Proceedings of Asia-Pacific Microwave Conference 2006

Analysis of Mutual coupling in MIMO antenna array by TARC Calculation

Sung ho Chae[1], Won il Kawk[1], Seong-Ook Park[1], and Kwangchun Lee[2]
[1]The School of Engineering, Information and Communications University,
119, Munjiro, Yuseong-gu, Daejeon 305-732, Korea
[2]Electronics and Telecommunications Research Institute, Daejeon, Korea
Tel: 042-866-6202, Fax: 042-866-6227

Abstract- **Mutual coupling is the one of the most important factor evaluating the performance of multiple input multiple output (MIMO) antennas. This paper presents the mutual coupling analysis by calculating total active reflection coefficient (TARC). PIFA is used for antenna arrays because of its low profile, good radiation characteristic, and robust of nearby antennas. We show that antenna spacing, antenna radiation pattern, and the number of antenna elements are more significantly considering factors in MIMO arrays. This paper demonstrates the optimized antenna elements allocation.**

Index Terms- **Mutual coupling, array antenna, TARC, radiation pattern.**

I. INTRODUCTION

Information theory has shown that an upper limit exists for the average spectral efficiency using a single antenna and single receiver [1]. Multiple Input Multiple Output(MIMO) has received a great attention because they can overcome the limit of channel capacity [2]. Theoretically, the capacity increases linearly with the number of antennas. However, when the correlation between antennas exists, the loss of spectral efficiency is occurred, the performance of a MIMO system is degraded [3]. Thus, the effect of mutual coupling is important factor for MIMO communication performance.

In this study, we focused on analyzing mutual coupling in 2×2 antenna array and 4×4 antenna array with respect to Total Active Reflection Coefficient (TARC) calculation. The mutual coupling is typically characterized by separation distance between antennas. It is interesting to note that each antenna's radiation pattern is an important factor to determine the mutual coupling and TARC. 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.

The proposed antenna arrays are composed of Printed Inverted -F Antenna (PIFA). 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 II, TARC values are investigated for two elements antenna arrays and four elements antenna arrays. Section III and Section IV show the analysis of mutual couplings in two and four PIFA elements arrays, respectively.

II. TARC

TARC is defined as the ratio of the squre root of total reflected power divided by the squre root of total incident power. The TARC at N port antenna can be describe as

$$\Gamma_a^{\ t} = \sqrt{\sum_{i=1}^{N}|b_i|^2} \Big/ \sqrt{\sum_{i=1}^{N}|a_i|^2} \qquad (1)$$

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

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

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} \qquad (2)$$

Each exciation signal in MIMO system is randomly phased. The signal phases are again randomized by the propagation environment before arriving receiver. 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

$$b_1 = s_{11}a_1 + s_{12}a_2 = s_{11}a_0e^{j\theta_1} + s_{12}a_0e^{j\theta_2} = a_1(s_{11} + s_{12}e^{j\theta}) \qquad (3)$$

$$b_2 = s_{21}a_1 + s_{22}a_2 = s_{21}a_0e^{j\theta_1} + s_{22}a_0e^{j\theta_2} = a_1(s_{21} + s_{22}e^{j\theta}) \qquad (4)$$

Therefore, TARC is described as follows;

$$\Gamma_a^{\ t} = \sqrt{(|a_1(s_{11}+s_{12}e^{j\theta})|^2 + |a_1(s_{21}+s_{22}e^{j\theta})|^2)} \Big/ \sqrt{2|a_1|^2}$$
$$= \sqrt{(|(s_{11}+s_{12}e^{j\theta})|^2 + |(s_{21}+s_{22}e^{j\theta})|^2)} \Big/ \sqrt{2} \qquad (5)$$

