DOA Estimation of Linear Patch Antenna Array Using USV - MUSIC Algorithm

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Abstract **— Universal steering vector (USV) is applied to estimate directional of arrival (DOA) using multiple signal classification (MUSIC) algorithm. The USV that includes effect of mutual coupling can be used in searching peak spectrum directly without compensation of the mutual coupling. The linear patch antenna is used as DOA receiving antenna for estimate of DOA. Comparison between results of CSV(conventional steering vector) and USV are presented in this research.**

Keywords — Direction of arrival, MUSIC, mutual coupling, steering vector.

I. INTRODUCTION

Direction of arrival estimation becomes one of the most important parts of smart antennas application. There are many algorithm can be used to estimate direction of arrival such as: MUSIC, Root-MUSIC, ESPIRIT, ect[1][2][3][4]. Multiple signal clarification is one of effective algorithms to estimated DOA. The original approaches of MUSIC algorithm do not include mutual coupling effect of array antenna. But in practical conditions, effect of mutual coupling can not be ignored. There are many researchers who have studied the problem to reduce the effect of mutual coupling from received voltage at the array terminal or from steering vector and then apply compensated received voltage or compensated steering vector to evaluate the MUSIC spectrum[3][5][6][7].

Many studies have been focused on the methods to compensate effect of mutual coupling on array antenna. Studies about the mutual coupling effect using a circuit theory approach have been done[8]. More recently, researchers tried to analyze the mutual coupling using the electromagnetic interaction approach and calibration method. But the compensated method in [8] can not be generally used. This method is only valid and accurate to small dipole antennas. Studies about effect of mutual coupling are also redefined by talking the open circuit scattering into account, but the problem is the current distribution has to be estimated in advance. Estimation of current distribution will become difficult when the structure of antennas is complicated. This is because current distribution depends on direction and polarization of incident waves.

In the previous researches, effect of mutual coupling that is compensated from steering vector has been studied. It is possible to use the USV to calculate MUSIC spectrum directly without compensation and the steering vectors has been evaluated by using method of moments (MoM) for array antenna with arbitrary geometry[1].

In this paper, linear patch antenna array using USV-MUSIC algorithm is applied to DOA Estimation. The USV is used to calculate MUSIC spectrum of linear patch antenna array. The result will be compared between USV-MUSIC and CSV-MUSIC.

II. DOA ESTIMATION USING MUSIC ALGORITHM

There are two subspaces that are divided by received signal space of M array elements. The first is incident signal subspace spanned by L incident signal eigenvectors ant the other is the noise subspace spanned by *M-L* noise eigenvector. Like many adaptive techniques, MUSIC is dependent on the correlation matrix of the vector of received signals. Both of signal eigenvector and noise eigenvector can be calculated by correlation matrix of received voltage $[V^r]$ at the terminals of the antenna element as

$$[R_{xx}] = E([V^r][V^r])^{\mathrm{H}} \qquad (1)$$

where $E()$ denotes the statistical expectation and superscript H denotes the complex conjugate transform.

The received voltages by array antenna, which is corrupted by noise, is expressed as:

$$[V^r] = \sum_{\mathrm{m}=1}^{\mathrm{L}} [A(\theta_m, \emptyset_m)] s(\theta_m, \emptyset_m) + \mathrm{Noise} \qquad (2)$$

$[A]$ represents steering vector that have M dimension. $s(\theta_m, \emptyset_m)$ denotes the electric field of mth incident wave.

MUSIC direction of arrival estimation utilizes orthogonality between signal eigenvector and noise eigenvector. DOA estimation can be done by searching peak of the MUSIC spectrum that given by:

$$P_{MUSIC}(\theta, \emptyset) = \frac{[A(\theta,\emptyset)]^H [A(\theta,\emptyset)]}{[A(\theta,\emptyset)]^H [E_N][E_N]^H [A(\theta,\emptyset)]} \qquad (3)$$

