered to be statistically stationary. is assumed to be a superposition of elementary plane waves without any phase relationship. We will make the simulation data by considering the polarization, wave number and phase of elementary plane waves, being uncorrelated. The polarization of the m-th elementary plane wave polarization ratio ($\ln|E_{\perp}^m/E_{\|}^m|$

and its argument, $\arg|E_{\perp}^{m}/E_{\parallel}^{m}|$) is assumed to be normally distributed and is given by the normal random distribution around the averages (ln r_0 and δ_0). The spatial distribution of an elementary plane wave constituting a wave source, its distribution is given by

$$\frac{1}{2\pi\sigma^2}\exp(-\frac{\Theta^2}{2\sigma^2}) \qquad (7)$$

$$\Theta = \cos^{-1}\cos\theta\cos\theta_0 + \sin\theta\sin\theta_0\cos(\phi - \phi_0)$$

where $(\theta_0.\phi_0)$ is the polar coordinate of the source center, and Θ is the solid angle expected for (θ_0,ϕ_0) . Furthermore, the phase of an elementary plane wave is assumed to be uniformly randomly distributed in the range $[0.2\pi]$. We try to have different wave source models by the superposition of the elementary plane waves described above, and we calculate the spectral matrix for each source model. In order to estimate statistically the spectral matrix, one sample is composed of 500 random elementary plane waves, and we make 20 samples of spectral matrix. By doing this, we are able to obtain the ensemble mean of the spectral matrix (to be used for the subsequent inversion) and its standard deviation (as the measurement error).

3.2 Inversion by applying the MEM to the simulated data

(a) A single wave source

The center of a single wave source is assumed to be $(\theta_1,\phi_1) = (45°,45°)$ and to be linearly polarized. Hence, the assumed source is decomposed into the RH and LH polarized mode waves with an equal amplitude as illustrated in Fig.2 ($\sigma = 20°$). The application of the MEM inversion to the simulated spectral matrix data for this source model, has yielded the inversion results in Fig.3. In the left panel of Fig.3 is given the wave energy distribution for the RH polarized mode component (i.e., $F^R(\omega.\theta.\phi)$), while the right panel of Fig.2, the corresponding distribution F^L for the LH polarized mode component. The centers of the reconstructed images for the RHC and LHC polarized mode components are estimated to be both $(\theta_1.\phi_1) = (45.4°.44.9°)$. So that, the difference in θ between the assumed and reconstructed peaks is only 0.5° . while the difference in ϕ is much smaller than this value. We can say that the agreement between the assumed and reconstructed images is excellent.

(b) Two noise sources

A few simultaneous noise sources are treated here, and it is important to have the good inversion results especially for this situation. We deal with the situation with two noise sources; one has a right-handed circular polarization and is centered at $(\theta_1,\phi_1) = (45°.225°)$, while the second source has a left-handed circular polarization, beinglocated at $(\theta_2.\phi_2) = (45°.45°)$. Fig.4 illustrates the assumed wave energy distributions for the RH polarized mode component (left panel), and the right panel is that for the LH polarized mode component. The MEM inversion was applied to this situation, and Fig.5 illustrates the reconstructed wave energy distributions, in which the left panel refers to the distribution for RH polarized component and right panel, LH polarized component. First of all, the peaks of the RH polarized component between the assumed and reconstructed distributions, are found to be exactly identical to each other. Also, the peak of the reconstructed distribution for the LH polarized component is estimated to be very close to that for the RH polarized component; the difference in $(\theta.\phi)$ being less than one degree. The wave shapes, or distributions for both polarized components are found to be very close to those of the assumed components.

4.Conclusion

A new method of DF for man-made noise source is proposed, which is based on the MEM inversion for the spectral matraix obtained from the simultaneous measurement of multiple field components at one observing station. This gives us snapshot wave eneergy distributions for the right- and left- handed components separetely at any time, so that we can know the directions of noise sources and also their polarization. The simulation experiments for both a single and double sources have yielded the inversion results which are found to be in good agreement with the assumed source position(s). Of course, the field experiment implemented by this method will be carried out in order to make the laboratory experiments.

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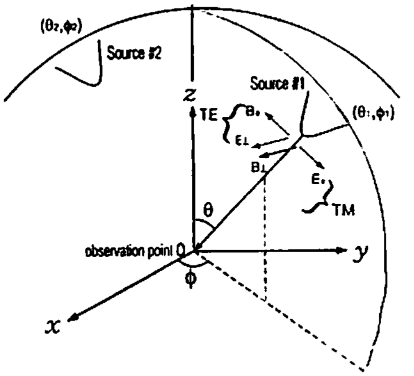

Fig.1 Statement of the direction finding for man-made radio noise sources. Multiple electromagnetic field components are simultaneously measured at one point (here at the origin). Two sources (#1 and #2) are assumed, and an elliptically polarized incident wave is decomposed into TM and TE mode components.

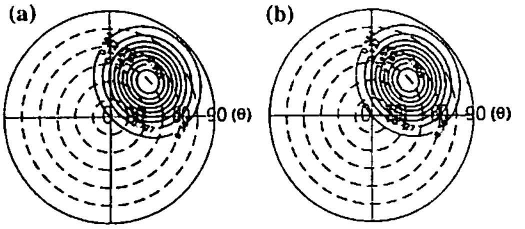

Fig.2 Wave energy distribution of the assumed source (one source). (a)RH component and (b)LH component.

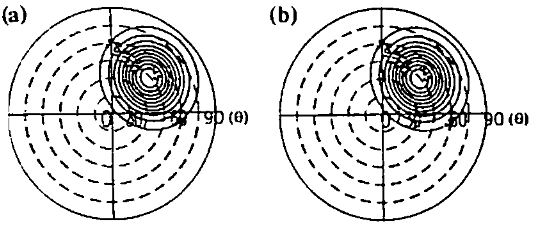

Fig.3 The corresponding reconstruction of wave energy distributions for Fig.2 for RH(a) and LH(b) components.

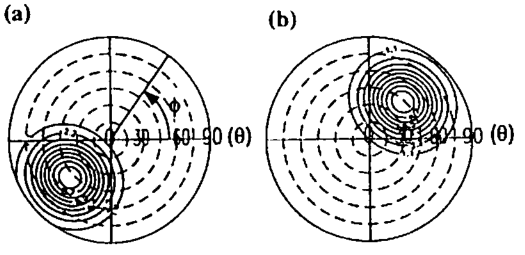

Fig.4 Wave energy distribution of the assumed source (two sources). (a)RH and (b)LH components.

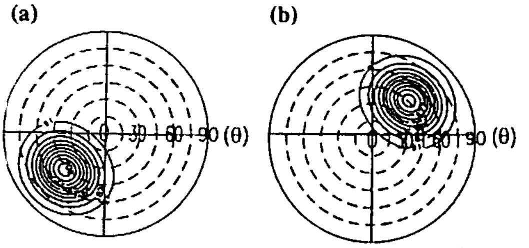

Fig.5 The corresponding reconstruction of wave energy distributions for Fig.4 for RH(a) and LH(b) components.