Analysis of Mutual coupling, correlations, and TARC in MIMO antenna array

Sung ho Chae[1], Se-keun Oh[1] and Seong-Ook Park[1]

[1]*The School of Engineering, Information and Communications University,*
119, Munjiro, Yuseong-gu, Daejeon 305-732, Korea
slapguitar@icu.ac.kr, skoh9@icu.ac.kr and sopark@icu.ac.kr

Abstract

This paper presents the evaluation of MIMO (multi-input multi-output) array by analyzing mutual coupling, correlation coefficient and TARC. PIFA is used for antenna arrays because of its low profile and robust of nearby antennas. We show that separation distance and antenna radiation pattern are important factors in MIMO arrays. This paper demonstrates the meaning of the three parameters and optimization of array antenna's allocation.

1. INTRODUCTION

Information theory has shown that an upper limit exists for the average spectral efficiency using a single antenna and single receiver [1]. Thus, Multiple Input Multiple Output (MIMO) has received a great attention because it can overcome the limit of channel capacity [2].

To study the performance of MIMO, some of the parameters need to be considered. Mutual coupling is the important factor because higher mutual coupling means lower antenna efficiency. The correlation coefficient between two antennas is another important parameter since it associates with the loss of spectral efficiency and degradation of performance of a MIMO system [3]. Also, Total Active Reflection Coefficient (TARC) must be considered. The reason why we use TARC rather than traditional scattering matrix is that the scattering matrix does not accurately characterize the radiating efficiency of an antenna array [4]. TARC provides a more meaningful measure of MIMO efficiency because it contains effect of mutual coupling.

In this study, we evaluated the performance of MIMO communication by analyzing above three parameters. We proposed the three types of 2×2 antenna array.

The proposed antenna arrays are composed of Printed Inverted-F Antenna (PIFA) with U-shaped slot. PIFA have low profiles, good radiation characteristics, and wide bandwidth. Also, a PIFA is relatively robust to influence from neighbor antenna because they have low profile and are close to ground [5].

In section 2, the theoretical backgrounds of three parameters are presented. Section 3 and 4 show the analysis of two PIFA elements arrays. Section 5 summarizes the conclusion.

2. THEORETICAL BACKGROUND

The mutual coupling between the antennas can be measured and simultated from S paramters; S_{21}. The correlation coefficient is usually calcuated from the 3-dimensional radiation patterns[6]. However, this process requires complex and advanced calculation. Recent studies show that in some case, such as a uniform random field case, the correlation coefficient can be calculated by S-parameters. [7]

$$\rho = \frac{\left|S_{11}{}^{*}S_{12} + S_{21}{}^{*}S_{22}\right|^2}{(1-\left|S_{11}\right|^2-\left|S_{21}\right|^2)(1-\left|S_{22}\right|^2-\left|S_{12}\right|^2)} \tag{1}$$

TARC is defined as the ratio of the squre root of total reflected power divided by the squre root of total incident power[4]. Each exciation signal in MIMO is randomly phased. The signal phases are again randomized by the propagation environment before arriving receiver [4]. The TARC at N port antenna can be describe as

$$\Gamma_a^{\,t} = \sqrt{\sum_{i=1}^{N}\left|b_i\right|^2} \Bigg/ \sqrt{\sum_{i=1}^{N}\left|a_i\right|^2} \tag{2}$$

where a_i is incident signal, and b_i is reflected signal.

In case of 2×2 antenna arrays, the scattering matrix can be described as

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{pmatrix}\begin{pmatrix} a_1 \\ a_2 \end{pmatrix} \tag{3}$$

We assume that signal will be randomly phased with independent and identically distributed (i.i.d) Gaussian random variable because MIMO channels are assumed as Gaussian and multi-path spread in the propagation channel.
Since sum or subtract of independent Gaussian random variable is also Gaussian, reflected signals are characterized as

$$b_1 = s_{11}a_1 + s_{12}a_2 = s_{11}a_0e^{j\theta_1} + s_{12}a_0e^{j\theta_2} = a_1(s_{11} + s_{12}e^{j\theta}) \tag{4}$$

$$b_2 = s_{21}a_1 + s_{22}a_2 = s_{21}a_0e^{j\theta_1} + s_{22}a_0e^{j\theta_2} = a_1(s_{21} + s_{22}e^{j\theta}) \tag{5}$$

