Multi-antenna Decoupling Technique
Exploiting MISO Channel on Neighboring Antennas

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Abstract

In this paper, a novel decoupling technique suitable for a compact array antenna is proposed. In this technique, an orthogonal excitation weight in MISO channel between 2 × 1 antennas are utilized. The simulation results demonstrate the excellent isolation and matching characteristics can be obtained when the proposed decoupling technique is applied to a compact three inverted-F array. Also, the proposed technique offers high radiation efficiency over the broad bandwidth.

1 Introduction

Recent mobile terminals require very compact antennas since they need to have many functions, such as camera, RF-ID, and so on. An inverted-F antenna is one of the most common techniques for miniaturizing the antenna, and a planar inverted-F Antenna (PIFA) has been well investigated and applied to many kinds of mobile terminals since it is compact and can be easily configured by printing on the substrate.

On the other hand, MIMO(Multiple-Input Multiple-Output) technology have been well investigated and applied to the latest wireless communication systems since it can offer a high datarate without expanding frequency band. In MIMO systems, we need to use multiple antennas at both transmitter and receiver. However, the size of the multiple antennas degrades the compactness of the mobile terminals. Otherwise, the antennas placed in a small area causes high mutual coupling among the antennas, and it seriously affects the radiation efficiency. This means that it is difficult to obtain the datarate enhancement using MIMO transmission since the low SNR(Signal-to-Noise Ratio) affects a MIMO capacity.

The use of the polarization or radiation pattern orthogonality of the antennas is effective in avoiding the mutual coupling of the antennas [1, 2, 3]. The drawback of this technique is degradation of the orthogonality when the space and locations for the antennas is limited. The antennas must be placed in very specific location and orientation to maintain the orthogonality of the antennas. This means this does not allow the arbitrary antenna arrangement, that will be required for designing the mobile terminal.

Other attractive solution for this problem is the use of a DMN(Decoupling and Matching Network). The DMN is attached to the feed ports of the array antenna, and it can not only cancel the mutual coupling but also offer the matching at the input port[4]. 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, a novel decoupling technique for a compact array antenna is proposed. Three neighboring antennas are used for two port system and the two ports are decoupled on the array antenna. This technique utilizes MISO (Multiple-Input Single-Output) channel among 2×1 antennas. 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 channel. Since the channel does not vary after antenna fabrication, this weight can be given analog feed circuit. Although the proposed technique requires three antennas, the high radiation efficiency can be expected since the decoupling is performed at the 'air'. Another benefit of this technique is that the antennas can be placed arbitrary in the terminal chases since we can use one degree of freedom out of three.

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2 Decoupling Technique Using MISO Channel in Multiple Antennas

Figure 1 indicates the sketch of the 2×1 MISO model. Here, $\boldsymbol{H}$ is the channel from the antennas, #1 and #2 to #3. The antennas, #1 and #2 are combined together by feed network, and its input port is defined as port $\#a$. The input port for the antenna, #3, is redefined as port $\#b$. The SVD of the channel can be expressed as,

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

where,

$$\boldsymbol{U} = 1 \tag{2}$$
$$\boldsymbol{S} = [\sqrt{\lambda}_1, 0] \tag{3}$$
$$\boldsymbol{V} = [\boldsymbol{v}_1, \boldsymbol{v}_2]. \tag{4}$$

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 #b when this vector is incident to the antennas, #1, and #2. This means that the port #a and #b are decoupled if the feed network can generate the incident wave,$\boldsymbol{v}_2$.]

