Simple Design of Decoupling Network Considering Mutual Admittance in Array Antenna

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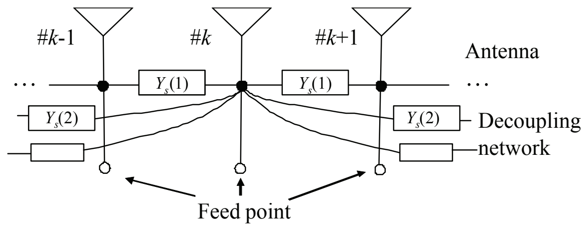
1. Introduction

In the next-generation mobile communication systems, high performance antennas are required for the base station, i.e., they must have high radiation efficiency and the radiation pattern suitable for the system requirement. In the base station, the transmitted signal from the base station leaks into the receiving antenna by mutual coupling. Therefore, it is difficult to process the received signal from the mobile terminal. Due to the influence of the mutual coupling, it is difficult to offer technical advantages of the antenna. A DMN (Decoupling and Matching Network) is an effective measure in reducing such mutual coupling [1], [2]. However, the circuit complexity is a serious problem in achieving a feasible DMN for the array antenna with three or more antenna elements when the conventional method is used [1]. Another research has shown that the DMN design using bridge susceptance using lumped element can offer a simple circuit configuration when the number of the antenna elements is two [2]. However, it is difficult for applying this method to the array with many more antennas. It is also problem that the radiation pattern of the antenna is changed and the bandwidth is decreased by employing conventional method. As described above, much simpler decoupling network is needed to offer a feasible DMN.

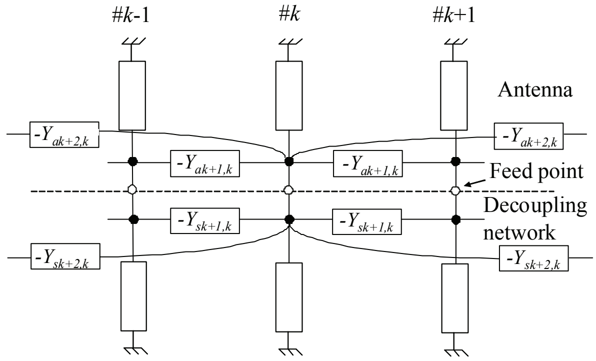
In this paper, a simple design of decoupling network considering a mutual admittance is proposed. For configuring decoupling network, microstrip line(MSL) is used. By using MSL, a low-less reactive element can be easily configured. In our technique, the mutual admittance can be cancelled by connecting MSL between two neighbouring antenna ports as bridge susceptance. In the following part of the paper, the idea and design method of the decoupling network are described. From measurement of S-parameter, the effectiveness of the proposed method is denoted.

2. Theory for designing Decoupling Network

Here, fundamental theory of proposed decoupling network in n element array is explained. Figure 1 shows the sketch of the model with the antennas and network. $\boldsymbol{Y_a}$ indicates admittance matrix of the array antenna. In this consideration, the mutual admittance is used for explaining the mutual coupling among the antennas. In $\boldsymbol{Y_a}$, mutual admittance part is $Y_{aj,i}$(i and j are integer numbers, where $i \neq j$) . For example, $Y_{aj,i} = 0$ means there is no mutual coupling between #i and #j antennas. When $Y_{aj,i}$ is purely imaginary number, the mutual admittance is cancelled by connecting reactance elements between two



(a) Proposed decoupling network model



(b) Equivalent circuit of (a)

Fig.1 Proposed decoupling network model.

neighbouring antenna ports. By using ideal reactance element, a lossless decoupling network can be achieved. $\boldsymbol{Y_s}$ describes admittance matrix of decoupling network. From Fig. 1 (b), antenna and decoupling network are connected in parallel, admittance matrix ***Y'*** ,after connecting decoupling network is denoted as (1)

$$\boldsymbol{Y}' = \boldsymbol{Y_a} + \boldsymbol{Y_s}\,. \tag{1}$$

Decoupling is realized by eliminating non-diagonal elements of admittance matrix ***Y'***. For the decoupling network, $Y_{sj,i} = 0$, $Y_{sj,i} = -Y_{aj,i}$ are required in order to avoid the influence on antenna matching

3. Designing Decoupling Network

3.1 **Design of Decoupling Network in *n* element array**

In this section, proposed designing method of the decoupling network for *n* element array is explained. When the mutual admittance of antenna is purely imaginary, the decoupling network can be configured by bridge susceptance. By using lossless transmission line, admittance parameters of $\boldsymbol{Y_s}$ are described as

$$Y_{si,i} = \frac{1}{Z_0}\frac{\cos\beta l}{j\sin\beta l} \tag{2}$$

$$Y_{sj,i} = -\frac{1}{Z_0}\frac{1}{j\sin\beta l}\,, \tag{3}$$

where l is the length of the bridge line that connects two neighbouring antenna ports. β is wave number and Z_0 is characteristic impedance of the bridge line. As described in section 2 , $Y_{sj,i} = 0$ is required. Therefore, $\beta l = \pi/2+n\pi$ must be satisfied. Hence, the length of the bridge line is constrained. The line length must be $l = \lambda_g/2(1/2+n)$, where, λ_g is effective wavelength. The length of bridge line is determined by considering antenna port distance. By assuming that antenna interelement distance is d, the line length must be larger than d. The sign of the mutual admittance is determined depending on the line length of bridge susceptance. Here, the proposed method is valid only when mutual admittance is purely imaginary. However, the mutual admittance is not always purely imaginary for the most case.

