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

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

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Abstract: The modulated scattering array antenna (MSAA) is composed of one normal antenna element and several modulated scattering elements (MSEs). In this report, a 2-element MSAA is used as the receiving antenna in a 2 by 2 multiple input multiple output (MIMO) system. The MIMO performance of the MSAA with various array spacing is measured to investigate experimentally the relation between the array spacing and the MIMO performance of the MSAA in the Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) indoor environment. It is found that the Error Vector Magnitude (EVM) and the Channel Capacity which reflect the MIMO performance can be affected by the array spacing. Furthermore, the measured result of the MSAA was compared with that of two-dipole array antenna at the same condition.

Keywords: array antenna, modulation, mobile handsets, wireless communication, MIMO

1. INTRODUCTION

Multiple input multiple output (MIMO) communication system has become a promising technology for the next-generation wireless communication system, because it could achieve much higher spectral efficiency and transfer reliability than the conventional wireless communication techniques with the same transmitted power and frequency bandwidth [1]. However, it is very difficult to develop array antennas suitable for mobile handsets, because of some problems such as the limited space on the handset to mount array antennas with sufficiently low mutual coupling and correlation between antennas [2], [3]. Moreover, because a number of separate RF front-end circuits are required corresponding to the number of array elements, a large amount of packaging space for the RF front-end circuits is necessary. Therefore, it is essential to develop array antennas with simple configurations which are suitable for mobile handsets in MIMO communications.

A new concept of array antennas, which is called modulated scattering array antenna (MSAA), based on the modulated scattering technique (MST) has been proposed [4], [5]. The MSAA consists of one normal antenna element and several modulated scattering elements (MSEs) without RF front-end circuit. The previous researches showed that the MSAA is suitable for mobile handsets in the MIMO communications where the space and the cost are limited because of its simple configuration [6].

It is apparent that reduction of 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 the MSAA in MIMO communications to see whether the MIMO performance of the MSAA for mobile handsets can be improved by regulating the array spacing. Experimental measurement was carried out to study the MIMO performance in the LOS and 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 along with the different array spacing to study the relation between the array spacing and the MIMO performance of the MSAA. Further, the MIMO performance of the MSAA was compared with that of two normal dipole array antennas.

The report is organized as follows. The experimental configuration of the MIMO communication system is described in Section 2. The experimental results are shown in Section 3. Finally, conclusions are given in Section 4.

2. EXPERIMENTAL CONFIGURATION

The geometry of a 2-element dipole MSAA is shown in Fig. 1. The MSAA is composed of two half-wavelength dipole elements with array spacing which was changed from 0.1 to 1 wavelength in the experiment. In the MSAA, the left element is the dipole antenna and the right one is the MSE. A Schottky diode is mounted at the center of the MSE which is used as the nonlinear impedance for modulation.

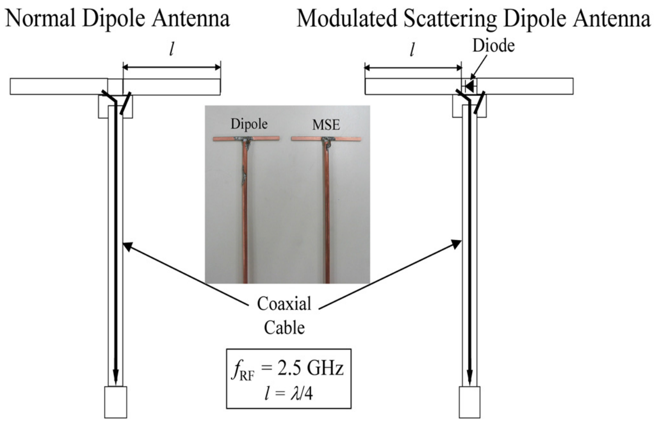


Fig. 1. Geometry of dipole antenna and modulated scattering dipole antenna

Fig. 2 shows the measurement system which was developed to demonstrate the MIMO performance of the MSAA in a 2 by 2 MIMO communication system operated with IEEE 802.11n protocol. Two log-periodic dipole array antennas with two wavelengths array spacing were used as the transmitting antennas. The Agilent 89600S vector signal analyzer with two 2.5 GHz 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.