Figure 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,

$$\boldsymbol{S}_A = \begin{pmatrix} \boldsymbol{S}_{aa} & \boldsymbol{S}_{ab} \\ \boldsymbol{S}_{ba} & S_{bb} \end{pmatrix}. \tag{5}$$

$\boldsymbol{S}_{ma}$, and $\boldsymbol{S}_{mb}$ are the S-parameter of the feed networks (a) and (b), respectively, and they can be expressed as,

$$\boldsymbol{S}_{ma} = \begin{pmatrix} S_{ma11} & \boldsymbol{S}_{ma12} \\ \boldsymbol{S}_{ma21} & \boldsymbol{S}_{ma22} \end{pmatrix}, \tag{6}$$

$$\boldsymbol{S}_{mb} = \begin{pmatrix} S_{mb11} & S_{mb12} \\ S_{mb21} & S_{mb22} \end{pmatrix}. \tag{7}$$

$\boldsymbol{a}_{ma}$ is the incident wave to the port #a, and it is transformed to $\boldsymbol{a}_A$ through the feed network #a. $\boldsymbol{b}_A$ is the reflected wave from the antenna ports #1 and #2. $\boldsymbol{a}_{mb}$ is also the incident wave to the port #b, and it is transformed to $\boldsymbol{a}_B$ through the feed network #b. $\boldsymbol{b}_B$ is the reflected wave from the antenna ports #3. The feed network (a) is designed to satisfy both the incident weight, $\boldsymbol{v}_2$, and matching condition at port #a. Since the feed network (b) is a single-input single-output circuit, it can be designed only by considering the matching.

However, the matching condition at the port #1 and #2 can vary if the matching circuit (b) is attached to port #3. Also, the matching condition at the port #3 varies if the feed network (a) is attached to the ports #1 and #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. At the first step, S-parameter of the feed network (a), $\boldsymbol{S}_{ma(1)}$, is determined by assuming that the port #3 is connected

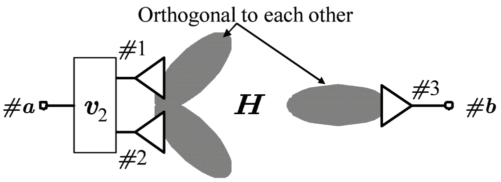


Figure 1: MISO model.

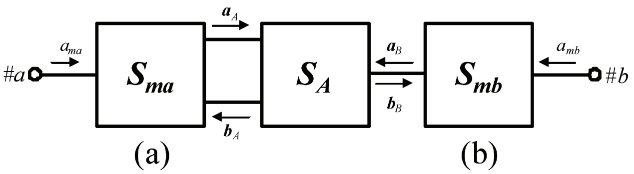


Figure 2: Circuit model.

to termination load. After that, S-parameter of the feed network (b), $\boldsymbol{S}_{mb(1)}$, is designed by assuming $\boldsymbol{S}_A$ is connected to $\boldsymbol{S}_{ma(1)}$. $\boldsymbol{S}_{ma(i)}$ of the i-th step can be calculated by using the $\boldsymbol{S}_A$ and $\boldsymbol{S}_{mb(i-1)}$. When $\boldsymbol{S}_A$ is connected to $\boldsymbol{S}_{mb(i-1)}$, the apparent S-parameter, $\boldsymbol{S}_{aa(i)}$, is expressed as,

$$\boldsymbol{S}_{aa(i)} = \boldsymbol{S}_{aa} + \boldsymbol{S}_{ab}(S^{-1}_{mb22(i-1)} - S_{bb})^{-1}\boldsymbol{S}_{ba}. \tag{8}$$

Based on (8), $\boldsymbol{S}_{ma(i)}$ is calculated. Also, the apparent S-parameter, $\boldsymbol{S}_{bb(i)}$ can be expressed as,

$$\boldsymbol{S}_{bb(i)} = \boldsymbol{S}_{bb} + \boldsymbol{S}_{ba}(\boldsymbol{S}^{-1}_{ma22(i)} - \boldsymbol{S}_{aa})^{-1}\boldsymbol{S}_{ab}. \tag{9}$$

By using (8) and (9)the S-parameter of the DMN is updated iteratively. For each iteration, the S-parameter of the DMN is determined mathematically [4, 5].

