The realization of pattern/polarization diversity by applying vertical excitation

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***Abstract-* This paper proposes the pattern/polarization diversity array for MIMO applications by applying vertical excitation. We show that antenna's pattern and polarization characteristics are changed due to vertical feeding. Then, we attempt to realize the two antenna diversity array by using different feeding method. In addition, the spatial correlations of different excitations are investigated. Finally, the analysis of the diversity system in the view point of capacity is presented.**

I. INTRODUCTION

Recently, Multiple Input Multiple Output (MIMO) systems have received a great attention for their ability to overcome the limits of SISO channel capacity [1]. They provide a very high spectral efficient by using multiple transmitter and receiver. However, the spatial correlation between antennas causes the loss of spectral efficiency. To reduce the spatial correlation, the space, polarization, and pattern diversity techniques are most widely used. In case of the spatial diversity, the distance between antennas needs to be multiple of the wavelength [2], so the size of ground must be much larger than typical compact MIMO arrays. Thus, space diversity technique is not suitable for 4G wireless handsets. Instead, pattern/polarization diversity might be practical solutions to reduce the array size.

The technique of changing the antenna pattern/polarization by using two different feed ports, vertical and horizontal feeding, is recently reported [3]. As the feeding directions are changed, the components of co-polarization are changed. For instance, if we assume that antennas are located in y-z plane, E_ϕ is the co-polarization component in horizontal feeding while the cross-polarization radiation in vertical feeding. This technique has the advantage that dose not need the additional circuit for changing the main radiation direction. By applying these techniques, the authors proposed pattern/polarization diversity system for dual band operation which can apply to Worldwide Interoperability for Microwave Access (WiMAX) application in 2.6GHz and wireless local area network (WLAN) systems in 5.2GHz. In addition, we presented the analysis of the two different diversity systems in the view point of capacity.

II. THEORETICAL BACKGROUND

The instantaneous ergodic channel capacity of MIMO with equal-power allocation has been shown to be [1]

$$C(H) = \log_2 \det(I + \frac{P}{T\sigma_N^{\ 2}} HH^\dagger) \tag{1}$$

where $P/\sigma_N^{\ 2}$ is the signal to noise ratio, H is channel matrix, and T denotes the number of transmit antennas. Since H is randomly changed, the capacity is also random variable. Therefore, we can quantify the capacity by complementary cumulative distribution function (CCDF). In case of the correlated Rayleigh channel, H can be factorized in form as follows [4]:

$$H = (\Psi^R)^{\frac{1}{2}} W (\Psi^T)^{\frac{1}{2}} \tag{2}$$

where Ψ^R and Ψ^T are the correlation matrix of transmit antennas and receive antennas, respectively and the entries of W are independent and identically distributed (i.i.d) complex circular symmetric Gaussian with mean 0 and variance 1. In this paper, transmit antennas are assumed to be uncorrelated and only receive sides are correlated. (*one sided correlation channel model*). Also, the incoming waves from base station are assumed to have the unity cross polar discrimination (XPD).

The entries of covariance matrix Ψ^R is defined by the following equation [5],

$$\Psi^R_{ij} = \frac{1}{\sigma_i \sigma_j} \int \left\{ E_{i\theta}^*(\theta,\phi) E_{j\theta}(\theta,\phi) + E_{i\phi}^*(\theta,\phi) E_{j\phi}(\theta,\phi) \right\} P(\theta,\phi) e^{j\Phi_{i,j(\Omega)}} d\Omega \tag{3}$$

where $E(\theta,\phi)$ and $P(\theta,\phi)$ are complex far-field patterns of the received antennas and the distribution of angle-of-arrival (AoA) of incoming waves, respectively. We assume the uniform AoA distributions, and they are assumed to be independent in terms of θ and ϕ directions. In addition, σ_i and σ_j are the standard deviations of each received signal. They can be expressed by following equations.

$$\sigma^2 = \int \left\{ \left| E_\theta(\theta,\phi) \right|^2 + \left| E_\phi(\theta,\phi) \right|^2 \right\} P(\theta,\phi) d\Omega \tag{4}$$

In the equation (3), $\Phi_{i,\, j(\Omega)}$ accounts for the phase difference due to antenna spacing. In this paper, because the two antennas are arranged in z-axis, the phase terms can be simplified as follows:

$$\Phi_{i,\, j(\Omega)} = kd \cos(\theta) \tag{5}$$

where k is wave number, and d is the separation distance between antennas. Theoretically, if the received antennas have orthogonal polarizations, uncorrelated received channels are created.