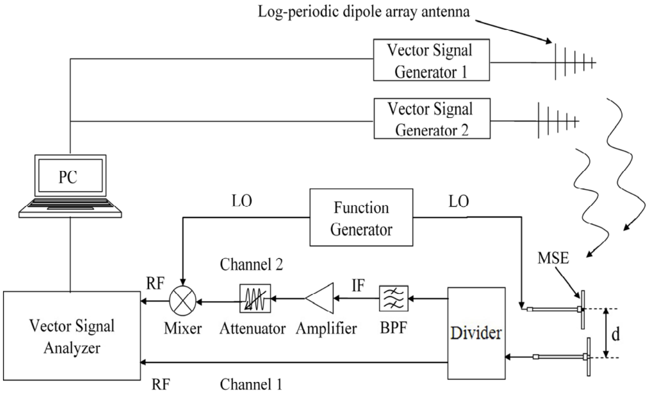


Fig. 2. 2-channal MIMO measurement system

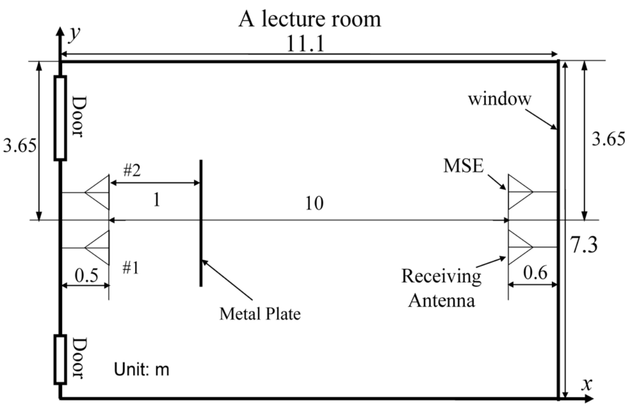


Fig. 3. 2-channal MIMO measurement environment

The experiment was implemented in a 7.3 × 11.1 meter lecture room with the concrete structure which is shown in Fig. 3. The distance between the transmitting and receiving antennas is about 10 meters in a LOS (line-of-sight) and NLOS (non-line-of-sight) environment. The NLOS environment includes two conditions that the distance between the transmitting antenna and the metal plate is 1 m in the case of the NLOS (a) environment, NLOS (b) environment is 0.6 m. 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 and the constellation diagrams of the demodulated IEEE 802.11n signals for 2 streams were recorded at each point. Further, the EVM was calculated from the constellation diagram for every location of the receiving antenna.

3. EXPERIMENTAL RESULTS

Fig. 4 shows the constellation diagram of 2 streams demodulated from IEEE 802.11n signals received by the MSAA, which includes QPSK-modulated data symbols and BPSK-modulated pilot symbols. It is shown that symbols of 2 streams are shifted slightly from their ideal location. The degradation of stream 2 is caused by the lower gain of the MSE as reported in [4] and [5], 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 CDF.

EVM is defined as:

$$EVM = \frac{|V_{error}|}{|V_{reference}|}$$

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

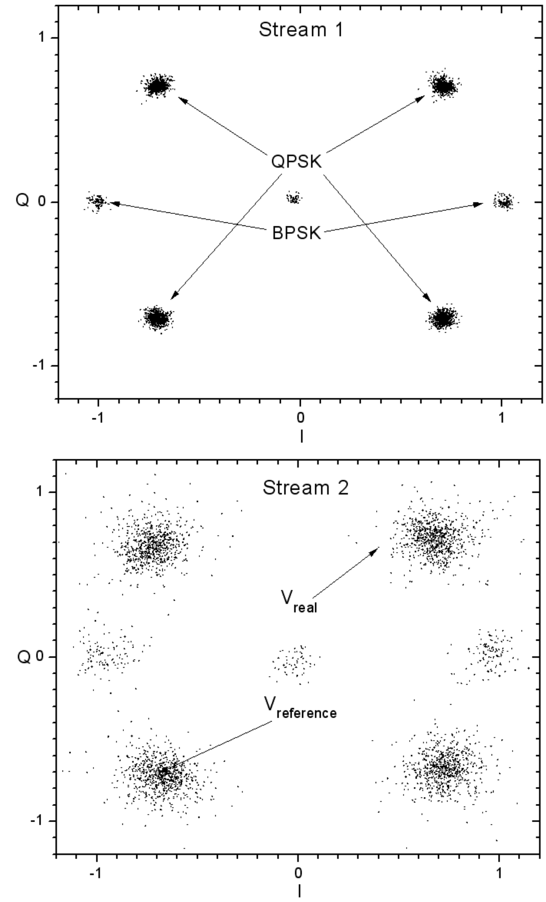


Fig. 4. Constellation diagram of 2 streams demodulated from IEEE 802.11n signals received by MSAA

Fig. 5 and Fig. 6 show the CDF of the EVM of MSAA with the 0.2 and 0.5 wavelengths array spacing in LOS and NLOS (b) environment, respectively. It is shown that the CDF of the EVM of stream 1 and stream 2 will be changed along with various array spacing. Moreover, the difference between the stream 1 and stream 2 at CDF=50% is also changed along with the different array spacing. When array spacing is increased, the difference is decreased. Fig. 7 and Fig. 8 show the result of the EVM of the stream 1 and stream 2 and K-factor along with various array spacing at CDF=50% in LOS environment, respectively, where the MSAA and two-dipole array antenna were used as the receiving antenna. The EVM can be improved by decreasing array spacing contrary to the case of two-dipole array antenna. And K-factor is increased by increasing array spacing, but it is decreased for the case of two-dipole array antenna.

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

$$C=\log_2\left|I_{M_0}+\frac{P_{Total}}{M\sigma_n^2}\mathbf{HH}^{\dagger}\right|$$

$$=\sum_{i=1}^{M_0}\log_2\left(1+\frac{P_{Total}}{M\sigma_n^2}\lambda_i\right)\quad M_0=\min(M,N)$$

Where superscript † for conjugate transpose, I_{M_0} for the $M_0\times M_0$ identity matrix, P_{Total} is the total transmission power, σ_n^2 is the 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.

K-factor is defined as:

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

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

Fig. 9 show the result of the MIMO channel capacity with various array spacing at CDF=50% in LOS environment where the MSAA and two-dipole array antenna is used as the receiving antenna. It is notable that the MIMO channel capacity is improved by compact array spacing in the case of MSAA. Contrarily, the MIMO channel capacity is decreased by decreasing array spacing of two-dipole array antenna.

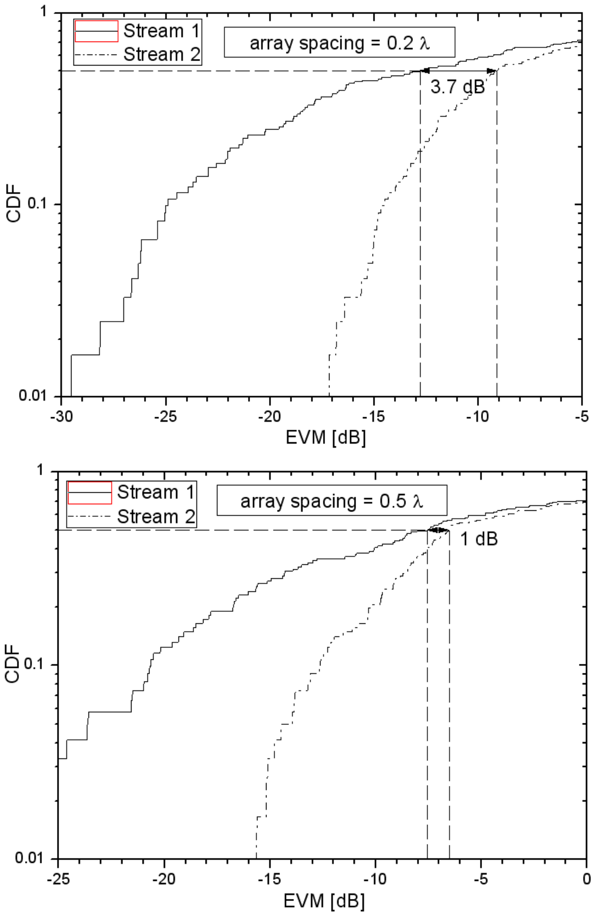


Fig. 5. CDF of EVM of MSAA with the 0.2 and 0.5 wavelengths array spacing in the LOS environment

