The Impact of a Matching Circuit of a Handset MIMO Antenna on the Wideband Channel Capacity

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1. Introduction

In the plan for future cellular systems, such as the LTE-advanced system, they are to be allocated a very wide frequency band. Hence, the wideband characteristics must be considered when a handset MIMO antenna is designed for such systems. In the literature [1], the authors have shown that there is a significant impact of a matching circuit on the channel capacity of a MIMO antenna over a wide frequency band. In [1], as a basic study, a MIMO antenna comprised of two half-wavelength dipole antennas arranged in a parallel orientation is used for the analysis. However, the mechanism or principle responsible for the enhancement of channel capacity was not fully examined. This paper studies the impact of a matching circuit of a handset MIMO antenna mounted on a commercial-handset based small metal housing on the wideband channel capacity. Through extensive studies, we will give full consideration to the reason why a large channel capacity can be obtained by choosing an appropriate matching circuit.

2. Analytical Model

Fig. 1 shows the configuration of a MIMO antenna mounted on a small metal case including a matching circuit. The dimensions of the metal case were determined to represent a typical smart phone available in a market. The MIMO antenna is comprised of two quarter-wavelength monopole antennas with spacing *d*. The analysis was conducted at a center frequency of 900 MHz with a bandwidth of 200 MHz (22 %). The matching circuit comprising components, A, B, C, which may be an inductor (L) or a capacitor (C), is connected to each antenna element, #1 and #2. The analysis was conducted by combining electromagnetic, circuit, and Monte Carlo propagation channel simulations, in which a uniform distribution in the horizontal plane for incident waves around the MIMO antenna was assumed [1].

In this paper, two extreme matching conditions are taken into consideration; simultaneous conjugate matching for both antenna elements, denoted as the CM match, and self-matching without mutual coupling between the antenna elements, denoted as the Z11 match. There two matching conditions are anticipated to show quite different behavior in the channel capacity since they have different gain and correlation characteristics, as will be mentioned in Sec. 3.

3. Comparison of Conjugate and Self-Matching

Fig. 2 shows the frequency characteristics of the Shannon average channel capacity with no feedback for SNR = 20 dB, assuming a 2-by-2 MIMO system. It can be seen from Fig. 2 that when *d* = 4 mm the CM match gives a smaller channel capacity than the Z11 match, whereas when *d* = 65 mm the CM match gives a larger channel capacity than the Z11 match over the entire frequency of 800 to 1000 MHz. In between them, when *d* = 15 mm the CM match provides a larger channel capacity than the Z11 match within a narrow frequency bandwidth of less than 40MHz (4.4%). Taking these observations into consideration, it can be seen that the most advantageous matching condition can be chosen depending on both the antenna separation and the required system bandwidth.

Hence, in the first step of out study, the channel capacity as a function of the antenna separation was investigated at the center frequency of 900 MHz, as shown in Fig. 3. As can be seen in the figure, there is a crossover behavior in the two curves; the CM exceeds the Z11 match in capacity beyond the 11mm-antenna separation. In order to clarify this phenomenon, the channel gain and correlation characteristics of the array were investigated, as shown in Figs. 4(a) and (b). The channel gain is defined as an average antenna gain of the two monopole antennas in the horizontal plane. It can be seen from Fig. 4(a) that the Z11 exceeds the CM match in channel gain, meaning that the Z11 match can provide a larger received power than the CM match. In contrast, as shown in Fig. 4(b), the CM match gives a smaller correlation coefficient, indicating that the CM match is suitable for MIMO transmission since a small correlation means that the separation of signals can be achieved efficiently by the singular value decomposition.

The crossover behavior mentioned above can also be considered from the eigenvalue characteristics derived from the channel response. Fig. 5 shows the 1st and 2nd eigenvalues with changing the antenna separation for the CM and Z11 match. As can be seen from Fig. 5, the Z11 match provides larger 1st eigenvalues, whereas the CM match provides larger 2nd eigenvalues, regardless of the antenna separation. The reason for this phenomenon can be supported by the fact that the Z11 exceeds the CM match in channel gain and the CM match gives a smaller correlation coefficient, as illustrated in Fig. 4.

4. Wideband Channel Capacity

The advantage of matching circuit in the channel capacity can be varied depending on the required bandwidth that MIMO transmission is performed, as described in Fig. 2. Thus the wideband channel capacity is analyzed in this section. Fig. 6 shows the bandwidth averaged channel capacity, referred to as the BAC [1], as a function of bandwidth. The BAC is a figure-of-merit for evaluating channel capacity with respect to the prescribed bandwidth. It is found from Fig. 6 that when the antenna separation is less than d = 15 mm the Z11 match is advantageous for achieving a larger BAC, whereas when the antenna separation is grater than d = 15 mm the CM match is advantageous. Consequently, when d = 15 mm, the Z11 is superior to the CM match for bandwidth more than 80 MHz, the CM exceeds the Z11 match for bandwidth less than 80 MHz. This fact indicates that the choice of matching circuit for achieving a large BAC depends not only on the antenna separation but also on the required system bandwidth.

