Decoupling method for compact MIMO antenna utilizing MISO channel response on neighboring antennas

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1 Introduction

MIMO (Multiple-Input Multiple-Output) technologies have been recently investigated because it can obtain high channel capacity without expanding frequency band. Implementation on multiple antennas within a limited space is one of the key important issue for MIMO terminal stations [1]. However, it is difficult to obtain the improvement on transmission rate even if MIMO transmission is employed using compact MIMO antennas because the radiation efficiency is degraded due to mutual coupling effect between antennas.

One of solutions for this problem is the use of a DMN (Decoupling and Matching Network) [2]. The DMN is attached to the feed ports of the array antenna can not only cancel the mutual coupling but also offer the matching at the input port. However, the slight resistance in DMN greatly affects the radiation efficiency of the antenna, and the bandwidth of the DMN can be extremely narrow since all decoupling and matching function relies on the feed network.

In this paper, we propose a novel decoupling method for compact multiple antennas. Three neighboring antennas are used for two port system and the two ports are decoupled on the array antenna. The orthogonality of two ports is achieved by giving orthogonal excitation weight to three antennas, where the weight is determined by SVD (Singular Value Decomposition) of the MISO (Multiple-Input Single-Output) channel. This paper also demonstrates the basic characteristics and improvement on radiation efficiency by the proposed method via the analysis using moment of method (MoM).

2 Proposed method

2.1 Basic principle

Fig. 1 shows a basic idea of proposed method. We consider 2×1 MISO channel. Here, $\boldsymbol{H}$ is the channel from the antennas, $\sharp 1$ and $\sharp 2$ to $\sharp 3$. The antennas, $\sharp 1$ and $\sharp 2$ are combined together by feed network, and its input port is defined as port $\sharp a$. The input port for the antenna, $\sharp 3$ is defined as port $\sharp b$. The SVD for MISO channel can be expressed as,

$$\boldsymbol{H} = U\boldsymbol{\Lambda}\boldsymbol{V}^H, \tag{1}$$

where $U = 1$, $S = [\sqrt{\lambda_1}, 0]$, and $V = [\boldsymbol{v}_1, \boldsymbol{v}_2]$. The vector $\boldsymbol{v}_1$ is the eigenvector corresponding to the eigenvalue, λ_1. As shown in Fig.1, $\boldsymbol{v}_2$ is the null space vector and no output is observed at $\sharp b$ when this vector is incident to the antennas, $\sharp 1$ and $\sharp 2$: the port $\sharp a$ and $\sharp b$ are decoupled if the feed network can generate $\boldsymbol{v}_2$.

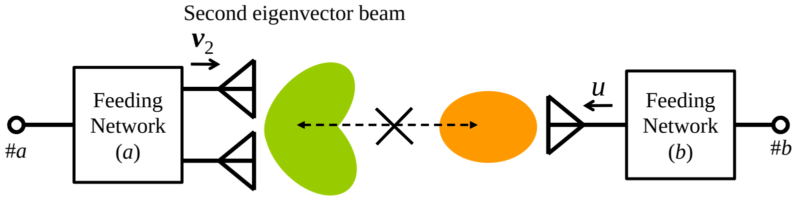


Figure 1: Basic idea of proposed method.

2.2 Derivation of feeding weight

Fig. 2 represents the block diagram of the circuit model for the proposed decoupling network. Here, $\boldsymbol{S}_A$ is the S-parameter of the array antenna, and can be expressed as,

$$\boldsymbol{S}_A = \begin{pmatrix} \boldsymbol{S}_{aa} & \boldsymbol{S}_{ab} \\ \boldsymbol{S}_{ba} & S_{bb} \end{pmatrix}, \tag{2}$$

where $\boldsymbol{S}_{ma}$, and $\boldsymbol{S}_{mb}$ are the S-parameter of the feed networks (a) and (b) in Fig. 2, respectively. The feed network (a) is designed to satisfy both the incident weight, $\boldsymbol{v}_2$, and matching condition at port $\sharp a$. Since the feed network (b) is a single-input single-output circuit, it can be designed only by considering the matching.