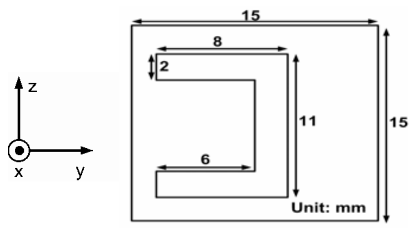
Therefore, TARC is described as follows;

$$\begin{aligned}\Gamma_a^{\,t} &= \sqrt{(\left|a_1(s_{11}+s_{12}e^{j\theta})\right|^2 + \left|a_1(s_{21}+s_{22}e^{j\theta})\right|^2)} \Big/ \sqrt{2\left|a_1\right|^2} \\ &= \sqrt{(\left|(s_{11}+s_{12}e^{j\theta})\right|^2 + \left|(s_{21}+s_{22}e^{j\theta})\right|^2)} \Big/ \sqrt{2}\end{aligned} \tag{6}$$

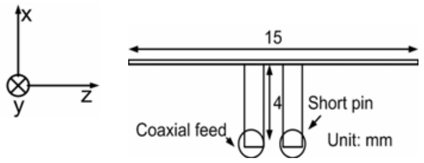
Using the equations (6), TARC for 2×2 antenna array can be directly calculated from the scattering matrix.

3. TWO ANTENNA ARRAYS

This paper proposes a novel PIFA with U-slot. The antenna volume has 15 × 15 × 4mm^3. The structure of antenna is described in Fig.1. The single antenna with the ground size 40 × 85mm^2 has basically resonance at 2.6GHz with covering the bandwidth of 200 MHz in VSWR 2:1. The proposed antenna is electrically small antenna (kr<<1), so it is suitable for MIMO implementation in handset. The CST Micro Wave Studio (MWS) is employed to simulate the S-parameters. The comparison results between the measured and simulated return losses are shown in Fig 2.



(a)



(b)

Fig.1 Geometries and dimensions of the PIFA (a) Top view. (b) Side view.

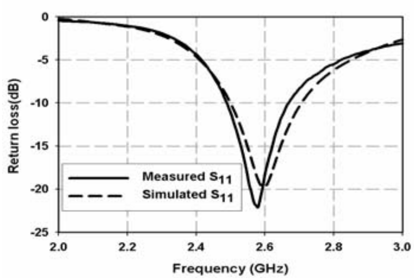
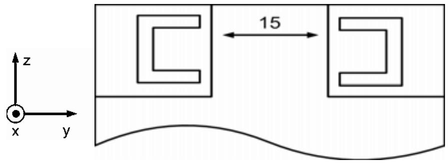
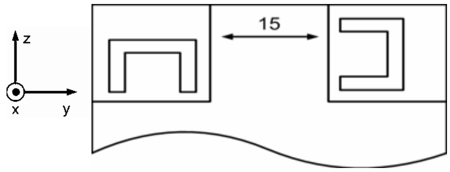


Fig.2 Measured and simulated return losses of single PIFA

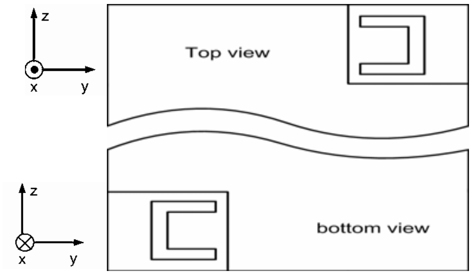
To analyze the effect of parameters with variation of separation distance and the position of the antenna, this paper investigates the three different types of two antenna locations. Each associated three types of location are shown in Fig 3. All of three different location are mounted on the ground size 40 × 85mm^2 (width × length). The three structures of two antenna elements are shown in Fig 3.



(a) Type 2_1



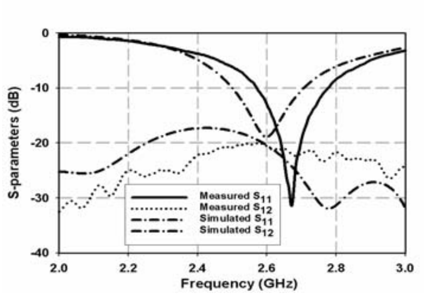
(b) Type 2_2



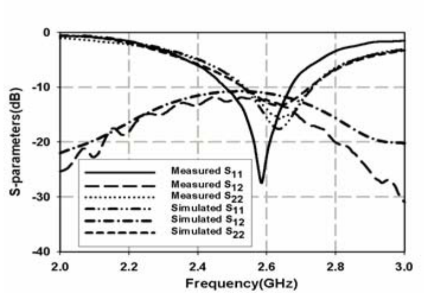
(c) Type 2_3

Fig.3 Proposed three types of dual arrays.
(a) Type 2_1. (b) Type 2_2. (c) Type 2_3.