The admittance parameters of the array antenna can be converted by inserting the transmission lines serially at the antenna ports. Figure 2 shows the circuit model of the antenna with the serial transmission lines and decoupling network. Since the serial transmission lines shift the phase of the port- to-port admittance, the apparent mutual admittance at the end of the lines can be purely imaginary when appropriate line length is given. Since admittance matrix of transmission line for phase rotation, $\boldsymbol{Y_l}$, is described by 2n×2n matrix. $\boldsymbol{Y_l}$ can be split into four partitioned matrices as

$$\boldsymbol{Y_l} = \begin{pmatrix} \boldsymbol{Y}_{l11} & \boldsymbol{Y}_{l12} \\ \boldsymbol{Y}_{l21} & \boldsymbol{Y}_{l22} \end{pmatrix}, \tag{4}$$

where the size of each partitioned matrix is n×n. From this, the observed admittance matrix, ***Y***, at the end of the serial lines is explained as

$$\boldsymbol{Y} = \boldsymbol{Y}_{l11} - \boldsymbol{Y}_{l12}\left(\boldsymbol{Y_a} + \boldsymbol{Y}_{l22}\right)^{-1}\boldsymbol{Y}_{l21}\,. \tag{5}$$

By using (3) and (5), the line length which achieves purely imaginary mutual admittance can be determined. This transformation is applicable even when the sign of mutual suscepttance is positive or negative. The arbitrary phase can be given by simply adding the serial lines.

In the actual design, the first step is determination of the length of the serial line that transforms the mutual admittance to purely imaginary value. The second step is determination of the bridge line based on (3).

3.2 **Design Decoupling Network for 4-element Microstrip Array using measurement**

This section describes design of the decoupling network using actual transmission lines. For simplification, only the mutual coupling between adjacent elements is focused. First, we determine the length l of the bridge line. As shown in Fig. 3, antenna's interelement spacing, d, is $0.51\lambda_g$. Therefore, the bridge line length l is $3\lambda_g/4$. That is $\beta l=3\pi/2$. Since $\beta l=3\pi/2$ yields the negative bridge susceptance, the mutual susceptance at the reference plane 1must be positive. For the reasons described above, the line length for phase rotation which eliminates the mutual conductance and makes the mutual susceptance positive is determined. In this study, characteristic impedance of transmission line for phase rotation is 50 Ω. All length of transmission lines for phase rotation were identical in this case. Line length l for phase rotation is determined by simulation. From the simulation results, it is found that the desired line length of the transmission line for phase rotation is $0.36\lambda_g$. The characteristic impedance of the bridge line is determined by the transformed mutual admittance as (5).

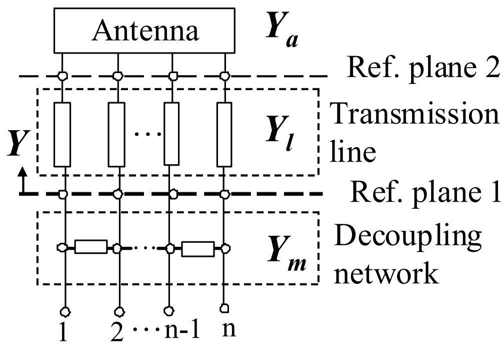


Fig.2 Proposed decoupling system.