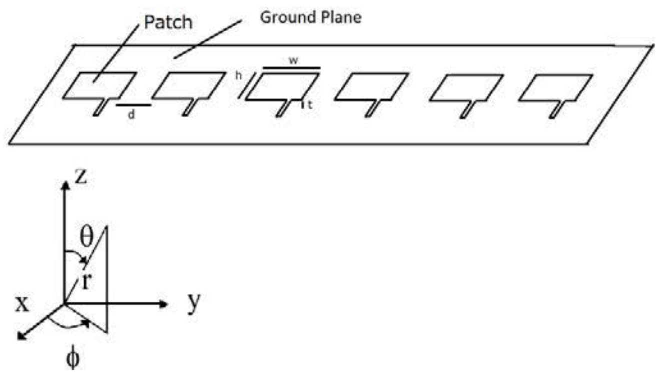

Fig 1. Six elements patch antenna array

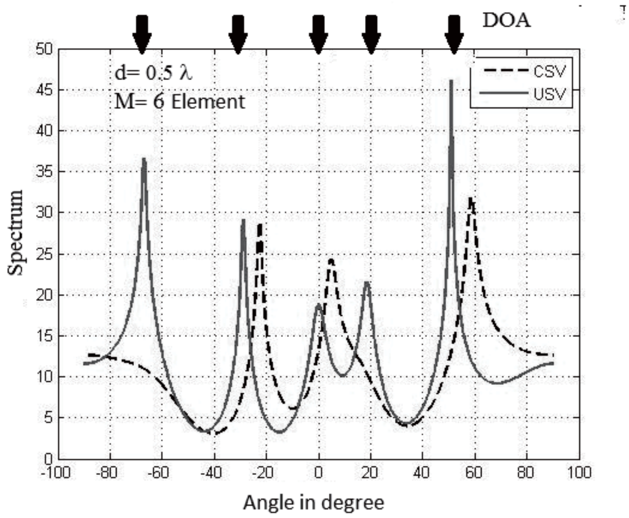

Fig 2. MUSIC Spectrum of six elements of patch antenna array d=0.5λ

θ and ∅ are searching angles, and the polarization of the incident wave is assumed to be known. [A] represents CSV and *[E_N]* is the signal eigenvector that have size $M \times (M-L)$ matrix whose are the noise eigenvectors of matrix correlation.

In this paper, USV is used which include effect of mutual coupling between antenna elements. MUSIC spectrum by using USV given by:

$$P_{MUSIC}(\theta,\emptyset) = \frac{[A^u(\theta,\emptyset)]^H[A^u(\theta,\emptyset)]}{[A^u(\theta,\emptyset)]^H[E_N][E_N]^H[A^u(\theta,\emptyset)]} \quad (4)$$

The spectrum is compared with that defined in eq (3) of the CSV.

III. Conventional and universal steering vector

A. Conventional Steering Vector

The received voltage vector with *M* dimensions and *L* incident waves are defined by

$$[V] = \sum_{m=1}^{L}[A(\theta_m,\emptyset_m)]f(\theta_m,\emptyset_m)s(\theta_m,\emptyset_m) + Noise \quad (5)$$

where $f(\theta_m,\emptyset_m)$ represents ideal isolated element pattern that is the same at all elements. $[A(\theta_m,\emptyset_m)]$ is the CSV that have *M* dimension. *m*th element of $[A(\theta_m,\emptyset_{jm})]$ is defined by

$$a_i(\theta_m,\emptyset_m) = e^{j\vec{k}_m.(\vec{r}_i-\vec{r}_0)} \quad (6)$$

B. Universal Steering Vector

The USV is evaluated using method of moments to get accuracy estimation. Each patch antenna is divided into several segments. Richmond's method give the rule that the length of segment must be less than $\lambda/2\pi$. Matrix equation for unknown current of all segments given by

$$[Z][I] = [V^{inc}(\theta,\emptyset)] \quad (7)$$

where [*Z*] is matrix or impedance whose element z_{ij} that represents mutual impedance between *i*th and *j*th segment. [*Z*] have size $N \times N$ impedance matrix is obtained by full wave analyze that become independent of the incident wave. [I] is the matrix of current that represents the current of all segments. This matrix have *N* size. The *N* voltage represents the inner product of the weighting function and the incident electrics from direction $(\theta,\emptyset)$ for all segments. The unknown current can be obtained by equation

