Estimation Method for Complex Radiation Pattern of MIMO Antennas Using Backscattering Waves

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***Abstract*—In this paper, we propose a novel method for measuring a complex radiation pattern of MIMO (Multiple-Input Multiple-Output) antennas, without connecting cables or small oscillators at ports of MIMO antennas. Results of the numerical simulation show that the proposed method gives the complex radiation pattern accurately when the signal-to-noise ratio at the receiving antenna is higher than 15 dB.**

***Keywords*—complex radiation patterns, MIMO antenna, channel estimation.**

I. Introduction

A complex radiation pattern is the most important parameter for MIMO (Multiple-Input Multiple-Output) antennas [1]. In general, complex radiation pattern is measured by using coaxial cables, small oscillators or optic fiber cables. However, by using the conventional methods, either low accuracy, or high measurement cost is inevitable.

In this paper, we propose a method for measuring the complex radiation pattern of MIMO antenna using scattering waves, without connecting cables or small oscillators with MIMO antenna. The proposed method is based on load modulation techniques [2] and complex radiation patterns are estimated by observing scattering field modulated at the MIMO antennas.

II. Estimating method of complex radiation patterns

Fig.1 shows a measurement system of the proposed method. The system includes transmitting antenna, receiving antenna and N elements of MIMO AUT (Antenna Under Test). Each MIMO AUT is terminated by a known impedance z_i, where i is the port number of MIMO AUT. The symbols, T, R, M denote the ports of transmitter, receiver and MIMO AUT, respectively. We define the reflection coefficients at the MIMO AUT as, $\Gamma = \mathrm{diag}[\gamma_1, \cdots, \gamma_{\mathrm{N}}]$. In the system shown in Fig. 1, we assume $\boldsymbol{S}_{MT} = \boldsymbol{S}_{RM}^T$, and $\boldsymbol{S}_{MM}$ is known, where $\boldsymbol{S}$ denotes S-parameter matrix. Now, when all elements of MIMO AUT are terminated by reference impedance z_0, the channel response between T and R, is expressed as

$$H_0 = S_{RT} \tag{1}$$

where, S_{RT} is the direct wave from T to R. When i-th port of MIMO AUT is terminated by z_i and all other ports are terminated by z_0, the channel response, H_i, is expressed as

$$H_i = S_{RT} + \left\{ \boldsymbol{S}_{MT}^{(i)} \right\}^2 \frac{\gamma_i}{1 - \boldsymbol{S}_{MM}^{(i,i)} \gamma_i}. \tag{2}$$

Therefore, the channel response corresponding to the reflected wave from MIMO AUT is calculated as $\Delta H_i = H_i - H_0$, and the S-parameter between transmitter and i-th MIMO AUT is estimated as

$$\boldsymbol{S}_{MT}^{(i)} = \pm \sqrt{\frac{1 - \boldsymbol{S}_{MM}^{(i,i)} \gamma_i}{\gamma_i} \Delta H_i}. \tag{3}$$

As shown in (3), estimated $\boldsymbol{S}_{MT}^{(i)}$ is non-unique. In this report, $\boldsymbol{S}_{MT}^{(i)}$ is uniquely determined so as to keep the continuity of the phase of complex radiation patterns. Other $\boldsymbol{S}_{MT}$ are estimated in the same manner. From estimated $\boldsymbol{S}_{MT}$, we can find the complex radiation patterns of MIMO AUT as

$$\boldsymbol{D}_M = \frac{4\pi d}{\lambda} \frac{\boldsymbol{S}_{MT}}{D_T} \tag{4}$$

where, $\boldsymbol{D}_M$ and D_T are complex radiation patterns of MIMO AUT and transmitter, respectively. d means distance between T and M, and λ means wavelength in a vacuum. The proposed method can estimate all complex radiation patterns by $N+1$ times observation of channel responses.

