MUSIC ALGORITHM FOR THE DELAY TIME AND THE POLARIZATION ESTIMATION

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1 INTRODUCTION

The superresolution technique (such as the MUSIC algorithm) is applicable to a swept frequency data set for the high resolution time domain estimation of arrival time of incoming waves[1]. Several applications based on the MUSIC algorithm[2] can be found in scattering center[3] and indoor multipath propagation estimations. In the scattering and the indoor propagation phenomenon, the polarization state of an incoming wave carries the information on reflected and/or diffracted point, thus enabling us to identify the target shape and the propagation path.

In the direction finding problem, the polarization state estimation using an array of antennas having diverse polarizations was reported[2],[4]. The resolution capability is also improved because of the polarization dependency of the mode vectors. Also, Li, *et. al.*, propose the ESPRIT algorithm for the polarization sensitive array[5].

In a delay time estimation problem, it is shown that both the polarization state and the delay time of an incoming wave can be estimated when a pair of the orthogonal polarimetric frequency domain data sets is provided. In this paper, we present the experimental results for the polarization estimation using the MUSIC algorithm, in which a polarization insensitive data matrix is defined. The result is compared with the polarization sensitive method[5] indicating the present method effective.

2 PROBLEM FORMULATION

We assume that a pair of frequency domain data were obtained with vertical and horizontal polarized antenna using a network analyzer. The number of target is assumed to be d, and the polarization state of wave from the target is assumed to be constant in the measurement frequency band.

The measured value at the frequency of f_k with the antennas are given by

$$r^{(H,V)}(f_k) = \sum_{i=1}^{d} s_i^{(H,V)} e^{-j2\pi f_k t_i} + n^{(H,V)}(f_k), \tag{1}$$

where $s_i^{(H,V)}$ and t_i denote the signal parameter and the delay time of the i-th target measured with the horizontally or vertically polarized antenna, respectively. $n^{(H,V)}(\cdot)$ is a noise component of the corresponding antenna. To reduce the signal coherence, we employ the spatial smoothing scheme to the data[1]. The N-uniformly sampled frequency-domain data (sampling frequency period of Δf) in m-th subarray can be written using the vector notations as

$$r^{(H,V)}{}_m = [r^{(H,V)}(f_m), r^{(H,V)}(f_{m+1}), \cdots, r^{(H,V)}(f_{m+N-1})]^T, \tag{2}$$

where T denotes transpose.

The data pair can be expressed in a vector form[5].

$$r^{(C)}(f_k) = \begin{bmatrix} r^{(H)}(f_k) \\ r^{(V)}(f_k) \end{bmatrix} = \sum_{i=1}^{d} \begin{bmatrix} -\cos\gamma_i \\ \sin\gamma_i e^{j\delta_i} \end{bmatrix} s_i e^{-j2\pi f_k t_i} + \begin{bmatrix} n^{(H)}(f_k) \\ n^{(V)}(f_k) \end{bmatrix}. \tag{3}$$

Then, the m-th subarray becomes

$$r^{(C)}{}_m = [z^{(C)T}(f_m), z^{(C)T}(f_{m+1}), \cdots, z^{(C)T}(f_{m+N-1})]^T. \quad (4)$$

3 DATA CORRELATION MATRIX OF THE MUSIC ALGORITHM

In this section, we define two different data correlation matrices for the MUSIC algorithm.

Type I First, we introduce the data correlation matrix as follows,

$$R_P = \frac{1}{M}\sum_{m=1}^{M}\left\{R_m^{(H)} + R_m^{(V)}\right\} \quad (5)$$

where $R_m^{(H)}$ and $R_m^{(V)}$ denote the correlation matrix of $r_m^{(H)}$ and $r_m^{(V)}$, respectively. The size of the matrix is $N \times N$. This matrix is a sum of the matrices defined by the orthogonal components. Thus, the signal mode vectors in this matrix representation does not depend on the polarization states of the waves. Therefore, the conventional time-domain search is applicable in the MUSIC estimation. That is,

$$P_{MUSIC}(t) = \frac{a(t)^H a(t)}{a(t)^H E_N E_N^H a(t)}. \quad (6)$$

where H denotes complex conjugate transpose, and $a(t)$ is a signal mode vector. The columns of E_N are the noise-related eigenvectors of R_P[1]. The individual signal parameter, and then the polarization state can be calculated from (1) (or (3)) when the delay-times are estimated.