$$[I] = [Y][V^{inc}(\theta,\emptyset)] \quad (8)$$

where $[Y]$ is inverse matrix from admittance matrix[*Z*]. Then, current matrix at terminal of antenna can be defined as

$$[I^{ter}] = [Y^{ter}][V^{inc}(\theta,\emptyset)] \quad (9)$$

$[I^{ter}]$ represents the current vector at terminal segment. $[Y^{ter}]$ is matrix that shows mutual admittances between the segments at terminals and all the segments of array antenna. $[Y^{ter}]$ is part of [Y] that include mutual coupling effect.

The USV that include effect of mutual coupling can be shown as follow

$$[A^u(\theta,\emptyset)] = zl[Y^{ter}][V^{inc}(\theta,\emptyset)] \quad (10)$$

Assuming the terminal of array is loaded by an impedance of Zl.

IV. SIMULATION RESULTS

Fig 1. Shows six elements patch antennas array where each element is loaded by impedance Z_l=50 Ω. The antenna is rectangular patch antenna that have ground. Fig. 2 shows spectrum MUSIC of six elements patch array with array spacing 0.5λ. All incident waves have signal to noise ratio (SNR) of 20 dB. Because the number of array antenna is 6, 5 DOA can be detected at same time. The DOA with θ polarization are -70^0, -30^0, 0^0, 20^0 and 50^0. It is demonstrated result in all the correct DOA, while MUSIC-CSV can only estimate 4 direction including a large error.

V. CONCLUSIONS

DOA estimation of linear patch antenna array using USV-MUSIC algorithm have been done. USV was used to calculate MUSIC spectrum of linear patch antenna array. It was demonstrated by the numerical simulation the USV that includes effect of mutual coupling gives more accurate results than CSV.

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REFERENCES

[1] Q. Yuan, Q. Chen, and K. Sawaya, "Accurate DOA estimation using array antenna with arbitrary geometry," *IEEE Transactions on Antennas and Propagation*, vol. 53, no. 4, pp. 1352–1357, Apr. 2005.

[2] M. M. Abdalla, M. B. Abuitbel, and M. A. Hassan, "Performance evaluation of direction of arrival estimation using MUSIC and ESPRIT algorithms for mobile communication systems," in *Wireless and Mobile Networking Conference (WMNC), 2013 6th Joint IFIP*, 2013, pp. 1–7.

[3] R. Goossens and H. Rogier, "A Hybrid UCA-RARE/Root-MUSIC Approach for 2-D Direction of Arrival Estimation in Uniform Circular Arrays in the Presence of Mutual Coupling," *IEEE Transactions on Antennas and Propagation*, vol. 55, no. 3, pp. 841–849, Mar. 2007.

[4] F. Gao and A. B. Gershman, "A generalized ESPRIT approach to direction-of-arrival estimation," *IEEE Signal Processing Letters*, vol. 12, no. 3, pp. 254–257, Mar. 2005.

[5] Q. Huang, H. Zhou, J. Bao, and X. Shi, "Accurate DOA Estimations Using Microstrip Adaptive Arrays in the Presence of Mutual Coupling Effect," *International Journal of Antennas and Propagation*, vol. 2013, p. e919545, Nov. 2013.

[6] Q. Bao, C. C. Ko, and W. Zhi, "DOA estimation in the presence of unknown mutual coupling and multipath propagation in a frequency hopping system," in *2004 IEEE International Conference on Communications*, 2004, vol. 5, pp. 2502–2506 Vol.5.

[7] H. S. Lui and H. T. Hui, "Mutual Coupling Compensation for Direction-of-Arrival Estimations Using the Receiving-Mutual-Impedance Method," *International Journal of Antennas and Propagation*, vol. 2010, p. e373061, Mar. 2010.

[8] I. J. Gupta and A. A. Ksienski, "Effect of mutual coupling on the performance of adaptive arrays," *IEEE Transactions on Antennas and Propagation*, vol. 31, no. 5, pp. 785–791, Sep. 1983.