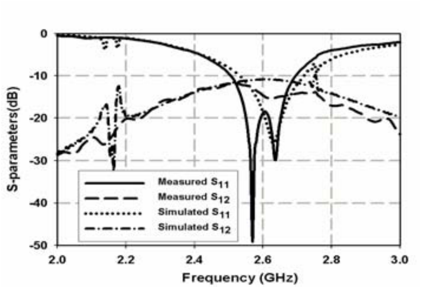
The measured scattering parameters corresponding to associated antenna structures are shown in Fig 4.



(a)



(b)



(c)

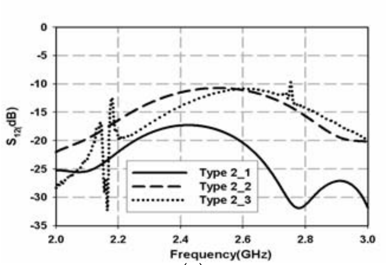
Fig.4 Scattering parameters of three dual arrays

(a) Type 2_1. (b) Type 2_2. (c) Type 2_3.

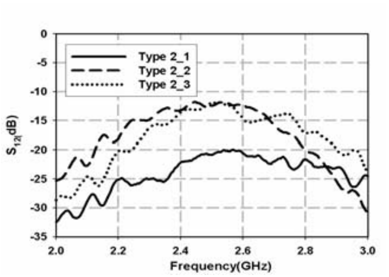
In all cases, dual array covers 200MHz bandwidth when we consider S_{11} value only. The center frequency of Type 2_1 is slightly increased compare to original antenna. In case of Type 2_2, the distance is identical with Type 2_1. However, one of the antennas is rotated by 90° so that return loss characteristic of rotated antenna is slightly different from original one. Type 2_3 provides the maximum separation distance among the proposed cases. Because of maximum separation distance, S_{11} has the lowest value at resonance frequency. However, resonance frequency shifts higher about 30MHz. Although Type 2_3 is the best case in terms of S_{11} values, we need to consider mutual coupling, correlation coefficient, and TARC to evaluate the MIMO performance.

4. Performance Evaluation

Mutual coupling can be obtained from S21 which can be measured and simulated relatively easily. Fig.5 shows the simulated and measured S_{21} values of each dual antenna array.



(a)



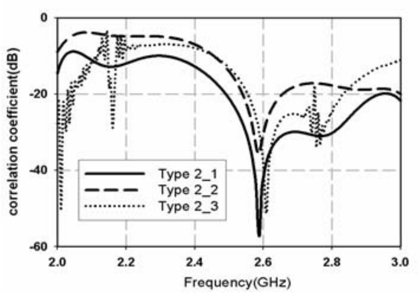
(b)

Fig.5 Mutual coupling for dual antenna array

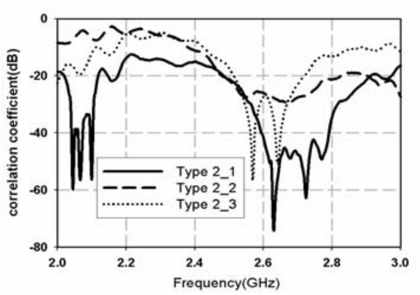
(a) simulated result (b) measured result. .

As shown in Fig 5, from both simulated and measured data, much higher mutual coupling occurred in case of Type 2_2 and Type 2_3. Thus, radiation efficiency of Type 2_1 will be higher. By comparing Type 2_1 and Type 2_2, we can infer the relationship between mutual coupling and radiation patterns of each antenna. Even though the distance between antennas is similar, mutual coupling is different according to each antenna's radiation pattern. Also, by comparing Type 2_1 and Type 2_3 case, we can notice that mutual coupling does not merely depend on separation distance.

Correlation coefficient is the important factor because when it increases, a loss of capacity becomes serious problem. Correlation coefficients of each dual antenna arrays are shown in Fig 6.