Because $C_1(H), C_2(H), \cdots$ is a sequence of i.i.d random variables with finite mean and finite variance, the central limit can be applied for the large number of each instance random capacity. The Gaussian- approximated CCDF of the capacity is described as follows:

$$\Pr(C \geq C_{th}) = \frac{1}{\sqrt{2\pi}\sigma} \int_{C_{th}}^{\infty} e^{-\frac{(x-\mu)^2}{2\sigma^2}} dx \qquad (6)$$

where μ is the mean and σ is the standard deviation of capacity. By applying Monte-Carlo method, we can obtain the mean, variance, and CCDF of the capacity.

III. Vertical and horizontal excitations

This paper proposes a novel Planner Inverted-F Antenna (PIFA) for dual band operation. The single antenna has a dual resonance at 2.6GHz and 5.2GHz with covering the bandwidth of 200 MHz in VSWR 2.5:1. Since the antenna is designed for MIMO application, the proposed antenna has a compact size with $17.5 \times 5.7 \times 5\text{mm}^3$. The CST Micro Wave Studio (MWS) is employed to simulate the scattering parameters and radiation patterns.

The dual polarization in a single antenna can be realized by two different types of feeding techniques; vertical and horizontal feeding. The horizontal feeding means that antenna is fed by feed-pin or coaxial cable, which is common feeding technique for PIFA. On the other hand, vertical feeding can be achieved by waist feeding as shown in Fig. 1 (b). Since antennas basically have vertical polarization because of feed-pin, our task is to find the way to achieve a horizontal polarization for polarization diversity.

In the comparison between the vertically and horizontally excited cases, the vertical fed antenna has wider bandwidth than horizontal one, but their return losses are not much different and have a similar tendency as shown in Fig. 2. However, Fig. 3 and Fig. 4 describes that the radiation patterns of two cases are different. In both cases, E_θ (i.e. solid line— and dotted line···) is similar in shapes, but it is co-polarization radiation in vertically excited antenna while cross-polarization components in horizontal excitation. In addition, E_ϕ (i.e. dash-dot line-·- and short-dash line---) is changed in both shapes and magnitude due to different feeding. Thus, we can conclude that the polarization and pattern of antennas are changed due to different feedings, and the horizontal polarization is achieved by vertical excitation. If we arrange the both excited antennas in same array, the pattern/polarization diversity systems of two antenna array can be realized.

IV. The Proposed Diversity array

As described above, vertical feeding changes the radiation and polarization of antennas. This paper proposes the diversity antennas by applying this property.

The structure of the proposed pattern/polarization diversity is shown Fig. 5 (a) (= Type 1). In order to evaluate the performance of the proposed antenna, we also designed the antenna arrays whose elements have same type of excitation as shown in Fig.5 (b) (= Type 2). The antennas are arranged