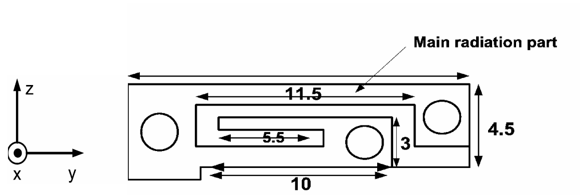
In the similar manner, TARC of 4×4 antenna arrays is calculated as

$$\Gamma_a^t = \sqrt{\begin{array}{l}\left|(s_{11}+s_{12}e^{j\theta}+s_{13}e^{j\theta}+s_{14}e^{j\theta})\right|^2+\left|(s_{21}+s_{22}e^{j\theta}+s_{23}e^{j\theta}+s_{24}e^{j\theta})\right|^2\\ +\left|(s_{31}+s_{32}e^{j\theta}+s_{33}e^{j\theta}+s_{34}e^{j\theta})\right|^2+\left|(s_{41}+s_{42}e^{j\theta}+s_{43}e^{j\theta}+s_{44}e^{j\theta})\right|^2\end{array}}/2 \quad (6)$$

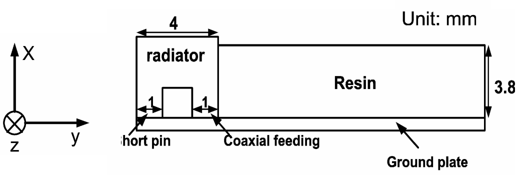
Using the equations (5) and (6), TARC for 2×2 and 4×4 antenna array can be directly calculated from the scattering matrix.

III. Two antenna Arrays

A noble PIFA design was adapted in this paper. The antenna volume has 18× 4.5×3.8mm^3. The structure of antenna is depicted in Fig.1. The indication of dominant behavior of radiation parts at resonance frequency is marked in Fig.1. The single antenna with the ground size 40× 85mm^2 has basically resonance at 2.64 GHz with covering the bandwidth of 120 MHz in VSWR 3:1. The radiation part is physically supported by resin whose dielectric constant is 2.54. 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 return loss and radiation pattern. 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.

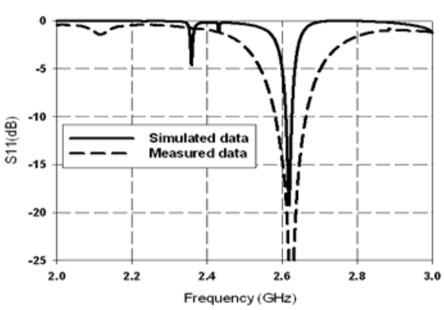
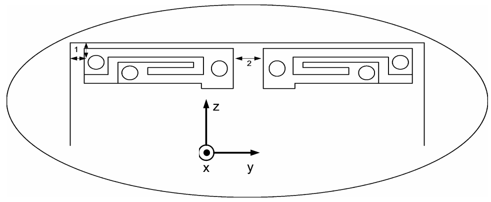
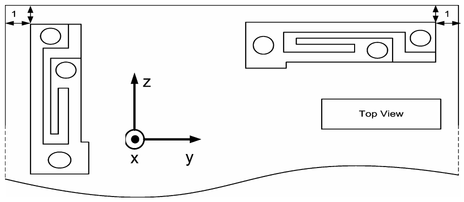


Fig.2 Measured and simulated return losses of single PIFA

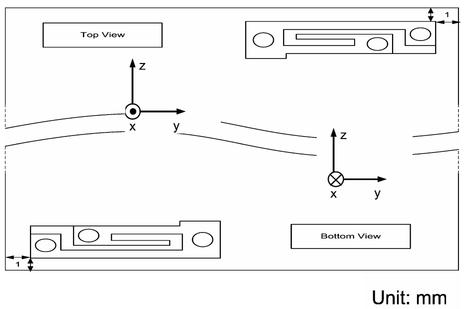
To analysis the effect of mutual coupling with variation of separation distance and radiation pattern of each antenna, this paper investigates the three different types of two antenna locations. Each associated three types of location are shown in Fig 3. All of three different location are mounted on the ground size 40 × 85 (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.

