Mutual Coupling Compensation for a Compact Array in Direction Finding

Yantao Yu\textsuperscript{1}, Choon Hock Niow\textsuperscript{2}, and Hon Tat Hui\textsuperscript{2}

\textsuperscript{1}College of Communication Engineering, Chongqing University, Chongqing, China
\textsuperscript{2}Department of Electrical & Computer Engineering
National University of Singapore, Singapore

Abstract— Multiport antenna arrays are more and more widely used in wireless communication systems. The strong mutual coupling effect between the elements of compact arrays may cause significant system performance degradation. Recently, a method using receiving mutual impedances has been proposed for mutual coupling compensation. In this paper, a compact monopole array is constructed and used in direction finding. For comparison, experiments are conducted with mutual coupling compensated by using the conventional mutual impedances and the receiving mutual impedances, respectively. The measured results show that the mutual coupling effect can be effectively removed using the receiving mutual impedances and the performance of direction finding can be greatly improved.

1. INTRODUCTION

Multiport antenna arrays are more and more widely used in wireless communication systems. The strong mutual coupling effect between the elements of compact arrays may cause significant system performance degradation. For application of direction-of-arrival (DOA) estimation, for example, MUSIC\textsuperscript{[1]}, the estimation errors are mainly contributed by the mutual coupling effect between array elements. When there is mutual coupling, compensation methods are usually required in order to obtain the correct array manifold. There have been many compensation methods\textsuperscript{[2, 3]} proposed in the past. A typical method is the one using the conventional mutual impedances (CMI)\textsuperscript{[4]} to characterize the mutual coupling effect. This method has been frequently used in both transmitting and receiving arrays. Recently, a modified method using receiving mutual impedance (RMI)\textsuperscript{[5]} has been suggested for use in receiving antenna arrays. Many theoretical results\textsuperscript{[5, 6]} have indicated that this new method is much more accurate in characterizing the mutual coupling effect in receiving arrays. In this paper, we report a group of experimental results by using the RMI to compensate for the mutual coupling effect in DOA estimation. A simple monopole array was constructed and its receiving mutual impedances and conventional mutual impedances were measured. DOA experiments were then performed inside the anechoic chamber.

2. THE DIFFERENT MUTUAL IMPEDANCES

The receiving mutual impedance was suggested in\textsuperscript{[7]} for use in receiving antenna arrays. It has been noted before\textsuperscript{[8]} that the mutual coupling problems are different in transmitting and receiving arrays. The difference between the receiving mutual impedance and the conventional mutual impedance is caused by the different current distributions when antennas are in different operational modes. The theoretical calculation of the receiving mutual impedance can be found from\textsuperscript{[7]}, while the measurement procedure is as in\textsuperscript{[9]}. With the receiving mutual impedances $Z_{ki}^r$, the relationship between the uncoupled voltages $U_k$ and the received voltages $V_k$ can be written as:

$$
\begin{bmatrix}
U_1 \\
U_2 \\
\vdots \\
U_N
\end{bmatrix} =
\begin{bmatrix}
1 & -\frac{Z_{12}^1}{Z_L} & \cdots & -\frac{Z_{1N}^1}{Z_L} \\
-\frac{Z_{21}^1}{Z_L} & 1 & \cdots & -\frac{Z_{2N}^1}{Z_L} \\
\vdots & \vdots & \ddots & \vdots \\
-\frac{Z_{N1}^1}{Z_L} & -\frac{Z_{N2}^1}{Z_L} & \cdots & 1
\end{bmatrix}
\begin{bmatrix}
V_1 \\
V_2 \\
\vdots \\
V_N
\end{bmatrix}.
$$

(1)

While with the conventional mutual impedances $Z_{ij}$\textsuperscript{[10]}, a different equation relating the open-
circuit voltages $V_{ok}$ to the received voltages $V_k$ is achieved.

