PAPER

Experimental Study on MIMO Performance of Modulated Scattering Antenna Array in Indoor Environment

Lin WANG[†a)], *Student Member*, **Qiang CHEN**[†], **Qiaowei YUAN**[††], *Members*, *and* **Kunio SAWAYA**[†], *Fellow*

SUMMARY The modulated scattering antenna array (MSAA) is composed of one normal antenna element and several modulated scattering elements (MSEs). In this paper, a 2-element MSAA is used as the receiving antenna in a 2 × 2 multiple input multiple output (MIMO) system. MIMO performance of MSAA with various array spacing is measured to investigate the relation between the array spacing and the MIMO performance of the MSAA experimentally in the non-line-of-sight (NLOS) indoor environment. It is found that the error vector magnitude (EVM) and the channel capacity, which reflect MIMO performance, can be affected by the array spacing. The measured results of the MSAA were compared with that of two-dipole antenna array at the same condition.

key words: *antenna, antenna array, modulation, wireless communications, mobile handset, MIMO*

1. Introduction

In the last decade, a great deal attention has been devoted to the deployment of multiple-element antenna arrays for multiple-input multiple-output (MIMO) communication system due to its higher spectral efficiency and transfer reliability [1]. However, it is very difficult to develop multi-antenna arrays suitable for mobile handsets, because of several problems such as the limited space on the handset to mount a number of antennas with sufficiently low mutual coupling and correlation between antennas [2]–[4]. Moreover, because a number of separate RF front-end circuits are required corresponding to the number of antenna elements, a large amount of packaging space for the RF front-end circuits is necessary. Therefore, it is essential to develop multi-antenna arrays with simple configurations which are suitable for mobile handsets.

Recently, a new concept of antenna arrays, which is called modulated scattering antenna array (MSAA), based on the modulated scattering technique (MST) has been proposed [5]–[7]. MSAA consists of one normal antenna element and several modulated scattering elements (MSEs) without RF front-end circuit. The previous researches just showed that MSAA is suitable for mobile handsets in MIMO communications since it can receive multi-channel signals [8]. Moreover, the experiment was only implemented in the line-of-sight (LOS) environment when array spacing of monopole MSAA was 0.4 wavelengths. In this paper, MIMO performance of dipole MSAA with various array spacing was measured to investigate the relation between array spacing and MIMO performance in NLOS environment. And it is easier to regulate the array spacing of dipole MSAA than changing that of monopole MSAA because it is necessary and inevitably to make new monopole MSAA with changing array spacing. Therefore, it is extremely efficiency way to save experimental period when dipole MSAA is used as the receiving antenna. Although the measurement system in [8] is similar to that of this paper, we have improved the accuracy of measurement by adding some filters simply in this paper. And numbers of the measurement points were also increased to 121 in this paper for improving the statistical characteristics. In [8], we have to move the location of the receiving antenna manually; here we can change the location by X-Y positioner. It is also gain an advantage over the previous system.

It is apparent that reducing the array spacing between the normal antenna element and the MSE can increase the scattering signal, but high correlation due to the compact array spacing may degrade the MIMO performance. Therefore, we investigated further MSAA in MIMO communications to see whether MIMO performance of the MSAA for mobile handsets can be improved by regulating the array spacing. Experimental measurements were carried out to study the MIMO performance in NLOS environment of an indoor 2 by 2 MIMO system where the MSAA was used as the receiving antenna. Because the error vector magnitude (EVM) and the channel capacity reflect MIMO performance, they were measured and compared for different array spacing. MIMO performance of the MSAA was also compared with that of two normal dipole antenna arrays.

The remaining part of the paper are organized as follows: in Sect. 2, the configuration of MSAA is introduced, and the experimental configuration of the MIMO communication system is also described. The experimental results are shown in Sect. 3. Finally, conclusions are given in Sect. 4.