By comparing between Type 2_1 and 2_3, the separation distance between two antennas are clearly observed. In case of Type 2_1, the minimized distance results into generating more mutual coupling. However, Type 2_3 has an advantage in term of mutual coupling. In case of Type 2_2, the distance (between centers of main radiation parts) is similar to Type 1. However, one of the antennas is rotated by 90° and MIMO radiation pattern will not be same as Type 2_1 or Type 2_3. The rotated antenna has nearly same return loss characteristic but different radiation pattern comparing to original single antenna. Thus, by comparing between Type 2_1 and Type 2_2, we can infer the relations between mutual coupling and radiation patterns of each antenna. Fig.4 and 5 shows the far-field patterns of a single

PIFA element and a single PIFA in the dual element array. In case of Type 2_1, the radiation pattern and efficiency of each antenna are influenced by two antenna locations with comparing to Type 2_2. Although Type 2_2 has similar antenna distance with Type2_1, the changes in radiation pattern and reduction of efficiency are much smaller.

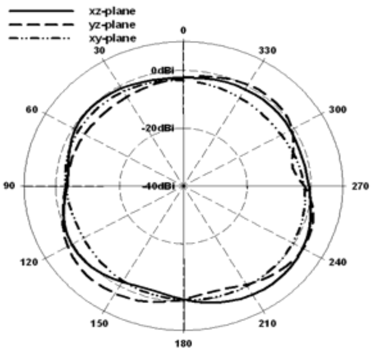
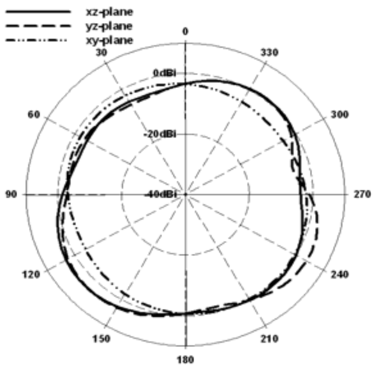


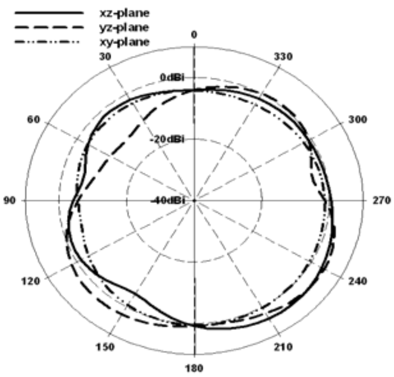
Fig.4 Calculated far filed pattern at 2.64GHz for a single PIFA in the dual element compact array.

Efficiency=0.156



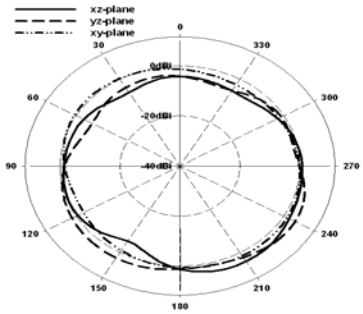
(a)

Efficiency=0.74



(b)

Efficiency=0.782



(c)

Fig.5 Calculated far filed pattern at 2.64GHz for a single PIFA in the dual element compact array (a) Type 2_1. (b) Type 2_2. (c) Type 2_3.

The calculated average TARC with 20 excitation vectors for Type 2_1, Type 2_2, and Type 2_3 are represented in Fig 6. TARC can be calculated by using the equation (5) at each random phase.

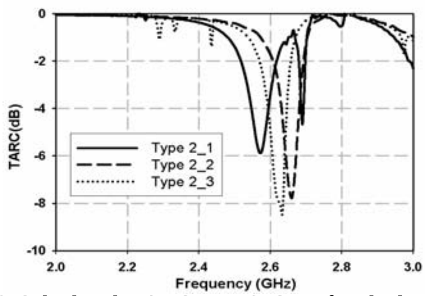
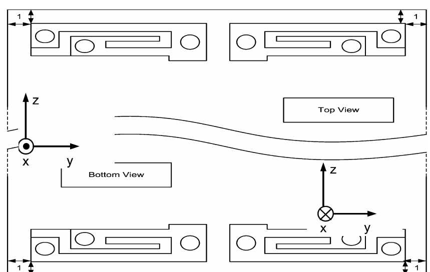


Fig.6 Calculated TARC at 2.64GHz for dual antenna arrays.

