LETTER

Novel Optimization Strategies for Isolation Structure Design in MIMO Systems

Dawei Ding¹, Dawei Li², Jing Xia² and Zhuang Li²

Abstract Isolation is one of the most important electric characteristics in a compact MIMO (multiple-input and multiple-output) system. Fragment-type structure receives much attention for acquiring high isolation due to its novel topology structure. In this paper, several novel boundary-based weighted sum filtering operators are proposed to obtain fragment-type isolation structure designs. Experiments on the isolation structure design of a compact MIMO PIFAs (planar inverted-F antennas) system are investigated. Comparison results show that the proposed hybrid filtering matrices could generate smoother structure, thus obtain wider impedance bandwidth and better radiation efficiency.

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1. Introduction

Multiple-input and multiple-output (MIMO) technique has been widely used in modern wireless communication [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]. It is a key point to achieve high isolation between closely-packed MIMO antenna elements in MIMO design.

Many structures, such as electromagnetic band-gap structures [11], slots [12, 13, 14], resonator structures [15, 16, 17], meta-surface [18], meta-material structures [19] and some other structures [20, 21, 22], have been proposed to improve the isolation among MIMO antenna elements. In [23], fragment-type isolation structures have been designed through MOEA/D-GO (multobjective evolutionary algorithm based on decomposition combined with enhanced genetic operators) [24, 25, 26, 27, 28]. In [29], MOEA/D-GO-II (MOEA/D-GO combined with two-dimensional median filtering operator) is proposed to speedup the searching process.

However, MOEA/D-GO-II converges too fast at the expense of population diversity, which might make the algorithm converge to local optimal and reduce alternative designs number. In order to overcome this problem, a boundary-based weighted sum filtering operator, metalizing the edge cell when it is bounded by metal, and non-metalizing the edge cell when it is bounded by air, is proposed in [30]. This operator has more possibility to maintain the connectivity of the boundary of the metal conductor, thus, 1) more metalized cells are remained to maintain the population diversity and to reduce backward radiation, and 2) it is beneficial for trapping the current into the isolation structure through conductor to obtain perfect return loss and isolation, and to increase the overall loss, and thus obtain wider impedance bandwidth [29, 30].

In this paper, in order to further ensure the electrical connectivity of the fragment-type structures, several novel boundary-based weighted sum filtering operators are proposed. Then, the fragment-type isolation structure is designed for a compact MIMO PIFAs (planar inverted-F antennas) system operating at 2.345-2.36 GHz. Comparison among the different optimization strategies is also conducted.

2. Novel filtering operators

A novel boundary-based weighted sum filtering operator is proposed in [30]. During the implementation of boundary-based weighted sum filtering operator, each cell is assigned with “1” or “0” according to the following equation.

\[ H(i, j) = \begin{cases} 
1 & \text{if } d(i, j) \geq \frac{|FM|}{2} \\
0 & \text{otherwise}
\end{cases} \]  

(1)

\[ d(i, j) = \sum_{m=1}^{M} \sum_{n=1}^{N} H(i+m, j+n) \times |FM| \]  

(2)

\( |FM| \) represents the sum of all elements of the filtering matrix, \( M \times N \) denotes the size of the fragment-type structure, and \( H(i, j) \) denotes the value of each cell of the fragment-type structure. The difference between the boundary-based filtering operator and the original...
median filtering operator [29] is the index of the calculation of \(d(i, j)\).

Fig. 1(c) gives two novel filtering matrices, called cross-shaped filtering matrices. It is shown that the proposed cross-shaped filtering matrix does not consider the impact of the diagonal elements. Therefore, it is easy to obtain the connected structures with less diagonal structures. Fig. 1(d) gives two five-order filtering matrices. This kind of filtering matrices could further ensure the connectivity of the fragment-type structures. Finally, two hybrid filtering matrices are proposed in Fig. 1(e) to combine the advantages of the two aforementioned matrices.

3. Fragment-type isolation structure designs

The proposed boundary-based weighted sum filtering operators are introduced into MOEA/D-GO to design fragment-type isolation structures [30]. Fig. 2 illustrates the basic configuration of a compact MIMO PIFAs operating at 2.345-2.36 GHz.

The objective functions are set as following.

\[
\begin{align*}
    f_1(x) &= \frac{10}{\min_{\omega \in [\omega_1, \omega_2]} |S_1|_{\text{dB}}} \\
    f_2(x) &= \frac{20}{\min_{\omega \in [\omega_1, \omega_2]} |S_2|_{\text{dB}}}
\end{align*}
\]

[\(\omega_1, \omega_2\)] indicates the operating band, \(|S_1|_{\text{dB}}\) represents the return loss, and \(|S_2|_{\text{dB}}\) represents the isolation between the MIMO PIFAs. The constants in (3)-(4) are used for normalization. It’s obviously seen that the smaller the value, the better the performance.

For each optimization strategy, several candidate designs are obtained. For simplification, only one design is fabricated and is tested in Fig. 3.

From Fig. 3(a), it is shown that great connectivity of the fragment-type structure is obtained. From Fig. 3(b), good agreement between simulated and measured results is observed. The antenna operates at 2.26-2.36 GHz with return loss of more than 10 dB and isolation of more than 20 dB. The isolation at 2.35 GHz could achieve 25 dB.
4. Comparison

For fair comparison, other filtering matrices in Fig. 1 are also used to design the fragment-type isolation structure. Fig. 4 illustrates the obtained isolation structures denoted as design #1, design #2, and design #3, respectively. Table I exhibits the comparison results, including electric characteristics, the number of alternative designs, and computational cost.

![Fig. 3. (a) Prototype of the design, and (b) measured S parameters.](image)

![Fig. 4. Obtained optimal structures by using (a) cross-shaped filtering matrix, (b) five-order filtering matrix, and (c) hybrid filtering matrix.](image)

### TABLE I. Comparison on the optimization results and the computational cost

| Design | Electric Characteristics          | Computational Cost |
|--------|-----------------------------------|--------------------|
|        | Relative bandwidth (%) | Radiation efficiency (%) | Iteration number | Candidate number |
| #1      | 9.3                             | 85                | 14              | 17               |
| #2      | 10.5                            | 83                | 12              | 15               |
| #3      | 16.7                            | 93                | 7               | 8                |

From Fig. 4 and Table I, it is observed as following.

1) All proposed optimization strategies could ensure the electrical connectivity of the fragment-type structures.

2) Hybrid filtering matrix could generate better smoothness than cross-shaped filtering matrix and five-order filtering matrix, thus it could obtain better radiation efficiency and wider impedance bandwidth [29].

3) Both cross-shaped and five-order filtering matrix has better population diversity than hybrid filtering matrix at the expense of searching speed.

5. Conclusion

Several novel boundary-based weighted sum filtering operators are proposed to ensure the electrical connectivity of the fragment-type isolation structures. Isolation structures of two closely-packed MIMO PIFAs are designed. Comparison on the experiment results shows that the proposed optimization strategies could improve the electrical connectivity of the fragment-type structures, and hybrid filtering matrices could generate smoother structure, thus obtain wider impedance bandwidth and better radiation efficiency.

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