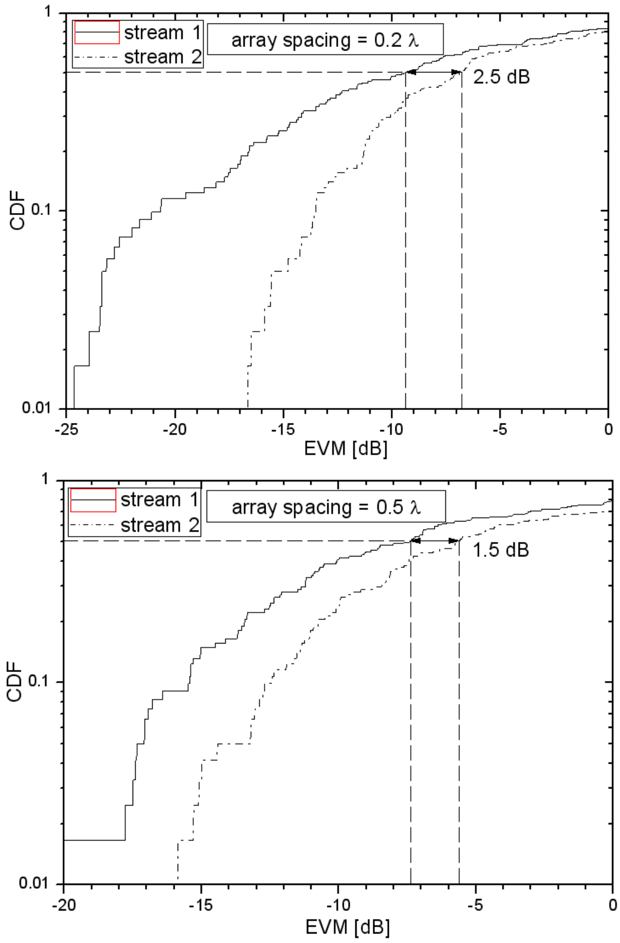


Fig. 6. CDF of EVM of MSAA with the 0.2 and 0.5 wavelengths array spacing in the NLOS (b) environment

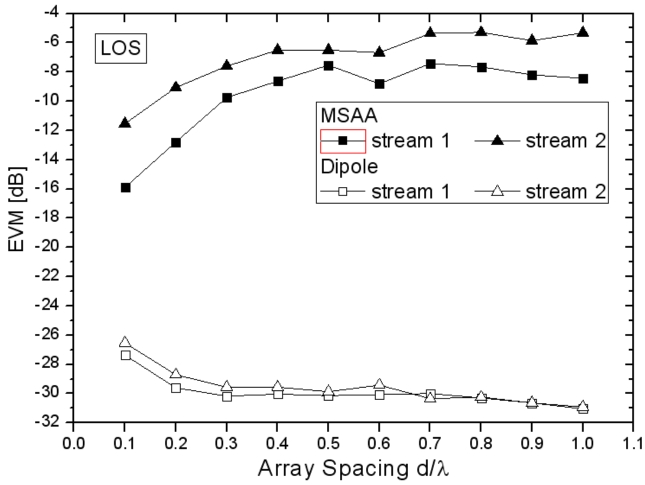


Fig. 7. The EVM of MSAA and two dipoles array antenna with various array spacing at CDF=50% in the LOS environment