5. Discussions

In this section, the mechanism responsible for the enhancement of channel capacity by choosing an appropriate matching circuit is fully examined. The Shannon theory tells that the second stream, corresponding to the 2nd eigenvalue, has greater effects on the enhancement of channel capacity than the first stream, corresponding to the 1st eigenvalue. In order to investigate this fact in more detail, the quantities showing the advantages of the two streams are defined in the following equations.

$$C_{d1} = C_1(Z_{11}) - C_1(CM) \quad (1) \qquad C_1 = \log_2(1+\lambda_1) \quad (2)$$

$$C_{d2} = C_2(CM) - C_2(Z_{11}) \quad (3) \qquad C_2 = \log_2(1+\lambda_2) \quad (4)$$

In Eq. (1), C_{d1} indicates the advantage of the Z11 with reference to the CM match when the channel capacity corresponding to the first stream, as defined by Eq. (2), is considered. In contrast, in Eq. (3), C_{d2} indicates the advantage of the CM with reference to the Z11 match when the channel capacity corresponding to the second stream, as defined by Eq. (4), is considered.

Fig. 7 shows C_{d1} and C_{d2} as a function of the antenna separation d. It can be seen from Fig. 7 that when d is less than 11 mm C_{d1} is larger than C_{d2}. This fact suggests that the advantage of the Z11 match for the first stream exceeds that of the CM match for the second stream. On the other hand, when d is beyond 11 mm C_{d2} is larger than C_{d1}, indicating that the advantage of the CM match for the second stream exceeds that of the Z11 match for the first stream. Consequently, when d = 11 mm both advantages for the two streams are balanced, and thus the channel capacities for the two matching conditions coincide with each other, as illustrated in Fig. 3.

6. Conclusion

This paper studies the impact of a matching circuit of a handset MIMO antenna mounted on a small metal housing on the wideband channel capacity. The results demonstrate that the optimum matching condition strongly depends on both the antenna separation and the required system bandwidth. Finally, through in-depth considerations, the mechanism causing the crossover behaviour for the channel capacity has been clarified.

References

[1] K. Ogawa, T. Hayashi, A. Yamamoto, "An analysis of frequency characteristics of a parallel dipole MIMO antenna considering the effects of impedance matching circuit," IEICE Trans. (B), J92-B, 9, pp.1416-1430, Sep. 2009