Type II The polarization sensitive data correlation matrix can be defined by

$$R_C = \frac{1}{M}R_m^{(C)} \quad (7)$$

where R_C denotes a correlation matrix of $r^{(C)}$. Note that the size of this matrix becomes $2N \times 2N$. The data vector, $r^{(z)}$, is arranged in the horizontally and vertically polarized data alternatively, then the signal mode vectors depend on the polarization states of the signals. Therefore, three dimensional search in t, γ, and δ is essentially required in the MUSIC analysis. The simple example of the scanning function can be expressed by

$$P_{MUSIC}(t,\gamma,\delta) = \frac{a(t,\gamma,\delta)^H a(t,\gamma,\delta)}{a(t,\gamma,\delta)^H E_N E_N^H a(t,\gamma,\delta)}. \quad (8)$$

In this method, the delay time and the polarization state of the signal can be estimated at the same time, however the computational burden becomes large compared with (6).

4 EXPERIMENTAL RESULTS

The experiment was carried out with a quasi-monostatic RCS measurement system using a network analyzer. We employed two standard gain horn antennas (operating frequency 12.4–18 GHz) as the transmitting and the receiving antenna. The transmitting antenna was fixed using the vertical polarization. We obtained two swept frequency data sets using the horizontally and vertically polarized receiving antenna(H-pol and V-pol), respectively. In the experiment, three linear targets were placed as shown in Fig.1.

The time domain responses of V-pol data after the execution of the inverse FFT were shown in Fig.2. The three targets can be resolved using the 4 GHz bandwidth (13–17 GHz) data. Also, a small response, that would be considered the reflection from the floor, can be detected around 33.7 ns. We cannot detect target responses separately in the data of 750 MHz bandwidth(14.5–15.25 GHz) . The time-domain estimation results of the MUSIC algorithms based on the type-I and type-II matrix are shown in Figs.3 and 4, respectively. In Fig.4, we show $\max_{\gamma,\delta}(P_{MUSIC}(t,\gamma,\delta))$ instead of $P_{MUSIC}(t,\gamma,\delta)$. Some estimated polarization parameters are also listed in Table.1. Using the type-II method, the polarization sensitive scheme improves the resolution, then the three targets can clearly be resolved with 735 MHz bandwidth(M=8). As can be seen in Fig.3, the required bandwidth for detecting the three peaks in the type-I method becomes approximately 10% larger (M=10, 805 MHz) than that in the type-II. The polarization states of the waves by target #1 and #2 were orthogonal in the experiment, that is, in a favorable condition to resolve them especially suited for the type-II method. However, it can be shown that the type-I method still holds good resolution capability in comparison with the type-II method in such a condition. The resolution performance of the MUSIC algorithm based on the type-I data correlation matrix has not been reported. however, in view of computational burden and resolution performance, we can conclude the method is also available.

5 CONCLUSIONS

The MUSIC algorithm for a pair of polarization data with two kinds of correlation matrix was examined by the experiment. It is found that the algorithm based on the power synthesis correlation matrix has a relatively good performance and attractive one in the view of computational burden.