First, we consider the termination for the port $\sharp b$. When the channel response is $\boldsymbol{S}_{aa}$ between $\sharp 1/\sharp 2$ and $\sharp 3$, the conditions, $\boldsymbol{S}_{ma22} = \boldsymbol{S}_{aa}^H$ and $\boldsymbol{S}_{ma}^H \boldsymbol{S}_{ma} = \boldsymbol{I}$ are required for the dispersion and orthogonality between $\sharp 1/\sharp 2$ and $\sharp 3$. In order to satisfy these conditions, the following relationships can be calculated as,

$$\begin{aligned} \boldsymbol{S}_{ma12} &= \boldsymbol{M}_a \mathfrak{C}(\boldsymbol{I} - \boldsymbol{S}_{aa}\boldsymbol{S}_{aa}^H), & (3) \\ \boldsymbol{S}_{ma21} &= \boldsymbol{S}_{ma12}^T, & (4) \\ \boldsymbol{S}_{ma11} &= -(\boldsymbol{S}_{ma12}^H)^{-1}\boldsymbol{S}_{ma22}^H \boldsymbol{S}_{ma21}, & (5) \end{aligned}$$

where $\mathfrak{C}$ is Cholesky decomposition [2]. $\boldsymbol{M}_{\boldsymbol{a}}$ is unitary matrix.

Next, we consider the termination for the port $\sharp b$. Here, the conditions, $S_{mb22} = S_{bb}^*$ and $\boldsymbol{S}_{mb}^H \boldsymbol{S}_{mb} = \boldsymbol{I}$ are needed. In order to satisfy these conditions, the following relationships can be calculated as,

$$\begin{aligned} S_{mb12} &= \mathfrak{C}(1 - S_{bb}S_{bb}^H), & (6) \\ S_{mb21} &= S_{mb12}, & (7) \\ S_{mb11} &= -(S_{mb12}^*)^{-1} S_{mb22}^* S_{mb21}. & (8) \end{aligned}$$

However, the matching condition at the port $\sharp 1$ and $\sharp 2$ can vary if the matching circuit (b) is attached to port $\sharp 3$. Also, the matching condition at the port $\sharp 3$ varies if the feed network (a) is attached to the ports $\sharp 1$ and $\sharp 2$. Therefore, it is difficult to obtain the S-parameter of the feed networks deterministically. In this study, we obtained the desired S-parameter of the feed networks by iterative optimization. Here, $\boldsymbol{S}_{aa}$ and S_{bb} are updated as,

$$\boldsymbol{S}_{aa} = \boldsymbol{S}_{a11} + \boldsymbol{S}_{a12}(S_{mb22} - S_{a22})^{-1}\boldsymbol{S}_{a21}, \tag{9}$$

$$S_{bb} = S_{a22} + \boldsymbol{S}_{a21}(\boldsymbol{S}_{ma22} - \boldsymbol{S}_{a11})^{-1}\boldsymbol{S}_{a12}. \tag{10}$$

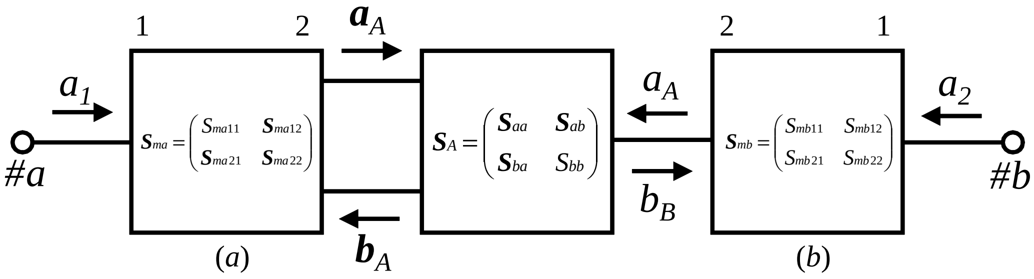


Figure 2: Equivalent circuit model.

By using Eqns.(9) and (10), the S-parameter of the DMN is updated iteratively. For each iteration, the S-parameter of the DMN is determined mathematically [2][3].

3 Numerical analysis

In this section, we demonstrate the effectiveness of proposed method by using an analysis using compact inverted-F antenna. Fig. 3 shows the analysis model of the antenna. Planer inverted F-antennas are arranged triangularly within 18×18 mm size and the height of antenna is 3.2 mm. The other size is shown in Fig. 3. The radio frequency is 2.4 GHz. The MoM with an infinite ground is used. Although the array antenna has symmetrical geometry, two out of three antenna are combined by the feed network $\sharp a$, and a rest of the antenna is connected to feed network $\sharp b$.