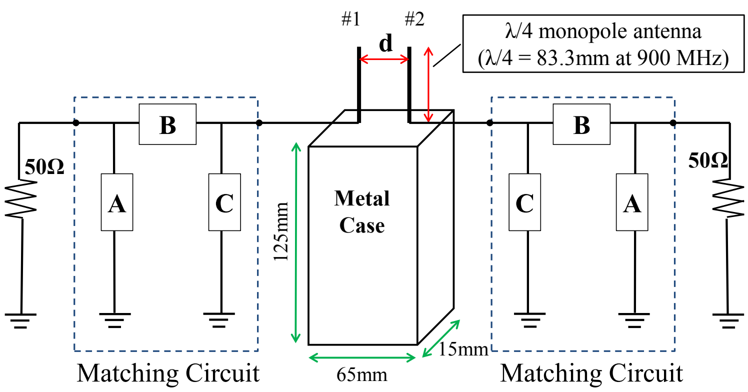


Fig. 1 Configuration of the handset MIMO antenna including matching circuit

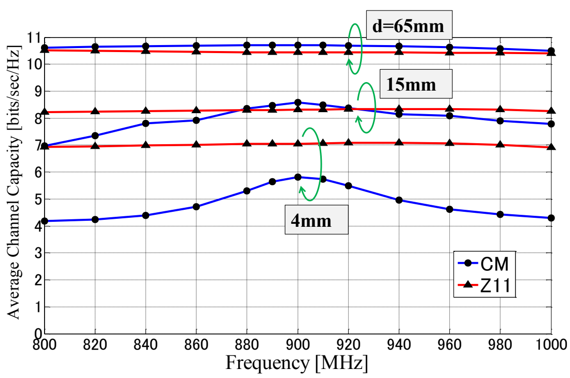


Fig. 2 Frequency characteristics of the channel capacity

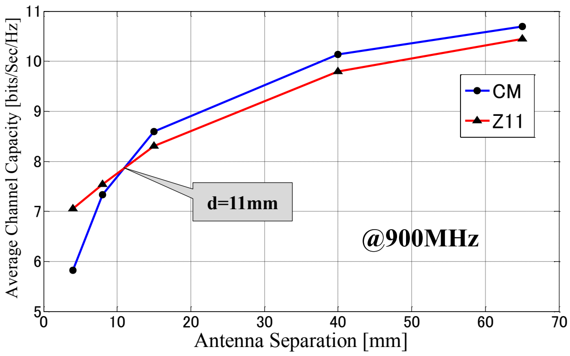
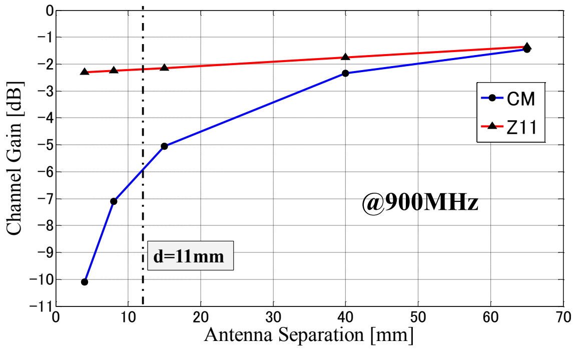
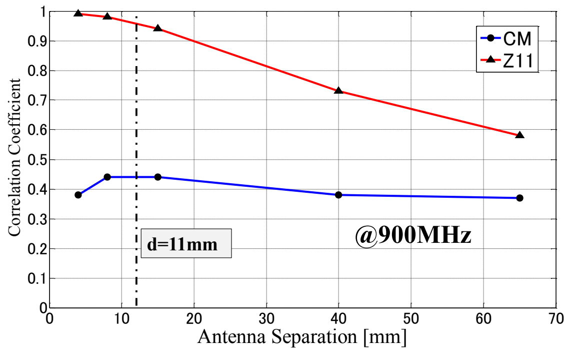


Fig. 3 Channel capacity vs. antenna separation

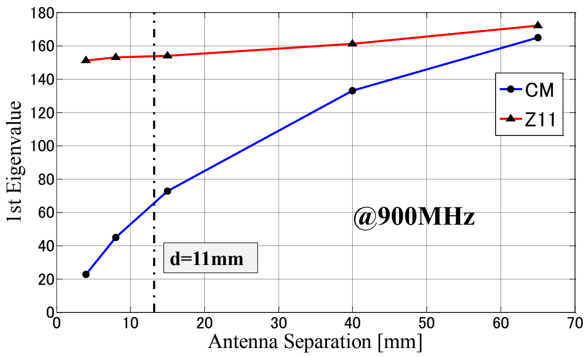


(a) Channel gain

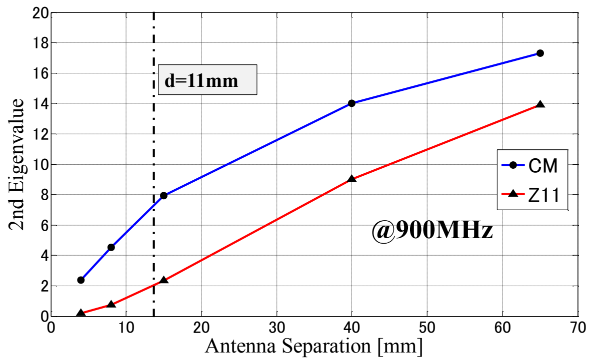


(b) Correlation coefficient

Fig. 4 Channel gain and correlation coefficient vs. antenna separation



(a) 1st Eigenvalue



(b) 2nd Eigenvalue

Fig. 5 1st and 2nd Eigenvalues vs. antenna separation

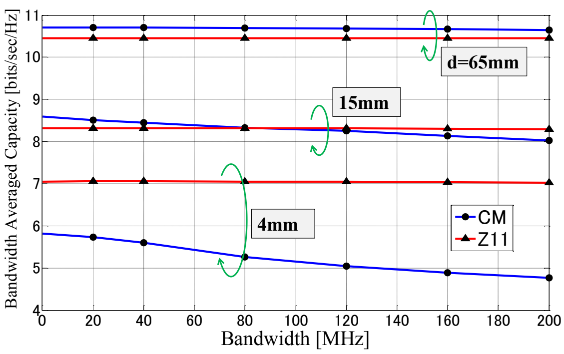


Fig. 6 Bandwidth averaged channel capacity

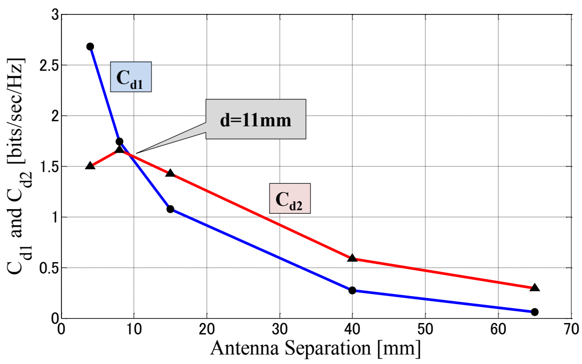


Fig. 7 Advantage of the two streams