$$
\begin{bmatrix}
V_{o1} \\
V_{o2} \\
\vdots \\
V_{oN}
\end{bmatrix} = \begin{bmatrix}
1 + \frac{Z_{11}}{Z_L} & \frac{Z_{12}}{Z_L} & \cdots & \frac{Z_{1N}}{Z_L} \\
\frac{Z_{21}}{Z_L} & 1 + \frac{Z_{22}}{Z_L} & \cdots & \frac{Z_{2N}}{Z_L} \\
\vdots & \vdots & \ddots & \vdots \\
\frac{Z_{N1}}{Z_L} & \frac{Z_{N2}}{Z_L} & \cdots & 1 + \frac{Z_{NN}}{Z_L}
\end{bmatrix} \begin{bmatrix}
V_1 \\
V_2 \\
\vdots \\
V_N
\end{bmatrix}
$$

(2)

3. THE EXPERIMENTS OF DIRECTION OF ARRIVAL

In this study, DOA estimation experiments were carried out with a seven-monopole array. The monopole has a length of 30 mm and a diameter of 1 mm. The distance between elements is 25 mm, which is about 0.2$\lambda$ at 2.4 GHz. The measured receiving mutual impedances were used to compensate for the mutual coupling effect in the received antenna terminal voltages and the measurement results were compared with the corresponding results obtained by using the conventional mutual impedances.

When there was only one incoming signal, a transmitting horn antenna serving as the signal source and the monopole array were mounted at the two ends of an anechoic chamber. The position of the horn antenna was set at an angle of $\phi = 105^\circ$ with reference to the center of the monopole array. The $S_{21}$ parameter which indicates the relative power received by the monopoles were measured and converted into a relative voltage quantity. In this way, all the received voltages on the antenna elements were measured, which were then compensated using the measured receiving mutual impedances. The signal direction was then estimated using the MUSIC algorithm based on the compensated received voltages. Fig. 1 shows the results of the MUSIC spectra which were obtained with the mutual coupling in the received voltages being compensated by different methods: (i) by using the receiving mutual impedance (RMI), (ii) by using the conventional mutual impedance (CMI), and (iii) no compensation at all (NC). It can be seen from Fig. 1 that mutual coupling did not have a significant effect on the DOA estimation when there was only one source. For the case with no compensation (NC), the estimated arrival angle was 104.3$^\circ$, which was 0.7$^\circ$ away from the actual source direction. The estimated arrival angles using CMI and RMI are 107.5$^\circ$ (with error of 2.5$^\circ$) and 104.1$^\circ$ (with error of 0.9$^\circ$), respectively. In the following experiment, it will be shown that when there were two signal sources, the RMI and CMI could make a much bigger difference.

In the case of two incoming signals, two horn antennas were fed from the output port of the vector network analyzer through a power divider. The MUSIC estimation results of the two sources coming from angles 68.6$^\circ$ and 111.7$^\circ$ are shown in Fig. 2. It can be seen that both the NC case and the CMI case failed to correctly indicate the directions of the two sources. While with the RMI used, the MUSIC spectrum correctly indicated the source directions with relatively small errors. It can be seen that the DOA estimations using RMI are much more accurate than that using CMI.

![Figure 1: The MUSIC spectra for the DOA estimation of a single source at $\phi = 105^\circ$.](image1)

![Figure 2: The MUSIC spectra for the estimation of two sources at $\phi = 68.6^\circ$ and $\phi = 111.7^\circ$.](image2)
4. CONCLUSIONS
The performance of DOA estimation using the receiving mutual impedances for mutual coupling compensation has been experimentally studied in this paper. A seven-monopole antenna array was used in DOA estimation employing the MUSIC algorithm. The measured results show the significant improvements in DOA estimation when the mutual coupling effect is compensated by using the receiving mutual impedances.

ACKNOWLEDGMENT
This work was supported by Natural Science Foundation Project of CQ CSTC (Project No. CSTC, 2011BB2070).

REFERENCES