Novel Decoupling Network for Two-Element Array Using Even-Odd-Mode Impedance Transformer

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Abstract - Without the neutralization line, a decoupling technique for two-element closely-spaced arrays is proposed in this paper. The core component of the proposed scheme is a coupled line section, which can be equivalent to an even-odd-mode impedance transformer. Through the even-/odd-mode analysis, the proposed network is able to simultaneously achieve good impedance matching and isolation.

Index Terms — Antenna arrays, coupled lines, decoupling of systems, multiple-input-multiple-output (MIMO) systems, mutual coupling.

I. INTRODUCTION

As the miniaturization technique has rapidly progressed, the limited space for the antennas in a MIMO system makes the element spacing much shorter than a half free-space wavelength, and therefore the system suffers significant performance deterioration owing to the mutual coupling [1]. The neutralization line is the most popular way to effectively eliminate the detrimental effects between the closely-spaced array elements in a compact platform [2]-[4]. However, it often requires a troublesome try-and-error process due to the lack of a systematic design procedure.

In this paper, we propose a new decoupling technique with rigorous design formulas using the even-/odd-mode analysis. As shown in Fig. 1, the proposed network comprises a pair of connecting lines and a coupled-line section. The coupled-line section is the core component of this design and serves as the even- and odd-mode quarter-wavelength impedance transformers at the same time. The design details will be introduced in the following sections.

II. DESIGN CONCEPT AND FORMULATION

As reported in [5], it is known that the requisite condition, to accomplish perfect matching and port isolation in a two-element array at the same time, would be $S_{11} = S_{21} = S_{22} = 0$, or equivalent to $S_{11e} = S_{11o} = 0$ for a symmetric structure.

Referring to Fig. 1, since the input impedance looking into the coupled-line section, in either mode, is purely real in the lossless case, the image part of the even-/odd-mode input impedances at the $t_2$ plane should be fixed as zero using the connecting line section as,

$$Z_{in} = Z_d (Z_{11} + jZ_{12}) + jZ_d \tan \theta_d = Z_{in} + j0 \ , \ (1)$$

where $Z_{11}$ and $Z_{12}$ are entries of the $Z$ matrix of the compact array system at the $t_2$ plane. The two unknowns ($Z_d, \theta_d$) can be solved using the simultaneous equations, (1) and (2), for the design parameters of the connecting lines. With $Z_d$ and $\theta_d$ specified, the input resistances looking into the antenna network at the $t_2$ plane, $R_{ine}$ and $R_{ino}$, can be calculated using (1) and (2) again. For perfect matching at the $t_3$ plane in either modes, $R_{ine}$ and $R_{ino}$ can be transformed into $Z_0$ using the quarter-wavelength coupled-line section, which suggests that the design parameters $Z_{Te}$ and $Z_{To}$ can be determined by,

$$Z_{Te} = \sqrt{R_{ine}Z_0} \ , \ (3)$$

$$Z_{To} = \sqrt{R_{ino}Z_0} \ . \ (4)$$

Finally, it therefore fulfills the ultimate design goal.

III. SIMULATED AND MEASURED RESULTS

To validate the design concept in Sec. II, two-element closely-spaced monopole arrays, without and with the proposed decoupling network, are designed at 2.45 GHz and fabricated on a 1.6mm FR4 substrate ($\varepsilon_r = 4.4, \tan\delta = 0.02$); the layouts are shown in Fig. 2. The element spacing ($s_a$) of the coupled arrays is about $0.1\lambda_0$. By converting the design parameters into physical footprints, the final dimensions (in mm) are $w_a = 3, w_d = 3.7, w_c = 0.2, w_1 = 3, l_a = 20.3, l_d = 26.5, l_c$.
\[ l_1 = 24.75, s_a = 14, s_c = 0.2, L_t = 105, L_g = 70, \text{ and } W_t = 55. \]

For comparison purpose, Fig. 3(a) and (b) shows the simulated and measured \( S \)-parameter results, before and after decoupling, respectively. At the center frequency, a significant improvement in port isolation can be observed, while the impedance matching of the decoupled array remains around 15 dB at the meanwhile.

Fig. 4 depicts the simulated and measured two-dimensional radiation patterns of the decoupled array in the principal cuts (\( xy \)- and \( yz \)-planes). Referring to the figures, the radiation patterns become more directional and uncorrelated with the proposed decoupling network. The simulated and measured peak gains and total efficiencies are summarized in Table I, and a noticeable improvement is achieved.

Finally, to quantify a MIMO array, the envelope correlation coefficient (ECC) in [6] can be calculated as a figure of merit (FOM). Using the complex electric field data from the full-wave simulator HFSS, the ECCs of the coupled monopole array, without and with the proposed decoupling network, are derived as 0.023 and 0.003, and it exhibits a great reduction in pattern correlation.

IV. CONCLUSION

In this paper, a new decoupling network for two-element closely-spaced arrays has been experimentally validated. The proposed topology depends on a pair of connecting lines and a coupled-line section in cascade, and it is capable of coping with the even- and odd-mode matching/decoupling conditions separately. A set of analytical formulas is also provided to achieve the design. Multi-band decoupling network would be a good topic worthy to study in the future.

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REFERENCES