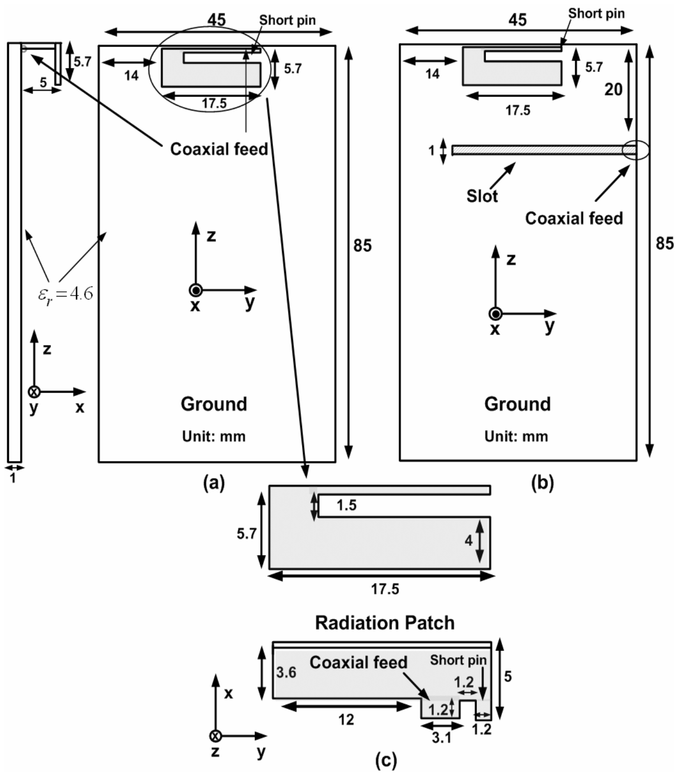


Fig. 1 Geometries and dimensions of the horizontally and vertically excited antenna (a) Horizontally excited antenna (b) Vertically excited antenna (c) Side view

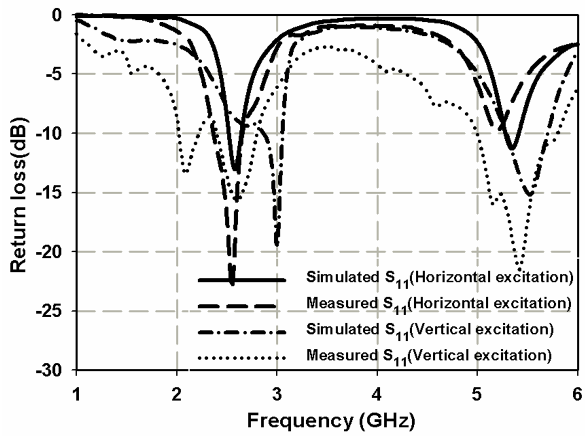


Fig. 2 Simulated and measured return loss for the proposed antennas

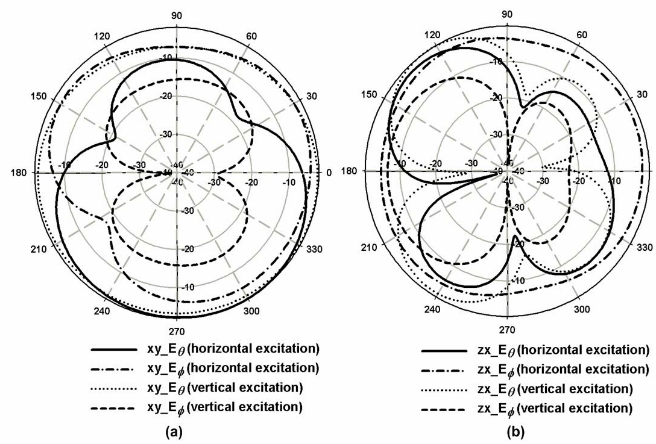


Fig. 3 Comparison of radiation patterns for the proposed antennas at 2.6GHz (a) *x-y* plane, (b) z-x plane

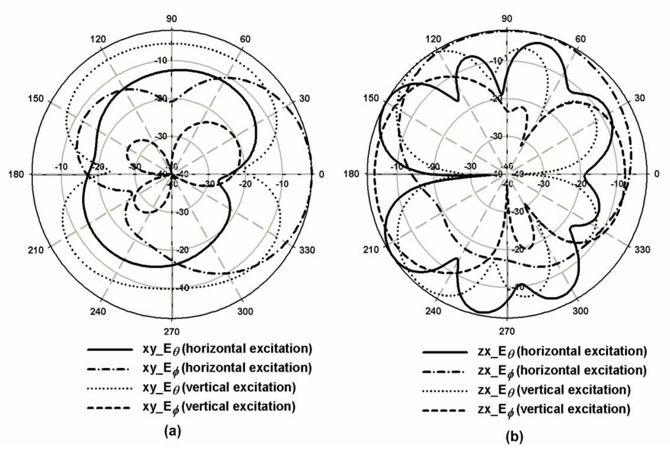
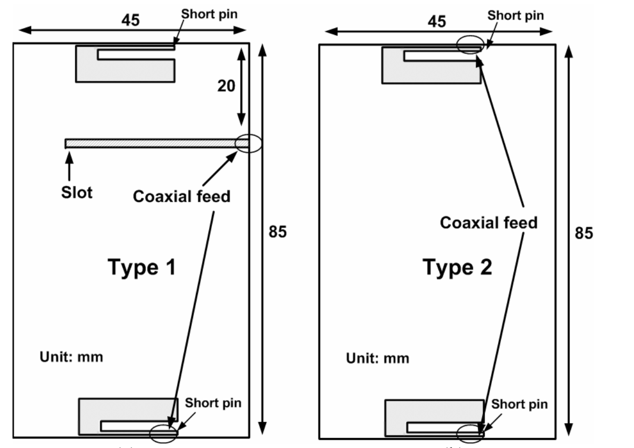