2. Experimental Configuration

The configuration of the MSAA with diodes is shown in Fig. 1. The MSAA is composed of two types of elements that normal receiving antenna element and MSEs, respectively. The normal antenna element is connected with the RF front-end circuit, while MSEs are seen as antennas or scatterers without their own receiving circuits. Nonlinear

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[†] The authors are with the Department of Electrical Communications, Faculty of Engineering, Tohoku University, Sendai-shi, 980-8579 Japan.
[††] The author is with Sendai National College of Technology, Sendai-shi, 989-3128 Japan.
a) E-mail: wanglin@ecei.tohoku.ac.jp

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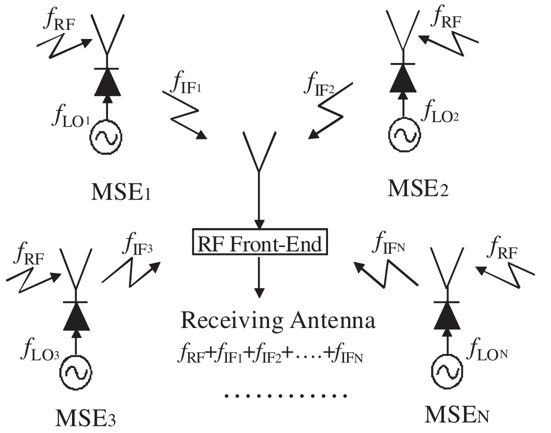

Fig. 1 Configuration of MSAA with diodes.

devices are mounted at MSEs for modulation and are fed by local signals with low frequencies f_{LOi}. When MSAA is excited by the radio frequency signal f_{RF}, new modulated scattering signals $f_{IFi} = mf_{RF} \pm nf_{LOi}(m, n = 0, 1, 2, \cdots, and\ i = 1, 2, \cdots, N)$ will be obtained because of the nonlinear loads connected to the MSE and will be received by the normal receiving antenna. Because only one branch of the RF receiver is needed in MSAA, this feature makes MSAA be very appealing when it is used as the receiving antenna for the mobile handset in MIMO systems where compactness and energy-saving are of primary concerns.

The geometry of a fabricated 2-element dipole MSAA is shown in Fig. 2. MSAA is composed of two half-wavelength dipole elements with array spacing from 0.1 to 0.7 wavelengths in the experiment. And two dipole elements are parallel. In Fig. 2 of MSAA, the above element is the dipole antenna which is connected with the receiver circuit, while the below one is the MSE. A Schottky diode is mounted at the centre of MSE which is used as the nonlinear impedance for modulation. Although received signals at receiving antenna have infinite number of frequencies, we only use secondary-order intermodulation scattering fields as the modulated scattering signal. In this paper, local frequency f_{LO} is 50 MHz which is produced by function generator. And secondary-order intermodulation scattering signal f_{IF} is 2.45 GHz.

Figure 3 shows the measurement system which was developed to demonstrate MIMO performance of MSAA in 2×2 MIMO communication system operated with IEEE 802.11n protocol. Two log-periodic dipole antenna arrays with two wavelength array spacing were used as the transmitting antennas. Agilent 89600S vector signal analyzer with two RF input channels and software option 89601X-B7Z for IEEE 802.11n MIMO modulation analysis were used to receive the signals from the measured MSAA. Because vector signal analyzer 89600s only can receive two same frequencies RF signals, we have to convert f_{IF} signal into f_{RF} signal by mixer. This is the reason that why the measurement system contains two receiving circuits.

The experiment was implemented in a room of a base-

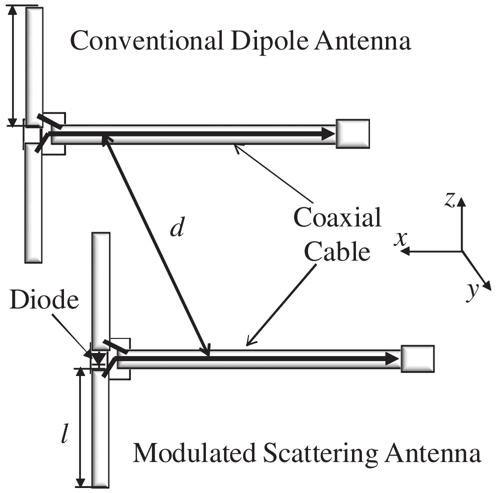

Fig. 2 Geometry of modulated scattering dipole antenna array.

