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Experimental Evaluation of Matching Method Based on Image Impedances for Near Field MIMO

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***Abstract* - In this paper, a novel matching method for near field MIMO is proposed. A concept of image impedance matching is extended to 2×2 MIMO. A proposed matching network was fabricated and tested. The measurement results indicated the proposed matching network offers a high channel capacity since it significantly improves SNR in near field MIMO scheme.**

***Index Terms* — matching network, near field MIMO, conjugate image impedances**

I. INTRODUCTION

Near field MIMO (Multiple-Input Multiple-Output) transmission using reactive field is expected to offer high power efficiency since the reactive field is confined just between transmitting and receiving antennas. However, use of a traditional matching method is difficult because the existence of the facing antennas and their feed network seriously affect the matching condition.

In this paper, we experimentally evaluate a matching method for near field MIMO by extending conjugate image impedances [1]. The matching networks are designed and fabricated based on measured *S*-parameter of the antenna. From the experimental evaluation, the effectiveness in enhancing the channel capacity of the proposed matching method is denoted.

II. THEORY FOR DESIGNING MATCHING NETWORK

Fig.1 shows equivalent circuit of 2×2 near field MIMO array. Antenna system is treated as four port network. Ports 3 and 4 receives the signals transmitted from ports 1 and 2. In the figure, ***Y*** shows admittance matrix of antenna system, and Y_{i1}, Y_{i3} represent the image admittances connected to ports 1 and 3. When we consider only two facing antenna ports and assume the effect of other ports is negligible, image impedances can be computed by the method shown in [1]. For example, Y_{i1} and Y_{i3} are calculated by

$$Y_{i1} = G_{11}(\theta_g + j\theta_b) - jB_{11} \tag{1}$$

$$Y_{i3} = G_{33}(\theta_g + j\theta_b) - jB_{33} \tag{2}$$

Where θ_g and θ_b are defined as

$$\theta_g = \sqrt{\left(1+\frac{G_{13}^2}{G_{11}G_{33}}\right)\left(1+\frac{B_{13}^2}{G_{11}G_{33}}\right)}\,, \tag{3}$$

$$\theta_b = \frac{G_{13}B_{13}}{G_{11}B_{33}} \tag{4}$$

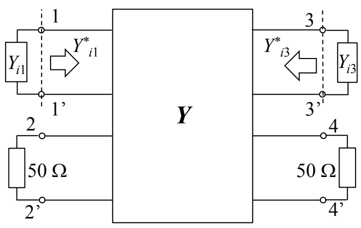

Fig.1 Equivalence circuit model of near field MIMO

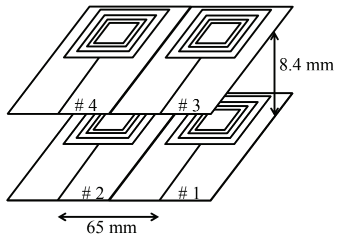

Fig.2 Antenna model

G and *B* represent $G_{pq} = \mathrm{Re}(Y_{pq})$, $B_{pq} = \mathrm{Im}(Y_{pq})$ (p = 1, 2, 3, 4, q = 1, 2, 3, 4), Y_{pq} shows the element of ***Y***. Matching can be achieved because input impedance and terminating impedance of ports 1 and 3 are in the complex conjugate relation. For ports 2 and 4, the matching conditions are able to be determined in the same manner.

Matching networks are designed on the basis of *S*-parameters. Reflection characteristics of matching network connected antennas need to be zero as design condition of matching network. Since input admittance of port is the conjugate image admittance, the reflection coefficient of input port Γ is defined as

$$\Gamma = \frac{Y_0 - Y_i^*}{Y_0 + Y_i^*}\,. \tag{5}$$

Where Y_i^* is the conjugate complex of the image admittance Y_i, and Y_0 is characteristic admittance. When *S*-parameters of matching network $\boldsymbol{S}_M$ are defined as

$$\boldsymbol{S}_M = \begin{pmatrix} S_{M11} & S_{M12} \\ S_{M21} & S_{M22} \end{pmatrix}, \tag{6}$$

reflection characteristics of antenna including matching network are calculated by

$$S_{ref} = S_{M11} + S_{M12}\left(\Gamma^{-1} - S_{M22}\right)^{-1} = 0\,. \tag{7}$$

Also, the design condition of matching network is given by

$$S_{M22} = \Gamma^*\,. \tag{8}$$

Additionally, the lossless matching network satisfies

$$\boldsymbol{S}_M \cdot \boldsymbol{S}_M^H = \boldsymbol{I}\,, \tag{9}$$

where the operation, $\{\}^H$, is the complex conjugate transpose. From (7) ~ (9), *S*-parameter of matching network is calculated.

III. EXPERIMENTAL RESULTS

Fig.2 illustrates the antenna model used in the experiment, and Fig.3 shows the photos of fabricated antennas and matching circuits. An antenna system consists of four planar square spiral antennas. A planar square spiral antenna is printed on FR-4 substrate, outer diameter is 40 mm, and number of turns is 17 [2]. #1 and #2 are transmitting antennas, and #3 and #4 are receiving antennas. Element spacing is 65 mm, and distance between transmitting and receiving antennas is 8.4 mm.

