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A Consideration on Simple Decoupling Circuit without Three-dimensional Structure for MIMO Antennas

Masahiro Mori, Nobuyoshi Kikuma, Hiroshi Hirayama and Kunio Sakakibara
Department of Computer Science and Engineering, Nagoya Institute of Technology
Gokiso-cho, Showa-ku, Nagoya, 466-8555, Japan

Abstract – **Mutual coupling between the antenna elements is a serious problem in the MIMO communication with small devices such as mobile terminals. Decoupling circuits have been proposed as a method for removing the mutual coupling, but the construction of the circuit is complicated. In this paper, we propose a simplified decoupling method for the three-element array antenna.**

Index Terms **- MIMO, mutual coupling, decoupling, correlation coefficient, capacity.**

I. Introduction

When using the MIMO communication system in small terminals such as mobile phones, it is necessary to arrange the antenna elements in a limited space. Since the element spacing is very narrow in that case, the performance of MIMO is degraded due to the decrease in antenna efficiency and the increase of the correlation coefficients (mutual coupling) between antenna signals in the terminal [1].

Decoupling circuits for removing the mutual coupling have been proposed and discussed [1]-[3]. However, the structures of the decoupling circuits are complicated and hence simplification of the circuits is required in order to implement MIMO antennas in the mobile terminal. In this paper, therefore, we propose a construction method that simplifies the decoupling circuits by adjusting the shape of antennas in the three-element array antenna. We apply the proposed method in two decoupling circuits with multi-port conjugate matching (MPCM) and with bridge susceptance (BS), respectively [2],[3]. Through computer simulation, we compare their characteristics in the MIMO communication.

II. Simple Configuration Method by MPCM

We show the MPCM circuit in Fig. 1(a). Letting $\mathbf{Y}_a = \mathbf{G}_a + j\mathbf{B}_a$ express the input admittance of antenna elements, $\mathbf{Y}_m = j\mathbf{B}_m$ the admittance of lossless decoupling circuit constructed by pure susceptances, and $\mathbf{Y}_0 = y_0\mathbf{I}$ the load admittance, the admittance $\mathbf{Y}$ seen from the antenna to the load is expressed by the following equation [2],[3].

$$\mathbf{Y} = j\mathbf{B}_{m11} - j\mathbf{B}_{m12}\left(\mathbf{Y}_0 + j\mathbf{B}_{m22}\right)^{-1} j\mathbf{B}_{m12}^T \quad (1)$$

$$\mathbf{Y}_m = j\mathbf{B}_m = j\begin{bmatrix} \mathbf{B}_{m11} & \mathbf{B}_{m12} \\ \mathbf{B}_{m21} & \mathbf{B}_{m22} \end{bmatrix} \quad (2)$$

The matching condition between the antenna and decoupling circuit is given by $\mathbf{Y}_a^H = \mathbf{Y}$. By using the matching condition, we can obtain the following relationship under the additional condition of $\mathbf{B}_{m22} = \mathbf{0}$.

$$\mathbf{B}_{m11} = -\mathbf{B}_a \quad (3)$$

$$\mathbf{B}_{m12}\mathbf{B}_{m12}^T = \mathbf{Y}_0\mathbf{G}_a \quad (4)$$

Here, we simplify the circuit by using only one element to connect individual ports. When $\mathbf{B}_{m12}$ is expressed as

$$\mathbf{B}_{m12} = \begin{bmatrix} b_{m14} & b_{m15} & b_{m16} \\ 0 & b_{m25} & b_{m26} \\ 0 & 0 & b_{m36} \end{bmatrix} \quad (5)$$

it is possible to determine the matrix components by substituting (5) into (4) as follows:

$$b_{m14} = \pm\sqrt{y_0 g_{a11} - b_{m15}^2 - b_{m16}^2} \quad (6)$$

$$b_{m15} = \frac{y_0 g_{a12} - b_{m16} b_{m26}}{b_{m25}} \quad (7)$$

$$b_{m16} = \frac{y_0 g_{a13}}{b_{m36}} \quad (8)$$

$$b_{m25} = \pm\sqrt{y_0 g_{a22} - b_{m26}^2} \quad (9)$$

$$b_{m26} = \frac{y_0 g_{a23}}{b_{m36}} \quad (10)$$

$$b_{m36} = \pm\sqrt{y_0 g_{a33}} \quad (11)$$

where g_{aij} is the (*i*, *j*) component of $\mathbf{G}_a$.