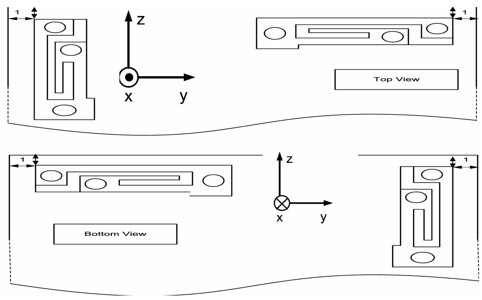
Fig.6 shows the comparing results among Type 2_1, 2_2 and 2_3. TARC values retain the original behavior of a single antenna characteristic with minimized the mutual coupling in terms of distance. Also, even though the distance between antennas is similar, mutual coupling is different according to each antenna’s radiation pattern.

IV. FOUR ANTENNA ARRAYS

In case of four antenna elements, all the antenna locations are similar structure as did in two elements. This paper presents the two types of 4 elements arrays. Fig.7 shows two types of four elements antenna arrays.



(a)



(b)

Fig.7 The proposed two types of four elements arrays. (a) Type 4_1. (b) Type 4_2.

The structure of Type 4_1 is based on the Type 2_1 and Type 2_3. Four antenna elements are located in symmetric positions with maximized the separation distance among each associated antenna. In case of Type 4_2, the basic structure is same one as did in Type 2_2, but the number of antenna elements increases as twice.

In Fig.8, the calculated average TARC between Type 4_1 and Type 4_2 are compared. The TARC can be calculated by the equation (6).

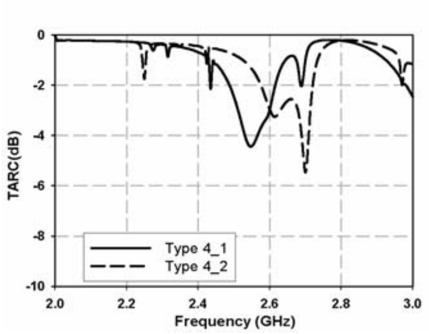


Fig. 8. TARC at 2.64GHz for four elements antenna arrays

The shape of TARC graph has a noticeable deviation from the original antenna's return loss due to the effect of increased mutual coupling. In case of Type 4_1, the mutual coupling at resonance frequency (2.64GHz) has higher one than Type 4_2. Thus, the TARC has severely deviated from the original S_{11} value.

As shown in Fig.8, TARC increases mainly with increasing the number of elements. Also, even though the average distance between antennas increases, when one of the pair of antennas is located close each other, TARC would not be better than the original antenna's return loss. Since Type 4_2 antenna is designed to minimize mutual coupling in order to maximize radiation efficiency, we suggest that the Type 4_2 antenna location can be a good candidate for MIMO antenna array.

V. Conclusion

This paper investigates MIMO antenna locations in handset antenna with considering mutual coupling and radiation pattern. TARC with two and four PIFA elements are calculated and analyzed. We assumed the 20 excitation vectors which are randomly phased.

Mutual coupling is affected by antenna spacing, radiation pattern of each antenna, and the number antenna elements. Mutual coupling is the dominating cause of correlation between antenna spacing and the number of antenna elements in limited handset phone. The mutual coupling effect in multi- element is deteriorated the MIMO channel capacity in limited space. This paper attempts to optimally allocate the four PIFA elements in MIMO antenna array.

Acknowledgement

This document was supported by the National Research Laboratory (NRL) of the Ministry of Science, Korea and Technology 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] 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.814