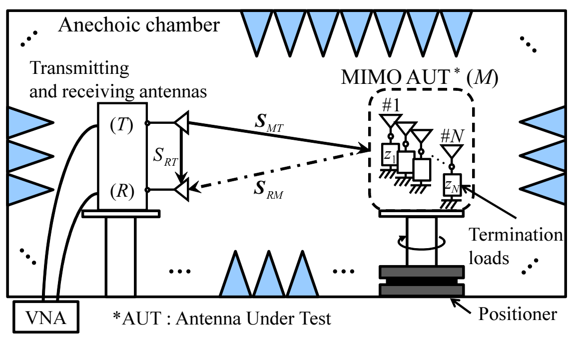

Fig. 1. Measurement system of proposed method

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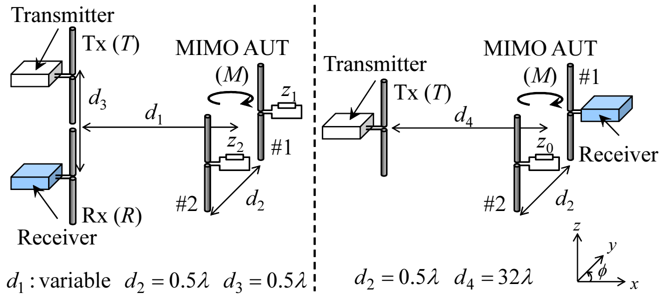

(a) Proposed configuration (b) Conventional configuration

Fig. 2. Simulation models

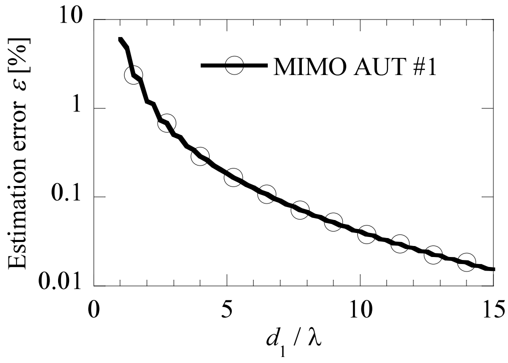

Fig. 3. Estimation error ε as a function of distance d_1

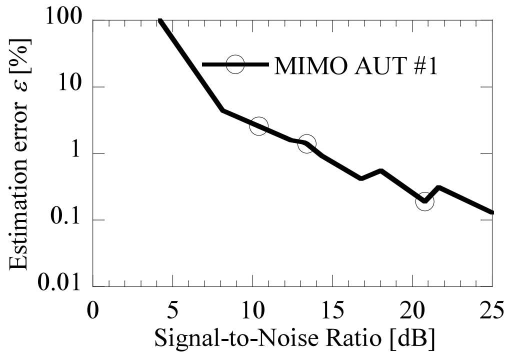

Fig. 4. Estimation error ε as a function of SNR

III. Simulation Model and Condition

Fig. 2 (a) shows simulation model of the proposed method. Both Tx and Rx antennas are half-wavelength dipole antennas. MIMO AUT is two elements half-wavelength dipole antenna array with spacing, d_2. Frequency is set to 2.4 GHz. To evaluate the accuracy of the proposed method, numerical simulation with conventional method was performed for comparison. In this model, we obtained channel responses between T and M, $\boldsymbol{S}_{MT}$, and calculated complex radiation patterns from $\boldsymbol{S}_{MT}$. Here, the distance d_4 is fixed to 32λ.

In this study, the estimation error, ε, is defined as

$$\varepsilon = \frac{\sum_{j=1}^{L} \frac{\left|D_P^{(j)} - D_E^{(j)}\right|^2}{\left|D_E^{(j)}\right|^2}}{L} \tag{5}$$

where, D_P and D_E are complex radiation patterns with the proposed method and the conventional method, respectively. L is number of observation points.

IV. Simulation Results

Estimation error, ε, as a function of distance d_1 is shown in Fig. 3. It shows that short distance d_1 causes large estimation error due to near-field observation, and ε is improved by extending d_1. However, a slight estimation error remains, even though both proposed and conventional method observed same MIMO AUT. This is because transmitting and receiving antennas in proposed configuration is shifted by 0.25λ toward z-axis, and observed complex radiation patterns are different between proposed and conventional configuration.

Fig. 4 shows SNR (Signal-to-Noise Ratio) versus estimation error ε. Here, SNR is defined as,

$$\mathrm{SNR} = \frac{\Delta H_i \overline{\Delta H_i}}{\sigma^2} P_t \tag{6}$$

where, ΔH_i is scattering channel. σ^2 and P_t are white Gaussian noise power and transmitting power, respectively. $\{\overline{\bullet}\}$ means complex conjugate. And d_1 is set to 10λ because lower than 0.05% estimation error is found when the distance is larger than 10λ in this model. This result shows that the proposed method gives accuracy with 1% error when SNR is 15 dB.

V. Conclusion

In this paper, we have proposed a novel estimating method for the complex radiation pattern of MIMO AUT, where the complex radiation pattern is estimated from channel responses obtained by switching termination loads at MIMO AUT. Results of the numerical simulation showed that the proposed method is able to estimate complex radiation patterns, without using cables, and small oscillators.

Acknowledgment

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