In the three-element array, the circuit connecting the first element and the third element requires the three-dimensional structure intersecting the circuit connected to the second antenna. It is necessary that (8) and (1, 3) component of (3) are equal to zero in order to eliminate such a three-dimensional structure. Therefore, we realize the circuit by using the antenna which makes (1, 3) component of $\mathbf{Y}_a$ equal to zero. We show this circuit in Fig. 1(b).

III. Simple Configuration Method by BS

In the conventional circuit, space of the transmission line is necessary because it connects the bridge susceptance after converting the admittance between antennas to susceptance only. It can be considered that we can realize a small circuit by using antenna whose admittance is almost pure susceptance. Furthermore, it is possible to eliminate the bridge susceptance that connects the first element and the third element by satisfying the condition that (1, 3) component of $\mathbf{B}_a$ is zero, which is used in Sec. II. In this way, we realize the circuit without three-dimensional structure. We show this circuit in Fig. 1(c).

IV. Computer Simulation

We carried out computer simulation of MIMO communications under the conditions of Table I. γ_0 is the average of received SNR when all power is transmitted from one antenna element.

Fig. 2 shows the channel capacity as a function of the element spacing of the receiving array. It can be seen that it is possible to achieve a higher channel capacity in narrow element spacing by using the decoupling circuit. Also, channel capacity of BS simple circuit is slightly lower than the MPCM one. BS simple circuit cancels only susceptance component of the admittance between the elements, and so it cannot remove the coupling between elements because of the remaining conductance components. That is the reason why BS version has degradation in channel capacity.

Fig. 3 shows the channel capacity when the frequency is varied for the element spacing of 0.2 wavelength. 2 × 2 MIMO that is decoupled completely under the same conditions has the channel capacity of 10 [bits/s/Hz]. Therefore, we consider the frequency bandwidth at which the channel capacity exceeds 10 [bits/s/Hz]. The fractional bandwidth of the MPCM simple circuit is 8% and that of the BS one is 9%. It is found that BS simple circuit has a broader bandwidth than MPCM simple circuit.

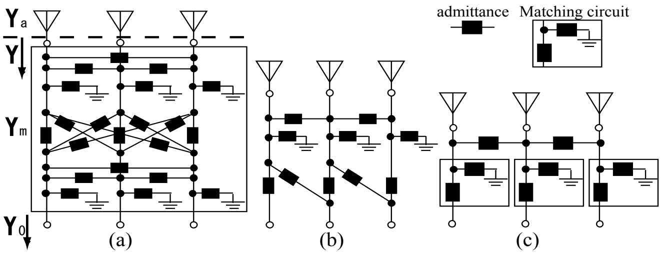

Fig. 1. Decoupling circuit for three-element array antenna: (a) MPCM, (b) Simple MPCM, (c) Simple BS.

TABLE I. Simulation Conditions.

Array	Uniform Linear Array
Transmit antenna spacing	1 wavelength
Antenna element	Half-wavelength dipole
Number of elements (receive × transmit)	3×3
γ_0	20dB
Number of trials	2000

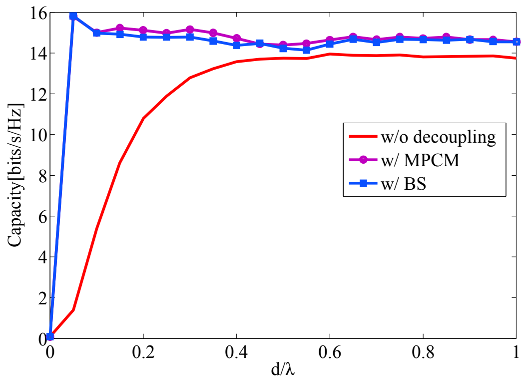

Fig .2. Channel capacity in 3×3 MIMO.

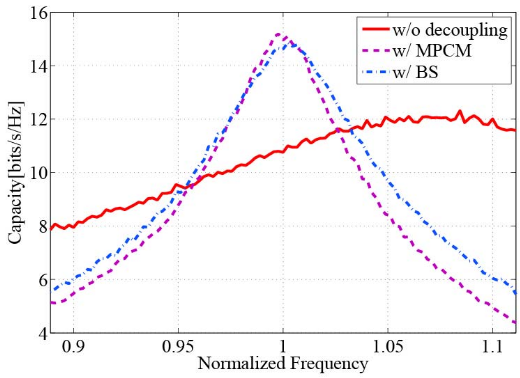

Fig. 3. Frequency characteristics of channel capacity in 3×3 MIMO.

V. Conclusion

In this paper, we proposed a configuration method of a simpler decoupling circuit that does not have a three-dimensional structure in a three-element array antenna. From computer simulation results, it is shown that higher channel capacity can be achieved while reducing the number of circuit elements by using the proposed simple circuit.

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