The central frequency is set to 150 MHz, and S-parameter of this antenna model is measured. The conjugate image impedances of transmitting and receiving sides calculated by measured *S*-parameters were

$$(Z_{i1} \quad Z_{i2}) = (68.58 + j123.6 \quad 86.16 + j137.0),$$

$$(Z_{i3} \quad Z_{i4}) = (57.44 + j128.3 \quad 50.22 + j133.1),$$

respectively, *S*-parameters of matching networks were calculated from (7) to (9). Chip inductor and capacitor were used to configure matching networks that were fabricated on the FR-4 substrate. Fig.3 shows the conditions of an experiment.

Fig.4 shows the measured frequency responses of the reflections. In this figure, continuous lines represent when fabricated matching networks are connected and broken lines represent that without fabricated matching networks. From Fig.4, it can be seen that all matching characteristics are significantly improved by the proposed matching networks. Fig.5 shows the frequency response of the transmission power of measurement results. From this figure, it is found that transmission powers S_{31} and S_{42} at 150 MHz are improved by 3.7 dB and 4.3 dB, respectively.

Fig.6 shows the frequency response of the channel capacity. The channel capacity is calculated using measured *S*-parameters, and transmitting and noise power is set to 0 dBm, and -90 dBm respectively. From this result, it can be seen that channel capacity is improved by using proposed matching networks.

IV. CONCLUSION

This paper has described the experimental results of the proposed matching method based on image impedances for near field MIMO. On the basis of the measurement result of *S*-parameters, it is found that reflection characteristics and transmitting power were improved by using proposed matching network. Also, the calculated result has shown that the channel capacity can be also increased when matching network is used. From these experiments, it is found that the proposed matching method is effective in enhancing capacity of near field MIMO.

ACKNOWLEDGMENT

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REFERENCES

[1] N. Inagaki and S. Hori "Fundamentals of wireless connections with near field coupled antennas", *IEICE Trans. Commun.*, vol. J94-B, no. 3, pp.436 -443, Mar. 2011

[2] U.-M. Jow and M. Ghovanloo "Design and optimization of printed spiral coils for efficient transcutaneous inductive power transmission", *IEEE* Trans. Biomed. Circuits Syst, vol. 1, no.3, pp.193 – 202, Sep.2007

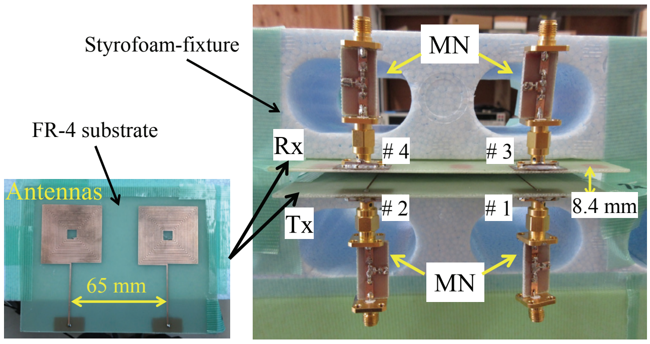

Fig.3 Photos of fabricated antennas and matching networks

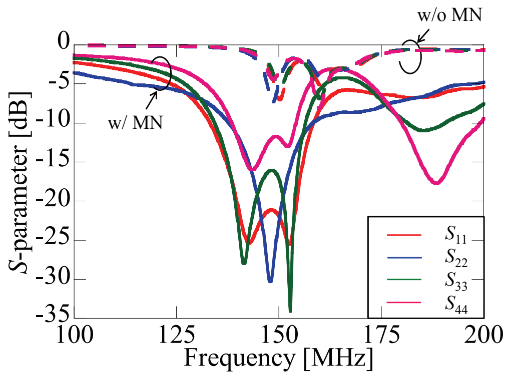

Fig.4 Reflection characteristics

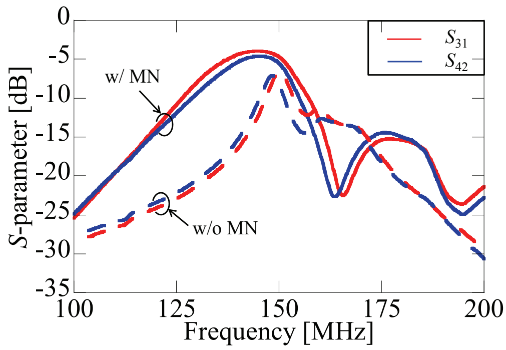

Fig.5 Transmission power

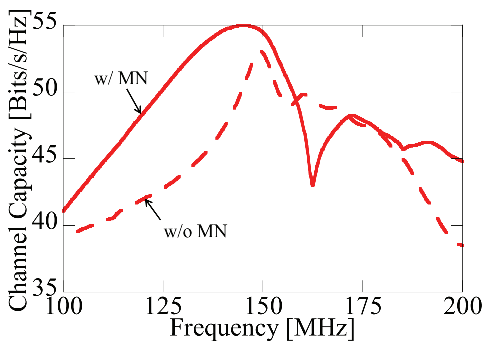

Fig.6 Channel capacity