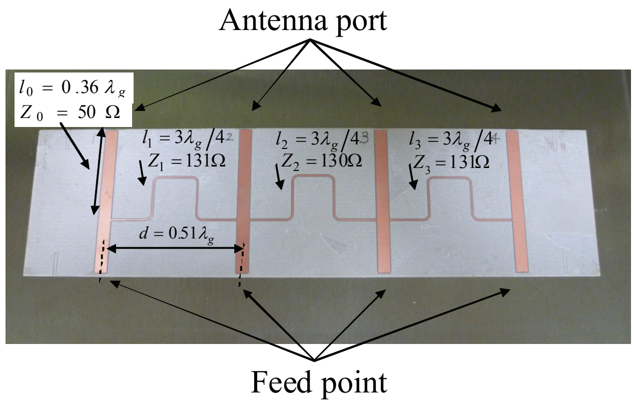


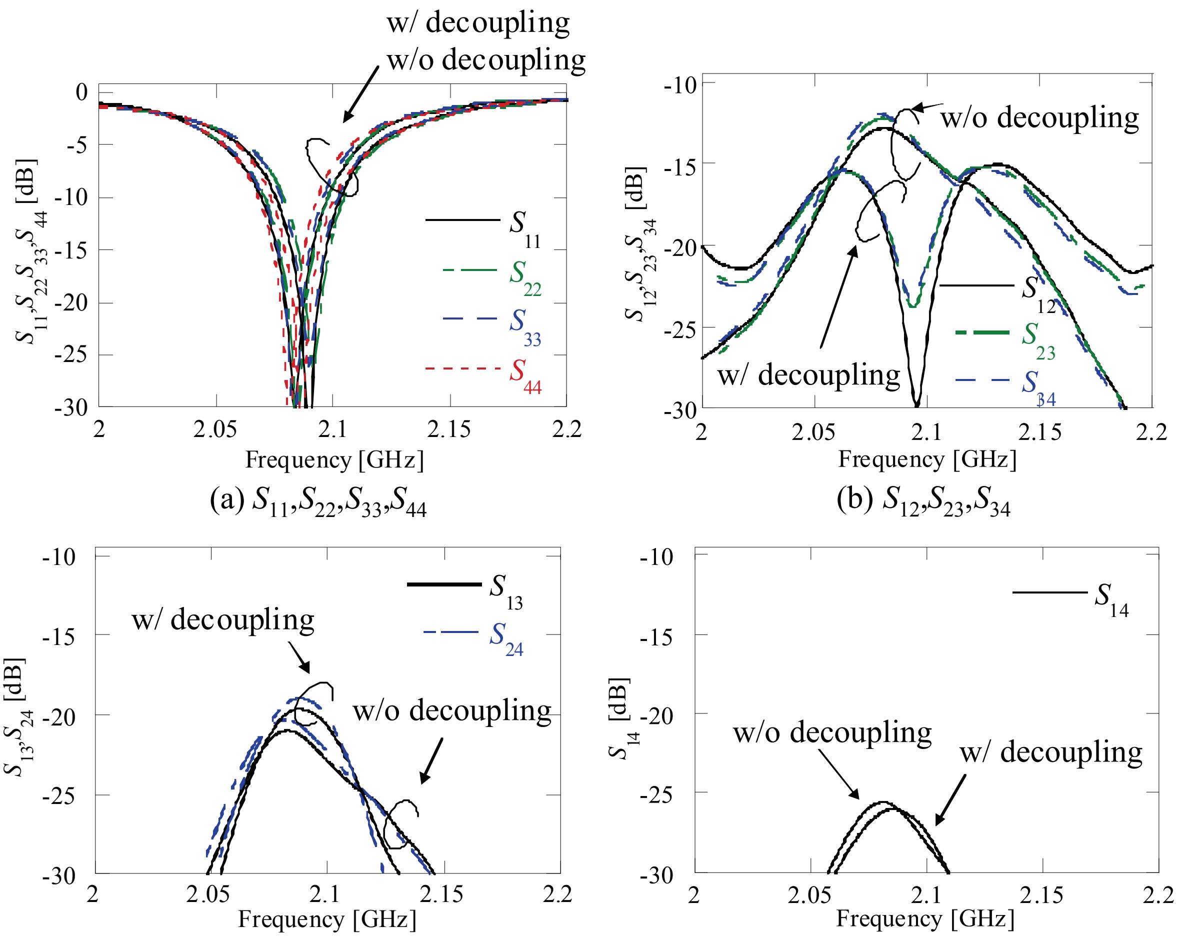
Fig.3 Decoupling network using proposed method, line length l_0 is for phase rotation, line length l_1, l_2,l_3 is for decoupling.

4. Measurement

Four element microstrip array by using proposed method is fabricated and measured. The operation frequency of the antenna is 2.085 GHz. Figure 3 is the photo of the fabricated network based on the proposed design method. The bridge lines are meandering so as to be configured within the antenna port spacing. The network is configured on the dielectric substrate whose relative permittivity is 2.2 and the thickness is 1.6 mm. The same substrate is used for microstrip array. Figure 4 shows the frequency characteristics of S-parameter. From Fig. 4 (a), it is found that the impact of the decoupling network on matching is low. Also, the bandwidth is 1.31% when the threshold is -10 dB. It can be noted that the bandwidth is hardly affected by the decoupling network. From Fig. 4 (b), adjacent element coupling is decreased about 8 dB at resonant frequency. Figure 4 (c) and (d) show S_{13}, S_{24} and S_{14}. These are not decoupled at all even with the decoupling network, but it can be seen that the decoupling network does not cause no negative effect on the other antenna characteristics. Decoupling is achieved without influence on antenna matching by using proposed method. From the results described above, the effectiveness of proposed method is clarified.

5. Conclusion

In this paper, the design method of the simple decoupling network considering mutual admittance of the array antenna has been presented. The design method of the bridge lines which connect between two neighbouring antenna ports for decoupling is presented. Experiment showed the decoupling network does not cause no negative effect on the antenna matching, and the mutual coupling is suppressed by up to 8 dB at the resonant frequency. These results prove that the proposed design method of the decoupling network is effective in achieving a low mutual coupling network with low hardware complexity.



(a) S_{11},S_{22},S_{33},S_{44} (b) S_{12},S_{23},S_{34} (c) S_{13},S_{24} (d) S_{14}

Fig.4 Frequency characteristic of S-parameter.

Acknowledgments

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