Fig. 4 Comparison of radiation patterns for the proposed antennas at 5.2GHz (a) *x-y* plane, (b) z-x plane



(a) (b)

Fig. 5 The proposed two antenna array (a) the proposed diversity array (b) array for comparative study and performance evaluation

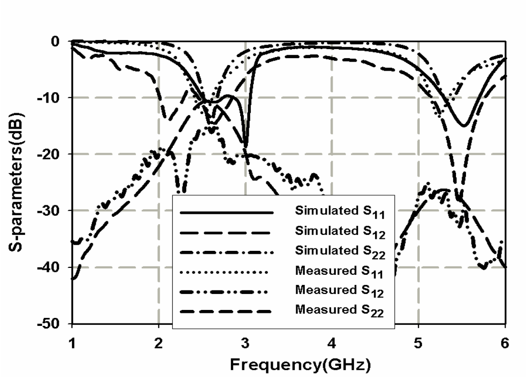


Fig.6 Scattering parameters of Type 1

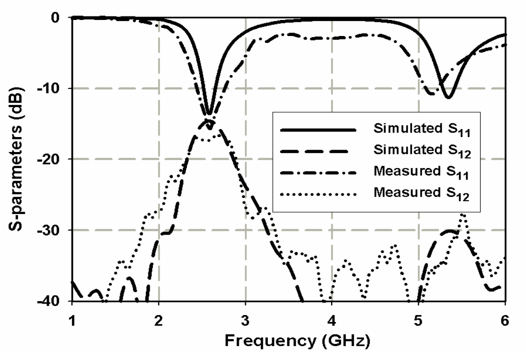
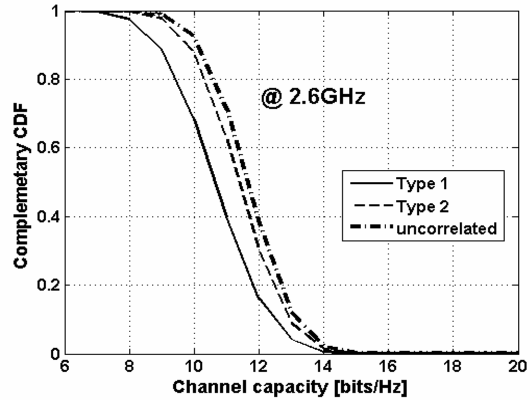
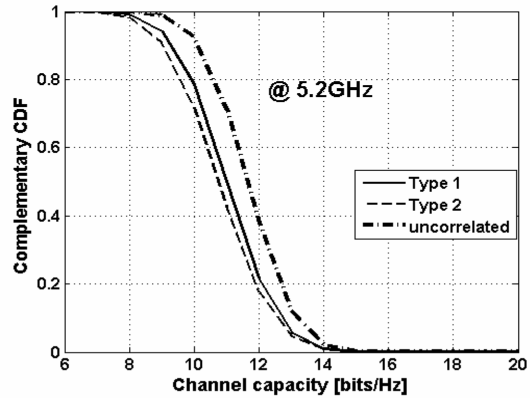


Fig.7 Scattering parameters of Type 2



(a)