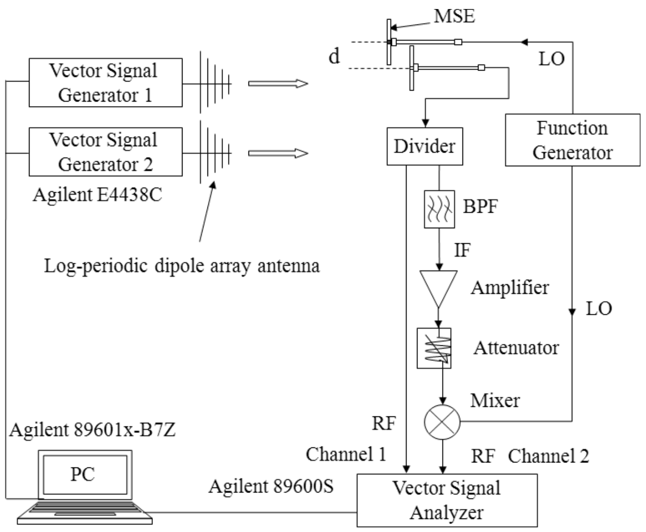

Fig. 3 2-channal MIMO measurement system.

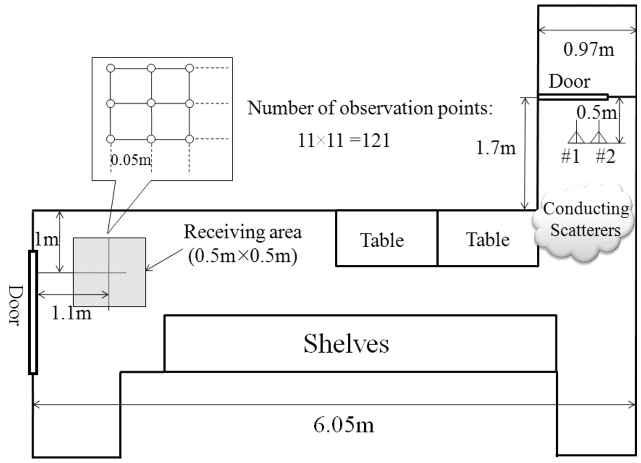

Fig. 4 MIMO measurement environment.

ment with the concrete structure shown in Fig. 4. The distance between the transmitting and receiving antennas was about 6 meters. In the transmitting path, several tens of conducting scatterers with a size of several wavelengths are distributed randomly around the transmitting antenna to form the Rayleigh fading environment. The location of transmitting antenna was fixed, while the receiving antenna was moved by a step of 5 cm in a 50 cm × 50 cm area. Therefore, measurement was repeated 11 × 11 times.

3. Experimental Results

Figure 5 shows the constellation diagram of 2 streams demodulated from IEEE 802.11n signals received by the MSAA, which includes QPSK-modulated data. It is shown that symbols of 2 streams are shifted slightly from their ideal location. The coordinate of the ideal location are [−0.7, 0.7], [0.7, 0.7], [−0.7, −0.7], [0.7, −0.7],respectively. The degradation of stream 2 is caused by the lower gain of the MSE as reported in [6], where it was found that the gain of the MSE element is usually 15–20 dB lower than that of the normal antenna element. Because the measurement was repeated 121 times while slightly changing the location of the receiving antenna, 121 values of the EVM were obtained and they were further expressed in the form of cumulative distribution function (CDF).

EVM is defined as:

$$EVM = \frac{|V_{error}|}{\left|V_{reference}\right|} \tag{1}$$

where the error vector is a vector between the ideal point and the real received point by the receiver in the constellation diagram.

Figure 6 shows the CDF of the EVM of MSAA with the 0.2 and 0.5 wavelength in the NLOS environment, respectively. It is shown that the CDF of the EVM of stream 1 and stream 2 is changed for various array spacing. Moreover, median EVM of the stream 1 and stream 2 is also shown along with the different array spacing in Fig. 7, where the dipole MSAA and dipole antenna array were used as the receiving antennas. In both the cases, the difference between EVM of the stream 1 and stream 2 was small. However, EVM of the dipole antenna array increases as the array spacing decreases, while EVM of dipole MSAA can be improved by decreasing array spacing.