References

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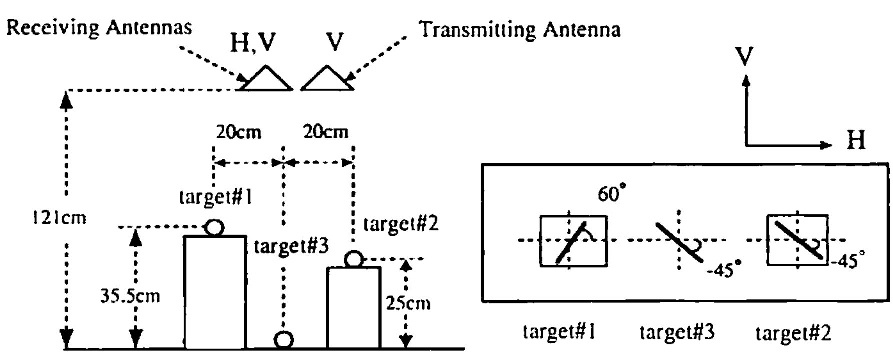

(a) Side view (b) Top view

Fig.1 Arrangement of the targets

Table.1 Estimated delay time and polarization parameters of the target #2.

Method	delay time (ns)	ellipticity angle (degree)	tilt angle (degree)
FFT (4GHz span)	31.97	-7.0	-40.5
MUSIC-Type I (M=8)	31.82	0.3	-37.9
MUSIC-Type I (M=10)	32.01	-6.7	-39.0
MUSIC-Type II (M=8)	32.09	-0.3	-40.0
MUSIC-Type II (M=10)	32.05	-5.9	-39.9

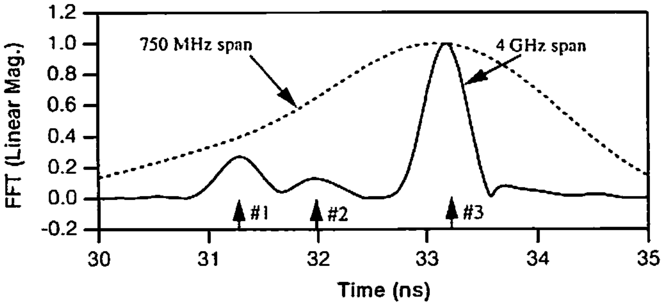

Fig.2 Time-domain responses estimated by the inverse FFT(V-pol data).
750 MHz span : 14.5 GHz - 15.25 GHz
4 GHz span : 13 GHz - 17 GHz.

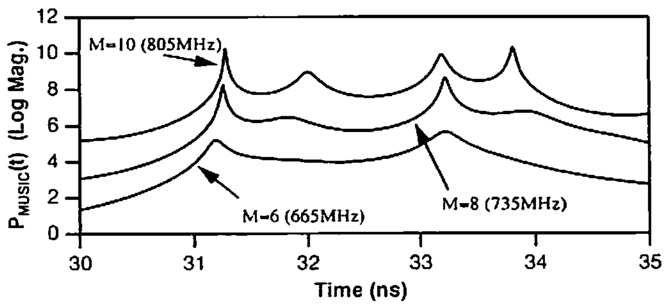

Fig.3 Time-domain responses estimated by the MUSIC algorithm (Type-I method). f_l = 14.5 GHz, Δf=35 MHz, N = 15. The value in the parenthesis denotes the total used frequency bandwidth in the analysis.

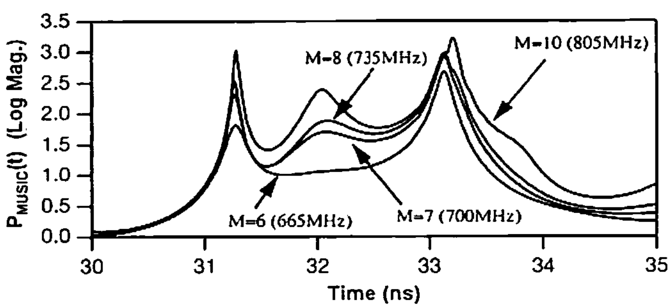

Fig.4 Time-domain responses estimated by the MUSIC algorithm (Type-II method). f_l = 14.5 GHz, Δf=35 MHz, N = 15. The value in the parenthesis denotes the total used frequency bandwidth in the analysis.