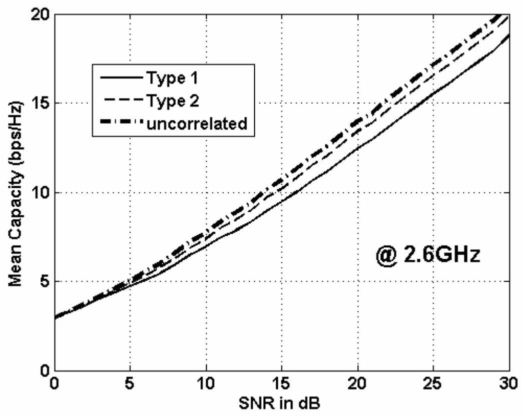
(b)

Fig.8 Complement CDF of capacity. (a) at 2.6GHz (b) at 5.2GHz.

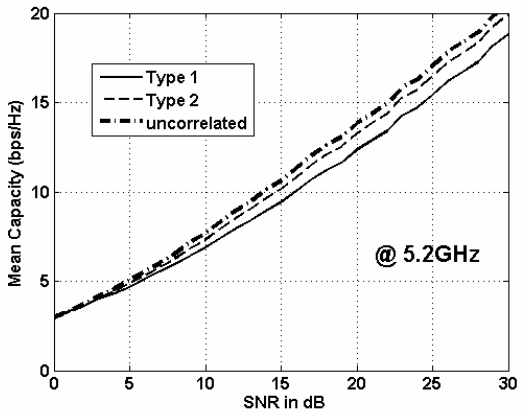
in z-axis, and the plane of symmetry is x-y plane in both cases. The length, width, and position of slot are the tuning parameters of the Type 1. As the length of the slot increases, the resonance frequencies of both dual bands become lower while the isolation (S_{12}) becomes higher. As the width increases, antenna has wider bandwidth in both dual bands, but the resonance frequency of upper band is slightly incremented. If the distance between slot and the middle point of ground, which describes the position of slot, become closer, the effect of vertical feeding on correlation rises because the variation of radiation pattern compared to horizontal feedings increases. However, impedance matching becomes hard to achieve. Therefore, with considering these parameters, we designed the optimum array for target dual bands.

The scattering matrix of these arrays is plotted in Fig. 6. Since isolations between antenna elements are similar, we can ignore the effect of isolations on the variation of spatial correlation.

The spatial correlation can be obtained from radiation pattern by using equation (3). In case of Type 1, the calculated correlation coefficient between two received antennas is 0.35 and 0.235 at 2.6 GHz and 5.2GHz, respectively. On the other hand, the correlation coefficient is 0.1 and 0.4 in case of Type 2. The results indicate that correlation of Type 1 is lower at 5.2GHz, but higher at 2.6GHz. We can infer the two reasons for this unexpected result. First, the variation of pattern and polarization due to the vertical feeding is smaller than effect of antenna's symmetry position at 2.6GHz. In addition, the co-polarized



(a)



(b)

Fig.9 Mean capacity versus SNR at 2.6GHz and 5.2GHz, respectively

component of horizontal excitation is asymmetry in x-y plane while symmetry in case of vertical excitation, as shown in Fig. 3 (a). Thus, the pattern diversity of Type 2 is much higher when the two antennas are arranged as Fig. 5 (b).

Finally, in order to analyze the proposed arrays from capacity point of view, we obtained the CCDF of capacity and mean capacity from the calculated covariance matrix. In this paper, 15,000 multi-path of Rayleigh fading are assumed to exist. By applying Monte-Carlo method, we can calculate the mean and variance of capacity on the assumption that SNR is 20dB. The CCDF of capacity and mean capacity versus signal noise to ratio are plotted in Fig. 8 and Fig. 9, respectively. We compared vertically and horizontally excited diversity antennas to uncorrelated model. In both graphs, the proposed diversity systems shows better performance at 5.2GHz, but lower at 2.6GHz, in the same manner as spatial correlation.

V. Conclusion

This paper proposes the pattern/polarization diversity antennas with applying vertical excitation techniques. It is obvious that the vertical excitations are able to change antennas' original co-polarization components and radiation pattern, but we discover that radiation pattern and location of antennas in array are important factors for applying vertical feeding. In order to maximize the effect of vertical feeding, the radiation pattern and array arrangement should be considered simultaneously.

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