Although signal processing and coding are important for MIMO systems, the performance largely depends on the propagation characteristics. Thus, Fig. 8 shows the results of median signal noise ratio (SNR) for various array spacing in NLOS environment where the dipole MSAA and two-dipole antenna array were used as the receiving antennas. Here noise is considered as temperature noise which depends on bandwidth. Because the bandwidth is 20 MHz, noise level is about −100 dBm in this research. In the case of two-dipole antenna array, when array spacing is decreasing, SNR of channel 1 and 2 will decrease little. However, SNR of RF signal is almost constant and SNR of IF signal will increase when array spacing of dipole MSAA is decreasing. And it is noticed that the difference between SNR of RF signal and IF signal will decrease with decreasing array spacing.

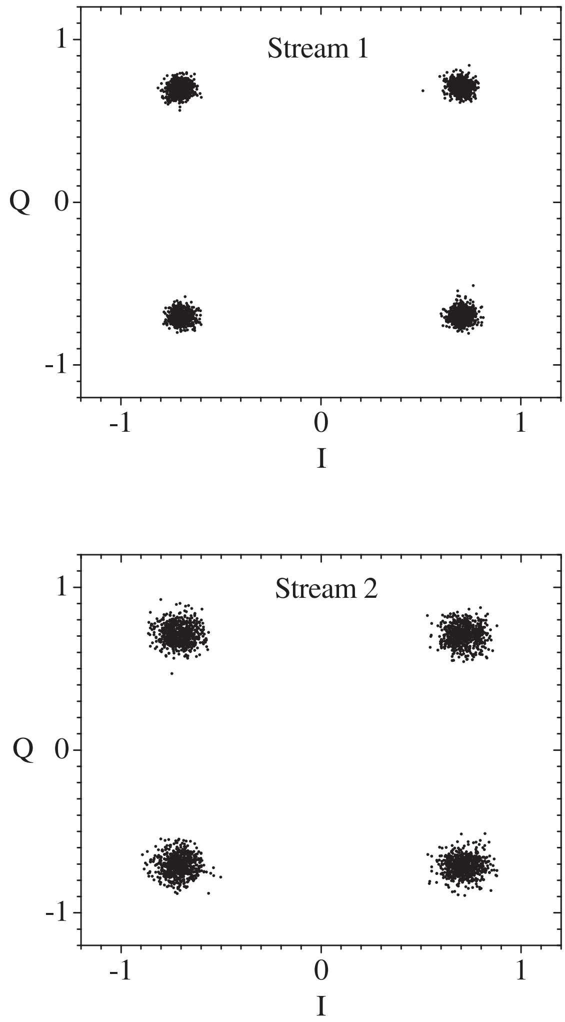

Fig. 5 Constellation diagram of 2 streams demodulated from IEEE 802.11n signals received by MSAA.

The channel capacity is also calculated for evaluating MIMO performance. The channel capacity can be expressed as:

$$\begin{aligned} C &= \log_2 \left| I_{M_0} + \frac{P_{Total}}{M\sigma_n^2} HH^{\dagger} \right| \\ &= \sum_{i=1}^{M_0} \log_2 \left(1 + \frac{P_{Total}}{M\sigma_n^2} \lambda_i \right) \end{aligned} \tag{2}$$

where superscript † for conjugate transpose, $M_0 = min(M, N)$, I_{M_0} for the $M_0 \times M_0$ identity matrix, P_{Total} is the total transmission power, σ_n^2 is the received noise power, H is the MIMO channel matrix, λ_i is the ith eigenvalue of $HH^{\dagger}$, M is the number of the transmitting antennas and N is the number of the receiving antennas.

Condition number κ-factor is defined as:

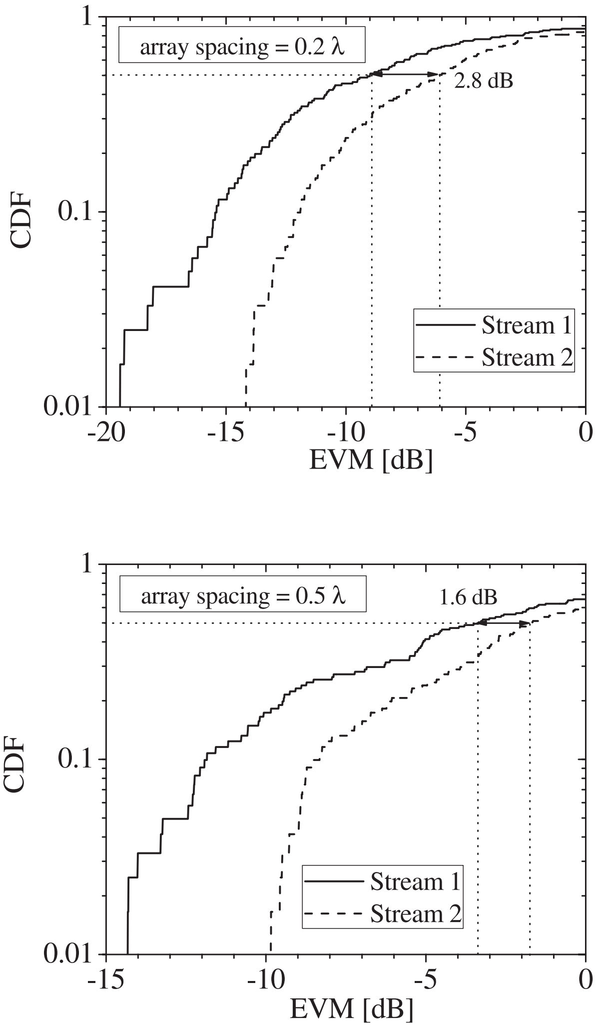

Fig. 6 CDF of EVM of MSAA with the 0.2 and 0.5 wavelength array spacing in the NLOS environment.

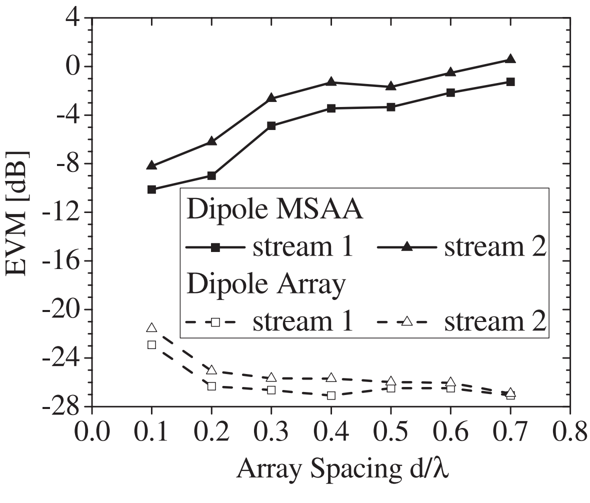

Fig. 7 Median EVM of dipole MSAA and two dipoles antenna array versus various array spacing in the NLOS environment.

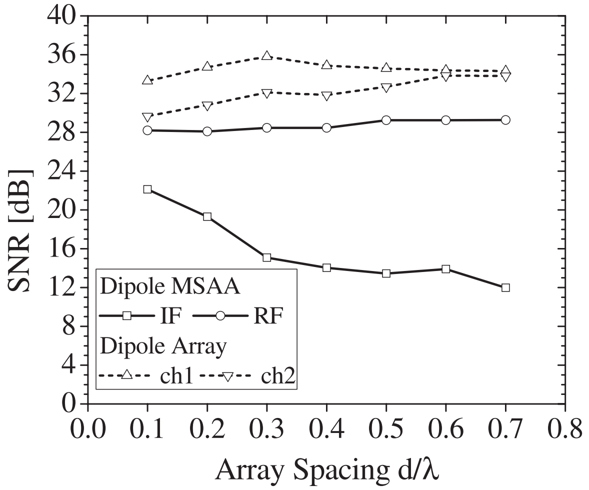

Fig. 8 Median SNR of dipole MSAA and two dipoles antenna array versus various array spacing in the NLOS environment.