(a)



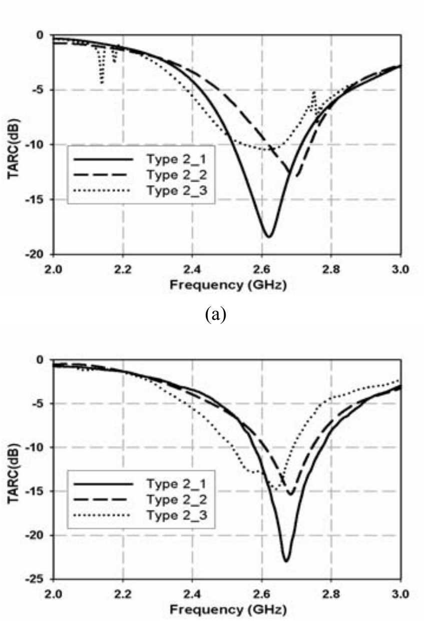
(b)

Fig.6 Calculated correlation coefficient for dual antenna array

(a) simulated result (b) measured result. .

Simulated and measured correlation coefficients were calculated according equation (1) from S-parameters. We focus on the frequency range around resonance in order to get clear comparison. Roughly, correlation coefficient has similar tendency with TARC of each dual array. Type 2_1 is the best case again because lower correlation coefficient means low loss of capacity.

The calculated average TARC with 20 excitation vectors for Type 2_1, Type 2_2, and Type 2_3 are represented in Fig 7. TARC can be calculated by using the equation (6) at each random phase.



(a)

(b)

Fig.7 Calculated correlation coefficient for dual antenna array (a) simulated result (b) measured result. .

Fig.7 shows the comparing results among Type 2_1, 2_2 and 2_3, TARC values retain the original behavior of a single antenna characteristic. Likewise previous two parameters cases, Type 2_1 shows the best performance and Type 2_2 and 2_3 performs similar results. The results show that the higher mutual coupling can result in the higher coefficient and TARC.

5. CONCLUSION

This paper investigates MIMO antenna locations in handset antenna with considering mutual coupling, correlation coefficient, and TARC. Two PIFA u-slot elements are calculated and analyzed. We assumed the 20 excitation vectors which are randomly phased in case of calculating TARC.

The results show that mutual coupling is not merely affected by antenna spacing. In case of small ground size, if the separation distance is enough to generate resonance frequency of each single antenna, mutual coupling does not decrease by simply increasing distance. Also, the results implies that radiation pattern of each antenna is considerable factor. One of the interesting fact is that mutual coupling, correlation coefficient and TARC are closely related to each other and have similar tendency. The variation of S_{12} is much higher than S_{11}, mutual coupling (S_{12}) determines the correlation coefficient and TARC.

Evaluating array antennas performance in terms of MIMO communication environment is important. This paper attempts to optimally allocate the two PIFA elements in MIMO antenna array.

ACKNOWLEDGEMENT

This document was supported by the National Research Laboratory (NRL) of the Ministry of Science, Korea and Electronics and Telecommunications Research Institute (ETRI) under contract No.M1-203-0015 and 2006EG0700, respectively.

REFERENCES

[1]C.E.Shannon, “A mathematical theory of communication,” Bell System Technical Journal, vol 27, pp.379-423 and 623-656, July and October, 1948.

[2]G.J.Foschini and M.J.Gans, “On Limits of Wireless Communications in a Fading Environment when Using Multiple Antennas”, Wireless Personal Communications, No 6, pp 311-335, 1998

[3]D.S.Shiu, G.J.Foschini, M.J.Kahn, “Fading correlation and its effect on the capacity of multielement antenna systems,” IEEE Trans, Commun., vol 48, pp.502-513,Mar.2000..

[4] M.Manteghi, Y. Rahmat-Samii, “Multiport characteristics of a wide-band cavity backed annular patch antenna for multipolarization operations,” IEEE Transaction on Antennas and Propagation, January 2005, vol 53, pp. 466-474.s

[5]Ying Z., et. Al., “Characterization of multi-channel antenna performance for mobile terminal by using near field and far filed parameters”, COST 237, TD(4)095,2004.

[6] M.A. Jesen and Y.Rahmat-Samii, “FDTD analysis of PIFA diversity antennas on a hand-held transceiver unit,” in IEEE Antennas propagation, Symposium.Dig. June 1993, pp.81

[7] Blanch S., Romeu J. and Corbella I., “Exact representation of antenna system diversity performance from input parameter description”, IEE Electronics Letters, vol.39, pp 705-707, May 2003.