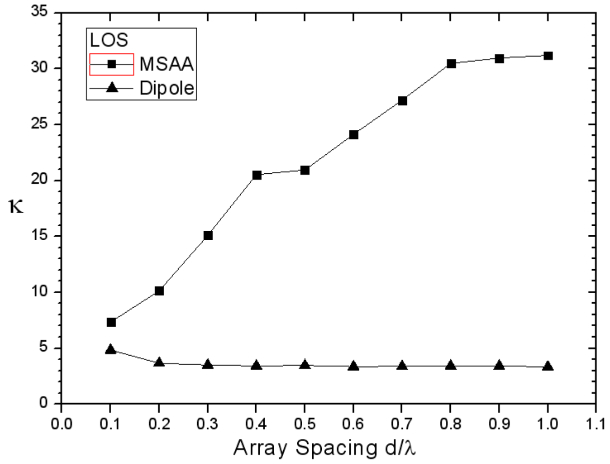


Fig. 8. The K-factor of MSAA and two dipoles array antenna with various array spacing at CDF=50% in the LOS environment

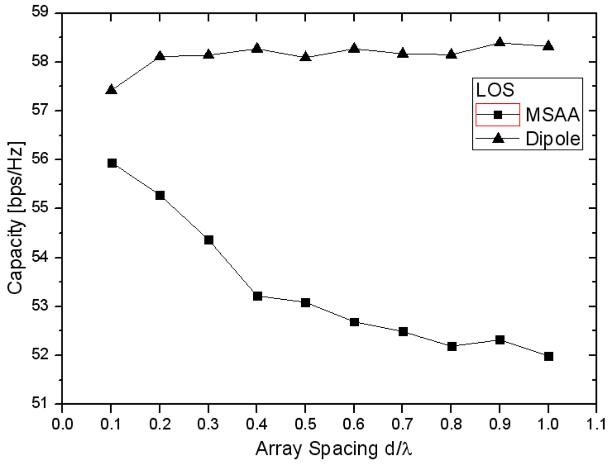
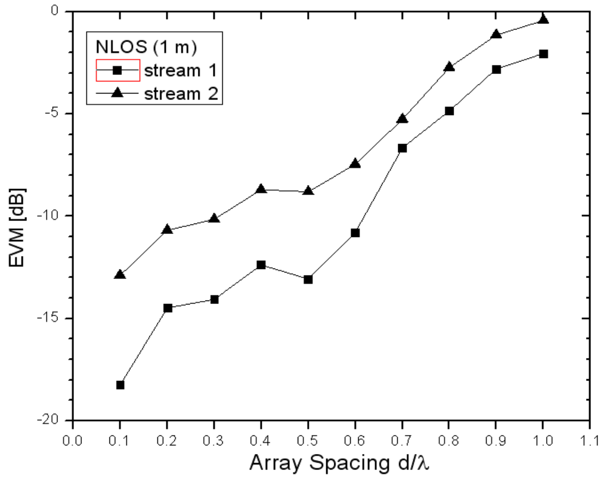
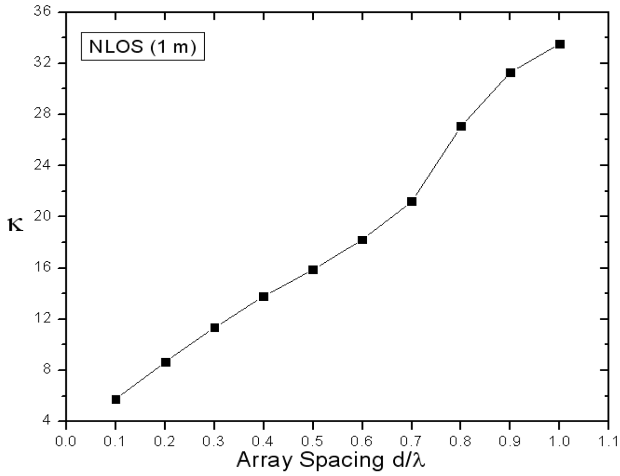