3 Numerical Analysis

In this section, the design scheme of the proposed decoupling network is demonstrated. Figure 3 and table 1 explain the analysis model of the antenna, that is an example for verifying the proposed decoupling network. Three inverted-F antennas are arranged triangularly within 18 mm × 18 mm size and the height of the antenna is 3.2 mm. The operation frequency is set to 2.4 GHz. The moment method with an infinite ground is used. Though the array antenna has symmetrical geometry, two out of three antennas are combined by the feed network #a, and a rest of the antenna is connected to feed network #b. Figure 4 shows the S-parameters at both ends of the feed network #a and #b. Here, S'_{aa}, S'_{ab}, and S'_{bb} are the S-parameters that can be observed by combining two feed networks to the array antenna. From this result, it is seed that the mutual coupling, S'_{ab} is sufficiently suppressed by the proposed feed network even without any iterations. It is also seen that S'_{aa} is quite small. This means that the proposed feed network can orthogonalize the ports successfully. On the other hand, it is seen that the high level of the reflection is observed at port #b when the number of the iteration is not enough. This is because feed network #a greatly affects the input impedance at port #b. After several hundreds of the iteration process, S'_{bb} is lowered sufficiently. From these results, the proposed design method can provide the design of the feed network with low reflection and mutual coupling. It can be understood that the proposed design utilizes a redundant degree of freedom in analog beam forming.

Figure 5 indicates the radiation patterns when the array antenna is excited through the proposed feed networks. It can be seen that both of the feed networks, #a and #b, can provide wide beam width even with maintaining orthogonality between two ports. It is found that the radiation efficiency at 2.4 GHz was about 50%. The bandwidth is also calculated and it is found that the bandwidth is over 5%, where the gain bandwidth is the relative frequency range with $\eta > 0.5\eta_{max}$ (η: radiation efficiency, η_{max}: maximum of η). These results showed that proposed design method can provide high radiation efficiency with a broad band width.

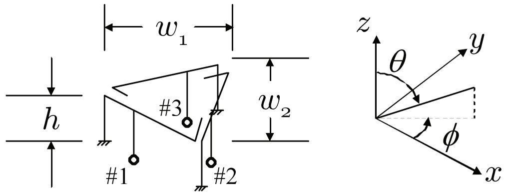


Figure 3: Antenna geometry.

Table 1: Analysis model

Antenna element	Inverted-F antennas
Number of antennas	3
Array size ($w_1 \times w_2 \times h$)	18 mm × 18 mm × 3.2 mm
Ground	Infinite
Number of antenna ports for #a	2
Number of antenna ports for #b	1
Operation frequency	2.4 GHz

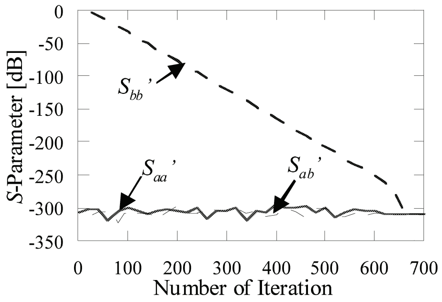
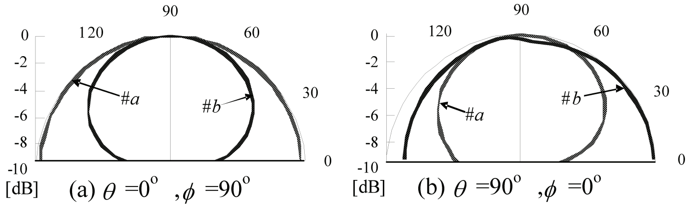


Figure 4: S-parameters versus number of iterations.



(a) θ =0°, ϕ =90° (b) θ =90°, ϕ =0°

Figure 5: Radiation patterns.

4 Conclusion

In this paper, a novel decoupling technique suitable for a compact array antenna has been proposed. In this technique, the MISO channel among 2 × 1 antennas are utilized. The design method of the proposed decoupling network has been briefly described and demonstrated. The circuit parameter can be obtained by the iterative process, and the excellent isolation and matching characteristics have been shown by the simulation results. The simulation results have also showed that the three inverted-F antenna with the proposed decoupling network provides the radiation efficiency of 50 % over the broad bandwidth. From these results, it is found that the proposed decoupling technique is effective in enhancing the radiation efficiency of the compact array antenna.

5 Acknowledgments

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