Fig. 4 represents the S-parameters at both ends of the feeding network $\sharp a$ and $\sharp b$ by iterative calculation. Here, S-parameters which are observed by combining two feed networks to the array antenna are S'_{aa}, S'_{ab}, S'_{bb}. As can be seen in Fig. 4, mutual coupling, S'_{ab} are sufficiently suppressed without any iteration. Moreover, S'_{aa} is quite small. On the other hand, the high level of the reflection is observed at port $\sharp b$ when the number of the iteration is small. This is because feed network $\sharp a$ greatly affects the input impedance at port $\sharp b$. However, after several hundreds of the iteration, the value of S'_{bb} is almost same with those of S'_{aa} and S'_{ab}. From these results, the proposed method can provide the design of the feed network with low reflection and mutual coupling.

Fig. 5 shows the radiation pattern in the xz and yz-planes when we assume the infinite ground plane. As can be seen in this figure, both of the feed networks, $\sharp a$ and $\sharp b$, can provide wide beam width even with maintaining orthogonality between two ports.

Fig. 6 depicts the radiation efficiency. As shown in Fig. 6, the radiation efficiency with $\sharp a$ is 65.4 %. Although the efficiency is very small when the iteration = 1 regarding $\sharp b$, the radiation efficiency of $\sharp b$ becomes almost same with that of $\sharp a$ by the iteration process. This result indicates that the proposed method can provide high radiation efficiency with a broad bandwidth.

4 Conclusion

This paper proposed a novel decoupling method which utilizes MISO channel responses among neighboring antennas for compact MIMO terminal antennas. In this

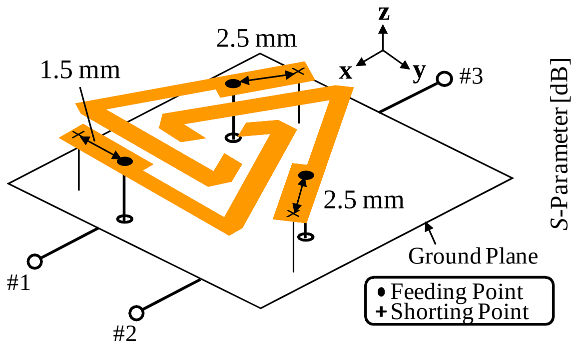


Figure 3: Antenna geometry.

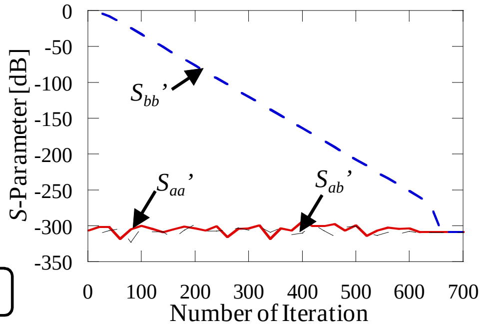
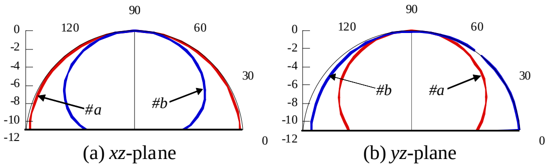


Figure 4: S-parameter versus number of iteration.



(a) *xz*-plane

(b) *yz*-plane

Figure 5: Radiation patterns.

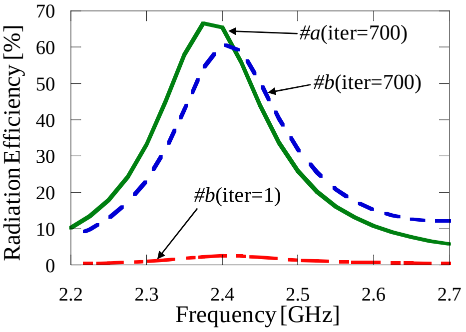


Figure 6: Radiation efficiency versus frequency.

paper, we described the basic idea and clarified the principle to obtain the decoupling network. The simulation results indicated that the perfect isolation and matching characteristics have been shown by the iterative process for the circuit parameters. Moreover, over 60 % radiation efficiency can be obtained by the iterative process in the proposed method. It is clarified that the proposed decoupling method is effective for enhancing the radiation efficiency for the compact MIMO terminal antennas.

Acknowledgment

The part of this work is supported by MEXT KAKENHI, Grant-in-Aid for Young Scientists (B) 22760272.

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