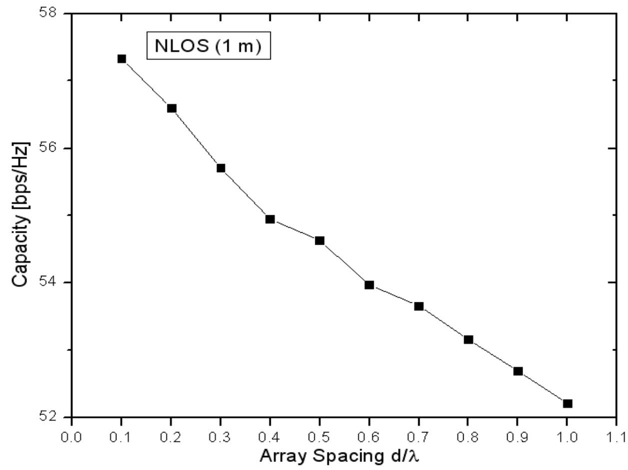
Fig. 9. The MIMO channel capacity of MSAA and two dipoles array antenna with various array spacing at CDF=50% in the LOS environment



(a) EVM result



(b) K-factor result



(c) MIMO channel capacity result

Fig. 10. The experimental result of MSAA with various array spacing at CDF=50% in the NLOS (a) environment

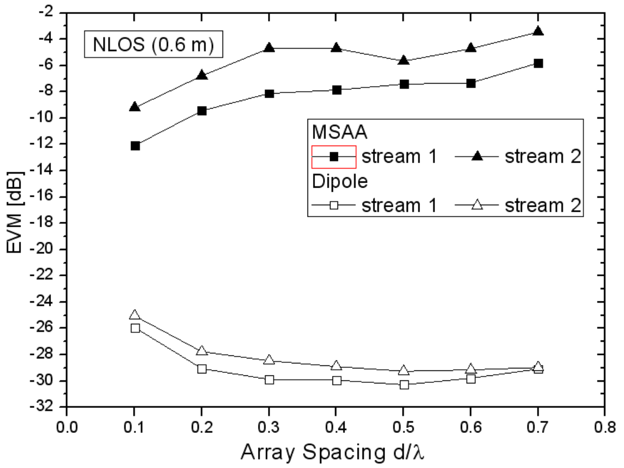
Fig. 10 and Fig. 11 show some experimental results with various array spacing at CDF=50% in the NLOS (a) and the NLOS (b) environment, respectively as follows.

(a) EVM result

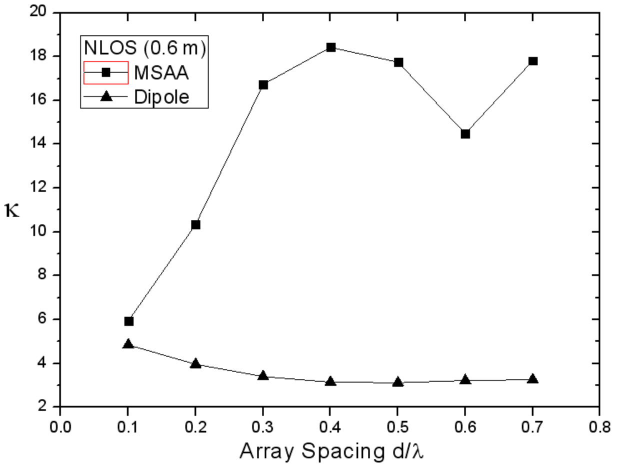
(b) K-factor result

(c) MIMO channel capacity result

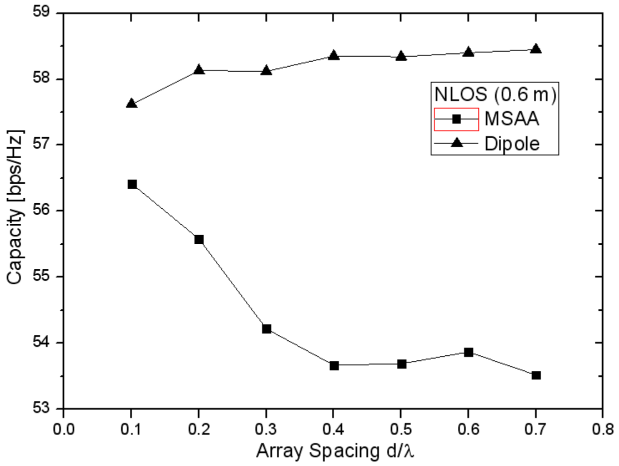
In the case of NLOS (a) environment, it is found that when the array spacing is increased, both the EVM of the stream 1 and the stream 2 become large in the range of 0.1-1.0 wavelengths. K-factor also increases by increasing array spacing. The compact array spacing as small as 0.1 wavelengths is beneficial to the MIMO channel capacity.