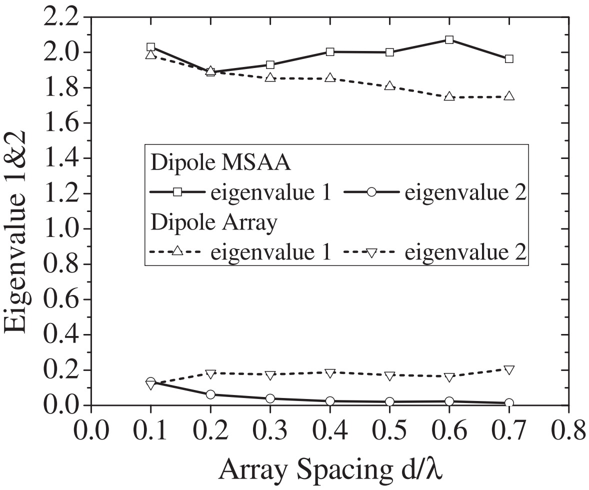

Fig. 9 Median eigenvaule 1 and 2 of dipole MSAA and two dipoles antenna array versus various array spacing in the NLOS environment.

$$\kappa = \sqrt{\frac{\lambda_1}{\lambda_2}} \tag{3}$$

where there are only two eigenvalues due to the 2 by 2 MIMO system in this experiment.

Figure 9 shows results of median eigenvalue 1 and 2 for various array spacing in the NLOS environment where the dipole MSAA and two-dipole antenna array were used as the receiving antennas. It is found that eigenvalue 1 of two-dipole antenna array is increased, but its eigenvalue 2 is decreased when array spacing is decreased. However, eigenvalue 1 will decrease, eigenvalue 2 will increase with decreasing array spacing in the case of dipole MSAA. Moreover, Fig. 10 shows the result of median condition number κ-factor for various array spacing in the NLOS environment where the dipole MSAA and dipole antenna array were still used as the receiving antennas. And κ-factor is decreased by decreasing array spacing in the case of the dipole MSAA, but it is increased for the case of two-dipole antenna array.

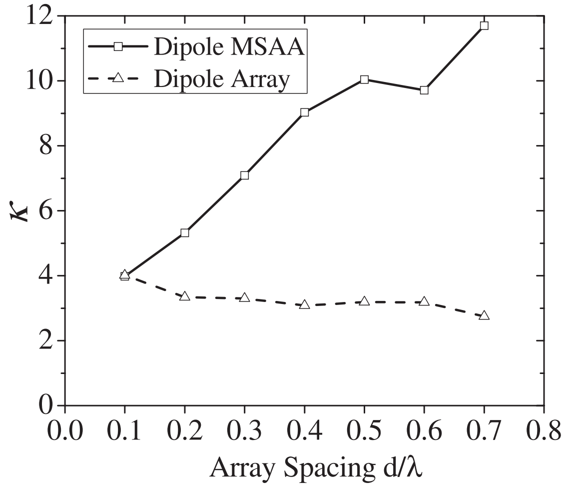

Fig. 10 Median condition number κ-factor of MSAA and two dipoles antenna array versus various array spacing in the NLOS environment.

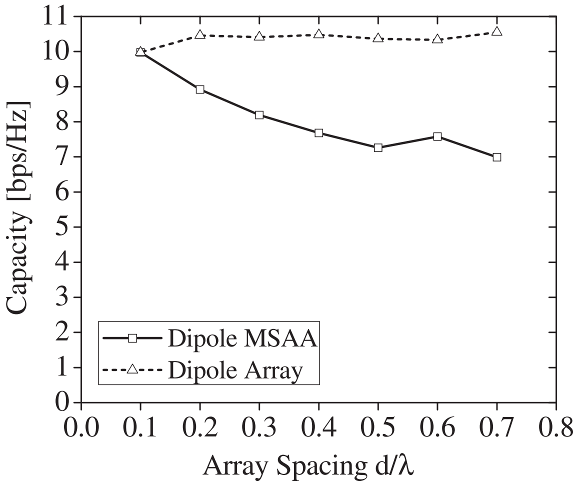

Fig. 11 Median MIMO channel capacity of dipole MSAA and two dipoles antenna array versus various array spacing in the NLOS environment.

Figure 11 shows the results of median MIMO channel capacity for various array spacing in the NLOS environment where the dipole MSAA and two-dipole antenna array were used as the receiving antennas. It is noted that the MIMO channel capacity is improved by compact array spacing in the case of dipole MSAA. On the other hand, the MIMO channel capacity decreases by decreasing array spacing of two-dipole antenna array. The MIMO channel capacity of the dipole MSAA is almost the same to that of dipole antenna array when array spacing is 0.1 wavelength.