(a) EVM result



(b) K-factor result



(c) MIMO channel capacity result

Fig. 11. The experimental result of MSAA and two dipoles array antenna with various array spacing at CDF=50% in the NLOS (b) environment

In the case of NLOS (b) environment, the result is similar to the LOS environment. The EVM can be improved by decreasing array spacing contrary to the case of two-dipole array antenna. K-factor is increased by increasing array spacing, but it is decreased for the case of two-dipole array antenna. The MIMO channel capacity is improved by compact array spacing in the case of MSAA. Contrarily, it is decreased by decreasing array spacing in the case of two-dipole array antenna.

The experimental results indicate that the EVM and the channel capacity which reflect the MIMO performance can be affected by the array spacing in the range of 0.1-1.0 wavelengths in LOS and NLOS environment. The EVM result is improved by decreasing array spacing in the range of 0.1-1.0 wavelengths. Similarly, the MIMO channel capacity is also improved by decreasing the array spacing at the same range. The EVM and the channel capacity of MSAA and two-dipole array spacing with various array spacing are compared at CDF=50% in the LOS and NLOS (b) environment, respectively. The result shows the case of two-dipole array antenna had better performance than that of the MSAA. However, the RF front-end circuit of the MSAA is much simpler than that of two-dipole array antenna.

4. CONCLUSIONS

In this report, an experimental measurement has been carried out to study the MIMO performance in the LOS and NLOS environment of an indoor 2 by 2 MIMO system where the MSAA was used as the receiving antenna. The EVM and the channel capacity which reflect the MIMO performance were measured with the different array spacing to study the relation between the array spacing and the MIMO performance of the MSAA. The result has shown that the EVM and the MIMO channel capacity can be improved by decreasing the array spacing in the range of 0.1-1.0 wavelengths in LOS and NLOS (a) environment. Similarly, the EVM and the MIMO channel capacity will be also improved by decreasing the array spacing in the range of 0.1-0.7 wavelengths in NLOS (b) environment. When two dipoles were used as the receiving antenna at the same condition, the measurement result has shown that the MIMO channel capacity has a little improvement by increasing the array spacing. It is shown that the dipole array had better performance than the MSAA. However, the RF front-end circuit of the MSAA is much simpler than that of the dipole array.

REFERENCES

[1] G.J. Foschini, and M.J. Gans: On Limits of Wireless Communications in a Fading Environment when Using Multiple Antennas. Wireless Personal Commun., Vol.6, No.3,(1998) 311–335

[2] S. C. K. Ko and R. D. Murch: Compact Integrated Diversity Antenna for Wireless Communications. IEEE Trans. Antennas Propagat., (June, 2001) 954–960

[3] Q. Yuan, Q. Chen, and K. Sawaya: Performance of Adaptive Array Antenna with Arbitrary Geometry in the Presence of Mutual Coupling. IEEE Trans. Antennas Propagat., Vol.54, No.7, (July, 2006) 2949–2951

[4] Q. Yuan, M. Ishizu, Q. Chen, and K. Sawaya: Modulated scattering array antennas for mobile handset. IEICE Electro. Express, Vol.2, No.20, (Oct, 2005) 519-522

[5] Q. Chen, Y. Takeda, Q. Yuan, and K. Sawaya: Diversity performance of modulated scattering array antenna. IEICE Electro. Express, Vol.4, No.7, (April, 2007) 216-220

[6] Q. Chen, L. Wang, T. Iwaki, Y. Kakinuma, Q. Yuan, and K. Sawaya: Modulated scattering array antenna for MIMO applications. IEICE Electro. Express, Vol.4, No.23, pp.745-749, 2007