4. Conclusions

In this paper, an experimental measurement has been carried out to study the MIMO performance in the NLOS environment of an indoor 2 by 2 MIMO system where a dipole MSAA was used as the receiving antenna. The EVM and the channel capacity which reflect the MIMO performance were measured with various array spacing to study the relation between the array spacing and MIMO performance of MSAA. The results showed that EVM and the MIMO channel capacity can be improved by decreasing the array spacing in the range of 0.1 to 0.7 wavelengths. Although we only showed a 2 × 2 MIMO communication systems in this paper, it is possible to use dipole MSAA in over 2 × 2 MIMO system because of its principle.

Acknowledgments

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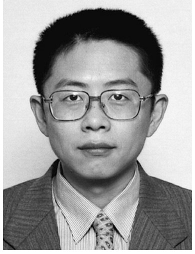
Lin Wang received the B.E. degree from Shenyang Institute of Chemical Technology, Shenyang, China, in 2006 and the M.E. degree from the Tohoku University, Sendai, Japan, in 2009, respectively. He is currently pursuing the Ph.D. degree in the Department of Electrical Communications, Tohoku University. His research interests include adaptive array antennas, MIMO wireless communications and antenna measurement.



Qiang Chen received the B.E. degree from Xidian University, Xi'an, China, in 1986, the M.E. and D.E. degrees from Tohoku University, Sendai, Japan, in 1991 and 1994, respectively. He is currently an Associate Professor with the Department of Electrical Communications, Tohoku University. His primary research interests include computational electromagnetics, array antennas, and antenna measurement. Dr. Chen received the Young Scientists Award in 1993, the Best Paper Award in 2008 from the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan. Dr. Chen is a member of the IEEE, IEICE. He has served as the Secretary and Treasurer of IEEE Antennas and Propagation Society Japan Chapter in 1998, the Secretary of Technical Committee on Electromagnetic Compatibility of IEICE from 2004 to 2006. He is now the Secretary of Technical Committee on Antennas and Propagation of IEICE, Associate Editor of IEICE Transactions on Communications.

Qiaowei Yuan received the B.E., M.E., and D.E. degrees from Xidian University, Xi'an, China, in 1986, 1989 and 1997, respectively. From 1990 to 1991, she was a special research student at Tohoku University, Sendai, Japan. From 1992 to 1995, she worked in Sendai Research and Development Laboratories, Matsushita Communication Company, Ltd., engaging in the research and the design of the compact antennas for 2rd generation mobile phone. From 1997 to 2002, she worked in Sendai Research and Development Center, Oi Electric Company, Ltd, engaging in the research and the design of small antennas for pager communication and the parabolic antenna for 26.5 GHz fixed wireless access communication. From 2002 to 2007, she was a researcher with Intelligent Cosmos Research Institute, Sendai, Japan, involved in the research and development of adaptive array antenna and RF circuits for mobile communications. From 2007 to 2008, she was an associate professor of Tokyo University of Agriculture and Technology. She is currently an associate professor of Sendai National College of Technology, Japan.

Kunio Sawaya received the B.E., M.E. and D.E. degrees from Tohoku University, Sendai, Japan, in 1971, 1973 and 1976, respectively. He is presently a Professor in the Department of Electrical and Communication Engineering at the Tohoku University. His areas of interests are antennas in plasma, antennas for mobile communications, theory of scattering and diffraction, antennas for plasma heating, and array antennas. He received the Young Scientists Award in 1981, the Paper Award in 1988, Communications Society Excellent Paper Award in 2006, and Zen-ichi Kiyasu Award in 2009 all from the Institute of Electronics, Information and Communication Engineers (IEICE). He served as the Chairperson of the Technical Group of Antennas and Propagation of IEICE from 2001 to 2003, the Chairperson of the Organizing and Steering Committees of 2004 International Symposium on Antennas and Propagation (ISAP'04) and the President of the Communications Society of IEICE from 2009 to 2010. Dr. Sawaya is a senior member of the IEEE, and a member of the Institute of Image Information and Television Engineers of Japan.